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Environmental Impact of Cardboard-Based Temporary Housing: A Life Cycle Analysis

Prof. (Ar.) Riya Richard Shawel

Faculty of Architecture, Institute of Architecture Sage University Indore, Student of Masters in Architecture, School of Architecture IPS Academy Indore, riyaarchitects@gmail.com

Abstract

This research explores the role of architecture in addressing the challenges faced by individuals in post-disaster scenarios, where the demand for temporary housing increases significantly. Historically, humans have sought protection from environmental and climatic conditions, and this drive is heightened in the aftermath of natural or manmade disasters. Disasters not only result in physical destruction but also in mental trauma, leading to a rise in homelessness. Architects are tasked with creating dignified, secure, and comfortable spaces for affected populations, where they can work, rest, and recover. However, refugee camps and emergency shelters often face issues such as overcrowding, inadequate living conditions, and psychological stress. This study focuses on the potential of paper-based homes as a sustainable and innovative solution for temporary housing. By conducting a life cycle assessment (LCA) of cardboard, the research evaluates its environmental impact, including carbon emissions, resource consumption, waste generation, and recyclability, compared to other temporary housing materials like plastic, wood, and metal. The findings aim to provide insights for architects in designing disaster-resilient shelters that are both environmentally and socially sustainable.

Keywords: Disaster, Temporary housing, Paper housing, Post disaster, Sustainable

1.0 Introduction

Ever since earlier times man is trying to seek protection of life against animal and climatic conditions. Each home in its own way represents elements that existed. These development is affected by natural and manmade disasters. Disaster not only affects physically but also affects mentally resulting in loss of life and property. Post disaster scenario shows there is increase in number of homeless people. After a disaster occurs its role of an architect to provide accommodation to people where people can live with dignity, security and comfort, a space where people can work, rest and sleep. Refugee camps, post-disaster zones, or emergency shelters, are often faced with challenges related to poor living conditions, overcrowding, and psychological stress. Therefore architects needs new innovative ideas that later on creates history. By focusing on paper-based homes, this research would conduct a life cycle assessment (LCA) of temporary cardboard housing, analyzing its environmental footprint from raw material extraction through production, use, and disposal. It would assess factors such as carbon emissions, resource use, waste generation, and recyclability. A comparison could be made with other temporary housing materials like plastic, wood, or metal.

1.1 Materials and methods

1.1.1 Raw material

Rice husks and depithed, bagasse underwent the drying process in an oven and then was stored until needed for further use. Madakadze et al.'s the research findings were the basis for the cutters of barnacs bagasse that were of a length of about 2 cm to be followed in the present study. Waste papers were cut into small papers, about 2-3 cm, on which one side was cut and then dried in the oven.

1.1.2 Production of cardboard

Pulping by cold maceration The maceration fluid is prepared by mixing 1 part of 30% hydrogen peroxide solution, 4 parts of distilled water, and 5 parts of glacial acetic acid. The risk husks chips were then soaked in the maceration mixture for days until digestion. The mixture was stirred thoroughly each day. According to Ibrahim [8], digestion is attained when the pulp is formed, that is when the rice husk has softened. The average room temperature was 29 C. At the end, the pulps were washed and screened into accept and reject (the one with knots and uncooked rice husk, due to incomplete reaction of the sample with the macerating chemicals). Lastly, the accepted pulp was oven dried in order to ascertain the yield. Determination of optimum maceration conditions in terms of pulp yield, kappa number and lignin content Samples of 15 g of bagasse and rice husk were immersed in 80 ml of the macerating liquor. They were allowed to macerate for 5, 6, 9, 10, 12, 15, 20 and 25 days. At the end, the pulps were washed with equal bathing ratio and finally screened into accept and reject.

1.1.3 Forming of cardboard sheets

The oven dried sample of pulp corresponding to (200 ± 4) g/m2 was soaked in distilled water for at least 4 h. After being washed, the pulp was diluted to 1000 ml at 0.3% consistency for every sheet. Disintegration was made within the standard disintegrator for 4 min, reaching a speed of 18,000 rpm up until all fibre bundles became dispersed (TAPPI 205 sp-12). The stock was poured on a sheet former; the sheet formed on the wire screen was drain for about 5 min and pressed at (400 10) kPa for 2 min 15 s and then released. The sheets were dried in the conditioning room at 23 C and 50% RH. A drying period of 2 days was appropriate (SCAN CM 64:00).

