# APPLICATION OF BIO-BRICKS & ITS BENEFITS

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## ABSTRACT

The practice-led research focuses on how agro-waste can be used to build a structure, gather relevant knowledge, and identify its various challenges. Based on the compressive strength of Bio-Bricks, it was decided to use a frame structure, and instead of using Bio-Bricks as a modular unit, the material used was cast in situ with the help of a specially designed mould. The roofing of the structure was also built using Bio-Bricks material over an MS frame. The prototype was plastered with cement mortar and finished with two coats of distemper paint. After the completion of the prototype structure, comprehensive documentation was done to analyse the data generated from the process to identify the desired improvements. A secondary study of sustainable building materials was done to understand the comparative strength and weaknesses of Bio-Bricks as construction materials. Based on the work done at different stages of construction, detailed lists of findings and inferences were drawn to improve the overall manufacturing process. The research project findings will help guide the future development of Bio-Bricks as a commercial building material.

**Keywords**: Sustainability, Prototyping, Design practice, Ecodesign

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# 1 INTRODUCTION

The research paper explores the practical application of Bio-Bricks in building construction. Bio-Bricks are sustainable bricks made upcycling agro-waste generated after each harvest. The report draws from the experience and learnings from previous research papers (Rautray et al., 2019, 2021). It tries to understand the making of Bio-Bricks samples and the economic benefits that can be gained from the material. Following practice-led research methodology, this paper documents the process and the insights of building a structure using Bio-Bricks. It also reports the challenges, material insights, and effects of weather. The prototype structure (6 feet by 10 feet guard room) was constructed in 2020, and it could withstand the impact of weather and lack of maintenance. It also gave a lot of insights into the choice of materials and building process. This research has also helped determine the future road map of Bio-Bricks and the scope of improvements.

**Practice-led Research Methodology**

This method implies that any new and innovative product or idea is as important as the knowledge embodied in it (Mäkelä, 2005). Making a product and learning through the process are inseparable and equally vital. Practice-led research has led to a generation of new knowledge and is usually undertaken by, but not limited to, artists, curators, architects, designers and musicians. Such research has been a robust methodology for generating original knowledge as well. However, a creative or practice-led process needs documentation to convert it into research data. And the research or thesis generated from such a practice-led process has to contain an original finding/ observation that can be published or presented (Candy, 2006). As a practice-led research, prototyping the Bio-Brick-based built structure generated a lot of knowledge and insights which would help improve the Bio-Bricks further.

# 2 BACKGROUND STUDIES

## 2.1 Summary of work done till now

The first research paper (Rautray et al., 2019) focused on developing and prototyping Bio-Bricks (a sustainable building material made up of agro-waste) and how they can be used as a sustainable material to fulfil the requirements for new building materials in the construction industry. The research found that the amount of agro-waste generated in India is almost 627.96MT per year, and it is challenging to consume all of it as fodder (Jain et al., 2014). The disposal has become so difficult that the farmers burn it, creating immense smog and health hazards for large swaths of the country. Bio-Bricks helps create a commercial prospect by converting this agro-waste into building material. These agro blocks can be manufactured by farmers or through small-scale industries in the locality of the village itself. This paper also explored the various ways of using these agro blocks. The second research (Rautray et al., 2021) focused on understanding the socio-economic impact of Bio-Bricks on the rural economy and how it can help create jobs at the grass root level. For this, the scope of the circular economy in India was studied regarding how Bio-Bricks fit into this model.

We analysed the Bio-Bricks through the direct economic benefit from manufacturing and selling them and the indirect benefits of a better environment, health and lesser pollution. In this part of the research, initial product testing was carried out, such as the compressive strength test, thermal resistance test, fire retardant test and water absorption test. It was found through the compressive strength test that the material's compressive strength is low, and it is only suitable as a filler material in frame structures or panels. The thermal and fire retardant test found that the material has a high thermal resistance and does not let fire propagate. A temperature of 600-800 degrees Celcius was applied with a blow torch on one side of a sample of 40mm thickness. On measuring the temperature on the other side, it was only in the range of 40-55 degrees Celcius. And due to Calcium carbonate as a constituent element, the carbon dioxide released due to heat application doesn't allow the fire to propagate, and it extinguishes very soon. Thirdly it was found that the water absorption of the Bio-Bricks is high, up to 60%; thus, BioBricks require protection from the rain. In the second paper, new product development methods were also explored. Bio-Brick can cast walls directly on the site and as a wall or roof cladding panel. It was found that Bio-Bricks or agro-waste blocks help solve multiple issues of environmental air pollution, soil degradation and agro-waste disposal. It was also found that bricks can be a potential source of secondary income for farmers and industries in rural areas. It also



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has a better recycling potential. However, specific challenges regarding the strength of the material were faced. It provided the opportunity to design Bio-Brick and its uses accordingly.

