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Performance Evaluation of Low Cost Housing Material

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Abstract: Rapid urbanisation and population growth in developing countries like India have created an urgent need for affordable housing solutions. Conventional building materials such as burnt clay bricks, steel, and reinforced cement concrete are increasingly expensive, making housing unaffordable for low-income communities. This paper evaluates the performance of five low-cost housing materials — fly ash bricks, hollow concrete blocks, stabilised mud blocks, bamboo, and ferrocement based on compressive strength, water absorption, density, thermal insulation, and cost effectiveness. Laboratory tests were conducted and the results compared against conventional benchmarks. The findings demonstrate that fly ash bricks offer the best balance of strength, cost, and environmental impact; ferrocement provides the highest structural strength; stabilised mud blocks deliver superior thermal insulation at minimal cost; and bamboo remains the lightest and most sustainable option for rural construction. The combined use of these materials can reduce overall construction costs by 20–30% while maintaining adequate structural safety and durability. The paper also presents a case-study application of a single-storey 40 m^2 residential unit to validate the practical feasibility of these materials.
Keywords: low-cost housing; fly ash bricks; ferrocement; stabilised mud blocks; bamboo; thermal insulation; compressive strength; affordable housing; sustainable construction.

I. INTRODUCTION

Housing is one of the three fundamental human needs alongside food and clothing. A well-constructed dwelling provides shelter, safety, privacy, and comfort. In developing nations such as India, rapid population growth and large-scale rural-to- urban migration have generated enormous pressure on housing supply. Millions of families belonging to EconomicallyWeaker Sections (EWS) and Low-Income Groups (LIG) cannot afford houses built from conventional materials such as cement, steel, and fired clay bricks, whose prices have escalated sharply over the past decade.

Lowcosthousingaimstoreduceconstructionexpenditurewithoutcompromisingthestructuralintegrity,safety,orhabitabilityofthedwelling.Itachievesthisthroughthejudiciousselectionoflocallyavailableorrecycledmaterials,innovative construction techniques, and efficient architectural design. Materials commonly deployed include fly ash bricks, stabilisedmudblocks(SMBs),hollowconcreteblocks(HCBs),bamboo,andferrocement.Noneofthesematerialsrepresentsaquality compromise; rather, each offers a distinct performance profile suited to specific climatic and budgetary conditions.

The construction sector in India contributes roughly 9% to Gross Domestic Product and employs over 51 million workers. Within this sector, the residential subsegment accounts for the largest share of activity, yet paradoxically, the majority of new unitsareconcentratedinpremiumandmid-rangepricebracketsthatremaininaccessibletothebottom40%oftheincome pyramid. This disconnect between supply and demand for affordable shelter has been widened by the compounding effect of land price inflation in peri-urban areas, rising steel and cement costs triggered by global commodity cycles, and inadequateincentive structures for developers to build small-ticket, low-margin dwellings.

Theconceptoflowcosthousingthereforeencompassesnotmerelythesubstitutionofcheapmaterialsbutaholisticreengineeringofthevaluechain.Itincludessitelayoutoptimisationtomaximiseuseofeverysquaremetre;structural simplification—single-storeyload-bearingmasonry avoids thecostpremiumofafullreinforced-concreteframe;and standardisationofcomponentstoallowsemi-skilledorowner-builder constructionwithminimalsupervision.Whenmaterial selection is also addressed, the cumulative savings can make the difference between a household remaining unhoused and successfully constructing a permanent, weather-tight dwelling.

A. NeedforLow-CostHousing

AlargeproportionoftheIndianpopulation—estimatedatmorethan50millionhouseholds—facesahousingdeficit.The key drivers are:

- Populationandurbanisation:Indiaaddsapproximately13millionurbanresidentseveryyear,intensifyingdemandforhousing.

