

Building Material Selection and Use

An Environmental Guide

2nd Edition



Northwestern
University

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World Wildlife Fund
1250 24th Street NW
Washington, DC 20037
USA
envirodm@wwfus.org
<https://envirodm.org>

Northwestern University
Institute for Sustainability and Energy
2145 Sheridan Road
Evanston, IL 60208
USA
isen@northwestern.edu
<https://isen.northwestern.edu>

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Authors and Contributors

Authors

Missaka Hettiarachchi PhD, CEng
Senior Fellow, World Wildlife Fund

Vidushi Dwivedi, MS
Research Assistant, Institute for Sustainability and Energy at Northwestern University
Currently Packaging R&D Engineer, Intel Corporation

William M. Miller, PhD
Professor of Chemical & Biological Engineering, Northwestern University

Stephen H. Carr, PhD, P.E.
Professor Emeritus of Materials Science and Engineering and Chemical and Biological Engineering, Northwestern University

Jennifer B. Dunn, PhD
Associate Professor of Chemical & Biological Engineering, Northwestern University

Mike M. McMahon
Strategic Partnerships Administrator, Institute for Sustainability and Energy at Northwestern University (ISEN)

Anita Van Breda
Senior Director, Environment and Disaster Management
World Wildlife Fund

Contributors

Jennifer Pepson-Elwood

Megan McConnell

Elham Ramyar

Vasanth Wakkumbura

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INTRODUCTION

Increasing populations, rising urbanization, economic expansion, and the emergence of new industrial centers are among the driving factors increasing demand for construction material around the world. Building materials required for reconstruction after disasters have further added to growing demands. The exponential increase in material extraction, processing, and disposal can cause significant environmental and social impacts such as soil erosion, deforestation, landslides, and floods; deprive communities of essential livelihood resources; and put people, infrastructure, and ecosystems at greater risk of future disasters.

Practical guidelines for responsible construction material selection and use are rare. This guide aims to fill a gap and provide guidance on better practices for government agencies, private sector companies, NGOs, and community-based organizations (CBOs) for environmentally responsible selection, sourcing, use and disposal of construction material.

A large variety of construction materials are available in different regions of the world. If builders select and use materials in an environmentally responsible manner while also using responsible construction technology and practices, future construction needs can be met while creating a safe and secure built environment.

AIM



The aim of this document is to provide a general guideline for engineers, architects, project managers, and technicians in construction projects to select, source (or procure), and use specific building materials in an environmentally responsible manner. It is assumed that the user has a basic knowledge about building materials and the construction process, but it is not necessary to have advanced technical training to use this tool.

The guide provides information on environmental better practices related to design, planning, storage, use, and disposal for common building materials, as well as key environmental costs and benefits. Quantitative information such as embodied energy, CO₂ footprint, water usage and several other engineering properties are also provided for each material. The guide also introduces the user to some useful overall concepts for environmentally responsible selection and use of building materials throughout a construction project and material life cycles.

This guide provides only general environmental information for each material; the actual process of material selection and use requires careful professional judgment in each individual case.

PROJECT CYCLE AND MATERIALS

Materials-related decisions in construction projects are not made at one given time. Different issues are addressed in material selection, sourcing, procuring, storage, use, and disposal and emerge at different stages of the project cycle. Figure 1 displays the typical building material-related decisions that need to be made and environmental issues at different stages of the project cycle.

For example, material selection can substantially impact the cost of construction and project management. This decision has to be made at the beginning of the inception stage even before the detailed designs are done—e.g., bricks versus rammed earth walls. More detailed issues, such as using water-based paints instead of solvent-based paints, can be addressed later in the design or construction stages. Disposal of waste material is an issue that arises in the construction stage, but the reuse or disposal methods and sites should be identified well in advance of commencing construction.

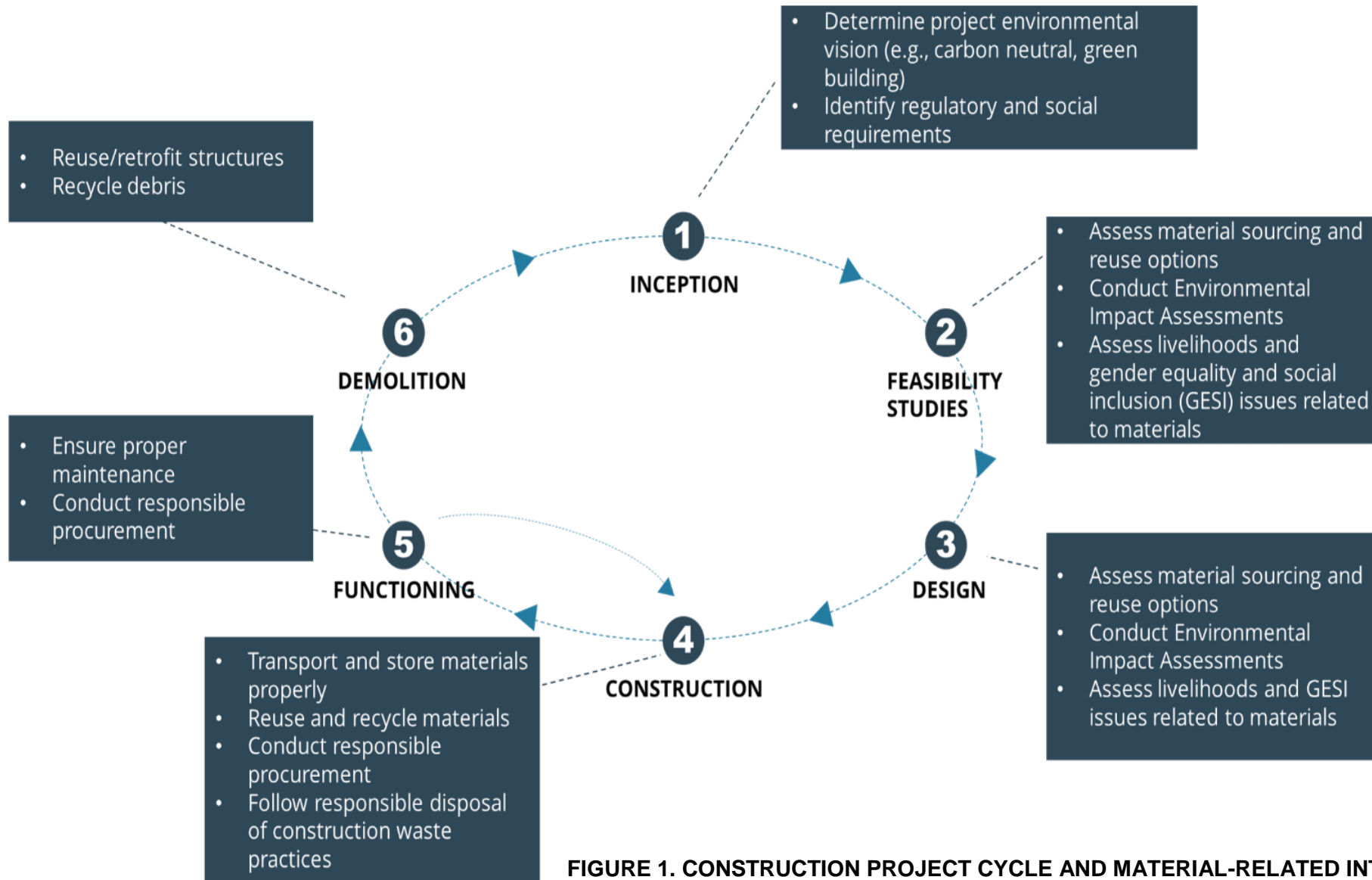


FIGURE 1. CONSTRUCTION PROJECT CYCLE AND MATERIAL-RELATED INTERVENTION POINTS

MATERIAL LIFE CYCLE

All materials come to the construction site through a process of extraction, transport, processing/manufacturing, packaging, and storage. Furthermore, the life of a material does not end after being used for construction; the structures are often demolished after a useful lifetime, and the materials are reused, recycled, repurposed, or disposed of. Some structures deteriorate with time, and the materials disintegrate into the environment. All these stages of the life cycle of a material may cause adverse environmental and social impacts.

Figure 2 displays the potential social and/or environmental impacts at different stages of a generic material life cycle.

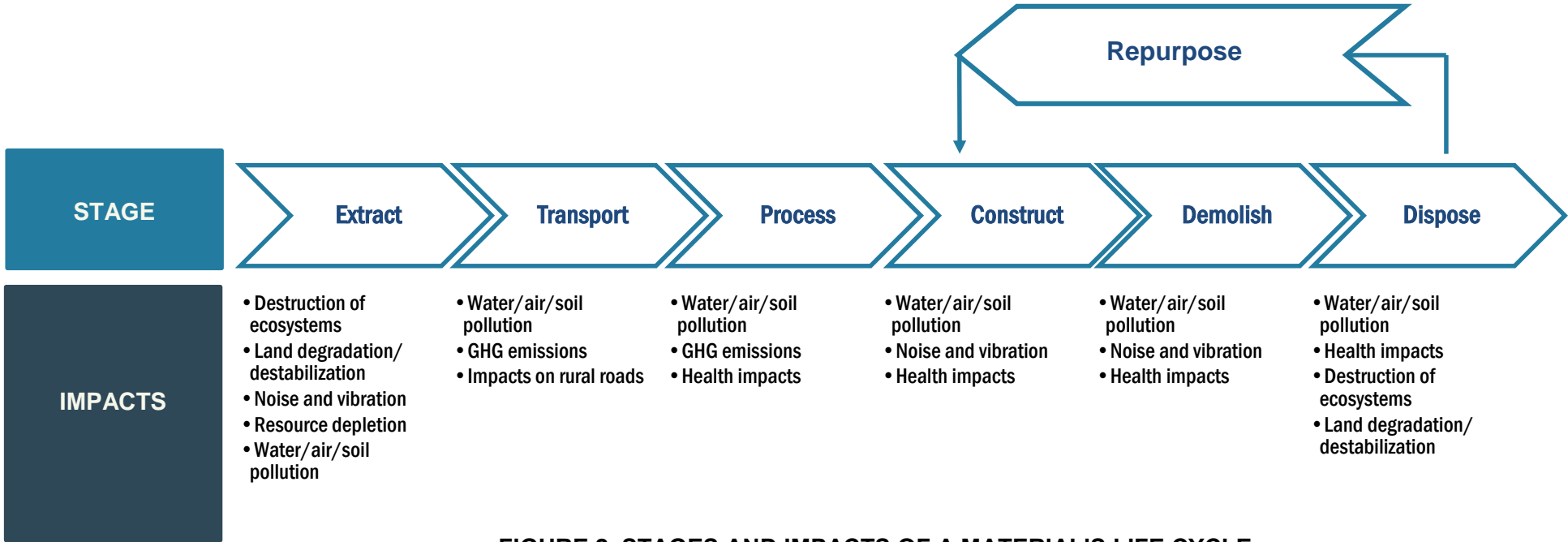


FIGURE 2. STAGES AND IMPACTS OF A MATERIAL’S LIFE CYCLE

RESPONSIBLE MATERIAL SELECTION AND USE: KEY CONCEPTS

1 Think through the whole supply chain. Environmental and social impacts from building materials can occur at any point in the supply chain, from sourcing raw materials, through processing and delivery to the site. This includes the social and environmental practices of manufacturers. For example, do working conditions at the processing plant meet responsible standards? Is the processing plant disposing of leftover material in an environmentally and socially responsible way?

The first criterion for an environmentally responsible material is the safety of the structure that will be built with it. “Not safe” is “not green.”

3 Design to use fewer materials and reduce waste. In designing structures, such as houses, project managers should consider ways to effectively meet humanitarian needs with fewer materials. Reducing packaging materials and designing structures with standard material sizes can help prevent waste of materials during the transportation and construction phases. Designing structures and specifying materials for optimal design rather than either overengineering or creating rigid requirements can reduce material waste by allowing some flexibility in construction and in material options. For example, if one material or size is not available locally, another can be used in its place to achieve optimal design instead of importing additional materials to fit a very specific requirement. Following material-specific storing and handling guidelines also helps extend the shelf life of materials and ensures that materials are not damaged and will not need to be replaced.

