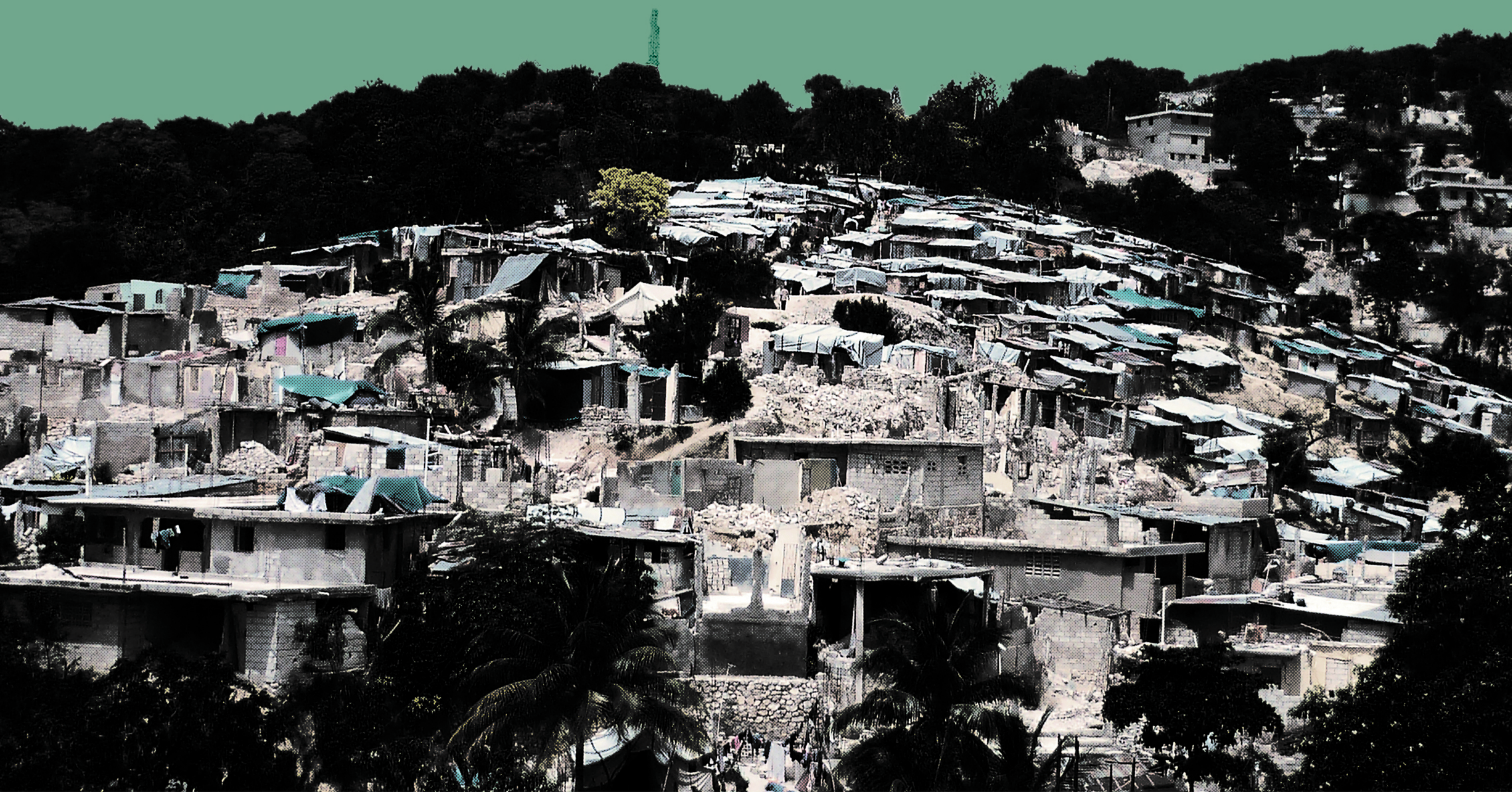
GLOBAL CALL TO ACTION

Sustainable Building Materials Management in Post-Disaster Situations



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An area impacted by the 2010 Haiti Earthquake, Port au Prince, Haiti. Temporary shelters built upon the debris of collapsed buildings. (Photo: Missaka Hettiarachchi)