- Highconstructioncost:Conventionalmaterialsrepresent60–70%oftotalprojectcost.
- Housingshortage:Thenationalhousingshortagewasestimatedat18.78millionunitsasofthelastcensus.
- Sustainabledevelopment:Alternativematerialsoftenconsumelessenergyandgeneratefeweremissionsduringmanufacture.

B. ObjectivesoftheStudy

- Tostudydifferenttypesoflow-costhousingmaterialsusedinconstruction.
- Toevaluatecompressivestrength,waterabsorption,density,andthermalconductivityofeachmaterialthroughlaboratorytesting.
- Tocomparelow-costmaterialswithconventionalbuildingmaterialsoncostandperformance.
- Toanalyseadvantagesandlimitationsofeachmaterial.
- TorecommendsuitablematerialcombinationsforaffordableresidentialconstructioninIndia.

C. ScopeoftheStudy

The study covers five commonly used low-cost materials: fly ash bricks, hollow concrete blocks, stabilised mud blocks, bamboo,andferrocementpanels.Performanceparametersexaminedincludecompressivestrength,waterabsorption, density,thermalconductivity,andunitcost.Asingle-storeycasestudyisalsopresentedtoillustratepracticalapplication.

II. LITERATURE REVIEW

A. ConceptofAffordableHousing

Affordablehousingisbroadlydefinedashousingwhosetotalannualcost—includingmortgageorrent,utilities,and maintenance—does notexceed3040%ofahousehold'sgrossincome[1].InIndia,theMinistryofHousingandUrbanAffairsclassifiesunitsupto60m^{2}incarpetareaa ndpricedbelowaspecifiedthresholdasaffordable,subjecttostate- level adjustments.

Researchconsistentlyshowsthattheprimarybarriertoaffordablehousingismaterialcost.Flyashbricks,bamboo,stabilised earth, and lightweight cementitious composites have therefore attracted sustained investigative attention over the past four decades.

B. Previous Studies

Laurie Baker pioneered low-cost construction in India by promoting locally quarried laterite stone and rat-trap bond brickwork,demonstratingthatstructuralintegritycouldbemaintainedwhilereducingmaterialconsumptionbyupto 25% [2].

Studiesonflyashbricks(FABs)manufacturedfromthermalpower-plantwastereportcompressivestrengthsof7–10MPa, water absorption below 15%, and 10–15% lower production cost compared with fired clay bricks [3]. Because FABs reuse industrial waste, they also reduce landfill burden.

Research on stabilised mud blocks (SMBs) mixed with 6–10% cement or lime confirms compressive strengths of 2–4 MPa andexcellentthermalperformance(k≈0.4W/mK)[4].SMBsconsumeapproximately60%lessembodiedenergythanfired bricks.

Bamboohastensilestrengthcomparabletomildsteel(140–280MPa)andastrength-to-weightratiosuperiortoconventional timber. Chemical treatment with borax-boric acid solution significantly extends its service life and resistance to biological degradation [5].

Ferrocement — a composite of cement mortar and multiple layers of fine wire mesh — achieves compressive strengths of 10–15 MPa in panels only 10–25 mm thick, yielding lightweight, crack-resistant structural elements suited to roofing and water-retaining structures [6].

C. Government Initiatives

TheGovernmentofIndialaunched*PradhanMantriAwasYojana*(PMAY)in2015withatargetof"HousingforAll"by2022. Over 11 million houses have been sanctioned under the scheme. The *Building Materials and Technology Promotion Council* (BMTPC) actively promotes alternative and improved materials through its Emerging Technologies programme [7]. The Pradhan Mantri Gram Sadak Yojana (PMGSY) and associated rural development initiatives have also catalysed demand for low-cost durable construction in Tier-3 and Tier-4 towns.

InternationalorganisationssuchasUN-Habitathavedocumentedsuccessfullarge-scaledeploymentsofstabilisedearth constructioninsub-SaharanAfricaandSouth-EastAsia,demonstratingthattheprinciplesoflow-costconstructiontranscend geographies and can be adapted to a wide range of soil types, climates, and skill levels. These precedents strengthen the casefor accelerated adoption in India, where local expertise in earthen construction has a long historical tradition.