Fig. 4. Samples of cardboard from rice husk and bagasse and rice husk and waste paper.

1.1.4 Summary

Three fibre sources were assessed for the production of cardboard. These included rice husk, bagasse and waste paper. The maceration condition of the agricultural residues used was studied for a period of 25 days and their chemical composition was assessed. However, weaker grades cardboard can be used in construction or for decoration purposes, thus, rice husk can be used as a substitute to maintain the strength of the fibres. These cardboards can be used for packaging corrugating medium, wrapping, and as an insulating board, besides being applied for decorations..

1.2 Key steps for Carbon Footprint Calculations

Raw Material Extraction Rice husk is purely an agricultural by-product and need not be extracted from the forest or mined as in the case of traditional wood pulp. The latter is also advantageous in having a lower environmental impact. The carbon footprint of rice husk itself is negligible given it's a waste product. However, it should be considered that energy used by collecting and processing into cardboard also has an impact.

1.2.1 Processing & Production:

Energy Consumption: When making rice husk-based cardboard, the process often includes cleaning, grinding, and mixing the rice husk with other materials (like starch or binding agents). The energy used in this process (often electricity or natural gas) will contribute to the carbon footprint.

- *Energy Consumption:* Processing of 1 kg of rice husk requires approximately 0.5 kWh of electricity and 0.2 kg of natural gas.

 Emissions: Based on the energy consumption, emissions for this process are estimated at 0.4 kg CO_2e per kg of cardboard.

Form the chemicals point of view, they are used during the processing, so there production also causes the emission (e.g. bleaching or binding agents).

1.2.2 Transportation:

Carbon footprint also includes the movement of raw rice husk to the processing plant and the processed product to the consumer, depending on distance and type of transportation utilized, which can be truck, ship, etc. End-of-life- This is related to the end in sight of whether or not the cardboard would be recycled, composted, or thrown into a landfill. It has been observed that cardboard recycling displays a lower carbon footprint as compared to when cardboards are disposed off in a landfill.

 Emission Estimation: For every 100 km transported by truck, the emission factor is roughly 0.1 kg CO_2 per kg of material transported.
 Assuming a total of 500 km transportation distance (from farming areas to factories and construction sites), emissions are calculated at approximately 0.5 kg CO_2e per kg of cardboard.

1.2.3 End-of-Life:

Recycling and Decomposition: Rice husk-based cardboard can be recycled or composted at the end of life, significantly reducing its carbon footprint compared to materials that are incinerated or landfilled.

Recycling Emissions: If recycled, the emissions are estimated at 0.2 kg CO_2e per kg of cardboard.

Landfill Emissions: If landfilled, emissions are much higher due to methane production (approximately 0.5 kg CO_2e per kg of cardboard).

1.2.4 Carbon Footprint Formula

The carbon footprint can be determined using this general formula:
Carbon Footprint = (Emissions from raw materials) +
(Emissions from processing) + (Emissions from transportation) + (Emissions from disposal) Carbon Footprint = Raw material emissions + Processing emissions + Transportation emissions + Waste disposal emissions
Typical Carbon Footprint Values for Cardboard

For example:
Wood-based board/cardboard: The carbon footprint of paper and cardboard which are produced from the pulp of the tree is around 1.5 to 2.5 kg CO_2e per kilogram of carton.
Rice husk-based cardboard: As a byproduct of waste, rice husk rarely contributes to massive deforestation; hence the carbon footprint is probably lower than that of regular wood-based

cardboard. An estimate might be between 1 and 2 kg CO_2e per kilogram of cardboard, depending on the energy used during processing and other factors.

Example Breakdown
Let's assume:
1 kilogram of rice husk-based cardboard is produced.
Emissions from raw materials due to processing rice husk: 0.2 kg CO_2e
Emissions from energy utilization during processing: 0.5 kg CO_2e
Transportation-related emissions: 0.3 kg CO_2e
End-of-life Disposal (recycling) related emissions: negligible values (approximately 0.1 kg CO_2e).