5 Use disaster debris as a reconstruction material. One of the most environmentally sustainable options for construction projects in a post-disaster setting is the reuse of building materials found in disaster debris. If using disaster debris, project managers must ensure that the debris meets applicable specifications for strength and safety.

2 Only support sound and legal sourcing of materials. In large-scale, post-disaster rebuilding, the demand for raw materials can quickly outstrip the supply of sustainably produced natural resources, such as clay for bricks, sand for cement, and wood for timber. For example, unsound excavation of clay or clear-felling of timber on steep hillsides to rebuild hundreds or thousands of houses increases the risk of landslides and topsoil erosion. Such environmental damage can increase risk and jeopardize the success of the overall recovery effort. Project managers should be aware of the sources of their building materials and make sure that they establish contract specifications for the use of sound and legally sourced materials. Using materials that have been credibly certified can be one strategy for ensuring that materials have been sourced sustainably. Material sourcing, processing, and use should be socially equitable. Any form of material sourcing that puts disproportionate burdens on women, children, differently abled or socially marginalized people is not sustainable. Furthermore, material sourcing should not disturb the established local livelihoods.

4 Use local sources—where this can be done in an environmentally responsible way. Local procurement of materials can be a more environmentally sound strategy than the procurement of distant materials because of reduced carbon emissions from transportation and natural resource use in packaging. Give priority to materials selected or processed with traditional knowledge. When using local materials, however, project managers should make sure that extraction, processing, and use do not put people’s health or environment at risk.

6 Use materials with recycled content and recycle. Materials with recycled content are widely available. One example is cement produced with fly ash from coal-fired power plants. Project managers should consider using building materials with recycled content where practical to reduce demand on natural resources and lower the project’s human and environmental impacts. Leftover material or material packaging should also be considered for reuse, repurposing, and/or recycling.

ACRONYMS

ABC	Aggregate Base Concrete
ACI	American Concrete Institute
BRE	Building Research Establishment
CBO	Community-based Organization
CGI	Corrugated Galvanized Iron
CSEB	Compressed Stabilized Earth Block
GESI	Gender Equality and Social Inclusion
HSE	Health and Safety Executive
NGO	Nongovernmental Organization

Definitions

CO₂ Footprint

In Table 1, we provide CO₂ footprint values for each material. We define CO₂ footprint as the CO₂ released per unit weight of finished material, including all the steps involved in obtaining, purifying, processing, transporting, and shaping each material into finished articles. CO₂ footprint values may not reflect locally-specific greenhouse gas emissions because, depending on location, supply chain and manufacturing methods may vary. Therefore, these values will serve as rough approximations rather than exact values.

Embodied Energy

In Table 1 we provide values for the energy expended in obtaining, purifying, processing, transporting, and shaping each material into finished articles. Embodied energy values may not reflect locally-specific values because, depending on location, supply chain and manufacturing methods may vary. Therefore, these values will serve as rough approximations rather than exact values.

Water Usage

In Table 1 we provide values for the water consumed while obtaining, purifying, processing, and shaping each material into finished articles. Water consumption values may not reflect locally-specific values because, depending on location, supply chain and manufacturing methods may vary. Therefore, these values will serve as rough approximations rather than exact values.

Table 1: ENVIRONMENTAL GUIDE TO SELECTION OF COMMON BUILDING MATERIALS

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives								
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)						
A. General Construction Material												
A1	River sand	<p>Types of Use</p> <p>Concrete, Cement mortar, Plaster (as a bedding material), Asphalt</p> <p>[None]</p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <table><tr><td>Embodied energy</td><td>0.06 MJ/Kg</td></tr><tr><td>CO₂ Emissions</td><td>0.004 Kg/Kg</td></tr><tr><td>Water Usage</td><td>3.60 l/Kg</td></tr></table>	Embodied energy	0.06 MJ/Kg	CO ₂ Emissions	0.004 Kg/Kg	Water Usage	3.60 l/Kg	<p>Extraction Erodes channel bed and banks, increases channel slope, and leads to changes in channel morphology. These impacts may cause:</p> <ul style="list-style-type: none">undercutting and collapse of riverbanksloss of adjacent land and/or structuresupstream erosiondownstream erosiondownstream changes in patterns of depositiondestruction of riverine habitats <p>Transport Transport using large trucks affects rural roads and may cause noise and air pollution.</p> <p>Production/Treatment None</p> <p>Toxicity None</p> <p>Benefits None</p>	Manufactured sand (crushed rock/gravel), Sea sand, Crushed rubble (debris), Fly ash/bottom ash, Recycled building and quarry dust	<ul style="list-style-type: none">Use alternatives to concrete/ mortar, e.g., stabilized earth walls (refer to section B)Use premixed concrete instead of in-situ mixingUse prefabricated concrete itemsOptimize concrete mix design to reduce material and energy requirementsUse standardized bricks to minimize mortar and plaster	<p>Storage Store in a manner free from contamination by other site materials, for example, by providing containment with proper base and curb. Protect from rain and other water sources.</p> <p>Use Adhere to the building specifications for mixing mortar and concrete and building. Overuse of the material will not add additional strength, and will cause waste. Mix in small adequate batches to minimize waste. Do not mix more fresh concrete/mortar than you will use in a two-hour period.</p> <p>Disposal Never dispose of washout cement, sand, cement mortar, or concrete in environment. They can be</p> <ul style="list-style-type: none">reused on-site/off-site for construction purposes (e.g., filling),safely transported to a construction material recycling facility, orsafely transported to a sanitary landfill
Embodied energy	0.06 MJ/Kg											
CO ₂ Emissions	0.004 Kg/Kg											
Water Usage	3.60 l/Kg											

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
A2	River gravel/ boulders [diverse rock minerals]	Concrete, Random rubble masonry, Aggregate base concrete (ABC), Road base, Manufacturing sand, Asphalt [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 7.8 - 8.7 CO ₂ footprint (kg/kg): 0.027 - 0.030 Water usage (l/kg): 3.85 – 4.17	Extraction Same as A1 Transport Transport using large trucks affects rural roads and may cause noise and air pollution. Production/Treatment Process often involves crushing into uniform sizes or fines (sand). Crushing plants cause noise, air pollution, silting of water bodies/ wetlands etc. Toxicity None Benefits In highly sediment or blocked streams, removal of river gravel and boulders may restore the flow.	Crushed rock, Crushed rubble (debris)	<ul style="list-style-type: none"> Plan and design construction to minimize waste Use alternatives to concrete/ mortar, e.g., stabilized earth walls Use premixed concrete instead of in-situ mixing Use prefabricated concrete items 	Storage Locate stockpiles to provide safe access for withdrawing material. Use Refer to A1 Disposal Refer to A1

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
A3	Quarried rock	<p>Concrete, Random rubble masonry, Aggregate base concrete (ABC),</p> <p>Road base, Manufactured sand, Asphalt</p> <p>[None]</p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 6.43 - 6.69 CO₂ footprint (kg/kg): 0.48 - 0.53 Water usage (l/kg): 13.0 - 14.4</p>	<p>Extraction Extraction from quarries involves blasting. Quarries cause noise, dust, air pollution, habitat destruction, and vibration if not properly managed. Unplanned rock quarrying can cause landslides and hydro-geological impacts. Without planning and protection blasting causes occupational hazards.</p> <p>Transport Transport using large trucks affects rural roads and may cause noise and air pollution.</p> <p>Production/Treatment Process often involves crushing into uniform sizes or fines (sand). Crushing plants cause noise, air pollution, silting of water bodies/wetlands etc.</p> <p>Toxicity None</p> <p>Benefits None</p>	Crushed concrete, Broken brick (for certain uses only)	<ul style="list-style-type: none"> • Use optimum mix design to minimize the quantity of quarried rock used • Select a quarry site close to the construction site to minimize distance of transportation • Consider mixing with recycled material (crushed concrete or broken brick) in design • Measures should be taken to prevent over-extraction. 	<p>Storage Locate stockpiles to provide safe access for withdrawing material and ensure minimum spill and waste.</p> <p>Use Refer to A1</p> <p>Disposal Refer to A1</p>

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
A4	<p>Ordinary Portland Cement (OPC)</p> <p>[63% CaO, 21% SiO₂, 6% Al₂O₃ + additions]</p>	<p>Concrete, Mortar, Plaster, Stabilized earth construction/ blocks</p> <p>[consistent quality, predictable structural strength]</p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 7.75 – 8.60 CO₂ footprint (kg/kg): 1.08 - 1.20 Water usage (l/kg): 35.1 - 38.8</p>	<p>Extraction Uses limestone and other minerals extracted from quarries or mines in manufacturing, which can cause severe mining impacts.</p> <p>Transport Transport using large trucks affects rural roads and may cause noise and air pollution.</p> <p>Production/Treatment Produces greenhouse gases both, directly through the production of carbon dioxide when calcium carbonate is heated (producing lime and carbon dioxide), and indirectly through the use of energy, particularly if the energy is sourced from fossil fuels.</p> <p>Toxicity None</p> <p>Benefits None</p>	Lime mortar, Other cement-derived material (not suitable for concrete)	<ul style="list-style-type: none"> • Use alternatives to concrete/mortar, e.g., stabilized earth walls • Use premixed concrete instead of in-situ mixing • Use prefabricated concrete items • Optimize concrete mix design (don't over-specify) • Use standardized bricks/blocks to minimize mortar and plaster • Use precast concrete designs for construction; precast concrete can be designed to optimize (lessen) the amount of concrete used in a structure or element 	<p>Storage Store cement in a building that is dry, leak-proof, and as moisture proof as possible. There should be a minimum number of windows in the storage building. Stack the cement bags off the floor on wooden planks in such a way, so that bags are about 150 mm to 200 mm above the floor.</p> <p>Use Use quantities as specified in the optimum mix design. Avoid wastage by calculating adequate hauling times when purchasing premixed concrete and use retarders in case of long hauls. Do not mix more fresh concrete or cement than you will use in a two-hour period. Also refer to A1</p> <p>Disposal Refer to A1 Never dispose of cement slurry or washout in streams or street drains. Never dispose of empty cement bags in the environment. Instead, dispose of them in a sanitary landfill. Never dispose of washout cement, sand, cement mortar, or concrete in environment. They can be:</p> <ul style="list-style-type: none"> • Reused on-site/off-site for construction purposes (e.g., filling), • Safely transported to a construction material recycling facility, or • Safely transported to a sanitary landfill

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
A5	Stone (e.g., granite, gneiss, sandstone, basaltic rocks)	<p>Concrete, Random rubble masonry, aggregate base concrete (ABC), Manufacturing sand, asphalt, walls</p> <p><i>[Building and cladding, used for high performance or vibration sensitive equipment]</i></p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 7.74 - 8.71 CO₂ footprint (kg/kg): 0.55 – 0.64 Water usage (l/kg): 3.23 - 3.57</p>	<p>Extraction Refer to A1</p> <p>Transport Refer to A1</p> <p>Production/Treatment Process often involves crushing into uniform sizes or fines (sand). Crushing plants cause noise, air pollution, silting of water bodies/wetlands etc.</p> <p>Toxicity None</p> <p>Benefits None</p>	Recycled debris	<ul style="list-style-type: none"> Plan and design construction to minimize waste Use alternatives to concrete/mortar, e.g., stabilized earth walls Use premixed concrete instead of in-situ mixing Use prefabricated concrete items 	<p>Storage Locate stockpiles to provide safe access for withdrawing material.</p> <p>Use Refer to A1</p> <p>Disposal Refer to A1</p>
A6	<p>Concrete (different Grades)</p> <p><i>[Water: OPC : Fine aggregate (sand): Coarse aggregate]</i></p>	<p>Walls, Foundation, Roofing</p> <p><i>[Has good compressional strength, but not good under tension. Hence, there is a need for reinforcement with steel bars/ timber or bamboo]</i></p> <p><i>If 30% coarse recycled aggregates are used, 17% lower elastic modulus is obtained, which makes concrete still usable depending on the desired strength requirements.</i></p>	<p>Extraction Refer to A1 to A5</p> <p>Transport Refer to A1 to A5</p> <p>Production/Treatment Refer to A1 to A5</p> <p>Toxicity Refer to A1 to A5</p> <p>Benefits Refer to A1 to A5</p>	<p>Stabilized earth blocks or walls, Straw clay walls, Bamboo/timber reinforced earth walls, Prefabricated wall panels</p>	<ul style="list-style-type: none"> Use alternatives to concrete/ mortar, e.g., stabilized earth walls (refer to section B) Use premixed concrete instead of in-situ mixing Use prefabricated concrete items Optimize concrete mix design (don't over-specify) (BRE mix design, ACI method of concrete mix design) Use standardized bricks to minimize mortar and plaster 	<p>Storage Refer to A1</p> <p>Use Refer to A1</p> <p>Disposal Refer to A1 Recyclable, Downcycle. Landfill, non-biodegradable, non-toxic, not a renewable source</p>