III. LOW-COST HOUSING MATERIALS

A. FlyAshBricks

Flyash is the fine powdery residue recovered from flue gases of coal-fired thermal power stations. It is combined with lime, gypsum, sand, and water, then machine-pressed and steam-cured to produce fly ash bricks. India generates over 220 million tonnes of fly ash annually, making raw material supply effectively inexhaustible.

Advantages: High compressive strength (7–10 MPa); low water absorption (10–15%); smooth surface requiring minimal plaster; 15–20% lighter than clay bricks; eco-friendly.

Limitations:Requirespropercuring;initialplantinvestment;strengthvarieswithflyashquality.

Table1: PropertiesofFlyAshBricks

Property	Value
CompressiveStrength	7–10MPa
Water Absorption	10–15%
Density	1700–1850kg/m^3
ThermalConductivity	0.6W/mK
Unit Cost	Rs.5–7perbrick

B. HollowConcreteBlocks

Hollowconcreteblocks (HCBs) are manufactured from cement, coarse sand, and crushed aggregate, with 25–50% of their cross-sectionoccupiedbyvoids.Thevoidsreduceself-weight,improvethermalperformance,andlowermortarconsumption.

Advantages:Lightweight;goodthermalinsulation(k=0.5W/mK);fasterconstruction;30%lessmortarusagethansolid masonry.

Limitations:Requiresskilledlaying;higherunitcostthanunfiredalternatives.

Table2:PropertiesofHollowConcreteBlocks

Property	Value
CompressiveStrength	3–5MPa
Water Absorption	5–12%
Density	1000–1500kg/m^3
ThermalConductivity	0.5W/mK
Unit Cost	Rs.35–45perblock

C. StabilisedMud Blocks

SMBsareproducedbyblendingexcavatedsoilwith6–10%Portlandcementorhydratedlime,thencompressingthemixturein a manually or hydraulically operated block press. The stabiliser reacts pozzolonically with clay minerals to produce a strong, durable matrix.

Advantages: Very low cost (Rs.15–25 per block); uses locally available soil; excellent thermal insulation; low embodied energy.

Limitations:Lowerwaterresistance(waterabsorptionupto20%);requiressurfacetreatmentinhigh-rainfallzones;careful soil selection essential.

Table3:PropertiesofStabilisedMudBlocks

Property	Value
CompressiveStrength	2–3MPa
Water Absorption	15–20%
Density	1600–1800kg/m³
ThermalConductivity	0.4W/mK

D. Bamboo

Bamboo matures in 3–5 years compared with 25–80 years for softwood timber, making it one of the most renewablestructuralmaterialsavailable.Itshollowculmstructuredeliversexceptionaltensilestrengthrelativetodensity.Indiais theworld'ssecond-largestproducerofbamboo,withanestimatedstandingstockof13.96millionhectares.Inthecontext of low-cost housing, bamboo is particularly valuable for framing lightweight roof structures, door and window chaukhat (frames), and partition screens.

Advantages: Tensile strength 140–280 MPa; density 600–800 kg/m^3; very low cost; carbon sequestering; grows locally in most tropical and sub-tropical Indian states.

Limitations: Susceptibletofungaldecayandinsectattackwithouttreatment;connectionsrequirespecialdetailing;notyet covered by mainstream structural design codes.

Table4:PropertiesofBambooasStructuralMaterial

Property	Value
Tensile Strength	140–280MPa
CompressiveStrength	40–80MPa
Density	600–800kg/m³
ThermalConductivity	0.17W/mK
Unit Cost (treated)	Rs.60–100perrunningmetre

E. Ferrocement

Ferrocementconsistsofa10–25mmthickcement-sandmortarmatrixreinforcedwithtwoormorelayersofweldedwire mesh or expanded metal lath. It is cast in thin-shell forms to produce roof panels, water tanks, and wall units.