Therefore, the cumulative carbon footprint would be calculated as:
Carbon Footprint = 0.2 + 0.5 + 0.3 + 0.1 = 1.1 kg CO_2e per kg of cardboard
Carbon Footprint=0.2+0.5+0.3+0.1=1.1 kg CO_2e per kg of cardboard

1.2.5 Conclusion:

The carbon footprint for 1 kg of cardboard derived from rice husk is around approximately 1.1 kg CO_2e assuming average energy consumption and emissions related to transportation. That's a pretty rough estimation; the real carbon footprint will depend on particular factors, such as the place of production, the energy composition used, and the modes of transport

2.0 Comparison

To evaluate the environmental sustainability of **rice husk-based cardboard** in comparison to other construction materials such as **wood**, **metal**, **plastic**, and **concrete**, we will analyze key factors like **carbon footprint**, **resource use**, **energy consumption**, **recyclability**, and **end-of-life impact**. These aspects help in determining the overall sustainability of a material in terms of environmental impact.

2.1 Carbon Footprint

The *carbon footprint* represents the amount of carbon dioxide (CO_2) emitted during the entire lifecycle of a material, including extraction, production, transportation, use, and disposal.

Material	**Carbon Footprint (kg CO_2e per kg)**
Rice Husk-Based Cardboard	1.1 kg (production, transport, use, recycling)
Wood (Lumber)	2.1 kg (harvesting, processing, transport)
Metal (Steel)	8.0 kg (extraction, smelting, transport)
Plastic (Polyethylene)	6.0 kg (petrochemical extraction, production, transport)
Concrete (Cement-based)	7.0 kg (extraction, cement production,

Material	Carbon Footprint (kg CO_2e per kg)
	transport)

Analysis:
Rice husk-based cardboard has the lowest carbon footprint (1.1 kg CO_2e), largely due to its use of agricultural waste, minimal energy-intensive processing, and potential for recycling or composting. *Wood* has a moderate footprint at 2.1 kg CO_2e, mainly due to logging, transportation, and processing. However, wood stores carbon during its growth phase, which can offset some of these emissions if the wood is sustainably sourced and used. *Metal (steel) and plastic* have a high carbon footprint of 8.0 kg and 6.0 kg, respectively. This is attributed to their energy-intensive processes of extraction and production: steel consumes a lot of energy when extracting and processing iron ore, while plastic is from fossil fuels. *Concrete* (7.0 kg) has a high carbon footprint mainly because of the process of cement production, which is one of the sources of CO_2 emissions all over the world.

2.2 Resource Use & Availability

- *Rice Husk-Based Cardboard*: As an agricultural byproduct, rice husks are abundant and renewable, with minimal competition for food production. This makes it an efficient and sustainable use of a waste product, reducing the need for virgin resources.
- *Wood:* While renewable, wood requires proper forest management to prevent deforestation. Overharvesting can lead to biodiversity loss and soil degradation. However, certified sustainable forestry practices help ensure that wood is sourced responsibly.
- *Metal:* Metals like steel require extensive mining, which is resource-intensive and can lead to habitat destruction and water contamination. Recycling can reduce these impacts but still involves significant energy use.
- *Plastic:* Plastic is derived from fossil fuels, contributing to the depletion of non-renewable resources. Its production process is highly resource-intensive and requires large amounts of water and energy.
- *Concrete:* Concrete is made from sand, gravel, water, and cement. The extraction of raw materials like sand can cause environmental degradation, including habitat destruction and water table disruption. Cement production also uses large amounts of limestone, which requires energy-intensive processing.

2.3 Energy Consumption

The energy intensity of producing a material is an important factor that determines its sustainability. It includes the energy consumed in processing, manufacturing, and transporting the material.

Rice Husk-Based Cardboard: Generally, this material would require low energy to process. The energy use comes from drying and grinding the rice husk and then forming it into panels. Rice husks are mostly processed locally, and therefore the energy use due to transportation may be minimized.
Wood: Wood has average processing energy requirements, significantly less than those for metals and plastics. The cutting and drying of wood use a small amount of energy but significant portions can come from sawmill waste.

