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Sustainable Building Materials for Proposed Modular Housing in Munshiganj

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Abstract: Bangladesh, especially Munshiganj, has regular relocation owing to river erosion and flooding. In response, local people built portable homes from wood and corrugated metal. These residences are flexible although their façade systems consist of large prefabricated panels. Extensive use of metal sheets diminishes interior thermal comfort owing to their high heat conductivity. This research examines dwelling typology utilizing methodology of literature review, field surveys, thermal performance assessments from current studies, and local resident questionnaires. These findings led to a design proposal for standardized façade modules and a material selection framework. Research suggests a sustainable, material-centric modular dwelling design where thermal efficiency, comfort and local availability determine infill selections and structural frames use widely available wood species. By providing local, high thermal performance infill choices, this hybrid modular system promotes flexibility, thermal comfort, material efficiency, reusability, and long-term resilience than non-eco-friendly for rural houses in erosion-prone areas.

Keywords: *Modular Housing; Sustainable Materials; Local Building Materials; Thermal Conductivity; Rural Housing.*

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I. INTRODUCTION

In the river erosion-prone areas of Munshiganj, residents have devised an innovative method for constructing dwellings that may be relocated in response to recurrent flooding and land degradation. The district is located within the dynamic floodplains of the Padma, Meghna, and Brahmaputra river systems; thus, it experiences frequent flooding during the monsoon season, rendering permanent housing more precarious (Islam, 2007). Approximately 47.92% of the area is susceptible to varying degrees of floods. The southern and eastern regions of the district frequently see significant erosion of riverbanks due to powerful currents (Islam et al., 2012; Huda, 2020). Erosion frequently necessitates relocation, prompting residents to construct lightweight modular homes mostly using wooden frames and corrugated iron sheets. These residences may be disassembled and reassembled swiftly in safer locations, facilitating mobility and material repurposing (Huda, 2020). The warm and humid environment is conducive to comfort due to the high stilt foundations of the houses, pitched roofs with attic spaces, and many openings. This locally designed construction technique is a community-oriented, climate-responsive kind of modular housing shaped by accessible materials, economic conditions, and the requirements of its future inhabitants (Rashid, 2007; Kwansuwan, 2014). The facades are predominantly prefabricated rather than modular, complicating shipping, installation, and maintenance. This is due to their flexibility, cost-effectiveness, and rapid construction. Current residences predominantly utilize single-skin metal envelopes, such as galvanized and corrugated iron sheets, which are ineffective in retaining heat (Bansala & Rezwan, 2022). Nonetheless, there are some disadvantages, including high thermal conductivity and inadequate thermal insulation, noise disturbances, condensation issues, corrosion and rust, low environmental sustainability, and subpar indoor air quality. This scenario offers a significant potential to enhance the current system by integrating sustainable building materials and an improved modular design framework suited for environmentally sensitive areas. The objective of the project

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is to develop a standardized modular housing system constructed from sustainable materials suitable for areas such as Munshiganj, which are susceptible to river erosion and aims to incorporates alternative thermal, environmentally sustainable, and cost-effective solutions to improve adaptability and resilience through the utilization of sustainable materials.

II. RESEARCH BACKGROUND

A. Problem Statements

River erosion and constant flooding in Munshiganj require rural populations to shift repeatedly, rendering permanent housing unfeasible. Current portable wooden-tin homes provide mobility and affordability; nevertheless, the prevalent usage of corrugated iron sheets leads to inadequate thermal comfort due to high thermal conductivity, while imported construction materials elevate overall building expenses. Consequently, a climate-responsive, cost-effective, and flexible modular housing system is required, employing sustainable locally sourced materials to enhance thermal comfort, mobility, and long-term resilience in erosion-prone rural regions.

B. Aim and Objective of the Research

This research aims to create a sustainable and adaptable modular housing system for erosion-prone rural regions of Munshiganj by incorporating locally sourced low-thermal-conductivity materials with an enhanced modular façade design to improve thermal comfort, affordability, and resilience. The purpose of this research is as follows:

- To examine the current movable wooden-tin dwelling typology in erosion-prone regions of Munshiganj.
- To assess the thermal efficiency, cost-effectiveness, and sustainability of locally sourced construction materials for modular housing applications.
- To formulate a sustainable hybrid material approach utilizing locally available structural and infill materials appropriate for climate-responsive modular homes.