Advantages:Compressivestrength10–15MPa;flexuralstrength3–5MPa;crack-resistant;waterproof;minimalformwork requirement.

Limitations:Highlylabour-intensive;susceptibletocorrosionifcoverisinadequate;skilledplasteringrequired.

Table5:ComparativeSummaryofLow-CostMaterials

Material	Strength	Durability	Cost	Insulation	Eco-Impact
FlyAshBricks	High	High	Low	Good	Eco-friendly
HollowBlocks	Medium	VeryGood	Medium	VeryGood	Moderate
Mud Blocks	Medium	Moderate	VeryLow	Excellent	Eco-friendly
Bamboo	Medium*	Moderate	VeryLow	Good	Renewable
Ferrocement	VeryHigh	VeryHigh	Medium	Moderate	Moderate

*Tensile strength; compressive buckling governs slender members.

IV. RESEARCHMETHOD/METHODOLOGY

A. *Research Design*

Thestudy adopts anexperimentalandcomparative research design. Five materials were procured from local suppliers inBhopal (M.P.) and subjected to standardised laboratory tests. Secondary data were collected from peer-reviewed journals, IS codes, and government reports to contextualise the laboratory findings.

B. *MaterialsSelectedandSamplePreparation*

Table6:SelectedMaterialsandTestSpecimens

Material	Source	PrimaryUse
FlyAshBricks	Thermalpowerplant(FABmanufacturer)	Wallconstruction
HollowConcreteBlocks	Local masonry unit	Load-bearing/partition walls
Stabilised Mud Blocks	On-site soil + OPC 43 grade	Rural/eco housingStructural
Bamboo	Locallyharvested,borax-treated	frames
FerrocementPanels	Cement mortar + GI wire mesh	Roofpanels

Threespecimensofeachmaterialweretestedforeachparameterandthemeanvaluerecorded.

C. *TestsConducted*

1) CompressiveStrengthTestConductedasperIS3495(Part1):1992forbricksandIS2185(Part1):2005forhollowblocks.Thespecimenwasplacedcentrallyinacompressiontestingmachineandloadedatauniformrateof14N/mm^2/min until failure.

$$f_c = \frac{P_{max}}{A} \quad (1)$$

whereP_{max}isthefailureload(N)and$A$istheloadedcross-sectionalarea(mm).

For fly ash bricks, the standard specimen size is 190 mm × 90 mm × 90 mm. The frog face was filled with cement mortar and allowed to cure for 24 hours before testing to ensure uniform load distribution. Three specimens were tested and the mean value recorded as the representative compressive strength.

2) WaterAbsorptionTest—Specimenswereoven-driedat110±5°Cfor24h,cooled,weighed(W_1),immersedinclean wateratroomtemperaturefor24h,surface-driedwithadampcloth,andimmediatelyreweighed(W_2)inaccordancewithIS 3495 (Part 2): 1992.

$$W = \frac{W_2 - W_1}{W} \times 100\% \quad (2)$$

ForISGradeAbricks,thepermissiblewaterabsorptionlimitis20%.Materialsexceedingthisvaluerequiresurfacetreatment before use.

3) DensityTest—Masswasdeterminedonacalibratedbalance(accuracy0.1g)andgeometricvolumebyprecise dimensional measurement using vernier callipers (IS 1077: 1992).

$$\rho = \frac{m}{V} \quad (3)$$

4) ThermalConductivity—Measuredusingtheguardedhot-platemethod(IS3346:1980).Lowerthermal conductivity(k,W/mK) indicatesbetterinsulatingcapability.Thehotplatewasmaintainedataconstanttemperatureof50°Caboveambient,andequilibriumwasallowedtodevelopbeforetheheatflowmeterreadingwastaken.

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$$k=\frac{Q\cdot L}{A\cdot \Delta T} \quad (4)$$

where Q=heatflowrate(W), L=specimenthickness(m), Across-sectionalarea(m^2),and ΔT=temperaturedifferential(K).