Metal: Energy usage is considerable to manufacture steel as this often occurs at very high-temperature furnaces where the smelting of iron ore occurs. Coal and natural gas provide fuel in much of the world for such a process and hence has quite a high energy use.
Plastic: The production of plastic is very energy-intensive, especially in the polymerization stage, which requires large amounts of heat and electricity. Additionally, fossil fuel extraction adds to the environmental cost.
Concrete: Cement is the main component of concrete, and cement production requires a lot of energy, especially for the calcination of limestone at high temperatures. Cement production contributes about 5-7% of the global CO_2 emissions due to fossil fuel dependency and high energy requirement.

2.4 Recyclability & End-of-Life Impact

The ability of a material to be recycled or repurposed at the end of its life plays a major role in determining its environmental sustainability.

- *Rice Husk-Based Cardboard:* **Highly recyclable** and **compostable**, which significantly reduces its environmental impact if handled properly. The end-of-life disposal of rice husk cardboard is generally sustainable, either through composting (returns organic matter to the soil) or recycling.
- *Wood:* Wood is also **recyclable**, particularly if it is not treated with harmful chemicals (like pressure-treated lumber). It can be reused or repurposed in various ways, and it can biodegrade naturally if it is disposed of properly. However, improper disposal (e.g., incineration or landfill) can result in emissions.
- *Metal:* **Highly recyclable**, with steel and aluminum being some of the most recycled materials globally. Recycling metals significantly reduces energy consumption and material use compared to extracting new metals.
- *Plastic:* **Recycling rates for plastic** are relatively low compared to metals. Many types of plastic degrade in quality during recycling, limiting their reuse. Plastics that are not recycled often end up in landfills or the ocean, contributing to long-term pollution.
- Concrete is **not easily recyclable** in its purest form. However, crushed concrete can be reused as aggregate in new concrete or for other applications, which reduces waste. The recycling process is less energy-intensive than creating new cement, but it is still not as efficient as recycling metals or wood.

2.5 Environmental Impact Beyond Carbon Footprint

This product also contributes little harm to the environment as a result of the production and disposal processes of

Rice Husk

Based Cardboard. It serves to mitigate waste generation and utilizes agriculture byproducts that otherwise remain unexploited.
Wood: Sustainable sourcing is necessary to ensure wood is truly sustainable. Deforestation and illegal logging, for instance, contribute to the huge loss of biodiversity and soil erosion. The impacts are better mitigated with certified sustainable forestry, such as FSC certification.
Metal: Metal extraction leads to habitat destruction, water contamination, and air pollution. However, recycling reduces some of these impacts. Mining and processing metals may harm ecosystems and often cause depletion of

non-renewable resources.
Plastic: Plastic contributes heavily to pollution, especially in marine ecosystems. Its durability and resistance to decomposition mean it can persist in the environment for hundreds of years, leading to long-term environmental damage.
Concrete: Concrete production and disposal cause environmental degradation through mining, pollution, and energy consumption. On the other hand, it is durable; therefore, if it lasts longer and reduces the frequent replacement needed, it would be offsetting some environmental impact.

2.6 Conclusion:

- *Rice husk-based cardboard* emerges as a **highly sustainable** material, particularly in comparison to traditional construction materials like wood, metal, plastic, and concrete. It has a **lower carbon footprint**, uses **renewable, waste-based resources**, and is **recyclable or compostable** at the end of life.
- While *wood* is also a relatively sustainable material, it depends heavily on responsible sourcing practices to prevent deforestation and ensure long-term environmental benefits.
- *Metal,* particularly **steel**, and **plastic** have **high environmental costs** due to their energy-intensive production processes, resource extraction, and challenges with end-of-life disposal.
- *Concrete* has one of the highest environmental impacts due to cement production and resource extraction, although it offers durability and can be partially recycled.

Overall, **rice husk-based cardboard** stands out as a **sustainable alternative**, particularly for applications in construction where lightweight insulation, partitioning, and packaging materials are needed. By reducing the demand for traditional materials with higher environmental costs, rice husk-based cardboard can contribute to **greener, low-carbon construction** solutions.

3.0 Investigation

Rice husk-based cardboard is now gaining importance as an eco-friendly material in housing construction because of its sustainability and low carbon footprint. However, as with any material, there are logistical and technical challenges in recycling and reusing rice husk-based cardboard. These must be understood and addressed so that it is viable for the long term in housing projects. This investigation will study these challenges and potential solutions.