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CALL TO ACTION

Disasters destroy hundreds of thousands of buildings annually. Rebuilding requires staggering volumes of material. The adverse socio-environmental impacts of poor post-disaster building materials management have reached truly global and alarming proportions. If not addressed soon, these issues will metastasise to catastrophic levels, exacerbated by rising disasters and climate change impacts. The immense destruction caused by conflict-related disasters will further aggravate this crisis. Despite the advanced tools and know-how available, sustainably managing building materials post-disaster and post-conflict is hindered by policy and governance gaps, limiting the use of more sustainable approaches. Therefore, we call for all responsible international and national authorities to consider sustainable building materials management as an integral part of post-disaster and post-conflict resilience, and to take urgent and concrete policy actions to ensure resilient reconstruction in line with Sendai Framework's Priority 4 – "Enhancing disaster preparedness for effective response and to build back better in recovery, rehabilitation and reconstruction." This is also a timely opportunity to raise ambitions of the next generation of Nationally Determined Contributions (NDCs 3.0), aligning reconstruction efforts with broader climate commitments.

Disaster-induced building-material demand threatens ecosystems and communities

Disasters pose critical threats to buildings worldwide

The 21st Century has been rife with major disaster events driven by natural hazards. Most major events destroyed or significantly damaged more than one hundred thousand buildings in a matter of hours or days (Table A1), showing that disasters generate the equivalent of 5 to 15 years' worth of waste in a matter of days [1,2]. For example, the 2004 Indian Ocean Tsunami destroyed over half a million buildings in Indonesia and Sri Lanka alone, while Typhoon Haiyan (2013) affected a record 1.2 million buildings. In more recent examples, the 2023 Turkiye and Syria Earthquake destroyed 164,000 buildings, in Afghanistan 4 consecutive earthquakes in 2023 affected almost 70,000 buildings, and in September 2024 over 400,000 buildings were affected by Typhoon Yagi in Vietnam, China, the Philippines, and Myanmar. Conflict-related disasters, such as wars and insurgency, also cause destruction of buildings at a similar scale. Climate-change-driven increases in natural hazards and globally escalating violent conflicts are likely to further increase disaster threats on the built-environment in the future.

Rebuilding housing and infrastructure is a socio-political priority in disaster aftermaths

Along with loss of life and health impacts, destruction of buildings (primarily housing) is one of the most serious issues in any humanitarian crisis, which affects the safety, quality of life and dignity of communities over many years after the disaster [1]. Communities rightly demand fast restoration of living conditions and livelihoods to pre-disaster levels. At national scales, governments and humanitarian actors regard housing and infrastructure reconstruction as an utmost priority in disaster aftermaths. Globally, the Sendai Framework for Disaster Risk Reduction (2015-2030) [3] calls for "building back [the communities] better" than the pre-disaster conditions, through "recovery, rehabilitation and reconstruction" (Sendai Framework: Priority 4).

Post-disaster reconstruction requires staggering amounts of building materials

The need to rapidly rebuild the hundreds of thousands of buildings destroyed by disasters every year – which may have initially taken decades or centuries to build – inevitably creates sharp increases in building-material demand at local and national scales. For example, following the Nepal Earthquake of 2015 which affected 500,000 buildings, the World Wildlife Fund (WWF)-Nepal estimated that rebuilding would require over 2 million tons of Ordinary Portland Cement (OPC), 2.5 million cubic meters of river sand and over 1 billion burnt clay bricks (among other materials). Sourcing and managing adequate building materials in such colossal scales is one of the most difficult post-disaster challenges for humanitarian and disaster management agencies [4]. Soaring demand causes: 1) building material shortages which hamper the reconstruction process and greatly increase material costs, and 2) acute social and environmental impacts due to unsustainable material extraction, processing and manufacturing. Resources and energy required to deliver the materials for reconstruction also cause unanticipated spikes in greenhouse gas (GHG) emissions of affected countries and supply chains, undermining climate goals and Nationally Determined Contributions (NDCs).