III. METHODOLOGY

This study employs a mixed-method approach that combines qualitative and quantitative analyses. An exhaustive literature analysis was undertaken to comprehend the implications of river erosion, mobility patterns, and the thermal behavior of prevalent rural construction materials. Subsequent field investigations were conducted in erosion-prone regions of Munshiganj to record house types, building methodologies, façade systems, and material utilization. A study of local homes gathered information on material preferences, affordability, and comfort assessments. The thermal performance investigation was based on comparative literature regarding metal sheets and other infill materials. A modular design concept was produced by synthesizing survey data and performance analysis, using standardized façade modules and recommendations for locally accessible materials to improve mobility, flexibility, and thermal comfort in erosion-prone rural homes.

IV. RESULT AND DISCUSSION

A. Proposed Modular Design

In the current construction practices of Munshiganj, craftsmen generally produce full-length wall panels that encompass the whole side of the home. Despite being prefabricated, these parts serve mostly as fixed façade panels rather than authentic modular components. Transporting, handling, and installing such massive panels is challenging, resulting in elevated labor demands and increased construction expenses. The utilization of imported Loha for wood frames and galvanized iron sheet infill increases the weight and length of these panels, hence restricting transportation, a crucial necessity in erosion-prone environments. To address these constraints, a reduced façade module measuring 4′ × 8′ has been implemented utilizing the same construction methodology. The frame will be simpler to construct, since it will not require an extended length of wood; a regular length will suffice. Additionally, bigger materials for the infill will be unnecessary, hence reducing the complexities associated with panel assembly. This modular method facilitates improved management, transportation, and on-site assembly, ensuring structural integrity upon installation. The method provides enhanced flexibility, allowing for the adjustment of housing measurements according to the number of modules utilized. An 8′ × 12′ structure may be constructed by integrating many standardized panels, facilitating scalable and flexible housing alternatives. Each modular element operates as an autonomous component that may be inserted, removed, or changed with minimal impact on the overall structure. The decreased weight of individual modules enhances mobility and reduces installation expenses compared to full-length premade panels. This methodology converts the current prefabricated technique into a genuine modular façade system appropriate for building in regions of Munshiganj susceptible to river erosion. The prefabricated modular wooden façade panels are illustrated in Figure 1. The left panel represents a standard 4′ × 8′ infill unit, subdivided by vertical and horizontal timber members for structural stability. The central panel is a full-height 4′ × 8′ door module incorporating a 2′6″ × 6′ double-leaf wooden door. The right panel illustrates a 4′ × 8′ window module, consisting of a 2′ × 4′ opening positioned in the upper portion of the panel and supported by multiple wooden shutters (Authors' research on Munshiganj's wooden houses). This proposed design allows for both vertical and horizontal growth. The modular structure allows for the addition or reduction of pieces, facilitating easy customization and adaptability to meet diverse spatial needs.

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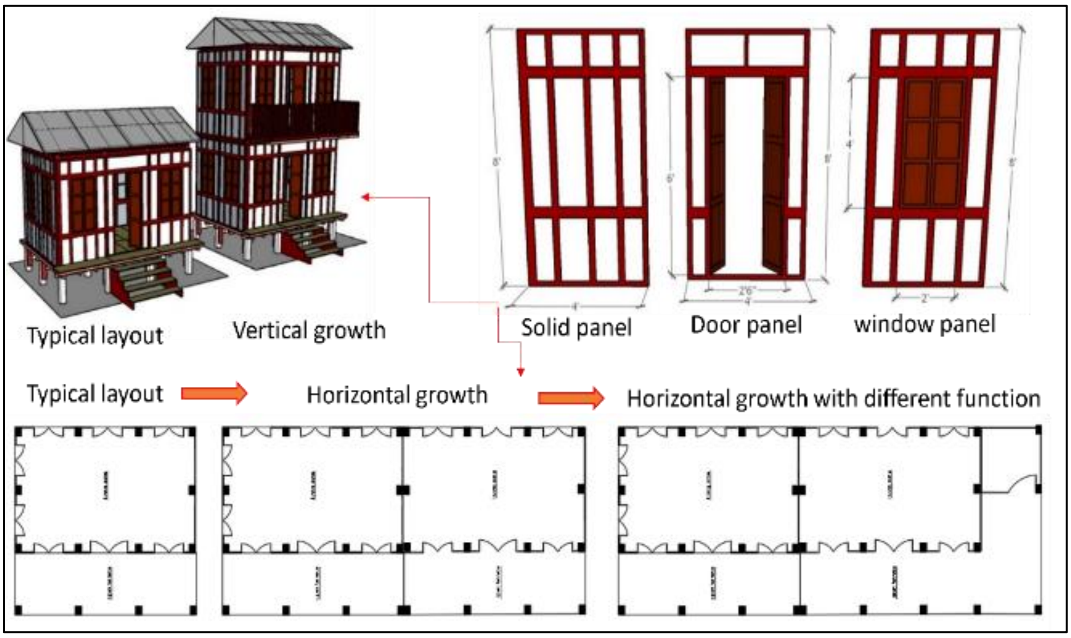

Fig 1. 4'/8' Modular Panel Integration in the Munshiganj Modular House (Authors).