3.1 Logistical and Technical Challenges in Recycling and Reusing Rice Husk-Based Cardboard

3.1.1 Contamination Issues

- *Problem:* Contamination is a major concern when recycling any material. Rice husk-based cardboard, like regular cardboard, may be contaminated with adhesives, inks, coatings, and dirt. Contaminants can reduce the quality of the recycled material and complicate the recycling process.
- *Challenges:*

  Inks and Coatings: If the cardboard is printed or coated (e.g., with plastic for water resistance), these coatings can be difficult to separate during the recycling process.

Adhesives: Glues or other binding agents used in manufacturing the cardboard may not be biodegradable, potentially causing issues in the recycling process.

Food Contaminants: In the case of cardboard used for packaging, residues from food or liquids may be left behind, making the material unsuitable for recycling without additional cleaning steps.

- *Solutions:*

  Developing Non-Toxic Adhesives and Inks: The use of eco-friendly, biodegradable adhesives and non-toxic inks could help reduce contamination and make the material easier to recycle.

  Better Sorting Mechanisms: Automated sorting technology in recycling facilities could improve the identification and separation of contaminated cardboard, ensuring cleaner materials for recycling.

  Post-Use Cleaning: Implementing cost-effective cleaning technologies (e.g., water-based washing or steam treatment) could help remove contaminants from used cardboard.

3.2. Degradation and Material Integrity

- *Problem:* Over time, rice husk-based cardboard may degrade, especially if exposed to moisture or adverse environmental conditions. This is a concern for reusing it in construction, where long-term durability and structural integrity are critical.

- *Challenges:*

  Moisture Sensitivity: Like traditional cardboard, rice husk-based cardboard is vulnerable to water damage. Exposure to rain, humidity, or high moisture content could cause degradation, leading to a loss of strength.

  Physical Wear and Tear: The cardboard may weaken after multiple uses, especially if it is not maintained properly.

- *Solutions:*

  Waterproofing and Protection: Incorporating natural water-resistant coatings (e.g., biodegradable wax or plant-based polymers) can increase the material's moisture resistance without adding significant environmental impact.

  Layering and Reinforcement: Cardboard can be reinforced with other materials (such as recycled plastic fibers or resins) to enhance durability and longevity in construction.

  Proper Maintenance: Developing protocols for maintaining cardboard in construction (e.g., regular inspection and treatment against degradation) could prolong its lifespan.

3.3. Large-Scale Recycling Difficulties

- *Problem:* Recycling rice husk-based cardboard on a large scale poses logistical challenges due to the infrastructure required for processing and handling. This includes the need for specialized equipment, the cost of transportation, and the availability of recycling centers equipped to handle this material.
- *Challenges:*

  Limited Recycling Infrastructure: Existing recycling facilities may not be equipped to process rice husk-based cardboard in the same way as standard cardboard, necessitating the development of new infrastructure.

  Collection and Transportation: Large-scale recycling requires an efficient system for collecting, transporting, and processing used cardboard. The need for transportation across wide distances can increase the carbon footprint, potentially negating some of the sustainability benefits.

  Economic Viability: The cost of recycling rice husk-based cardboard may be higher compared to traditional materials. In some regions, it may not be economically feasible due to limited recycling technology or insufficient demand for recycled cardboard.

  Solutions:

  Investment in Recycling Infrastructure: Governments and industries could invest in specialized recycling plants designed to process agricultural waste-based materials, including rice husk-based cardboard. Localized collection points and streamlined transportation could reduce the overall cost and environmental impact.

  Collaborations with Agricultural Industries: Partnering with the agricultural industry could help create an efficient waste collection system for rice husks, ensuring a steady and reliable supply of raw material for recycling.

  Economies of Scale: As demand for sustainable building materials increases, economies of scale could make the recycling of rice husk-based cardboard more cost-effective.

3.4. Challenges in Reuse for Construction

- *Problem:* Reusing rice husk-based cardboard in housing structures poses several challenges, particularly related to structural safety, material standards, and public perception
- *Challenges:*

  Structural Integrity: Unlike traditional construction materials like concrete or steel, rice husk-based cardboard may not meet the strength requirements needed for load-bearing elements, such as walls or roofs, without significant modification or reinforcement.

Building Codes and Regulations: Housing construction is heavily regulated, with strict building codes that materials must comply with. Cardboard, especially rice husk-based, may not currently meet the requirements in many regions for fire resistance, load-bearing capacity, or durability.