Alarming global environmental impacts of the building materials industry are further aggravated by post-disaster demand spikes

Building material use for development activities is growing worldwide at an unprecedented scale. Between 1990 and 2020, the global demand for metals and non-metallic construction minerals approximately tripled from 20 gigatonnes (Gt; trillion kilograms) per annum to 60 Gt per annum [5]. By 2060 non-metallic minerals consumption alone is expected to reach 86 Gt per annum and concrete and cement industries will contribute 12% of global GHG emissions. These consumption patterns put immense pressure on Earth's natural resources and intensify climate change. It is well documented that over-extraction of common construction minerals such as sand in these proportions is destroying entire ecosystems and causing alarming social impacts, especially in the Global South [6]. Demand spikes induced by disaster reconstruction are adding to this rapidly growing building material demand for development needs, contributing to increased carbon emissions and other ecological impacts.

Türkiye–Syria Earthquake, 2023

164,000 damaged buildings generated a record 100 million cubic meters of debris … 40 times the size of the Great Pyramid of Giza.

Construction machinery demolishing damaged buildings: Gaziantep, Türkiye (Photo – © European Union, 2025, CC 4.0)

Nepal Earthquake, 2015

Estimates indicated reconstruction of 500,000 affected buildings required over a billion clay bricks … if laid on a single line, it would traverse the earth 6 times.

Excessive clay mining for brick burning: Kathmandu Valley, Nepal (Photo – Judy Oglethorpe)

Indian Ocean Tsunami, Sri Lanka, 2004

Demand to build over 50,000 new houses added to the growing issue of river sand over-extraction and caused catastrophic destruction of two major river ecosystems (Deduru Oya and Ma Oya) in the western coast of Sri Lanka.

Massive river-bank erosion, due to excessive sand mining: Gal Oya, Sri Lanka (Photo – Irrigation Department of Sri Lanka)

Challenges of post-disaster building materials management are unique

Challenges of sourcing and managing building materials for post-disaster reconstruction arise from difficult conditions unique to disaster aftermaths and not experienced in regular construction projects. While there are many overlaps between post-disaster and post-conflict challenges, extremely complex challenges unique to post-conflict reconstruction (e.g., managing unexploded ordinances) are not addressed in this document. Post-disaster building materials management issues and resulting environmental impacts can be largely grouped into three categories (based on investigating fifteen major disaster aftermaths between 2005-2020, see Annex: Table A1 and Fig A1 for details):

> ***Building material shortages and price escalation:*** The massive scale of damaged buildings creates a sudden spike in building material demand after a disaster, which overwhelms the normal building materials supply chains and leads to material shortages [7]. Post-disaster material demand can be several times higher than at normal times [8]. Shortages are further exacerbated by severe disruptions to industries and supply chains caused by the disaster event. Material shortages inevitably lead to price escalation unless government agencies intervene. Shortages of common building materials (e.g., sand and burnt bricks) and price escalations (some as high as 30-40%) were experienced in almost all major disaster aftermaths in the past 20 years, in the Global North and South alike: e.g., Typhoon Haiyan in 2013 (the Philippines), Nepal Earthquake in 2015, and California Wildfires in 2019 (USA). See Table A1.
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> ***Unsustainable building material extraction and use:*** Processes such as sand or clay mining, cement production and brick burning can create large-scale environmental and social impacts even under normal conditions. In disaster aftermaths these impacts are exacerbated not only by the sheer scale of material demand but also by disruptions to environmental safeguards due to the disaster event or temporary relaxation of construction or environmental regulations to expedite reconstruction projects. Post-disaster price escalation of building materials also provides perverse incentives to over-extract resources such as sand or timber. For example, river sand over-extraction caused large-scale ecosystem degradation, loss of livelihoods and deadly social conflicts, and was a recurring problem across the Indian Ocean Tsunami in 2004 (Sri Lanka) and the Nepal Earthquake (2015). Similar issues but of lesser magnitude were caused by excessive clay mining in the aftermath of Cyclone Idai (2017) in Mozambique.
>
> ***Unsustainable management of disaster debris:*** Managing the debris from destroyed or damaged buildings (rubble) is also a major material-related challenge post-disaster. The massive volumes of rubble (primarily masonry and concrete), mixed with hazardous materials (i.e. asbestos), cause severe environmental and health problems such as toxic dust generation and degradation of waterways. Debris also affects communities and humanitarian workers, impacting access paths and severely hampering the recovery process. The breakdown of environmental regulatory procedures during disaster aftermaths creates conditions for illegal disposal of debris in natural ecosystems, causing irrecoverable degradation. For example, the 2013 Typhoon Haiyan generated more than 750,000 cubic meters of rubble in the Philippines (over 50,000 large trucks), where many cases of ad hoc dumping of debris in wetlands and waterways were reported. The 2023 earthquake in Turkiye and Syria has generated an estimated 100 million cubic meters of rubble (highest in recorded history of disasters). This rubble is still mostly waiting to be cleared and is ending up in landfill.