## 2.2 Comparative analysis

### *2.2.1 Agro-waste-based gypsum hollow blocks*

In this agro-waste gypsum hollow block, the researchers have created blocks using rice husk and gypsum as the primary material. They used 25% of rice husk by weight percentage. Multiple tests highlighted the material's various mechanical and thermal properties. The material was mixed with water and then cast into moulds to create 300mm x 200 mm x 150mm bricks per Indian Standard Code. The blocks were also designed with a male-female joint to facilitate interlocking when building the walls. (Singh et al., 2022).

### *2.2.2 Burnt clay brick using agro ash*

In this type of bricks, the researchers mixed clay with ash generated from agro-waste in various proportions. And the bricks were sun-dried and then burnt in a kiln like regular burnt clay bricks. They achieved high compressive strength M.S. 76:1972 (Malaysian Standard) as Class 2 load-bearing bricks (Figaredo & Dhanya, 2018). However, clay and burning processes are unsustainable as they produce greenhouse gases and cause loss of topsoil.

### *2.2.3 Hempcrete*

In this type of agro brick, the researchers have used Hemp plant shives to create it by mixing it with lime-based binders. The material is light with good insulation properties. It also has low compressive strength (less than 2MPa), so it can't be used as a load-bearing masonry wall. Instead, it can be used for non-load-bearing constructions (Tronet et al., 2016). However, the issue with such a material is that hemp is not produced in India on a large commercial scale; hence, it is not readily available. It is currently limited to only specific industrial and medicinal uses.

### *2.2.4 Mycelium bricks*

In this kind of brick, Fungi are grown with the help of some medium, such as sugarcane molasses, and then it is allowed to grow on agro wastes such as sawdust, rice husk, straw etc. The bricks achieved the minimum compressive strength needed for masonry bricks, i.e. 3.5MPa and can be as high as 11Mpa in some cases. However, the material takes a long time to form due to the time taken for the fungus to grow and bind the agro waste and requires a temperature-controlled facility and skilled labours (Maximino C. Ongpeng et al., 2020).

### *2.2.5 Cow dung stabilised earth bricks*

These bricks use clay (80%) mixed with a binder like a cow dung (20%). It has a good dry compressive strength ranging from 4.5MPa to 5.7Mpa, higher than the minimum requirement for load-bearing masonry bricks (3.5MPa). Such bricks can be easily made in village localities in India. However, the bricks' stability reduces considerably under wet conditions. Hence walls built with such bricks must be protected from constant rainwater. Such a brick can provide an alternative to traditional burnt clay bricks (Yalley & Manu, 2013).

### *2.2.6 Compressed rammed earth blocks*

In this type of block, clay is stabilised with cement (up to 10% of weight) and then curing is done. Samples of 100mm x 100mm x 100mm were formed in a wooden mould and rammed using a steel hammer. Compressive strength was tested per Indian Standard IS 4332 Part-5 of the cured sample, which varied between 3.73-6.43Mpa. The compressive strength of samples with 4% cement was half of the sample with 10% cement content. Such bricks can be used for a load-bearing masonry wall (Tripura & Singh, 2015).

Table 1 highlights the comparative analysis between currently available sustainable building materials based on strengths, weaknesses and ease of making the materials.



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*Table 1: Comparision table of Bio-Bricks with other sustainable building material*

| Name of Bricks | Material Used | Strength | Weakness | Ease of Making |
|---|---|---|---|---|
| Bio-Brick | Use up to 90% Agro-waste, lime binder | No burning required, carbon negative, waste to wealth. It can be used as panels and filler material | Low compressive strength, water absorption | Can be made with minimum investment at the grassroots level |
| Agro-waste-based gypsum hollow blocks | Agro waste (5-25%), gypsum as the binder | No burning, no CO2 production, waste to wealth | Low agro waste content. Gypsum as a material is not suitable for the environment | It can be made easily |
| Burnt Clay brick using agro ash | Clay (65%) and agro ash (35%) | Higher compressive strength compared to agro-blocks | The use of non-renewable fuel for burning produces a lot of CO2 and uses clay (topsoil) | Similar to making standard clay bricks |
| Hempcrete | Hemp shiv(35%-65%), rest is lime binder | Compressive strength is higher than Bio bricks and ecofriendly | Not available in India and hence is not generated as a waste | Making hempcrete is similar to bio-bricks and is of low investment |
| Mycelium Bricks | basidiomycete fungi, straw waste, rice bran, coconut husk, sawdust | Compressive strength is relatively high | Long duration to produce the bricks | Manufacturing such bricks need proper training, time and temperature controlled facility |
| Cow dung stabilised bricks | Clay(80%) and Cow dung (20%) | High dry compressive strength | It needs to be saved from direct rainwater as it loses compressive strength | It can be easily manufactured locally and manually |
| Compressed Rammed Earth Blocks | Rammed earth (90%), cement (up to 10% ) | No burning process, high compressive strength (up to 12Mpa) | No agro waste used and requires skilled labour | Labour intensive |