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
		<p><i>Lowering water to cement ratio helps in reducing permeability (can be used in areas having high rainfall)]</i></p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 3.16 - 3.58 CO₂ footprint (kg/kg): 0.24 - 0.27 Water usage (l/kg): 3.23 - 3.57</p>				<p>Reuse: Can be directly re-used during land rehabilitation, concrete can be crushed manually and re-used as filler for abandoned pits, drainage trenches and other surface irregularities. This also provides local income. Should never be directly re-used for structural purposes.</p> <p>Recycle Concrete can be crushed and recycled as aggregate or for building and road base material or foundation bedding etc. Concrete can be crushed manually; with a mobile crushing unit or transported to a specialised concrete crushing plant. Location, volume of concrete waste, local demand for aggregates and availability of other types of aggregates are determining factors in the choice of crushing method. If the concrete is reinforced, material such as steel rebar may block crushing machines if they are not designed to separate the steel from the concrete. Proper assessment must take place to ensure no asbestos is present prior to crushing.</p>
A7	<p>Concrete (insulating, lightweight)</p> <p><i>[Water: OPC: sand: lightweight coarse aggregate – e.g., shale, slate, clay]</i></p>	<p>Refer to A6</p> <p><i>[None]</i></p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 1.60 – 1.76 CO₂ footprint (kg/kg): 0.177 - 0.128 Water usage (l/kg): 14.3-15.8</p>	Refer to A6	Refer to A6	Refer to A6	Refer to A6

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
A8	<p>Aerated concrete (low density)</p> <p><i>[Water: OPC: Foam or chemically induced gas bubbles: fine filler – crushed sand]</i></p>	<p>Walls, Roofing, Sound insulation, Fire resistance</p> <p><i>[None]</i></p> <p><i>[As compared to ordinary concrete, aerated concrete has a lower density, hence it is lightweight and provides intentionally entrained air voids to improve resistance to freezing and thawing in moist areas.</i></p> <p><i>Easy to nail, shape and render, but it has low wear resistance.]</i></p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 1.73 - 1.86 CO₂ footprint (kg/kg): 0.187 - 0.207 Water usage (l/kg): 14.30 - 15.80</p>	Refer to A1 to A5	<p>Stabilized earth blocks or walls, Straw clay walls, Bamboo/timber reinforced earth walls, Prefabricated wall panels</p>	Refer to A6	<p>Storage Refer to A1</p> <p>Use Refer to A1</p> <p>Disposal Refer to A6</p>

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
A9	High volume fly ash concrete [(0.8:1:1:4.67:1.33:5) Water, Ordinary Portland Cement, Fly ash, Coarse sand, Gravel, Rock]	Walls, Foundation, Roofing [Fly ash makes the concrete stronger, more durable and easier to work with] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 6.09 – 6.73 CO ₂ footprint (kg/kg): 0.116 - 0.128 Water usage (l/kg): 3.23 - 3.57	Refer to A1 to A5	Stabilized earth blocks or walls, Straw clay walls, Bamboo/timber reinforced earth walls, Prefabricated wall panels	Refer to A6	Storage Refer to A1 Use Refer to A1 Disposal Refer to A6
A10	Latex concrete [0.8:1.1:1:1:4.67:1.33:5 Water, Latex admixture, Ordinary Portland Cement, Fly ash, Coarse sand, Gravel, Rock]	Walls, Foundation, Roofing [Makes the cement highly moisture resistant, highly durable] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 6.09 – 6.73 CO ₂ footprint (kg/kg): 0.116 - 0.128 Water usage (l/kg): 3.23 - 3.57	Refer to A1 to A5	Stabilized earth blocks or walls, Straw clay walls, Bamboo/timber reinforced earth walls, Prefabricated wall panels	Refer to A6	Storage Refer to A1 Use Refer to A1 Disposal Refer to A6

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
A11	Polyvinyl Alcohol (PVA) and cellulose fiber-cement <i>[2-4% PVA, 8-10% cellulose, 10-15% carbonate filler, 4-6% silica fume, 65-70% OPC (% by volume)]</i>	Walls, Foundation, Roofing <i>[PVA fibers increase flexural and compressive strength properties of concrete]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 6.09 – 6.73 CO ₂ footprint (kg/kg): 0.116 - 0.128 Water usage (l/kg): 3.23 - 3.57	Extraction High energy consumption to extract cellulose from plant materials Production/Treatment High energy consumption and cost Toxicity None Benefits Non-hazardous, cellulose is a renewable material	Stabilized earth blocks or walls, Straw clay walls, Bamboo/timber reinforced earth walls, Prefabricated wall panels	Refer to A6	Refer to A6
A12	Polypropylene Fiber-Reinforced Concrete <i>[<0.5% polypropylene fibers by volume, OPC, fine aggregate]</i>	Walls, Foundation, Roofing <i>[Polypropylene fibers reduce shrinkage and temperature cracking and increase toughness and impact resistance]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 6.09 – 6.73 CO ₂ footprint (kg/kg): 0.116 - 0.128 Water usage (l/kg): 3.23 - 3.57	Refer to A1 to A5	Asbestos concrete, Stabilized earth blocks or walls, Straw clay walls, Bamboo/timber reinforced earth walls, Prefabricated wall panels	Add fibers to concrete mix at the site if it takes more than 30 minutes to get to the site. Refer to A6	Refer to A6

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
A13	Cellulose Fiber-Reinforced Concrete <i>[0.2-0.5% cellulose by weight]</i>	Walls, Foundation, Roofing <i>[Cellulose can be obtained from agricultural waste, wood, plants.</i> <i>Cellulose fibers are used for the control and mitigation of plastic shrinkage cracking]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 6.09 – 6.73 CO ₂ footprint (kg/kg): 0.116 - 0.128 Water usage (l/kg): 3.23 - 3.57	Refer to A1 to A5	Asbestos concrete, Stabilized earth blocks or walls, Straw clay walls, Bamboo/timber reinforced earth walls, Prefabricated wall panels Alternatives to cellulose: Synthetic fibers, Steel reinforcing bars	Refer to A6	Refer to A6
A14	Glass Fiber reinforced composite (GFRP) <i>[Epoxy + glass fiber reinforcement]</i>	Reinforcing concrete <i>[Can be used as an alternative to steel rebar. Enhances strength significantly]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 115 – 129 CO ₂ footprint (kg/kg): 7.17 – 7.80 Water usage (l/kg): 212 - 240	Extraction Manufactured using glass fiber and epoxy. Refer G3 and E3 Production/Treatment Refer G3 and E3 Toxicity Refer G3 and E3 Benefits Non-corrosive, high strength	Steel rebar, Natural reinforcing materials	Use only in special cases where steel or natural forms of reinforcement is not applicable. The environmental costs of GFRP are generally higher. Design carefully to minimize overuses, do not over specify. Minimize cutting at site.	Storage Store in place protected from extreme weather and fire. Refer E3 Use Refer G3 and E3 Disposal Cannot be recycled, non-biodegradable, non-renewable, cannot be combusted for energy. Can be put in landfill or downcycle

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A15	Low carbon steel [<0.3% carbon content]	<p>Reinforcing concrete. Used in bars of different diameters, for columns, beams, slabs and structural walls of building. Also used in reinforcing foundations.</p> <p>Available in different standard diameters (e.g. 6mm, 10 mm, 12mm, 16mm, 20mm). Made in mild or yield steel of compressive strength grade 250 N/mm².</p> <p><i>[Surface treatment by: Carburizing, pickling, zinc or zinc-nickel pickling, phosphate or chromate treatments, galvanization and passivation.]</i></p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 35.8 – 39.6 CO₂ footprint (kg/kg): 2.53 – 2.80 Water usage (l/kg): 43.2 - 47.7</p>	<p>Extraction Requires large scale extraction of iron ore, causing significant environmental impacts including deforestation, land degradation, and hydrological modifications. High energy consumption and greenhouse gas (GHG) emissions, in extraction and transport. Mining often releases toxic and pollutive minerals.</p> <p>Production/Treatment Smelting of iron ore and forging and drawing of steel bars is highly energy intensive and releases massive quantities of GHGs. Produces potentially hazardous waste material, which can be damaging health and environment, if not properly managed.</p> <p>Toxicity None</p> <p>Benefits Commonly available, easily recyclable into other steel products</p>	GFRP, Natural reinforcing materials	<ul style="list-style-type: none"> • Use certified products and avoid using in corrosive environments • Avoid contact with ground or high levels of moisture • Encourage reuse of uncorroded sheets from old buildings • Use standard sizes 	<p>Storage Store in a dry place</p> <p>Disposal Will have lost its some of its structural properties during use. Recycle, downcycle, landfill. Non-biodegradable, cannot be combusted for energy, non-renewable</p>

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B. Wall Material						
B1	<p>Burnt brick (common)</p> <p><i>[Made of fired clay, with impurities of potash, lime, soda and oxides of iron (which is responsible for imparting the red color) and aluminum]</i></p>	<p>Walls, Columns, Foundations, Floor paving</p> <p><i>[Most bricks are porous and are glazed if they need to resist water. To do this, the surface of the fired brick is painted with a mixture of glass-forming fluxes. The brick is then fired again, which melts the glaze, and forms a glassy surface on the brick.</i></p> <p><i>Engineering brick is used where high strength, low porosity, and high frost resistance are required. Common brick is used where appearance is not important, or where it will be rendered/plastered.]</i></p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 11.9 - 15.7 CO₂ footprint (kg/kg): 0.75 – 1.03 Water usage (l/kg): 5.27 - 5.83</p>	<p>Extraction Mining of surface clays, shales, and some fire clays occurs in open pits with power equipment; then the mixtures require transport to plant storage areas.</p> <p>Transport Transport using large trucks affects rural roads and may cause noise and air pollution.</p> <p>Production/Treatment Brick firing is an energy-intensive process. The brick industry is therefore one of the largest consumers of firewood and coal and, hence, is also a significant air polluter. Air pollution and the use of good-quality agricultural soil are the major environmental concerns related to the use of bricks. Brick kilns may emit toxic fumes (suspended particulate matter, carbon monoxides, and oxides of sulphur—SO_x) that are harmful to eyes, lungs, and throat.</p> <p>Toxicity None</p> <p>Benefits None</p>	<p>Cement blocks, Stabilized earth blocks, Stabilized earth walls, Straw clay walls, Bamboo/timber reinforced earth walls, Prefabricated wall panels</p>	<ul style="list-style-type: none">• Produce bricks on-site (e.g., stabilized earth blocks)• Encourage reuse of bricks from demolished buildings• Use standardized, quality-controlled bricks for construction• Reduce wastage by accurately estimating brick requirement• Use standard lengths and optimal wall thicknesses in design to minimize brick waste	<p>Storage Properly package/load bricks during transport and store in a dry place in suitable stack heights.</p> <p>Use Not significant</p> <p>Disposal Never dispose of bricks/blocks in streams, wetlands, coastal areas or agricultural lands. Non-biodegradable, cannot be combusted for energy recovery, can be downcycled or put in landfill.</p> <p>Reuse Bricks/blocks in sound condition can be directly reused for on-site/off-site construction purposes (e.g. walls), if damaged can be used for filling or paving. They can be resold to the community and/or re-used in reconstruction programs. The presence of cement mortar or glues can hinder re-use as they are unable to be cleaned off.</p> <p>Recycle Safely transport to a construction material recycling facility. Can be recycled into coarse aggregate, fillers, base, paving material, or landscaping applications.</p>

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B2	Cement blocks [Refer to A6]	Walls <i>[None]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 7.75 – 8.60 CO ₂ footprint (kg/kg): 1.08 -1.20 Water usage (l/kg): 35.10 - 38.80	Extraction Requires cement, quarried and mined material (e.g., sand, rock chips, and gravel). (see A1 , A2 , A3 , and A4) Transport Transport using large trucks affects rural roads and may cause noise and air pollution. Production/Treatment Manufacturing uses power or manually operated pressure moulds. Casting yards can cause dust, noise and silt problems. Toxicity None Benefits <ul style="list-style-type: none">• No firewood demand• Minimal air pollution	Stabilized earth blocks, Stabilized earth walls, Straw clay walls, Bamboo/timber reinforced earth walls, Prefabricated wall panels	<ul style="list-style-type: none"> • Use standardized and good quality blocks for construction • Use accurate estimates to purchase blocks—this will minimize wastage • Produce concrete blocks on-site • Ensure quality control in manufacturing and use standard lengths and optimal wall thicknesses in design to minimize brick waste • Use proper packaging/loading practices in transporting 	Storage Refer to B1 Use Not significant Disposal Refer to B1 Reuse Refer to B1 Recycle Refer to B1 . Apart for landscaping applications.