Figure 1 illustrates how these challenges and the resulting environmental impacts combine and compound to pose long-term risks to ecosystems and communities.

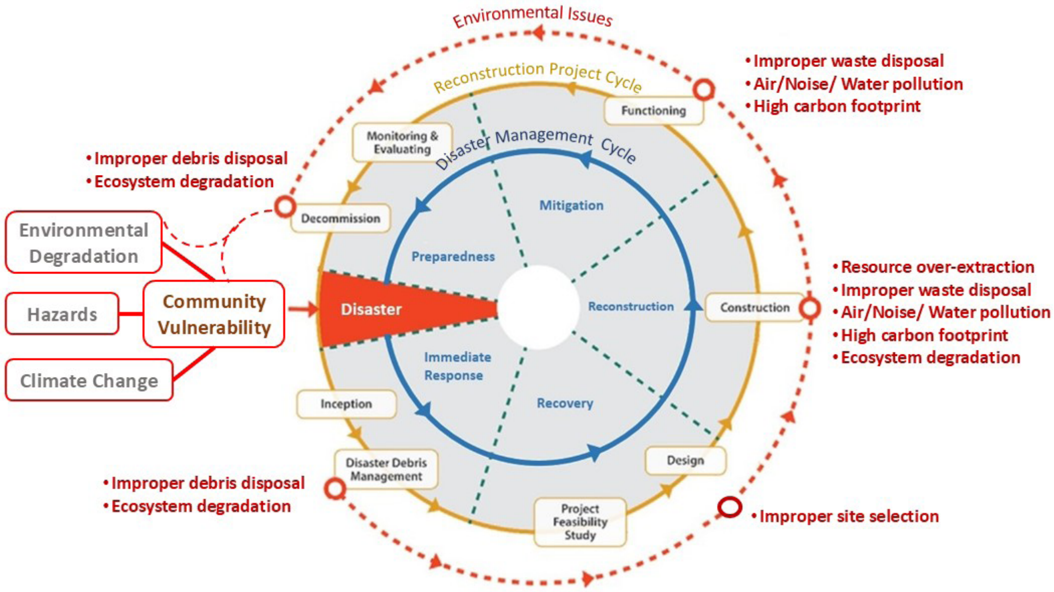

Figure 1: Environmental issues associated with the disaster management and reconstruction project cycles that lead to increased environmental degradation and increased community vulnerability to hazards and climate change.

Policy gaps hamper post-disaster building materials management

Physical destruction caused by disasters poses immense challenges, yet the key impediments for sustainable post-disaster building materials management come from the gaps and weaknesses in policy and governance, which in most cases do not consider climate mitigation and resilience within their core objectives. Policy frameworks and actors in both construction and disaster management sectors lack preparedness to address the unique challenges of post-disaster building materials management such as disaster-induced material shortages or resultant socio-environmental impacts. These policy and governance gaps continue despite the growing recognition of the need for sustainability in both construction and disaster management sectors.

- Over the past few decades, there have been significant global policy advancements towards sustainability in the construction sector. Also, there is growing recognition in the disaster management sector of the need to address environmental concerns during post-disaster reconstruction and risks reduction:

    In the construction sector, there are examples such as: Global voluntary material certification schemes (e.g., Forest Stewardship Council), systematic Construction and Demolition Waste (CDW) management (e.g., the European Union's target to recover and reuse 70% of CDW) and the global initiatives towards circularity in the construction industry (e.g., United Nations Sustainable Buildings and Construction Program).

    Developments in the disaster management sector include: The Sendai Framework for Disaster Risk Reduction (2015-2030) calls for mainstreaming environmental management and resource efficiency in Disaster Management. The Global Shelter Cluster, United Nations High Commission for Refugees (UNHCR), United Nations Development Program (UNDP), United Nations Environment Program, World Wildlife Fund, and World Green Building Council have published guidelines on sustainable post-disaster reconstruction, which refer to building materials issues – e.g., Building Materials Environmental Guide – BMEG [9]. See Annex 3 (Table A3) for more information.