From the above analysis, we can conclude that Bio-Bricks has the potential to utilise the vast amount of agro-waste generated after each harvest as it is made up of 90% agro-waste. However, there is a need to develop more compositions and test them to improve the compressive strength of the Bio-Bricks. At the same time, these bricks can be used in filler walls, panelling, insulation panels, etc., for which there is a need to develop a comprehensive design manual.

## 3 PROTOTYPING

This section documents the process of making the Bio-Bricks material, designing the building, constructing the moulds, in-situ casting process, making the roof with Bio-Bricks material, and



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finishing the structure. The documentation of the research project was done through photography and videography, followed by daily observations and reflections. After completion of the construction, the building was observed for two years for any defects or weathering effects.

## 3.1 Making of Bio-Bricks

### *3.1.1 Chopping of agro-waste*

The process of prototyping starts with selecting the right tools for the project. Considering the budget and allotted time, an electric chaff cutter, an electric mixture machine and a pneumatic rammer were procured. After an initial survey to collect agro-wastes, we selected a hardy shrub found at our campus site as the main component of the Bio-Bricks as a replacement for agro-waste. Once the shrubs were cut, they were left on site to dry. They were collected using manual labour and transported to a base location where they were chopped to size, the following Figure 1 and 2 show the agro-waste collection and chopping process.

*Figure 1: Hardy shrub selected and collection process of dry agro waste*

*Figure 2: Chopping of dry agro-waste*

### ***3.1.2*** *Preparing the Bio-Bricks material*

The copped agro-waste was mixed with a lime binder and water using the electric mixing machine. After a few trials and errors, the correct amount of the lime binder and water was finalised, and all the subsequent mixes were made of the same proportion. The mixing follows a process where the water is added to the chopped agro-wastes, and once the mixture is sufficiently wet, the lime binder is added using a measuring bucket. The constituents were mixed for five minutes before being transferred to the site. Figure 3 highlights the different stages of the mixing procedure.

*Figure 3: Preparing the Bio-Bricks mixture*

**Observations:**

- Collection and transportation of agro-waste is labour and time intensive.
- The chaff-cutting machine could not maintain the size of chopped agro-waste.
- There were many kickbacks and flying debris.



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- The amount of water needs to be monitored; if the mixture has too much water, the lime binder seeps during in-situ casting making the structure weak.
- The size of agro-wastes directly impacted the compaction and strength of the structure. Thus, we must maintain the agro-wast size (15mm to 25mm). Lager size agro-waste creates voids and weakens the overall brick.

## 3.2 Design of the structure

After conducting the initial study of Bio-Bricks, it was evident that this building material could not be used in load-bearing construction and had a high water absorption capacity. Thus, inspired by vernacular architecture, a pitched- roof with vents, project roof, or overhangs provides some shed from direct rainfall. Figure 4 highlights the use of a pitched roof with vents to keep the indoor space comfortable during the hot and humid months. And during the rainy season, the use of a 'Vahranda' or projected roof provides shade and rain protection on the wall.


*Figure 4: Vernacular architecture of India used as inspiration for the structure*

The structure was based on corner supports, which took the dynamic load of the roof structure. This structure was inspired by thatched mud brick homes constructed in rural India, where they use wooden or bamboo supports at the four corners and tie them at the lintel level. Mild Steel (M.S.) square sections (25mm) were used to replicate the traditional construction techniques for ease of construction. The modular frame structure was designed to transport them from the workshop to the site. Figure 5 showcases the design of the M.S. frame structure and how the frame was fixed with the PCC foundation at the site.