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B3	Compressed stabilized earth blocks/ CSEB [5% cement, 95% mud (compressed into blocks) (by vol)]	Walls [not suitable for high-moisture environments or load-bearing walls, unless tested specified by a structural engineer]	<p>Extraction Requires soil with small amounts of sand and cement. Soil extraction can cause habitat destruction and landslides and can pollute water bodies and alter hydrology.</p> <p>Transport Transport using large trucks affects rural roads and may cause noise and air pollution.</p> <p>Production/Treatment Manufacturing uses power or manually operated pressure molds. Casting yards can cause dust, noise and silt problems.</p> <p>Toxicity None</p> <p>Benefits</p> <ul style="list-style-type: none"> • No firewood demand • Minimal air pollution • Minimal demand for quarried material • Minimal transport requirement 	Stabilized earth walls, Straw clay walls, Bamboo/timber reinforced earth walls, Prefabricated wall panels	<ul style="list-style-type: none"> • Design the building to match available block dimensions • Produce CSEB on-site with proper quality control, this will reduce the cost of transportation and production 	<p>Storage Refer to B1</p> <p>Use Not significant</p> <p>Disposal Refer to B1</p>

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B4	<p>Earth walls (stabilized earth, clay-straw, rammed earth, bamboo reinforced earth)</p> <p><i>[stabilized earth, claystraw, rammed earth, bamboo reinforced earth; 75%-85% soil (40%-70% sand, 10%-20% clay, 30%-60% gravel), 6%-10% cement, 9.5% - 11% water]</i></p>	<p>Walls</p> <p><i>[not suitable for high-moisture environments or load-bearing walls, unless tested specified by a structural engineer]</i></p>	<p>Extraction Requires soil with small amounts of sand and cement. Soil extraction can cause habitat destruction and landslides and pollute water bodies and alter hydrology.</p> <p>Transport Transport requirement is minimal.</p> <p>Production/Treatment Fabricating is in-situ using wooden or steel formwork and soil/clay.</p> <p>Toxicity None</p> <p>Benefits</p> <ul style="list-style-type: none"> • No fire wood demand • No air pollution • No demand for quarried material • Minimal transport requirement • Readily available in tropical climates, particularly in Sri Lanka* 	<p>Straw clay walls, Bamboo/timber-reinforced earth walls, Prefabricated wall panels</p>	<ul style="list-style-type: none"> • Match available steel or wood formwork dimensions with the structural dimensions of the building • Reduce construction time with proper planning • Use only in areas where earth can be extracted without causing hazards or environmental impacts • Use standard lengths and optimal wall thicknesses • Allow for sufficient curing time (4 days) to accommodate drying, shrinkage, and cracking 	<p>Storage Store soil in a dry, enclosed space.</p> <p>Use Use optimum mix proportions and only mix in small and adequate batches.</p> <p>Disposal Never dispose of demolished wall material in streams, wetlands or coastal areas.</p> <p>Reuse: Reuse demolished walls material for on-site/off-site construction.</p>

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C. Timber						
C1	Forest timber [Cellulose, Hemicellulose, Lignin, 12% water]	Roof structure, Beams, Columns, Door and window frames, Decks, Floor paving, Roof tiles, Wall panels, Formwork [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 10.4 -11.6 CO ₂ footprint (kg/kg): 0.885 - 0.978 Water usage (l/kg): 665 - 735	Extraction Extraction can cause forest destruction, landslides, land degradation, and habitat destruction and can increase flood risk. Transport Transport of logs can further damage forests and rural roads. Production/Treatment Processing takes place in timber mills. Mills that are poorly managed cause solid-waste pollution and noise and air pollution. Toxicity Requires treatment for pest control. Using toxic chemicals for treatment causes environmental and health hazards. Benefits <ul style="list-style-type: none">A renewable resource, if well managed	Farmed timber, Plywood, Fiber boards, Bamboo	<ul style="list-style-type: none">Do not over design/over specify— where possible, conduct proper structural design for timber buildings and calculate the timber need accordinglyMinimize cutoffsTreat timber properly for long term durabilityMinimize the use of timber for formwork and use reusable modular formwork instead	Storage Store timber as close as practicable to your site. Properly store in a covered dry place, with proper stack heights. Allow air circulation and support well to avoid sagging. Keep it away from moisture as much as possible. Use Schedule timber delivery in-line with the phase of the project when it will be required to prevent unnecessary exposure of timber to the elements. Take extra care when handling to ensure that products are not spoiled while being moved. Use protection when handling and cutting chemically treated timber. Disposal Encourage timber reuse (e.g., door and window frames, roof members). Never dispose of timber in streams, wetlands, or coastal areas. Chemically treated timber trimmings should be considered a hazardous material; never use as firewood. Renewable resource, biodegradable Downcycle, combust for energy, landfill.

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				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
						<p>Reuse Wood can be reused for a variety of different purposes, ranging from low-quality, temporary work like survey pegs and boxing for concreting, to high-quality, permanent uses like floor boards, beams, and other architectural features if the recovered material is in a suitable condition. Depending on the type of disaster, rotting, humidity, or splitting, presence of nails or screws can affect the potential for reuse.</p> <p>Recycle Untreated timber off-cuts can be chipped into mulch and used in landscaping, animal bedding or used as fuel. Depending on the context, wood from construction and demolition waste competes with forestry and manufacturing wood waste as an input for industrial furnaces and boilers, particularly in pulp and paper mills.</p>
C2	Farmed timber [Refer to C1]	Roof structure, Beams, Columns, Door and window frames, Decks, Floor paving, Roof tiles, Wall panels, Formwork [None] Refer to C1	Same as C1 Benefits <ul style="list-style-type: none"> • A renewable resource, if well managed • Minimal impact on natural forests • Over-extraction can be managed 	Forest timber, Plywood, Fiber boards, Bamboo	<ul style="list-style-type: none"> • Refer to C1 	Refer to C1

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C3	Plywood/ laminated panels, Chip boards, Fiber boards <i>[Cellulose/Hemicellulose/Lignin/ 12% water/ adhesive]</i>	Wall panels, Floor panels, Formwork, Partition walls, Insulation <i>[only suitable for temporary use in external work.</i> <i>Properties depend on moisture content.</i> <i>Plywood is made from multiple layers of thin solid wood glued together to form a panel of a specific thickness. The plies are oriented so that the grain direction in one ply is rotated 90° relative to adjacent plies. This enhances both the strength and dimensional stability of the plywood. Plywood over 10mm thick is almost equal in strength in both directions as opposed to solid wood.]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 34.5 -38.0 CO ₂ footprint (kg/kg): 2.23 – 2.45 Water usage (l/kg): 665 - 735	Extraction Extraction can cause forest destruction, landslides, land degradation, and habitat destruction and can increase flood risk. Transport Transport of logs can further damage forests and rural roads. Production/Treatment Manufacturing uses timber mill by-products or farmed soft wood and chemical binders. It takes place in large factories with energy-intensive processes. Processing results in air pollution. (see C1) Toxicity Using binding material and treatment chemicals in manufacturing can cause environmental and health hazards. Benefits <ul style="list-style-type: none"> Minimal impact on natural forests Uses timber mill by-products Ability to be pre-formed into efficient sizes and thicknesses 	Engineered bamboo (Woven bamboo panels, laminated bamboo, bamboo scrimber)	<ul style="list-style-type: none"> Refer to C1 Design to use standard panel sizes (minimize trimming) 	Storage Refer to C1 Use Refer to C1 Disposal Refer to C1 Downcycle, combust for energy, landfill, biodegradable. Cannot be recycled.

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C4	Bamboo [Refer to C1]	<p>Roof structure, Woven wall panels, partitioning, Concrete reinforcement</p> <p><i>[Properties depend strongly on moisture content, needs protective coating to protect from moisture and attack from insects and termites (Borax coating, resins, adhesives)]</i></p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 21.7 - 24.0 CO₂ footprint (kg/kg): 1.63 -1. 80 Water usage (l/kg): 6.65 - 7.50</p>	<p>Extraction Extracted from natural or farmed bamboo groves. Unmanaged extraction may cause habitat destruction, riverbank degradation</p> <p>Production/Treatment/Toxicity Usually used directly without any processing. However, bamboo can be processed into high-quality products such as panels and mats. Some products require energy intensive factory processes. These processes may cause air and water pollution if not properly managed.</p> <p>Benefits</p> <ul style="list-style-type: none"> • Fast growing and renewable (fastest growing woody plant). • Minimum impact on natural forests, unless forests are removed to plant bamboo. • Supports indigenous livelihoods and knowledge. Can be a substitute for slower growing timber. Bamboo stabilizes the earth with its roots, preventing erosion. Regrows from shoots; no need for replanting • Rapidly renewable. Mechanical properties similar to timber • Sustainable • Cost effective 	Timber	<ul style="list-style-type: none"> • Use only when sustainable harvesting is possible • Have a harvesting plan • Encourage reuse in formwork • Treat for long term durability and procure value-added products from local industries (use natural seasoning or non-toxic certified treatment chemicals. Borax or boric acid treatment is common, though should be carried out with care and training, as both chemicals have proven health hazards). 	<p>Storage Ensure storage in a good place, with proper stack heights. Allow air circulation. Support well to avoid sagging</p> <p>Use Refer to C1</p> <p>Disposal Renewable resource, biodegradable Downcycle, combust for energy, landfill</p> <p>Recycle: Other uses include compost or chip. Dry and use as fuel.</p>

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C5	<p>Bamboo scrimber (bamboo fiber based, composite manufactured timber)</p> <p><i>[Bamboo + phenol formaldehyde resin]</i></p>	<p>Roof structure, Woven wall panels, partitioning, Formwork props, Scaffolding</p> <p><i>[None]</i></p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 21.7 – 12.3 CO₂ footprint (kg/kg): 1.63 – 1.80 Water usage (l/kg): 6.65 - 7.50</p>	<p>Extraction Refer to C4</p> <p>Production/Treatment/Toxicity Might require energy intensive factory processes to make the scrimber strong. These processes may cause air and water pollution if not properly managed. Formaldehyde resins used in manufacture is identified as potential human carcinogen. Therefore, long term exposure to dust or inhalation of fumes while burning this material can be hazardous.</p> <p>Benefits</p> <ul style="list-style-type: none"> • Less moisture content than bamboo, highly moisture resistant • Much more resistant to termites, mold attacks, adverse climate conditions • Comparable mechanical properties to timber and bamboo • Higher flexural strength than other natural composites 	Timber, raw bamboo	Refer to C4	<p>Storage Refer to C4</p> <p>Use Refer to C1</p> <p>Disposal Renewable resource, not biodegradable. Combustion for energy is not recommended. Carefully dispose in a sanitary landfill.</p>

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C6	Laminated bamboo [Bamboo + resin + polyurethane adhesive]	Roof structure, Woven wall panels, Partitioning, Formwork props, Scaffolding [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 21.7 - 24.0 CO ₂ footprint (kg/kg): 1.63 - 1.80 Water usage (l/kg): 6.65 - 7.50	Extraction Refer to C4 Production/Treatment/Toxicity Refer to C5 No direct toxicity risk, unless the product contains formaldehyde resins or other hazardous chemicals (check product information) Benefits Refer to C5	Timber, Raw bamboo	Refer to C4	Storage Refer to C4 Use Refer to C1 Disposal Renewable resource, slow biodegradation. Combustion for energy should be done only after checking the material details and safety data sheets, otherwise landfill.