- Some gaps in these policies and guidelines limit their effectiveness in post-disaster building materials management. For example, the current sustainable construction guidelines depend on non-disaster conditions in material availability and supply chains, as well as undisrupted functioning of governance, for successful implementation. However, these conditions are not met in a disaster aftermath. Although the International Federation of Consulting Engineers (FIDIC) published a Disaster Management Guide [10] that recognizes the need for disaster preparedness in the construction sector, it requires further development to address the unique post-disaster challenges of material management. Some guidelines, such as UNDP Standard Operating Procedures for post-disaster material management, partially assess sustainability, but do not adequately consider the full material life-cycle.

- Policy documents and guidelines from the disaster management sector lack standing or influence in the construction sector, where construction regulatory bodies decide how building materials are managed. Currently, there is no integration between the governance frameworks of the construction and disaster management sectors to address the specific building materials and environmental concerns in reconstruction. Awareness and understanding of building materials sourcing and use, in a post disaster context, is limited. This remains a major barrier for a sustainable lifecycle-based approach for post-disaster building materials management. The shortage of up-to-date data on material availability makes reconstruction supply-chain management difficult, while poor understanding of material types used in the existing building stock hampers debris reuse planning post-disaster. Furthermore, there is a lack of actionable guidelines to address post-disaster material shortages and supply chain disruptions.

- On the positive side, ample technical knowhow and tools for sustainable building materials management have been developed in the past two decades. However, they are not always readily available or applicable in vulnerable contexts, particularly in emerging economies. For example, a wide range of construction sustainability assessment tools are now available and a majority of them include life-cycle assessment (LCA) guidelines for building materials management (see Annex 2: Table A2 for more details). Mathematical optimization tools can help alleviate some of the complexities in post-disaster application of existing sustainability tools [11]. Reuse of post-disaster debris has gained traction in recent years – e.g., rubble was used as filling material and aggregate for rebuilding projects following the 2004 tsunami in Indonesia and Tohoku Earthquake (2011) in Japan [12] and research breakthroughs are being made in transforming disaster debris into new building materials [13]. Technology, innovation and Artificial Intelligence are also opening doors to data-driven post disaster support. The United Nations Office for Project Services (UNOPs) is using systems such as Cloud-based Information, environmental simulations and geomapping to analyse damaged areas at scale. Policy support is needed to adapt these technical advancements to post-disaster reconstruction, create wider awareness (e.g., about sustainable building materials and debris reuse), and conduct further research.

Proposed policy action towards sustainability

The overarching challenge for sustainable post-disaster building materials management is the disconnect between the construction and disaster management sectors in addressing post-disaster reconstruction issues. For this, we propose the following policy-level initiatives in both sectors, at global or national scales:

- Include sustainable building materials management as an essential step of "building back better" (under Priority Area 4 of the Sendai Framework) in the future strategic frameworks of UNDRR, and facilitate its cascading to the regional, national and local disaster management action plans, particularly in the developing country context. Building back better strategies after a crisis should integrate with the climate goals and NDCs of the country, incorporating sustainable, local, low-emissions materials and circular construction practices. We also argue that emphasizing that the phrase "build back better" encompasses safer reconstruction with less environmental impact may encourage the decision-makers to consider environmentally responsible and resilient materials and techniques for reconstruction.

- The Global Shelter Cluster (GSC) bears the mandate for internationally coordinating post-disaster shelter provision and reconstruction with a regenerative settlement approach to build back better, aiming for long-term sustainable development after disasters. GSC should work with stakeholder agencies to make sustainable building material management a key performance indicator for reconstruction projects, build awareness on sustainable materials among state and humanitarian partners, and support local producers and suppliers as part of disaster preparedness.

- A global construction industry regulator or alliance, such as the International Federation of Consulting Engineers (FIDIC) or the Global Alliance of Buildings and Construction (GlobalABC), should develop guidelines on disaster-preparedness measures for construction sector stakeholders (e.g., national level regulators, contractors, consultancy firms, materials suppliers). Such guidelines could build upon FIDIC's Disaster Management Guide (International Federation of Consulting Engineers, 2014), but also address specific issues such as material shortages, supply chain disruptions, and sudden price escalation (e.g., measures such as maintaining contingency stocks and special insurance or subsidy schemes for suppliers).