Public Perception: There may be resistance to using cardboard in housing construction, as it is often associated with packaging and perceived as a temporary or low-quality material.

- *Solutions:*

  Hybrid Building Materials: Cardboard can be used as part of a hybrid system, combined with more durable materials like wood, steel, or concrete. For example, cardboard panels could be used as insulation, partition walls, or non-load-bearing elements, while stronger materials provide structural support.

  Innovation in Building Design: Research into new architectural designs and construction methods could allow rice husk-based cardboard to be used effectively in housing structures, focusing on its insulation properties and lightweight nature.*Standards Development:* Collaborative efforts with industry bodies and regulators could lead to the development of new building codes and standards specifically tailored to sustainable, waste-based materials like rice husk-based cardboard.

3.5 Potential Solutions for Large-Scale Recycling and Reuse

3.5.1. Scaling Up Collection and Recycling Systems

- *Create Regional Collection Hubs:* Setting up regional hubs to collect, clean, and process rice husk-based cardboard could reduce transportation costs and ensure a steady supply of materials for recycling. These hubs could be linked to local construction projects, encouraging a circular economy.
- *Advanced Sorting and Cleaning Technology:* Introducing automated sorting and cleaning technologies could help separate contaminants and prepare rice husk-based cardboard for high-quality recycling. These technologies could be deployed in large-scale facilities to process mixed-material waste.

3.5.2. Improving Durability and Protection

- *Coating and Treatment:* Research into sustainable coatings, such as plant-based waxes or biodegradable polymers, could provide moisture and pest resistance to rice husk-based cardboard, making it more viable for long-term use in construction.
- *Reinforced Cardboard Products:* Cardboard can be combined with other recycled materials (e.g., fibers, resins, or plastics) to reinforce its strength, moisture resistance, and fire performance. These products could be marketed as eco-friendly alternatives to traditional construction materials.

3.5.3. Public Awareness and Acceptance

- *Educational Campaigns:* To overcome public skepticism, awareness campaigns could focus on the benefits of rice husk-based cardboard in housing construction, emphasizing its sustainability, low environmental impact, and potential cost savings.
- *Pilot Projects:* Demonstration projects showcasing the successful use of rice husk-based cardboard in residential or commercial buildings could help gain public and regulatory approval.

3.6 Conclusion

Recycling and reusing rice husk-based cardboard in housing structures presents several **logistical and technical challenges**, including contamination, degradation, and difficulties in large-scale recycling. However, by addressing these issues through **innovative recycling technologies**, **improved durability treatments**, and **collaboration with agricultural industries**, it is possible to create a more sustainable building material for the future. Additionally, **hybrid building designs** and **modified building codes** could enable the wider adoption of rice husk-based cardboard in construction, contributing to a more **sustainable and circular economy** in the construction industry.

4.0 Conclusion:

Rice husk-based cardboard offers significant environmental advantages, with a carbon footprint of approximately 1.1 kg CO_2e per kilogram, making it a highly sustainable material compared to traditional construction materials such as wood, metal, plastic, and concrete. It uses renewable, waste-based resources and is recyclable or compostable at the end of its life. While wood remains a sustainable option, it requires responsible sourcing to avoid deforestation. In contrast, metals, plastics, and concrete have high environmental impacts due to their energy-intensive production processes and disposal challenges.

Rice husk-based cardboard proves to be an excellent alternative, particularly for lightweight applications in construction, such as insulation, partitioning, and packaging materials. Despite challenges in recycling and reusing this material—such as contamination, degradation, and logistical difficulties—innovative solutions, including advanced recycling technologies, enhanced durability treatments, and collaborations with the agricultural industry, can address these issues. With appropriate modifications to building codes and the integration of hybrid building designs, rice husk-based cardboard could see broader adoption, contributing to a more sustainable and circular economy in construction. Ultimately, its use can help reduce the reliance on materials with higher environmental costs and promote greener, low-carbon construction practices.

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Author's Biography

Riya Richard Shawel is a member of Council of Architecture and Assistant Professor at the University, Sage Indore. She is a M.arch student at SOA IPS Academy Indore. She has made contribution in the field of construction industry. In her experience, she has the opportunity to participate in several consultancy projects in India.