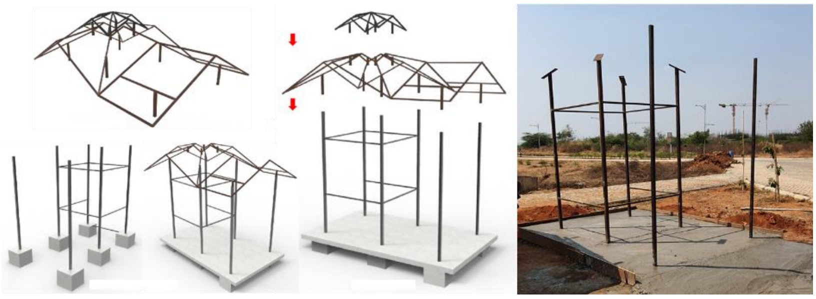

*Figure 5: Frame structure for prototyping*

**Observations:**

- The corner support needs to be connected at two locations to improve the structural strength.
- The wall must be built over a PCC layer or waterproof course for protection from water damage.
- The proper slope of the PCC layer needs to be maintained.

## 3.3 Mould and is-situ casting

18mm Plywood was selected for the formwork and was designed in a modular and openable manner so that it can be reused repeatedly. The mould height was one and a half feet. The inside of the moulds was painted with acrylic paint to make the surface smooth and easy to remove after casting. Toggle latches were used to connect and clamp the formwork securely before casting. After the moulds were fixed at the site, the Bio-Bricks material was poured into the mould and compacted using a hand or pneumatic rammer. The moulds were left for two days, after which they were removed and reassembled over the previous layer. The process was repeated six times to reach a height of nine feet.
The door and window frames were fixed during the casting to be bound adequately to the Bio-Brick wall.



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*Figure 6: Transporting and installing the formwork at the site*

*Figure 7: Pouring of Bio-Brick material, rand ramming and completion of the first layer*

*Figure 8: Photographs showing the layered casting of the wall*

Figure 6, Figure 7 and Figure 8 highlight the process of mould making and in-situ casting of Bio-Bricks based wall.

**Observations:**

- We used 18mm ply with cross members as stiffeners, but there were a few buckling issues while ramming.
- The moulds designed for the prototype were open from the top, so there was a bit of expansion in the casting's top layer, which is unsuitable for uniform strength.

### 3.4 Roof with Bio-Bricks material

Taking inspiration from vernacular architecture and based on the findings from our initial research, we decided to use the Bio-Bricks material to develop the pitched roof for the structure. The design harnesses the advantage of a split-pitched roof with vents to improve ventilation during hot and humid months. The main frame for the roof structure was designed using a 20mm by 20mm M.S. square section. Next, 20mm M.S. flats were added to the frame as intermediate supports for fixing the PVC sheet as the backing to hold the Bio-Bricks material. Once the roof frame was securely fixed onto the base frame, a removable Wood Plastic Composite (WPC) skirting was added to the outer roof frame to stop the Bio-Bricks material from sliding from the sloped roof. Figure 9 and Figure 10 showcase the making of the roof using mild steel frames and Bio-Bricks.

*Figure 9: Making of the roof frame*



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*Figure 10: Fixing of the roof frame and casting of the roof*

**Observations:**

- Although the M.S. square section was used for ease of construction, they can be easily replaced with bamboo or wooden members in the actual scenario based on material and labour availability.
- As the casting was done on a sloped surface, we had to reduce the amount of water and increase the amount of the lime binder added to the mix to lower the leaching of the lime binder.
- After pouring the material, it must be levelled adequately by hand to remove any air gaps.
- The roof surface must be covered during the curing process to protect it from rain.

## 3.5 Plaster and finishing

The exterior wall was plastered with 12mm cement mortar to protect the outer surface from rain, external damage and insect attack. Similarly, to provide a smooth and proper working surface, the internal wall was also plaster with 12mm cement mortar. Finally, the surface was finished with two coats of distemper paint. The door and window frame were painted with two coats of enamel paint. After adequately drying the roof structure, the sloped roof surface was plaster with 12mm cement mortar, followed by two coats of cement punning with red-oxide powder to give a distinct red colour. After finishing, the roof was adequately protected from leakages and any damage from rain. The finishing process of the Bio-Bricks wall and the roof is shown in Figure 11 and Figure 12.

*Figure 11: Plastering process of the Bio-Bricks wall*

*Figure 12: Finishing of the roof with cement plaster and cement punning*

**Observations:**

- Due to the textured surface and small cavities in Bio-Bricks, it could hold to cement mortar without any issue.
- The Bio-Bricks wall is dry; the surface can be plastered using lime mortar, cement mortar or clay mortar, depending on the availability and cost.
- Cement punning or coating the roof surface with a waterproofing compound improves protection against leakages and water damage.