- A global hub for sustainable post-disaster building materials management should be established jointly by the leading agencies from the construction and disaster management sectors to: 1) function as a global observatory for issues in post-disaster building materials sourcing, use, and disposal; 2) develop and periodically update guidelines to address all aspects of building materials management in disaster aftermaths; and 3) campaign for increased resource allocation from both state and private sectors for expanding research and creating broader awareness on sustainable building materials and disaster debris reuse for reconstruction. UNDRR, GSC, GlobalABC, and FIDIC could lead such an initiative given their current mandates and outreach, along with other key actors in the humanitarian, and development sectors.

These broad policy developments can facilitate the specific steps required for sustainable post-disaster building materials management throughout the reconstruction project cycle (see Figure 2).

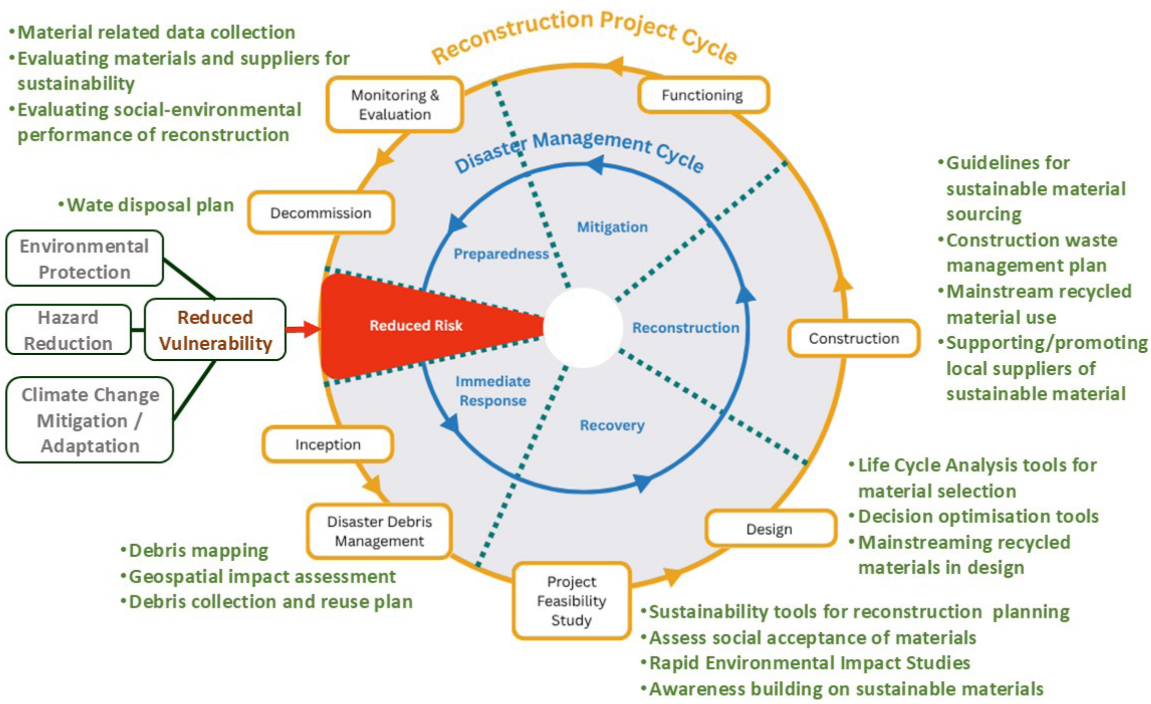

Figure 2: Specific steps for sustainable post-disaster building materials management will minimize environmental degradation and decrease community vulnerability to hazards and climate change.

References

[1] C. Brown, M. Milke, and E. Seville, "Disaster Waste Management: A Review Article," Waste Management, vol. 31, no. 6, 2011, pp. 1085–1098.

[2] D. Amaratunga and R. Haigh, "Introduction," in Post-Disaster Reconstruction of the Built Environment: Rebuilding for Resilience, D. Amaratunga and R. Haigh, Eds., Wiley-Blackwell, 2011, pp. 1-11.

[3] UNDRR, "Sendai Framework for Disaster Risk Reduction 2015-2030," United Nations Office for Disaster Risk Reduction (UNDRR), Geneva, 2015.