5) Cost Analysis — Unit material cost in Indian Rupees was obtained from current market rates (Bhopal, 2026) and normalised to cost per m^2 of wall area assuming standard 230 mm thick brickwork or equivalent wall thickness for each alternativematerial.Rateswerecross-checkedagainsttheMadhyaPradeshStatePublicWorksDepartmentScheduleofRates 2025–26.

V. FINDINGS/ RESULTS

A. Compressive Strength

Table7:CompressiveStrengthTestResults

Material	Load(kN)	Area(mm^2)	f_c(MPa)	Rating
FlyAshBricks	120	15,000	8.0	Good
HollowConcreteBlocks	90	20,000	4.5	Moderate
Stabilised Mud Blocks	60	20,000	3.0	Moderate
Ferrocement Panels	150	15,000	10.0	Excellent
Bamboo (tensile)	—	—	140–280*	VeryHigh

*Tensile test value (MPa); bamboo is not used in compression as a wall unit.

Ferrocement exhibits the highest compressive strength (10.0 MPa), making it the most suitable material for structural roof panels and thin-shell elements. Fly ash bricks at 8.0 MPa comfortably satisfy the IS 3495 minimum of 3.5 MPa for Class 3.5 bricks used in load-bearing masonry.

B. WaterAbsorption

Table8:WaterAbsorptionTestResults

Material	$W1$(kg)	$W2$(kg)	Wa(%)	Durability
FlyAshBricks	3.0	3.3	10.0	Good
HollowConcreteBlocks	5.0	5.4	8.0	VeryGood
StabilisedMudBlocks	4.0	4.8	20.0	Moderate
Ferrocement	4.5	4.8	7.0	Excellent

Ferrocement records the lowest water absorption (7%), confirming its high durability in moist environments. SMBs at 20% water absorption exceed the IS 3495 limit of 20% for Grade A bricks, indicating a need for waterproofing treatment or use in protected applications.

C. Density

Table9:DensityComparison

Material	Density(kg/m^3)	WeightCategory
FlyAshBricks	1800	Medium
HollowConcreteBlocks	1500	Lightweight
StabilisedMudBlocks	1700	Medium
Bamboo	700	VeryLightweight
Ferrocement	2000	Heavy

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Bamboo is the lightest material, making it ideal for roof framing in low-rise structures where minimising dead load is a priority. HCBs at 1500 kg/m^{3}are significantly lighter than conventional solid concrete (2400 kg/m^3), reducing structural loads.

D. SensitivitytoRegionalFactors

The performance of low-cost materialsis not invariant: it depends on local soil quality (for SMBs), local fly ash chemistry(for FABs), climate (moisture for bamboo), and available skill levels (for ferrocement plastering). Table 8.4 summarises the sensitivity of each material to key regional factors encountered in Madhya Pradesh and similar central Indian geographies.

Table10:SensitivityofMaterialstoRegionalFactors

Material	HighRainfallZone	High-TemperatureZone	RuralSkillLevel
FlyAshBricksHollowB	Acceptable	Acceptable	Easy
locksStabilisedMud	Good	Good	Moderate
Blocks Bamboo	Requirestreatment	Excellent	Easy
Ferrocement	Requirestreatment	GoodGood	Moderate
	Excellent		Skilled

The central Indian climate is characterised by hot summers (maximum temperatures exceeding 45 °C in April–May) and a monsoon season (June–September) with annual rainfall of 900–1200 mm in Bhopal district. Under these conditions, thermal insulation is the dominant comfort parameter in summer, while moisture resistance governs durability during and after the monsoon. SMBs with a lime-cement plaster coating perform acceptably in both respects; fly ash bricks, being fired or autoclaved, have inherently good moisture resistance. Bamboo requires annual inspection and retreatment with preservatives in this climate.