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### 3.6 Inference

After completing the Bio-Briks project, the following are the inference that can help develop better composition and systems to construct Bio-Bricks-based buildings. We must build machines and tools to chop agro-waste at sites/ farms to reduce labour costs and the required time. Alternatively, small or medium-scale cottage industries can be developed that cater to a specific region where farmers can dump their agro-waste for further processing. The chopping machine needs to be calibrated to produce the desired size of agro-waste (15 to 25 mm), as large pieces negatively impact the material's strength. Proper protective gear is necessary to protect the users during the cutting and chopping. The ratio of lime-binder and water has to be maintained for a uniform mix. There is a need to create a waterproof layer between the Bio-Bricks wall and the ground to reduce water damage and seepage. The slope of the base should be able to direct water away from the structure. Based on the experience of in-situ casting, a better mould must be developed (through design and suitable materials) that can handle pressure while compacting the material and reducing deformities. We need to experiment with traditional materials and building processes to minimise the base frame's overall cost and optimise the construction process. During construction, due care must be taken to protect the structure from heavy rain. Their inherent properties make Bio-Bricks conducive to cement mortar, lime mortar or clay plastering. Based on the availability and cost, either of the processes can be applied. Even after two years of construction, the Bio-Bricks-based guard room has hardly shown any crack, deterioration or damage due to the vagaries of weather.

## 4 THERMAL COMFORT EVALUATION

Once the structure was ready and officially inaugurated for formal usage as a guard room, we decided to investigate the thermal comfort of the built form as compared to the old metal shed. A dry bulb thermometer was used to measure the ambient inside temperature of a metal shed, the Bio-Bricks structure and the outside for two months to verify the effectiveness of the Bio-Bricks-based design. The temperature was recorded at four different periods, such as 10:00 AM, 12:00 PM, 2:00 PM and 4:00 PM; these recordings helped understand the thermal comfort by analysing the temperature differences. The recording process was done for May and June, some of the hottest months in Hyderabad, India. This selection was selected to simulate the hot conditions prevailing Indian subcontinent.


*Figure 13: Location of the dry bulb thermometer*

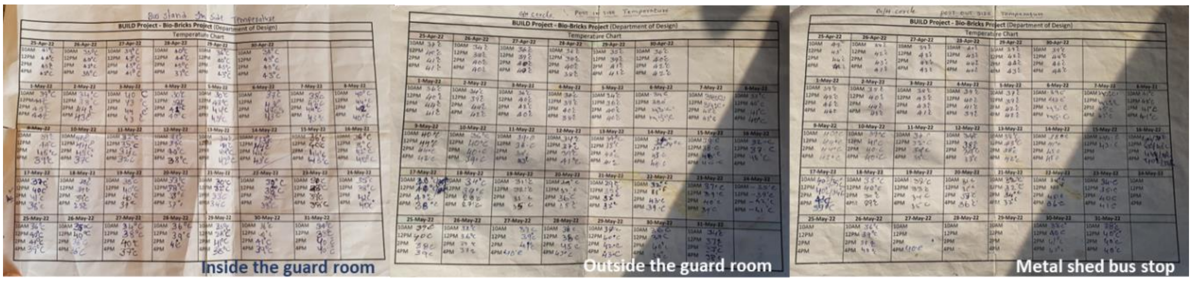


*Figure 14: Actual temperature readings*

**Observations:**

- Comparing the tables from both months, it was found that there was a difference of 3-4 degrees between the Bio-Bricks structure and the metal shed.
- As the Bio-Brick structure was comparatively small with large openings, we need to recreate this study to have a better understanding.



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- This study needs to be supplemented with user feedback to understand user comfort in such a building.

## 5 CONCLUSION

The practice-led research project gave valuable insights into the intricacies and challenges of making a large-scale structure using Bio-Bricks. It helped in identifying building processes and correct methodologies. In previous experiments, Bio-Bricks were developed in different geographical locations with varied types of agro-waste, which led to the formulation of varying composition and mix ratios. For this research paper, a hardy shrub commonly found in Hyderabad was used, for which the composition was modified to suit the material. Thus, considering the varied agro-waste types generated in India, the composition of Bio-Bricks need to be appropriated. For Bio-Bricks to be developed as a commercial building material, there needs to be two-pronged research and development. Firstly, to design and develop types of machinery suitable to process agro-waste at the farm and convert them into Bio-Bricks. Secondly, centralised cooperative industries can be developed to cater to local demand. Thus, the future roadmap for Bio-Bricks is to scale manufacturing and revenue generation by collaborating with appropriate agencies and providing hands-on workshops and training facilities to various stakeholders.


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