[4] C. Brown and M. Mike, "Recycling disaster waste: feasibility, method and effectiveness," Resources Conservation and Recycling, vol. 106, pp. 21-32, 2016.

[5] OECD, "Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences," OECD Publishing, Paris, 2018. 10.1787/9789264307452-en.

[6] V. Beiser, The World in a Grain, New York, NY: Riverhead Books, 2018.

[7] G. Celentano, E. Z. Escamilla, V. Göswein and G. Habert, "A matter of speed: The impact of material choice in post-disaster reconstruction" International Journal of Disaster Risk Reduction, 2018. 10.1016/j.ijdrr.2018.10.026.

[8] Y. Chang, S. Wilkinson, R. Potangaroa and E. Seville, "Resourcing for a resilient post-disaster reconstruction environment," International Journal of Disaster Resilience in the Built Environment, vol. 1, no. 1, pp. 65-83, 2010.

[9] M. Hettiarachchi, V. Dwivedi, W. M. Miller, S. H. Carr, J. B. Dunn, M. M. McMahon and A. van Breda, Building Material Selection and Use: An Environmental Guide, 2nd ed., Evanston IL: World Wildlife Fund, Washington DC and Northwestern University, 2022. envirodm.org/green-recovery/#Infrastructure.

[10] FIDIC, "FIDIC disaster management guide," International Federation of Consulting Engineers (FIDIC), Geneva, Switzerland, 2014. fidic.org/books/disaster-management-guide-2014.

[11] M. Izadinia, E. Ramyar, M. Alzayer, S. H. Carr, G. Cusatis, V. Dwivedi, D. J. Garcia, M. Hettiarachchi, T. Massion, W. M. Miller and A. Wächter, "A versatile optimization framework for sustainable post-disaster building reconstruction,," Optimization and Engineering, 2022. 10.1007/s11081-022-09766-9.

[12] T. Norton, "Lessons Learned from Debris Management of the 2011 Great East Japan Earthquake and Tsunami," in The 2011 Japan Earthquake and Tsunami: Reconstruction and Restoration, 1st ed., i. Springer, Ed., Advances in Natural and Technological Hazards Research, 2017, pp. 67-91.

[13] I. Maruyama, W. Kotaka, B. N. Kien, R. Kurihara, M. Kanematsu, H. Hyodo, H. Hirao, R. Kitagaki, M. Tamura, M. Tsujino, S. Fujimoto and T. Noguchi, "A New concept of calcium carbonate concrete using demolished concrete and CO2," Journal of Advanced Concrete Technology, 2021.

Annexes

Buildings Damaged (1000's) vs. Materials Management and Environmental Issues across Fifteen Major Disasters (2004-2023)		Environmental Issues				
		Over-Extraction of Building Materials (60%)	Ecosystem Degradation (67%)	Improper Debris Disposal (67%)	Improper Site Selection for Reconstruction (47%)	All Environmental Issues
Materials Management Issues	High Price Fluctuation (67%)	3801	3154	2950	1797	4,260
	Poor Distribution Logistics (53%)	2928	2158	2909	1924	2,938
	Materials Shortage (80%)	2561	2694	1855	1501	3,184
	Poor Regulations and Standards (33%)	1042	1042	1206	982	1,206
	All Materials Management Issues	4,533	3,886	3,827	2,693	

Figure A1. Magnitude (thousands of buildings damaged) of materials management and environmental issues across the 15 major disasters in Table A1. The number within each heat map square represents the total number of buildings damaged in those disasters for which that combination of materials management and environmental issues was identified. The number within each square outside the heat map represents the total number of buildings damaged in those disasters for which that materials management or environmental issue was identified. The values in () within the row and column labels represent the percentage of disasters for which that materials management or environmental issue was identified.