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D. Roofing Material						
D1	Asbestos (chrysotile) [Asbestiform varieties of mineral silicates belonging to the serpentine or amphibole groups of rock forming minerals. Mg ₃ (Si ₂ O ₅)(OH) ₄ , Chrysotile accounts for 90% of the asbestos that is mined and used most commonly.]	Roofing sheets (mixed with cement), floor, thermal insulation, water pipes (mixed with cement), asbestos artex <i>[Banned in many countries due to its health hazards.</i> <i>Hazardous asbestos waste can be generated by a disaster and during search and rescue operations, clean-up operations, demolition, and transitional settlement and reconstruction activities.</i> <i>All forms of asbestos are considered to be carcinogenic by IARC. Chrysotile is less carconogenic in comparison to other forms. Chrysotile has been investigated as a tumorigenic and mutagenic effector. It can enter the body through inhalation, ingestion, and skin. Fibers are loose and easily released into the air. Breathing these fibers can cause severe lung issues. Asbestosis is the most common disease caused by asbestos.</i>	Extraction Requires conventional mining practices to bring underground asbestos deposits and ore to the surface. Production/Treatment Involves complicated processes that include mining and separating. Toxicity Extremely hazardous to human health. Benefits None	PVA and cellulose fiber-cement, Polypropylene and cellulose fiber-cement, Bamboo fiber-cement (Taiheyo cement), Clay roofing tiles, Galvanized iron roofing (zinc-coated steel), Clay roof tiles, Thatching material, Aluminum sheets, Plastic roofing sheets, CGI sheets Alternatives to asbestos-cement pipes: Cast iron and ductile iron pipe; High-density polyethylene (HDPE); polyvinyl chloride (PVC) pipe, Pre-stressed (metal reinforced) concrete pipe; Clay pipe	<ul style="list-style-type: none">Do not recommend for any new constructionDo not recommend for any new constructionIdentify the areas using it and assess the risks, ensure people are aware of the risks and handling practicesMinimize risk of using asbestos containing materials, and minimize human contact in all ways. Air-borne asbestos fibers are the main problemAsbestos containing waste needs to be labeled properly and stored securelyIn case of a disaster, trained personnel should handle the asbestos containing waste. Public awareness is important	Storage Do not receive, store, distribute, or dispatch asbestos products from any place of work unless they are suitably sealed and labeled. Use Strictly follow health and safety guidelines in removal. Disposal Strictly follow health and safety guidelines in removal and disposal, as it is an extremely hazardous material. Avoid recycle and reuse in any form. Minimize disturbance of asbestos containing materials Minimize interaction with asbestos containing materials Never burn, as that will release the fibers into the air The materials should be kept wet while disposal as that reduces the risk of airborne fibers Asbestos waste needs to be kept separate from other wastes and treated Break the cycle: avoid using new asbestos-containing materials in transitional settlement and reconstruction programs.

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		<p><i>Lung cancer and mesothelioma. Dangerous to use because of potential degradation/ damage which will release the fibers into the air. Respirable fiber level of 0.1 fibers/ml of air can be hazardous. Respirable asbestos means an asbestos fiber that is less than 3 micronmeters (µm) wide, more than 5 micronmeters (µm) long, and has a length to width ratio of more than 3:1.]</i></p> <p><u>Embedded Energy/CO2 Footprint</u></p> <p>Embodied energy (MJ/kg): 0.51 - 0.56 CO₂ footprint (kg/kg): 0.0268 - 0.0295 Water usage (l/kg): 37.7 - 41.7</p>			<ul style="list-style-type: none">	

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D2	Clay roof tiles <i>[63% Al₂O₃ (alumina), 36.7% SiO₂ (silica), <1% Fe₂O₃, K₂O, MgO]</i>	Roof sheltering <i>[provide high level of thermal comfort]</i> <u>Embedded Energy/CO2 Footprint</u> Embodied energy (MJ/kg): 13 - 14.4 CO ₂ footprint (kg/kg): 1.82 - 2.01 Water usage (l/kg): 5.27 - 5.83	Extraction Requires clay, and clay mining causes habitat destruction, fouling of water bodies, and alters hydrology. Transport Transport of clay from pits can damage rural roads. Production/Treatment Manufacturing uses wood-fired kilns, but the process is more managed than brick-making. Kilns can cause severe air pollution due to improper quality control. Toxicity None Benefits None	Plastic/fiber glass roofing sheets, Thatching material	<ul style="list-style-type: none"> Minimize use in areas with widespread clay mining impacts Minimize roof area in design Encourage reuse from old buildings Procure proper estimates to minimize wastage 	Storage Store in a dry place in suitable stack heights and use proper packaging and loading/ unloading in transport. Use Handle carefully. Broken tiles leads to wastage and may cause injuries. Disposal Refer to B1 Can be downcycled or landfilled. Not biodegradable, not recyclable, cannot be combusted for energy recovery.

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D3	Corrugated Galvanized Iron (CGI) sheets <i>[Corrugated Iron sheets coated with zinc]</i>	Roof sheltering, Wall panels <i>[low thermal comfort, low durability in corrosive environments, use for wall panels suitable only in temporary installations]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 40.9 – 45.1 CO ₂ footprint (kg/kg): 3.08 - 3.39 Water usage (l/kg): 56.30 - 62.20	Extraction Manufacturing process requires large quantities of steel, zinc, and other metals. May contribute to mining impacts. Transport Not significant Production/Treatment Manufacturing takes place in large-scale factories, using energy-intensive processes. Factories can cause severe air and water pollution if poorly managed. Manufacturing processes may release toxic heavy metals. Toxicity None Benefits None	Clay roof tiles, Aluminum sheets, Plastic/reinforced plastic roofing sheets, Thatching material	<ul style="list-style-type: none"> • Use optimum design calculations to minimize cut wastes • Use certified products and avoid using in corrosive environments • Avoid contact with ground or high levels of moisture if using for wall panels • Encourage reuse of un-corroded sheets from old buildings • Use standard sizes • If used for roofing, high noise will be produced during rainfall, and insulators will be needed • Avoid using in extreme temperatures, else use insulators along with it 	Storage Store in a dry place in suitable stack heights and use proper packaging and loading/unloading procedures in transport. Use Not significant Disposal Never dispose of CGI in the environment; it can be easily sold as scrap metal.

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
D4	Thatching material <i>[Straw, coconut, reeds. Grasses. seaweed]</i>	<p>Roof sheltering</p> <p><i>[low durability, only usable in certain types of roof designs. If placed well, has high durability, is lightweight, and thus lesser amount of wood is needed to support it. Risk of fire, labor intensive, hence more expensive to thatch a roof than to cover it with tiles. Very common in UK.]</i></p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): straw: 0.24 CO₂ footprint (kg/kg): straw: 0.01 Water usage (l/kg): 670 - 730</p>	<p>Extraction Natural or farmed vegetation (e.g., palm leaves, reed, grasses) is used in harvesting. Without proper management, it may have impacts on forests and natural vegetation.</p> <p>Transport Not significant</p> <p>Production/Treatment Households or small-scale industries process material. Material needs seasoning and may cause water pollution if not properly managed.</p> <p>Toxicity None</p> <p>Benefits</p> <ul style="list-style-type: none"> • No firewood or energy requirement • Can support indigenous livelihoods and knowledge • No requirement for quarried material or clay 	Clay roof tiles	<ul style="list-style-type: none"> • Use local knowledge where possible • Use basic building designs • Use local knowledge where possible • Use basic building designs • Support local livelihoods and industries • Consider fire risk in planning and design since thatch is combustible 	<p>Storage Store in a dry place in suitable stack heights and order at correct time to avoid wastage.</p> <p>Use Use local thatching material that can be obtained without environmental damage.</p> <p>Disposal If thatching is not chemically treated, it is biodegradable. However, avoid disposing of large quantities in streams, estuaries and coastal areas.</p> <p>Reuse The type and quality of thatching material can vary. It is prone to decay in damp conditions and can be ruined by vermin. Thatched roofs are also very flammable.</p> <p>Recycle In decommissioning shelter/buildings, thatching can be composted or spread on the ground or ploughed into the soil and left to decompose naturally – provided it is not chemically treated.</p>

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D5	AluminumAluminum sheets (3000 and 5000 series) <i>[Al+Mn,Mg, Cu, Si, Fe/Zn]</i>	Roof sheltering, Wall panels, Window and door frames <i>[use for wall panels suitable only in temporary installations]</i> <i>Aluminum is lightweight but a strong metal which is not prone to corrosion, non-toxic, durable, and can be shaped as desired.</i> <i>Much more durable than CGI sheets, but more expensive.]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 200 - 221 CO ₂ footprint (kg/kg): 12.5 - 13.8 Water usage (l/kg): 1140 - 1260	Extraction Manufacturing process requires large quantities of aluminum and other metals. May contribute to mining impacts. Transport Transport can damage rural roads. Production/Treatment Manufacturing takes place in large-scale factories using energy-intensive processes. Factories can cause severe air and water pollution if poorly managed. Toxicity None Benefits None	CGI sheets, Tin sheets, Plastic/fiber-reinforced plastic roofing sheets, Clay tiles, Thatching material	<ul style="list-style-type: none"> Refer to D3 Corrosion resistance makes aluminum sheets more environmentally appropriate in corrosive environments 	Storage Refer to D3 Use Not significant Disposal Refer to D3 Can be easily recycled or downcycled, non-biodegradable. Aluminum is not a renewable resource. Non-reusable portion can be disposed in a landfill.

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D6	Fiber-reinforced plastic (FRP) <i>[PVC-80%, glass fiber (short fiber (<5mm))- 20% (by weight)]</i>	Roof tiles, Window and door frames, Flooring, Wall panels <i>[use for wall panels suitable only in temporary installations]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 56.2 - 62 CO ₂ footprint (kg/kg): 2.79 - 3.08 Water usage (l/kg): 214 - 236	Extraction None Transport Transport can damage rural roads. Production/Treatment Manufacturing takes place in medium- to large-scale factories using energy-intensive processes. Factories can cause severe air and water pollution if poorly managed. Toxicity No toxicity in use, but can emit hazardous fumes if burnt. Benefits Reduce environmental damage by using natural fibers and safe petroleum byproducts in manufacturing.	Plastic sheets, Thatching material	<ul style="list-style-type: none"> Encourage the use of natural fibers (e.g., coir) in fiber reinforced plastic sheets Design to optimum criteria to minimize wastage Also refer to D3 	Storage Store in proper sized stacks: raised from ground and in ways that would not sag. Can be combustible, store away from direct flames. Use Use protection when cutting the sheets as dust and fumes may cause health hazards. Disposal Never dispose of in the environment; only dispose of in a sanitary landfill. Never burn plastic sheets. High temperature incineration under expert supervision is possible as a last resort. Encourage reuse of material. Non-biodegradable, cannot be recycled. Can be put in landfill, combusted for energy, or downcycled.