Note. This 3D model and plan demonstrates the proposed 4′ × 8′ modular façade system would enhance transportation, assembly, flexibility, and material replacement efficiency for erosion-prone rural houses, making the process faster and more straightforward analyzed and built from the authors field survey and design concept development.

This approach will enable customers to select infill according to cost, material availability, and thermal performance. will also permit the substitution of interim infill with enhanced alternatives as necessary. This design enables the utilization of lightweight and low-thermal-conductivity materials such as bamboo, jute, or fiber cement boards, which are easy to manufacture, install, and manage.

B. Proposed Wooden Frame Materials

The utilization of imported timber, such azobe or teak the usage of Chambal in modular home construction substantially elevates the total building cost owing to elevated material prices and transportation charges. Imported timbers are priced at roughly 3,500–3,700 BDT per CFT, whilst locally sourced options including koroi, gamari, and mahogany vary from 600 to 1,900 BDT per CFT. Consequently, residences constructed using imported lumber may be five to six times more expensive than those with koroi and roughly double the cost of locally derived wood systems. Conversely, local timber resources enhance cost and accessibility for middle- and low-income families in Munshiganj. Their accessibility diminishes transit demand, bolsters local artisans, and mitigates environmental damage. The suggested modular system can decrease material costs by roughly 18–24% through the utilization of local timber (Table 1). This research advocates for the use of locally sourced wood species as the principal structural frame material for modular homes, assuring economic viability, sustainability, and contextual appropriateness (Authors' research on Munshiganj's wooden houses).

Table 1. Cost Comparison of Different Wood for the Components (Source: Authors)

Criteria	**Azobe wood**	**Koroi wood**	**Mahagony wood**	**Garjan/Jam/local Sal**	**Teak Chambal**	**Gamari**
Structural post, beam	41,976	6996	23,320	25,652	43,142	22,154
Floor and roof Frame	66,600	11,100	37,000	40,700	68,450	35,150
Floor	43,200	7200	24,000	26,400	44,400	22,800
Façade frame	47,880	7980	26,600	29,260	49,210	25,270
Total cost	199,656	33276	110,920	122,012	205,202	105,374

Note. The table compares the projected building expenses for different wood species utilized in modular home components, emphasizing the financial benefits of domestically supplied timber compared to imported options analyzed from the authors field survey

C. Proposed Infill Materials

According to the literature review, analysis, local field surveys, and user feedback, it is evident that traditional rural housing in Bangladesh predominantly utilizes locally sourced materials that are economical, low-maintenance, and resource-efficient, despite their lack of thermal and ecological sustainability.to identify superior solutions An essential criterion for evaluating the appropriateness of these

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materials is their thermal conductivity, which directly influences interior thermal comfort and overall livability. Thermal conductivity denotes a material's capacity to conduct heat, defined as the rate of heat transfer through a unit thickness and area under a unit temperature gradient (Latif et al., 2011). Materials exhibiting reduced thermal conductivity enhance heat resistance, consequently augmenting interior comfort in hot and humid situations. To assess the thermal performance of locally sourced materials, thermal conductivity measurements were aggregated by a comprehensive assessment of current literature. Research conducted by Rahman et al. (2023) and associated studies provide essential information to facilitate educated material selection for climate-responsive and sustainable architectural design. The subsequent Table 2 displays the thermal conductivity ratings of frequently utilized traditional materials in rural Bangladesh.

Table 2. Thermal Conductivity and Lifespan of Local Building Materials from Natural Material to Industrial Materials.

Material	Thermal Conductivity (W/m·K)	Life span (Years)
Bamboo (Longitudinal, Transverse direction)	0.55 – 0.59 0.39 – 0.43	≈20-100 (With proper treatment)
Wood	0.14 – 0.19	≈25-80 (With proper treatment)
Unburnt Brick	0.837	≈30-40
Tin (Corrugated Iron Sheet)	204	≈ 40-50
Fiber cement sheet	≈ 0.35 – 0.60	≈ 50 +
Fiber Cement Board	≈0.35–0.60	≈40–50
Jutin sheet	≈ 0.038–0.055	≈ 50

Note. The table displays the thermal conductivity and projected lifespan of frequently utilized natural and industrial construction materials, highlighting the thermal benefits of locally sourced low-conductivity materials for modular housing applications and studies cited from Rahman et al., 2023; Latif et al., 2011and authors local survey study.