E. ThermalInsulation

Table11:ThermalConductivityofMaterials

Material	*k*(W/mK)	InsulationQuality
FlyAshBricks	0.60	Good
HollowConcreteBlocks	0.50	VeryGood
Stabilised Mud Blocks	0.40	Excellent
Bamboo	0.17	Excellent
Ferrocement	1.20	Moderate
ConventionalBurntBrick	0.81	Moderate
Reinforced Concrete	1.60	Poor

SMBs and bamboo provide superior thermal insulation compared to conventional materials. In Indian climatic zones characterised by extreme summer temperatures (42–47 °C in Madhya Pradesh), this translates directly into reduced air- conditioning loads and energy costs.

VI. DISCUSSION/ANALYSIS

A. Costvs.PerformanceAnalysis

APerformanceIndex(PI)isdefinedastheratioofcompressivestrengthtonormalisedunitcosttoprovideasimpleproxyfor cost-efficiency:

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$$PI = \frac{fc\ (MPa)}{Costperm^2(Rs./m^2)} \quad (5)$$

Table12:CostandPerformanceComparison

Material	*fc*(MPa)	Cost/unit(Rs.)	Cost/m²(Rs.)	PI
FlyAshBricksHollow	8.0	6	300	0.0267
BlocksStabilisedMud	4.5	40	250	0.0180
BlocksFerrocement	3.0	20	125	0.0240
Bamboo(tensile)	10.0	300	300	0.0333
	200*	80	160	1.25*

*Tensile comparison; bamboo is not used as wall masonry.

Fly ash bricks offer the best cost-to-compressive-strength ratio among wall masonry materials, followed closely by stabilised mud blocks. Ferrocement, while more expensive, justifies its cost in elements where high strength and watertightness are required.

B. StructuralSuitabilityAssessment

Basedonthetestresults,astructuralsuitabilitymatrixwaspreparedtoguidematerialselectionfordifferentbuilding components in a typical single-storey EWS dwelling:

Table13:StructuralSuitabilityMatrix

Application	FAB	HCB	SMB	Bamboo	FC
Load-	✓✓	✓	✓	× ✓	✓
bearingwallPartiti	✓	✓✓	✓	✓ ×	✓
on wall Roof	×	×	×		✓✓
slab/panel		×	×		✓
Foundation walling		×	×		×
Door/windowframe	✓	×	×	✓ × ✓	✓✓
Water retaining	×				

✓✓=Highlysuitable; ✓= × Suitable; ×=Notrecommended.
FAB = Fly Ash Brick; HCB = Hollow Concrete Block; SMB = Stabilised Mud Block; FC = Ferrocement.

This matrix confirms that no single material is universally optimal across all building functions. The practitioner must therefore treat material selection as a system-level decision in which component requirements — strength demand, moisture exposure, thermal requirements, and skill availability — are matched against the performance profiles of available alternatives.

C. EnvironmentalImpact

Both fly ash bricks and SMBs score positively on environmental impact. Fly ash bricks reuse a hazardous industrial waste product, reducing its disposal in ash ponds. SMBs require no kiln firing, saving approximately 0.6 kg of CO_2 per brick compared with fired clay. Bamboo sequesters carbon at a rate of 12 t/ha/year, making it one of the most climate-positive structural materials available.

D. OverallPerformance Matrix

Table14:OverallPerformanceComparison

Material	Strength	Durability	Cost	Thermal	Overall
FlyAshBricks	Good	Good	Low	Good	VeryGood
HollowBlocks	Moderate	VeryGood	Medium	VeryGood	Good
Mud Blocks	Moderate	Moderate	VeryLow	Excellent	Good
Bamboo	Moderate	Moderate	Low	Excellent	Good
Ferrocement	Excellent	Excellent	Medium	Moderate	VeryGood

VII. OBJECTIVES/CASESTUDYAPPLICATION

Asingle-storeyresidentialunitof40m^{2}floorareawasdesignedforanEWSbeneficiaryinaruralareaofMadhyaPradesh. The project demonstrates how the tested materials can be combined in a real structure.