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D7	Plastic sheets (Polyethylene) [(-CH ₂ -CH ₂ -) _n]	Roof sheltering, Wall panels <i>[use for wall panels suitable only in temporary installations]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 82.0 – 90.4 CO ₂ footprint (kg/kg): 2.21 – 2.44 Water usage (l/kg): 61.2 – 68.4	Extraction Crude oil is the main raw material used for production. Large scale environmental issues are caused by the petroleum industry. Transport Not significant Production/Treatment Manufacturing takes place in medium-to large-scale factories using energy-intensive processes. Factories can cause severe air and water pollution if poorly managed. Toxicity No toxicity in use, but can emit hazardous fumes if burnt. Benefits None	Thatching material, Cement fiber sheets, Plywood	<ul style="list-style-type: none"> • Design to optimum criteria to minimize wastage • Use optimum design calculations to minimize cut wastes • Use certified products and avoid using in corrosive environments • Avoid exposure to direct sunlight where possible • Encourage reuse of undamaged sheets from old buildings 	Storage Store in a covered place, away from direct sunlight or rain. Stack in an easily retrievable way to reduce tearing and damage. Highly combustible, store safe from all fire hazards. Use Use carefully to reduce damage and wastage. Don't expose to flames. Use personal protection when cutting large scale; dust and fumes may cause health hazards. Disposal Never dispose of in the environment; only dispose of in a sanitary landfill. Encourage reuse of material. Never burn plastic sheets. High temperature incineration under expert supervision is possible as a last resort. Polyethylene is easily recyclable if not coated with other materials Can be incinerated to recover energy

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D8	Plastic sheets (PVC) [Refer to C7]	Roof sheltering, Wall panels [use for wall panels suitable only in temporary installations] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 85.0 – 93.9 CO ₂ footprint (kg/kg): 4.59 – 8.05 Water usage (l/kg): 197 - 218	Extraction Refer to D7 Transport Refer to D7 Production/Treatment Refer to D7 Toxicity Refer to D7 Benefits None	Thatching material, Cement fiber sheets, Plywood	Refer to D7	Storage Refer to D3 Use Refer to D6 Disposal Refer to D7
D9	Galvanized steel [Fe (base material), Mn, C, Si, P, coated with Zn]	Roofing, Wall panels [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 38.1 - 42.0 CO ₂ footprint (kg/kg): 2.87 - 3.16 Water usage (l/kg): 56.3 - 62.2	Extraction Refer to D3 Transport Refer to D3 Production/Treatment Refer to D3 Toxicity None Benefits None	Aluminum sheets, tin sheets	Refer to D3	Storage Store in a dry place in suitable stack heights and use proper packaging and loading/unloading procedures in transport. Use Not significant Disposal Never dispose in the environment; it can be easily sold as scrap metal.

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D10	Stone (slate) [63% CaO, 21% SiO ₂ , 6% Al ₂ O ₃ + additions]	Roofing (slate tiles) <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 11.0 - 12.2 CO ₂ footprint (kg/kg): 0.81 - 0.09 Water usage (l/kg): 3.23 - 3.57	Extraction Refer to A3 Transport Refer to A3 Production/Treatment Refer to A3 Toxicity None Benefits None	Clay tiles, Reinforced cement sheets, Reinforced plastic sheets, Corrugated Galvanized Iron sheets	Refer A3	Storage Refer to A1 Use Refer to A1 Disposal Refer to A1
E. Finishing Materials						
E1	Ceramic tiles [63% Alumina, 37% Silica, <1% of ferric oxide, potassium oxide, magnesia]	Floor tiling, Wall tiling [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 14.6 - 15.1 CO ₂ footprint (kg/kg): 1.84 - 2.10 Water usage (l/kg): 12.0 - 13.2	Extraction Requires clay, and clay mining causes habitat destruction, pollutes water bodies, alters hydrology. Transport Transport can damage rural roads. Production/Treatment Manufacturing takes place in large industrial kilns. It is highly energy intensive, and if not properly managed, factories can cause air and water pollution. Toxicity Glazing may use toxic compounds. Benefits None	Terracotta tiles, Cement tiles, Vinyl tiles, Polymer composite tiles	<ul style="list-style-type: none"> Use optimal design (use only where necessary, limit aesthetic use) Use standard sizes and shapes to minimize cut-offs 	Storage Requires proper transport and handling. Store in safe, dry place in proper stack heights. Use Use protection when cutting. Disposal Refer to B1 Non-biodegradable, downcycle, landfill. Reuse if in undamaged condition. Recycle: Recovered tiles can be crushed and used as aggregate, landscaping, or infill purposes.

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E2	Parquet [Timber]	Floor paving [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 45.8 - 107 CO ₂ footprint (kg/kg): 4.4 - 7.1 Water usage (l/kg):	Extraction Manufacturing uses timber. (see C1) Transport See C1 Production/Treatment See C1 Toxicity See C1 Benefits None	Ceramic tiles, Terracotta tiles, Cement tiles, Vinyl tiles, Polymer composite tiles	<ul style="list-style-type: none"> Limit foot traffic on finished wood flooring Complete wood flooring toward the end of the construction project Use optimal design (use only where necessary, limit aesthetic use) Use standard sizes and shapes to minimize trimmings and cut-offs 	Refer to C1 and C3
E3	Lime mortar/ Lime putty [Lime, water, sand (fine aggregate)]	Plastering Filler, Paint [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 732 CO ₂ footprint (kg/kg): 0.15 - 0.23 Water usage (l/kg):	Extraction Manufacturing uses limestone or coral. Coral extraction causes serious environmental damage. Mining small outcrops of limestone may also have significant environmental impacts. Transport Transport can damage rural roads. Production/Treatment Requires kilning to produce usable non-hydraulic or hydraulic lime. The kilning process (especially small-scale) causes air pollution. Toxicity None Benefits None	Cement mortar, Chemical fillers	<ul style="list-style-type: none"> Do not use lime made from coral or illegally mined limestone Minimize the use of lime from small-scale producers with wood-fired kilns Mix only required amounts to minimize waste Use prefabricated concrete items and standard sized bricks or blocks to minimise the lime mortar and plaster requirement 	Refer to A4

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E4	Chemical fillers [pulverized glass, limestone powder, recycled plastics/rubbers]	Filler [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): CO ₂ footprint (kg/kg): Water usage (l/kg):	Extraction Requires mined and quarried material. See A3 Transport See A3 Production/Treatment Manufacturing takes place in large-scale factories and can cause air and water pollution if not properly managed. Toxicity Production may use toxic compounds that can cause environmental and health hazards. Benefits Reduce the demand for lime produced in harmful small-scale industries	None	<ul style="list-style-type: none"> Refer to the Material Safety Data Sheets before design or purchase Avoid toxic fillers unless absolutely necessary and educate the crafts person about safe use and disposal Do not over-specify 	Storage Store the properly closed containers (airtight) in safe places. Use Finish the walls smoothly before application and apply in optimum thicknesses (do not over-specify). Mix only required amounts to minimize waste. Strictly follow Health and Safety guidelines when working with chemical fillers. Disposal Never dispose of hardened filler or their containers in the environment. Instead, dispose of them in a sanitary or hazardous waste disposal facility (for toxic fillers).

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E5	General emulsion or latex paint <i>[water-borne dispersion of sub-micrometer polymer particles]</i>	Painting <i>[None]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 68.0 CO ₂ footprint (kg/kg): 3.56	Extraction Requires a variety of base chemicals in addition to mined and quarried material. Transport Transport can damage rural roads. Production/Treatment Manufacturing takes place in large-scale factories and can cause air and water pollution if not properly managed. Toxicity Enamel paint uses solvents. Some solvents may be harmful to human health and the environment. Benefits None	Natural pigments	<ul style="list-style-type: none"> Refer to the Material Safety Data Sheets before design or purchase Avoid toxic paints unless necessary, and educate the craftsperson about safe use and disposal Specify only the required number of coats of paint Limit the use of solvents and educate the craftsperson about safe use and disposal of solvents 	Storage Store the properly closed containers (airtight) in safe places. Use Use protection when mixing and applying paints. Disposal Never dispose of hardened fillers or their containers in the environment; instead dispose of them in a sanitary or hazardous waste disposal facility (for toxic paints or solvents).

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E6	Epoxy paints/oil-based enamel paints/solvent-based paints/strong adhesives/paint remover	Painting, Metal protection (as adhesives) <i>[generally expensive and used only for specific purposes]</i>	Extraction Requires a variety of base chemicals in addition to mined and quarried material. Transport Transport can damage rural roads. Production/Treatment Manufacturing takes place in large-scale factories that can cause air and water pollution if not properly managed. Production processes of some of these chemicals may be extremely damaging to the environment and human health. Toxicity May release heavy metals and harmful organic compounds into the environment. Benefits None	None	<ul style="list-style-type: none"> • Use certified products only • Use only where it is absolutely necessary and avoid if possible • Specify only if essential for the strength or durability of the building—not for ease of construction • Refer to E5 	Storage Store the properly closed containers (airtight), in a safe, secured place—away from fire and flooding hazards. Use Should be handled only by trained crafts persons, using protective equipment and strictly following Health and Safety Executive (HSE) guidelines in mixing and use. Disposal Treat strictly as hazardous waste in disposal of excess material and containers.

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E7	Termite treatment chemicals	Chemical treatment to eradicate termites (applied to soil around the perimeter and the subfloor of a building)	<p>Extraction Requires a variety of chemicals.</p> <p>Transport Transport can damage rural roads.</p> <p>Production/Treatment Large-scale factories produce.</p> <p>Toxicity Production process may release heavy metals and toxic organic compounds into the environment. Industrial accidents may cause serious hazards to humans and the environment.</p> <p>Benefits None</p>	Use of ground electrocution Integrated pest management	<ul style="list-style-type: none"> Only use certified products Try to use integrated pest management methods to get rid of pests 	<p>Storage Store the properly closed chemical containers (airtight), in a safe, secured place—away from fire and flooding hazards.</p> <p>Use Only use in specified dosages and with trained and certified persons. Use protective equipment and strictly follow Health and Safety guidelines in mixing and use.</p> <p>Disposal Treat strictly as hazardous waste in disposal of excess material and containers.</p>
E8	Glass [73% SiO ₂ , Al ₂ O ₃ , Na ₂ O, MgO, CaO]	<p>Window panes</p> <p><i>[Glass is a fully recyclable material and is chemically inert]</i></p> <p><u>Embedded Energy/CO₂ Footprint</u></p> <p>Embodied energy (MJ/kg): 17.8 – 20.6 CO₂ footprint (kg/kg): 1.35 – 1.56 Water usage (l/kg): 1.54 (Dai, 2015)</p>	<p>Extraction Requires quarried and mined material in production.</p> <p>Transport Transport can damage rural roads.</p> <p>Production/Treatment Results in mass combustion of fossil fuel. Emits sulphur dioxide (SO₂), and if unmanaged, it may cause water pollution.</p> <p>Toxicity None</p> <p>Benefits None</p>	Plastic polycarbonate	<ul style="list-style-type: none"> Use standard sizes and minimize trimming Use only the required thickness; however, thin plate glass is susceptible to easy breaking and waste of material 	<p>Storage Transport, handle, and store with care in proper stack height to avoid breakage and waste. Glass can be hazardous to children.</p> <p>Use Handle carefully, using proper equipment; broken glass can cause serious injury.</p> <p>Disposal Glass can be easily sold for recycling, and it should never be disposed of in the environment. Recycle, downcycle, landfill. Non-renewable, non-biodegradable, not combusted for energy recovery.</p>

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E9	Tarpaulin sheets [polyester]	Shelter material and wall panels (in temporary structures), Weather proofing building sites [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 82.5 – 92.7 CO ₂ footprint (kg/kg): 4.387 - 5.225 Water usage (l/kg):	Extraction Tarpaulin sheets are layered sheets that sandwich a polyester woven fabric base between plastic films. Refer to D7 Transport Refer to D7 Production/Treatment Refer to D7 Toxicity Refer to D7 Benefits None	Waterproof canvas, Thatching material	Refer to D7 (Tarpaulin sheets have a higher durability in outdoor uses than single film plastic sheets)	Refer to D7
F. Insulation Material						
F1	Polystyrene foam/expanded polystyrene [Polystyrene foam closed cell (0.025 specific gravity)]	Insulation [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 116 - 128 CO ₂ footprint (kg/kg): 5.61 - 6.20 Water usage (l/kg): 433 - 479	Extraction Polystyrene foam is made out of the common plastic polystyrene. Refer to D7 Transport Refer to D7 Production/Treatment Refer to D7 Toxicity Refer to D7 Benefits None	Natural fiber insulation, glass, or rock wool	<ul style="list-style-type: none"> Non-biodegradable, hence plan how much amount is needed and don't overuse Avoid using poor quality products 	Refer to D7