Materials like bamboo, wood, and jute demonstrate thermal conductivity values under 1 W/m·K, offering enhanced heat resistance and superior habitability. Bamboo and indigenous timber species such as koroi, gamari, mahogany, and Garjan provide an optimal blend of cost-effectiveness, durability, and thermal efficiency for applications as structural components, façade panels, or flooring. When adequately treated with chemicals and seasonings, these materials can attain prolonged durability while staying economically viable and environmentally sustainable. Their local availability diminishes transportation expenses and bolsters local craftsmanship, rendering them suitable for modular housing in Munshiganj. Regarding the utilization of jute, which is not yet widely popular but possesses significant potential, both natural jute fiber and industrial materials such as resin and binders are required. If manufactured locally or regionally, it may serve as a suitable thermally efficient building material. Selecting lightweight local infill materials lowers total panel weight, facilitating the human lifting, transportation, and assembly of modules. Natural or composite infill panels are more amenable to repair or replacement than entire metal-sheet façades and are breathable (bamboo and jute), hence mitigating condensation and moisture buildup. Conversely, corrugated iron (CI) or galvanized iron sheets exhibit exceptionally high thermal conductivity, leading to rapid heat gain and inadequate indoor comfort when utilized without insulation. Despite their widespread use stemming from availability and durability, their thermal inefficiency constrains long-term habitability. It also has drawbacks like as susceptibility to corrosion, deterioration from weathering, and a lack of sustainability and environmental friendliness. Fiber cement sheets and fiber cement boards, as industrial materials, outperform CI or GI metal sheets and can enhance comfort when integrated with ventilated or layered assemblies. However, cost remains a concern, and these materials may need to be sourced from Dhaka or nearby regions. Among the materials examined, jutin exhibits superior thermal insulation characteristics and significant potential as a sustainable infill material. Due to its lightweight nature, renewability, and local sourcing, it is especially appropriate for modular panel systems. A hybrid technique utilizing indigenous hardwood frames combined with bamboo, jute, and fiber cement infill presents a cost-effective, climate-responsive, and sustainable material strategy for modular housing in erosion-prone regions of Munshiganj.

D. Proposed Design Findings

The current dwellings in Munshiganj exemplify effective community-based climate adaptation. Although the existing façade systems operate as extensive prefabricated panels rather than authentic modular sections as envisaged Compact standardized façade modules (4′ × 8′) enhance transportation, adaptability, and replacement efficiency. Conversely, corrugated iron and galvanized iron sheets have exceptionally high heat conductivity, leading to inadequate interior thermal comfort. Locally sourced wood species offer economical and resilient substitutes for imported timber in modular construction frameworks. Materials like bamboo, wood, and jute have poor heat conductivity, making them more suitable and cost-effective for local applications. Industrial materials such as fiber sheets or ferrocement sheets also have potential. The hybrid material strategy enhances environmental performance while ensuring affordability for rural communities. The suggested modular panel design allows for the installation of any chosen filler material based on cost, hence enhancing its potential. The interchangeable infill technique facilitates material enhancement over time, permitting the substitution of temporary or inexpensive materials with more resilient alternatives as economic conditions advance. This flexibility improves the long-term adaptation and lifecycle efficacy of the residence. Furthermore, the lightweight modular components enable

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straightforward repair, reuse, and relocation, so minimizing construction waste and promoting circular building practices. The method promotes local skill-based fabrication, enhancing community engagement and local job opportunities. The suggested modular design promotes thermal comfort and cost while also improving user flexibility, housing resilience, scalability, and sustainability, rendering it particularly appropriate for rural areas susceptible to river erosion, such as Munshiganj.

V. CONCLUSION

The analysis indicates that although the current modular housing approach in Munshiganj successfully tackles mobility and cost, it is constrained by non-modular façade design and the use of thermally inefficient materials. The prevalence of metal sheet enclosures undermines interior comfort, notwithstanding structural flexibility. Implementing standardized modular façade pieces and emphasizing locally sourced materials can substantially mitigate these constraints. The suggested system and methodology augment mobility, boost thermal comfort, promote local handicraft, and bolster long-term resilience. The results indicate that enhancing current methods via material optimization and modular refinement might yield a feasible housing concept for at-risk rural areas in Bangladesh.

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