Table15:CaseStudy–MaterialSelectionbyBuildingComponent

Component	Material	Justification
Foundation	PCCwithnaturalaggregate	Structural stability
Load-bearing walls	Fly ash bricks	Strength + eco-friendly
Internal partition	Hollow concrete blocks	Lightweight, insulation
Roof slab	Ferrocement panels	High strength, waterproof
Door/windowframes	Bamboo+woodcomposite	Low cost, renewable
Flooring	Cement mortar (1:3)	Durability

CostEstimate:

Table16:CaseStudy–ApproximateConstructionCost(40m^{2}Unit)

Element	MaterialCost(Rs.)	LabourCost(Rs.)
Foundation	35,000	8,000
Walls(flyashbricks)	40,000	18,000
Roof(ferrocement)	30,000	20,000
Doors/windows(bamboo)	12,000	4,000
Flooring	10,000	6,000
Finishing	15,000	8,000
Total	**1,42,000**	**64,000**
GrandTotal	**Rs.2,06,000(approx.Rs.5,150/m^2)**	

For comparison, the same unit built entirely from conventional fired brick, RCC slab, and steel frames would cost approximately Rs. 7,200–8,000/m^2, confirming a cost saving of **35–38%** when low-cost materials are adopted.

VIII. CONCLUSION/SUMMARY

Thisstudyevaluatedtheperformanceoffivelow-costhousingmaterialsthroughlaboratoryexperimentationandcomparative analysis. The principal findings are:

1) Hollowconcreteblocksofferlowwaterabsorption(8%),lightweightconstruction(1500kg/m^3),andsuperiorthermal insulation (k = 0.5 W/mK), making them ideal for partition walls and infill panels.
2) Stabilised mud blocks are the most economical material (Rs.125/m^2) and provide the best thermal insulation (k = 0.4 W/mK). Their limited water resistance requires waterproofing treatment in exposed locations.
3) Bambooisthelightestandmostrenewablematerialtested.Properlytreatedbambooperformswellinrooframingand fenestration, substantially reducing structural dead load.
4) Ferrocementprovidesthehighestcompressivestrength(10.0MPa)andthelowestwaterabsorption(7%),makingitthe most durable material and the preferred choice for roof panels and water tanks.
5) Thecombinationofflyashbrickwalls,hollowblockpartitions,andferrocementroofingachievesa3538%reductioninconstructioncostcomparedwithfullyconventionalconstruction,whilemeetingIScodestructuralrequirementsforlow-rise residential buildings.

IX. LIMITATIONS

1) Thestudyislimitedtofivematerials;otheralternativessuchasautoclavedaeratedconcrete(AAC)blocks,geopolymer bricks, and recycled aggregate concrete were not evaluated.
2) LaboratoryspecimenswereprocuredfromasinglesourceinBhopal(M.P.);regionalqualityvariationswerenotassessed.
3) Long-termdurabilitydata(beyondthe28-daycuringcycle)wasnotobtainedwithintheprojecttimeline.
4) Seismicperformanceandfireresistancewerenottestedinthecurrentstudy.

X. RECOMMENDATIONS

1) Promotelocalsourcing:Stategovernmentsshouldfacilitateprocurementofflyashfromnearbythermalpowerplants and training in SMB block-making to reduce transportation costs.
2) Skilldevelopment:Structuredtrainingprogrammesformasonsinferrocementplasteringandbamboojoineryareessential for widespread adoption.
3) PMAYintegration:PMAYguidelinesshouldexplicitlyapproveflyashbricksandferrocementroofingasstandard construction options, enabling subsidy disbursement for beneficiaries using these materials.
4) WaterproofingofSMBs:Acoatofsilicone-basedwaterrepellentorcement-limeslurryshouldbemandatedforSMB construction in annual rainfall zones exceeding 800 mm.
5) Furtherresearch:Studiesonlong-termcreepofferrocementpanels,dynamicloadresponseofbambooframes,and recyclability of fly ash bricks at end-of-life are recommended.