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E2	<p>Gypsum board</p> <p><i>[calcium sulfate dihydrate (gypsum) with or without additives and normally pressed between a facer and a backer]</i></p>	<p>Wall partition, Fire protection, Repair and finishing material</p> <p><i>[Easier to install and cheaper than plaster]</i></p> <p><u>Embedded Energy/CO2 Footprint</u></p> <p>Embodied energy (MJ/kg): 10.4 – 11.6 CO₂ footprint (kg/kg): 0.88 - 0.98 Water usage (l/kg): 665 - 735</p>	<p>Extraction Extraction can cause forest destruction, landslides, land degradation, and habitat destruction and can increase flood risk.</p> <p>Transport Transport can damage rural roads.</p> <p>Production/Treatment Processing takes place in timber mills. Mills that are poorly managed cause solid-waste pollution, and noise and air pollution.</p> <p>Toxicity Requires treatment for pest control. Using toxic chemicals for treatment causes environmental and health hazards.</p> <p>Benefits None</p>	Cement plaster, plasterboard	<ul style="list-style-type: none"> • Use standard sizes • Can even be installed by amateur carpenters • Much faster process than plastering walls 	<p>Storage Refer to C3</p> <p>Use Refer to C3 Cutting or breaking of gypsum board release fine particulate matter. Cutting or breaking should be minimised and done off-site if possible.</p> <p>Disposal</p> <p>Plasterboard is likely to be damaged during a disaster and therefore unsuitable for reuse.</p> <p>Can be disposed in an engineered landfill.</p> <p>Recycle: Gypsum makes up approximately 90% of the weight of a piece of plasterboard. Gypsum can be recovered and used :</p> <ul style="list-style-type: none"> • in the manufacture of new drywall • as an ingredient in the production of cement • for application to soils and crops to improve soil drainage and plant growth • an ingredient in the production of fertilizer products • an additive to composting operations. However, this is unlikely in most emergency responses

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E3	Low strength glass fiber [59.5% SiO ₂ , 5% Al ₂ O ₃ , 7% B ₂ O ₃ , 14.5% Na ₂ O, 8% TiO ₂ , 4% ZrO ₂]	Insulation fiber [The legal permissible exposure limit has been set to 15 mg/m ³ and 5 mg/m ³ in respiratory exposure over an 8 hour workday by occupational Safety and Health Administration (OSHA)] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 25.7 - 28.3 CO ₂ footprint (kg/kg): 0.831 - 0.917 Water usage (l/kg): 43.7 - 48.3	Extraction Manufactured using glass. Refer to E8 Transport Refer to E8 Production/Treatment Refer to E8 Toxicity Refer to E8 Benefits None	Polystyrene foam, Natural fiber insulation, Rock wool	<ul style="list-style-type: none">Safety practices are required. The Materials Safety Data Sheet (MSDS) should be consulted	Use Should never be left exposed in an occupied area. Avoid unnecessary contact with dusts and fibers by using Personal Protection and good local exhaust ventilation. Disposal Landfill, downcycle, non-biodegradable. Cannot be recycled. Cannot be combusted for energy.
E4	Fiberboard [Different from plywood as that is made from sheets of wood, while this is made from fibers. Cellulose/hemicellulose/lignin/ 12% water/ adhesive]	Insulating formboard, Roof insulating board, Sound insulation [Refer to C3] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 10.9 - 11.9 CO ₂ footprint (kg/kg): 0.39 - 0.41 Water usage (l/kg): 665 - 735	Extraction Manufactured using cellulose/hemicellulos fibers. Refer to C3 Transport Refer to C3 Production/Treatment Refer to C3 Toxicity Refer to C3 Benefits None	Engineered bamboo (Woven bamboo panels, bamboo scrimber, laminated bamboo), thatching material	Refer to C3	Refer to C3

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G. Special Materials						
G1	Polyurethane foam [Polyurethane closed cell flexible foam]	Sealants, Concrete jointing, Foundation repair, Insulation [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 117 - 130 CO ₂ footprint (kg/kg): 7.52 – 8.30 Water usage (l/kg): 280 - 310	Extraction Foam is made of the hydro-carbon polymer type Polyurethane. Refer to D7 Transport Refer to D7 Production/Treatment Refer to D7 Toxicity Refer to D7 Benefits None	Natural fiber insulation, glass or rock wool for insulation applications. Polystyrene foam in sealing and joining applications.	<ul style="list-style-type: none">Non-biodegradable, hence plan how much amount is needed and don't overuseAvoid using poor quality products	Refer to D7
G2	Polypropylene [(C ₃ H ₆) _n]	Sound insulation, Wall insulation, Water pipes, Waste pipes, Can also be used to reinforce concrete [None] <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 114 - 126 CO ₂ footprint (kg/kg): 5.82 – 6.39 Water usage (l/kg): 37.2 - 41.2	Extraction Made of hydro-carbon polymer type Polypropylene. Refer to D7 Transport Refer to D7 Production/Treatment Refer to D7 Toxicity Refer to D7 Benefits None	Polyuerethane foam, Natural fiber insulation, Glass or rock wool for insulation applications. PVC or High Density Polyethylene (HDPE) for pipes	<ul style="list-style-type: none">Non-biodegradable, hence plan how much amount is needed and don't overuseAvoid using poor quality products	Refer to D7

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G3	High strength glass fiber <i>[E grade fiber (0.4-12 micron filament) 54% SiO₂, 15% Al₂O₃, 12%CaO]</i>	Reinforcement <i>[Refer to F3]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 89.9 – 99.0 CO ₂ footprint (kg/kg): 6.10 – 6.72 Water usage (l/kg): 89.8 - 99.2	Extraction Manufactured using glass. Refer to F3 Production/Treatment Refer to F3 Toxicity Refer to F3 Benefits None	PVA and cellulose fiber-cement, Polypropylene and cellulose fiber-cement, Bamboo fiber-cement (Taiheyo cement), Clay roofing tiles, Galvanized iron roofing (zinc-coated steel),	Refer to F3	Refer to F3
G4	Natural Rubber <i>[latex of the rubber tree]</i>	Anti-vibration pads, Window seals, Sound insulation, Flooring <i>[Easy to handle and install, good energy storage capacity]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 85.8 – 94.9 CO ₂ footprint (kg/kg): 3.67 – 4.05 Water usage (l/kg): 15000 - 20000	Extraction Rubber is manufactured using latex of the rubber tree. A renewable resource. However, rubber plantations are monoculture and can cause long term ecological degradation, if managed without responsible plantation practices. Transport Not significant Production/Treatment Rubber production is a large scale process involving many hazardous chemicals, such as ammonia. Can cause air and water pollution if not properly managed. Toxicity Not significant Benefits None		<ul style="list-style-type: none"> Use certified products as standards and quality varies with location Where possible sustainably sources and environmentally certified rubber. There are many certification programs available. Consider vibration control strategies early in the product design process and consulting with an engineering expert when selecting materials and mounts Optimize the use of material to reduce wastage 	Storage Always store rubber products away from direct flames and other fire hazards. Store in place above ground, away from excessive moisture and direct sunlight. Store in way that is easy retrievable to avoid damage. Disposal Refer to F3

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
G5	Neoprene Rubber [Polychloroprene]	Seals, Adhesives <i>[higher resistance to heat but lower resistance low-temperature stiffening compared to natural rubber]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 81.9 – 90.0 CO ₂ footprint (kg/kg): 2.25 - .2.58 Water usage (l/kg): 126 - 378	Extraction Manufactured by polymerisation of the chlorinated hydro-carbon chloroprene. Refer to D7 Transport Refer to D7 Production/Treatment Refer to D7 Toxicity Some incidents of skin irritations and allergy reported due to residues of Ethylene Thiourea. Benefits None	Natural rubber, Butyl rubber, Polyisoprene	<ul style="list-style-type: none"> Non-biodegradable, hence plan how much amount is needed and don't overuse Avoid using poor quality products 	Refer to D7

Item No.	Material [composition]	Technical Information [special technical remarks]	Environmental Costs / Impacts / Benefits	Management & Alternatives		
				Potential Material Alternatives	Environmental Better Practices (Design/Planning)	Environmental Better Practices (Storage/Use/Disposal)
G6	Styrene Butadiene Rubber (SBR) <i>[23% styrene and 77% butadiene reinforced with typically 30% carbon black]</i>	Anti-vibration pads, Window seals, Sound insulation, Flooring <i>[weaker and lower fatigue resistance compared to natural rubber]</i> <u>Embedded Energy/CO₂ Footprint</u> Embodied energy (MJ/kg): 129 - 143 CO ₂ footprint (kg/kg): 7.64 – 8.45 Water usage (l/kg): 63.7 - 191	Extraction Manufactured using hydro-carbons Styrene and Butadiene. Refer to D7 Transport Refer to D7 Production/Treatment Refer to D7 Toxicity Some incidents of skin irritations and allergy reported due to residues of Ethylene Thiourea. Benefits None	Natural rubber, Neoprene rubber, Polyisoprene	<ul style="list-style-type: none"> Non-biodegradable, hence plan how much amount is needed and don't overuse. Avoid using poor quality products 	Refer to D7

Table 2: ENVIRONMENTAL GUIDE TO PROPERTIES OF COMMON BUILDING MATERIALS

No.	Material [composition]	MECHANICAL PROPERTIES						THERMAL PROPERTIES			Electrical resistivity (μΩcm)	DURABILITY					
		Density (kg/m3)	Young's modulus (GPa)	Tensile strength (MPa)	Compressive strength (MPa)	Flexural strength (MPa)	Shape factor	Max service temp (°C)	Min service temp (°C)	Thermal conductivity (W/m.°C)		Water (fresh)	Water (salt)	UV radia- tion	Flammability	Insects, mold, and termite	Comments
												1 = Poor 2 = Limited 3=Acceptable 4 = Good 5 = Excellent			1 = High 2 = Flammable 3 = Slow 4 = Self extinguishing 5=None		
A1	River sand	2600	0.01-0.69	2.2-3.75	38-46	3.09-3.98	-	-	-	1.5-1.8	-	5	5	5	5	3	
A2	River gravel/ boulders	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	
A3	Quarried rock	2550-2600	35-55	8-22	30-200	8-22	15	330-380	-	0.92-2.15	1e8-1e12	5	5	5	5	3	
A4	Portland Cement	1800-2200	30.2-41.6	1.9-3	24-27	2.2 - 2.5	3	627-857	-160- -150	0.8-0.9	2e11-2e12	5	5	5	4 (until 450 °C)	3	Poor with sulfates and not acceptable with sulfuric acid
A5	Stone (sandstone)	2000-2600	14-25	4-22	50-155	4 - 22	15	400-600	-273	5.4 - 6	1e10 - 1e14	5	5	5	5	3	Excellent durability in acidic and alkaline soils
A6	Concrete (not reinforced)	2300-2600	16-25	1-1.5	14-50	1.7 - 2.4	3	480-510	-163- -153	0.8-2.4	1.85e12-1.85e13	5	5	5	5	3	Excellent durability with soils, poor with sulfates, SO ₂ and not acceptable with sulfuric acid
A7	Concrete (insulating, lightweight)	900-1400	0.6-1.53	0.1-0.3	0.5-8.2	0.3-5	3	560-640	-160	7-12	3.16e11-3.16e12	5	3	5	5	3	Limited use with acids and alkalis

No.	Material [composition]	MECHANICAL PROPERTIES						THERMAL PROPERTIES			Electrical resistivity (μΩcm)	DURABILITY					
		Density (kg/m3)	Young's modulus (GPa)	Tensile strength (MPa)	Compressive strength (MPa)	Flexural strength (MPa)	Shape factor	Max service temp (°C)	Min service temp (°C)	Thermal conductivity (W/m.°C)		Water (fresh)	Water (salt)	UV radia- tion	Flammability	Insects, mold, and termite	Comments
												1 = Poor 2 = Limited 3=Acceptable 4 = Good 5 = Excellent			1 = High 2 = Flammable 3 = Slow 4 = Self extinguishing 5=None		1 = Susceptible to attack 3 = Good 5 = Excellent
A8	Aerated concrete (low density)	400-900	12-18	0.6-1.1	1.2-1.87	0.7-1.3	3	200-300 (decrease from normal concrete due to air gaps)	-160 - -150	0.7-0.8	3.16e11- 3.6e12	5	3	5	5	3	Excellent with soils, poor with sulfates, not acceptable with sulfuric acid
A9	High volume fly ash concrete	1830-2200	30-41	1.5-2.5	45-58	1.5-2.5	3	873-973	-	1.11-125	2e11-2e12	5	3	5	5	3	Excellent with soils, poor with sulfates, unacceptable with strong acids
A10	Latex concrete	2300-2600	20.39-34.56	3-5	21-38	3-6.5	-	480-510	-163- -153	0.8-2.4	1.85e12- 1.85e13	5	5	5	5	3	
A11	PVA and cellulose fiber-cement	1610-1870	0.25-3.90	34.1-84.9		19.2	-	226-240				4			4	3	High alkaline environments can cause degradation of natural fibers (Pacheco-Torgal, 2011)

No.	Material [composition]	MECHANICAL PROPERTIES						THERMAL PROPERTIES			Electrical resistivity (μΩcm)	DURABILITY					
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												1 = Poor 2 = Limited 3=Acceptable 4 = Good 5 = Excellent	1 = High 2 = Flammable 3 = Slow 4 = Self extinguishing 5=None	1 = Susceptible to attack 3 = Good 5 = Excellent			
A12	Polypropylene fiber-reinforced concrete	360-567	12.8±2.3	1.08-5.40	12.6-81.6	2.50-6.84	-	300-600				3	3		5	3	
A13	Cellulose fiber-reinforced concrete	2050-2250	13.3±1.2	2.69-3.41	35.8-38.7	5.46-6.35	-			1.8-2.7		3	3				
A14	Glass Fiber reinforced composite (GFRP) rebar	1750-1900	15-28	138-241	138-207	-	-	140-220	-73.2	0.4-0.55	2.4e21-1.91e22	5	5	3	3		Limited use in acidic (peat) and alkaline soils (clay)
A15	Low carbon steel	7800-7900	200-215	345-580	250-395	1.52e3 - 1.68e3	14	350-400	-68.2- -38.2	49-54	15-20	3	2	5	5	5	Better durability with alkaline that acidic environment
B1	Brick (common)	1600-2100	15-30	5-14	10-70	-	15	927-1230	-	0.46-0.73	1e14-3e16	5	5	5	5		

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		Density (kg/m3)	Young's modulus (GPa)	Tensile strength (MPa)	Compressive strength (MPa)	Flexural strength (MPa)	Shape factor	Max service temp (°C)	Min service temp (°C)	Thermal conductivity (W/m.°C)		Water (fresh)	Water (salt)	UV radia- tion	Flammability	Insects, mold, and termite	Comments
												1 = Poor 2 = Limited 3=Acceptable 4 = Good 5 = Excellent			1 = High 2 = Flammable 3 = Slow 4 = Self extinguishing 5=None	1 = Susceptible to attack 3 = Good 5 = Excellent	
B2	Cement blocks	1800-2200	30.2-41.6	1.9-3	24-27	2.2 - 2.5	3	627-857	-160- -150	0.8-0.9	2e11-2e12	5	5	5	4 (until 450 °C)		Poor with sulfates and not acceptable with sulfuric acid
B3	Compressed stabilized earth blocks/ CSEB	1900-2200	0.7-1	1-2	2-3	1-2	-			0.46-0.81		2			4		5-10 wt% absorption of water durability against water increases with cement content
B4	Earth walls (stabilized earth, clay-straw, rammed earth, bamboo reinforced earth)	1800-2000	2.51	0.13-0.27	1.38 - 3.09	0.30 - 0.92				1.51		3			4		Proper soil selection is necessary to maintain durability during heavy rainfalls
C1	Forest timber	850-1030	20.6-25.2	132-162	68-83	114 - 140	5.1 - 5.7	120-140	-100- -70	0.41-0.5	6e13-2e14	3	3	4	1	1	Acceptable in acidic soils (peat)/ limited use in alkaline soils (clay)
C2	Farmed timber	850-1030	20.6-25.2	132-162	68-83	114 – 140	5.1 - 5.7	120-140	-100- -70	0.41-0.5	6e13-2e14	3	3	4	1	1	Acceptable in acidic soils (peat)/ limited use in alkaline soils (clay)

No.	Material [composition]	MECHANICAL PROPERTIES						THERMAL PROPERTIES			Electrical resistivity (μΩcm)	DURABILITY					
		Density (kg/m3)	Young's modulus (GPa)	Tensile strength (MPa)	Compressive strength (MPa)	Flexural strength (MPa)	Shape factor	Max service temp (°C)	Min service temp (°C)	Thermal conductivity (W/m.°C)		Water (fresh)	Water (salt)	UV radia- tion	Flammability	Insects, mold, and termite	Comments
												1 = Poor 2 = Limited 3=Acceptable 4 = Good 5 = Excellent			1 = High 2 = Flammable 3 = Slow 4 = Self extinguishing 5=None		
C3	Plywood/ laminated panels, Chip boards, Fiber boards	700- 800	6.9-13	10-44	8-25	80-115	5	100-130	-100- -70	0.3 - 0.5	6e13-2e14	3	3	4	1	1	Limited used in acidic soils (peat)/ unacceptable in alkaline soils (clay)
C4	Bamboo	600- 800	15-20	160-320	60-100	80-160	5.6	120-140	-73- -23	0.16-0.18	6e13-2e14	2	2	4	1	1 (treating or coating can help)	Unacceptable with strong acids and alkalis, limited use with weak acids and alkalis
C5	Bamboo scrimber	1160	0.05-0.06	120	86	119	-	120	-	0.1625	6e13-2e14	4	4	4	2	3	-
C6	Laminated bamboo	686	11-13	90	77	77-83	-	120	-	0.186	6e13-2e14	4	4	4	2	3	-
C7	Hardwood (oak)	850- 1030	20.6-25.2	132-162	68-83	114 – 140	5.1 - 5.7	120-140	-100- -70	0.41-0.5	6e13-2e14	3	3	4	1	1	Acceptable in acidic soils (peat)/limited use in alkaline soils (clay)
D1	Asbestos (chrysotile)	2400 – 2600	161 - 169	2.95e3 - 3.35e3	-	-	1	852 - 980	-273	2 - 6	1e22 - 1e24	5	5	5	5	-	2400 - 2600

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		Density (kg/m3)	Young's modulus (GPa)	Tensile strength (MPa)	Compressive strength (MPa)	Flexural strength (MPa)	Shape factor	Max service temp (°C)	Min service temp (°C)	Thermal conductivity (W/m.°C)		Water (fresh)	Water (salt)	UV radia- tion	Flammability	Insects, mold, and termite	Comments
												1 = Poor 2 = Limited 3=Acceptable 4 = Good 5 = Excellent			1 = High 2 = Flammable 3 = Slow 4 = Self extinguishing 5=None		
D2	Clay roof tiles	1.9e3 - 2.75e3	4 - 8	15 - 20	25 - 28	16.6 - 29.5	13	673 - 773	-	0.5 - 1.52	-	3	5	5	5	-	-
D3	Corrugated Galvanized Iron (CGI) sheets	78e3- 7.9e3	200-215	420-600	250-395	250-395	60	150-180	-68.2- -43.2	50-54	15-20	5	3	5	5		Limited use with acids and alkalis. Galling resistance is poor. Zinc coating has tendency to gall.
D4	Thatching material	-	-	-	-	-	-			reed: 0.11 date palm leaves: 0.122-0.210						1	Reed in Europe, Cadjan (Palm/Coconut leaf) in South India/SE Asia, Straw in North India/Middle East
D5	Aluminum sheets (3000 and 5000 series)	2500- 2900	68-72	70-360	30-286	59 – 105	42	130-220	-273	119-240	2.5-6	5	3	5	5		Unacceptable with acidic soils (peat)
D6	Fiber-reinforced plastic (FRP)	1750- 1900	15-28	138-241	138-207	-	-	140-220	-73.2	0.4-0.55	2.4e21- 1.91e22	5	5	3	3		Limited use in acidic (peat) and alkaline soils (clay)
D7	Plastic sheets (Polyethylene)	939 – 960	0.621 - 0.896	20.7 - 44.8	19.7 - 31.9	18.6 – 37	3.5	90 - 110	-123 - -73.2	0.403 - 0.435	3.3e22 - 3e24	5	5	2	1	PVC: 3	Treat with fire retardant
D8	Plastic sheets (PVC)	1303 – 1580	2.14 - 4.14	40.7 - 65.1	42.5 - 89.6	82 – 90	5.3	60 - 70	-123 - -73.2	0.147 - 0.293	1e20 - 1e22	5	5	4	4		-

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												1 = Poor 2 = Limited 3=Acceptable 4 = Good 5 = Excellent			1 = High 2 = Flammable 3 = Slow 4 = Self extinguishing 5=None		
D9	Galvanized steel	7800-7900	200-215	420-600	250-395	250-395	60	150-180	-68.2- -43.2	50-54	15-20	5	3	5	5		Limited use with acids and alkalis. galling resistance is poor. Zinc coating has tendency to gall.
D10	Stone (slate)	2600-2800	60-90	15-30	120-175	15-175	15	350-500	-50 - -30	1.2-2.1	1e12-1e14	5	3	5	5	3	
E1	Ceramic tiles	2050-2400	4-8	3-6	20-50	3-6	15	673-1070	-	0.75-0.85	1e14-3e14	5	5	5	5	3	Unacceptable with alkalis
E6	Epoxy paints/ solvent based paints/anticorrosive paints/strong adhesives/paint remover	1110 – 1400	2.35 - 3.08	45 - 89.6	39.6 - 78.8	-	-	140 - 180	-123 - -73.2	0.18 - 0.5	1e20 - 6e21	5	5	3	3		
E8	Glass	2440-2490	68-72	31-35	360-420	40 – 45	15	170-400	-	0.7-1.3	7.9e17- 7.9e18	5	5	5	5		
E9	Tarpaulin sheets	1450 – 1550	61.4 - 128	400 - 938	-	-	1	400 - 420	-	0.25 - 0.35		5	5	4	1		
F1	Polystyrene foam/ expanded polystyrene	75-85	3.3e-4 - 4e-4	0.125-0.15	0.023-0.03	0.025-0.03	1.9	72-77	-53 - -23	0.024-0.028	1e18-1e19	5	3	3	3		Unacceptable with strong acids and alkalis
F2	Gypsum board	623-770	1.7 - 2.5	1.0 - 2.0	2.40-2.75	2.25-3.79		320		0.125 - 0.50							623-770

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												1 = Poor 2 = Limited 3=Acceptable 4 = Good 5 = Excellent			1 = High 2 = Flammable 3 = Slow 4 = Self extinguishing 5=None		
F3	Low strength glass fiber	2540-2590	57.8-76.7	25.6-34.4	256-344	57.8-76.7	1	157-426	-	0.9-1.2	1e22-1e24	5	2	5	5	-	2.54e3-2.59e3
F4	Fiberboard	160-480	0.3-0.9	1.8-4.2	0.05-0.1	1.8-8.3	5.6	120-140	-73 - -23	0.3-0.35	3e12-7e14	2	2	4	1	1	160-480
G1	Polyurethane foam	75-85	3.3e-4 - 4e-4	0.125- 0.15	0.023-0.03	0.025- 0.03	1.9	72-77	-53 - -23	0.024-0.028	1e18- 1e19	5	3	3	3		Unacceptable with strong acids and alkalis
G2	Polypropylene	36-70	0.023- 0.08	0.45- 2.25	0.37-1.7	-	-	100-115	-113 - -73.2	0.023-0.04	1e17- 1e21	5	5	4	4		Excellent with acidic and alkaline soils
G3	High strength glass fiber	2550-2600	72-85	1.95e3- 2.03e3	4e3-5e3	3300- 3450	1	350-360	-	1.2-1.35	1e22-1e23	5	5	5	5	-	
G4	Natural Rubber	920-930	0.0015 - 0.0025	22-32	22-33	36.8 - 47.2	1.5	68.9-107	-56.2 – -43.2	0.1-0.14	1e15-1e16	5	5	1	1		
G5	Neoprene Rubber	1239 – 1300	0.00165 - 0.0021	12 - 24	14.4 - 28.8	0.00165 - 0.0021	1.5	102 - 112	-55 - -40	0.15 - 0.2	1e17 - 1e19	5	5	1	4		
G6	Styrene Butadiene Rubber (SBR)	940 – 961	0.002 - 0.01	1.4 - 3	0.002 - 0.01	7.73 - 10.1	1.7	70 - 110	-50 - -40	0.19 - 0.25	5.01e21 - 7.94e21	5	5	1	1		

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**PREFABRICATED TIMBER FRAMES
STACKED FOR CONSTRUCTION OF
INTERMEDIATE SHELTERS. 2010
EARTHQUAKE RECONSTRUCTION
IN PORT-AU-PRINCE, HAITI.**



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