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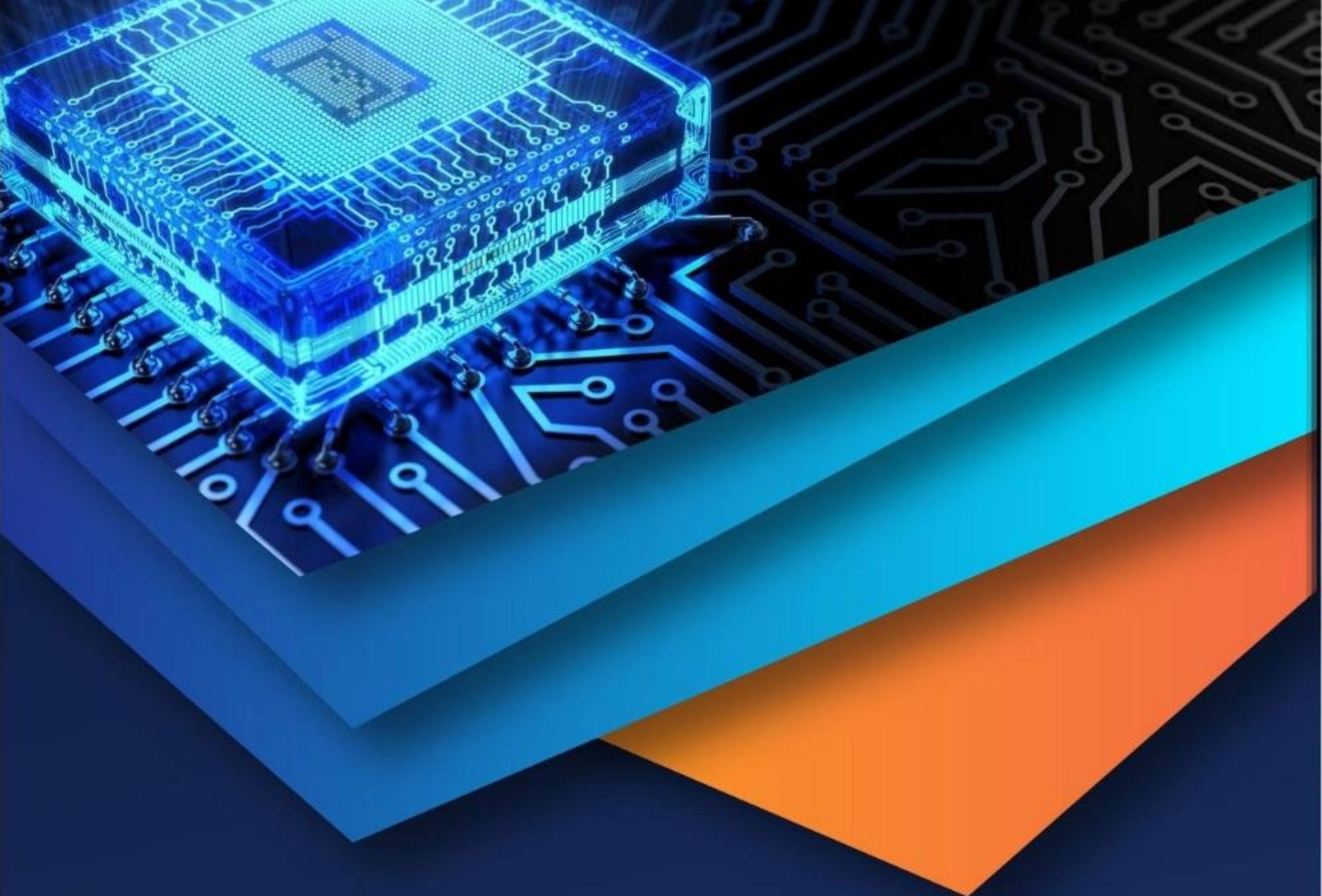

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