Table A1: Building-materials related issues and environmental issues from 15 major disasters from 2004-2023

Disaster	Country	Year	Buildings damaged & destroyed	Construction Material Related Issues	Commonly cited environmental Issues	Source
Tsunami	Sri Lanka	2004	105,000	Overall price escalation in building material within 40-60% Shortages of construction materials such as sand, soil, clay roofing tiles Sand, bricks, steel reinforcement bars and cement showed higher growth of prices. Ceramic tiles, cement block, timber, electrical wiring items had a lower rate of increase in prices Due to urgency of reconstruction and time pressure, there was a lack of adherence to regulatory procedure and material quality standards **Main materials used** – Concrete, Cement, Bricks, Timber	Improper tsunami debris disposal Filling and destruction of wetlands Localized deforestation Improper shelter site selection and increased climate change vulnerability Increased human-elephant conflict Improper solid waste management Excessive clay mining for brick and roof tile production Excessive and illegal sand extraction and destruction of river ecosystems	1, 2, 3
Tsunami	Indonesia (Ache)	2004	419,000	Lack of needs assessments and site-specific information, absence of directives and coordination from authorities Absence of differentiation between emergency shelters and transition and permanent houses Sudden influx of local and foreign experts, culturally inappropriate and non-sustainable house designs Absence of standard construction drawings or building specifications, larger focus on quantity of reconstruction than quality Shortage of building materials: sand, stone, cement, timber and brick **Main materials used** – Bamboo, Steel, Sand, Stone, Timber	Absence of safe disposal of debris and rubble GHG emissions due to material demand and reconstruction Timber over-extraction Improper shelter site selection and increased climate change vulnerability Sand and gravel over-extraction and illegal extraction, both from rivers and hill slopes Localized deforestation	4, 5, 6, 7
Hurricane Katrina	USA	2005	300,000	Price escalation at the transitionary stage Shortage of material (wood and metal) to adhere to Federal Emergency Management Authority (FEMA) guidelines in reconstruction Price escalation of construction materials **Main materials used** – Various	Carbon monoxide poisoning Chemical contamination due to the hurricane (a general environmental issue to be tackled during reconstruction) Use of high carbon footprint materials in reconstruction	8, 9

Earthquake	Pakistan	2005	780,000	Price escalation of tents - inflated by 10 times Survivors were trained and encouraged to conduct their own reconstruction from retrieved debris. However, in some cases the knowledge was inadequate and materials were used in structurally unsound and unsafe ways Religious beliefs and emotional ties which hinder the removal, handling and reuse of potentially useful scrap material from the destroyed houses. Note: This was in a different region than the one in which survivors were trained and encouraged to conduct reconstruction using retrieved debris **Main materials used** – Timber, Bricks, Cement mortar, Stone, Corrugated Galvanized Iron (CGI) sheets	Accumulation of debris from chemical warehouses, hospitals and pesticide storages Over extraction of locally sourced materials such as stone and gravel	10, 11
Earthquake	China (Sichuan)	2008	>1,000,000	Scarcity of local raw minerals Shortages in brick supplies Inadequacy of local production capacity Increased prices of brick and aggregate Shortage in steel supplies due to regulated prices Increased transportation fees with rise in oil and coal prices **Main materials used** – Various	Potential emissions due to energy use in material extraction (implied) Potential emissions due to long-distance transportation of construction material Degradation of riverbanks Logging resulting in increasing incidence of floods and landslides Inappropriate sourcing approaches leading to building material over-extraction	12, 13, 14
Earthquake	Haiti	2010	294,000	Inadequate supply of shelter materials Disorderly distribution of building materials Deviation from traditional, more environmentally friendly materials to modern, more disaster-resilient materials Religious beliefs and emotional ties which hinder the removal, handling and reuse of potentially useful scrap material from the destroyed houses Approval of reconstruction projects without proper environmental impact assessments was one example of poor regulation **Main materials used** – Timber, Steel, Plastic sheeting	Use of fertile lands for resettlements and leaving steeper lands for agriculture Timber over-extraction (especially for poles to build temporary shelters) Widespread destruction of urban vegetation Environmental regulatory processes disrupted due to earthquakes and long-standing social unrest. Approval of reconstruction projects without proper environmental impact assessments Improper handling and disposal for disaster debris	15, 16, 17
Tōhoku earthquake and tsunami	Japan	2011	123,000	Raw-material and labor shortage for building material production Sudden increases in the prices of construction materials. **Main materials used** – Various	In areas hit by the tsunami, production ceased due to flooded buildings, facilities, and debris influx. PVC, which is widely used in wiring and construction materials, when burned improperly released harmful dioxins, proven human carcinogens. Pollution and contamination of land and waterways with hazardous material fallen buildings Difficulties in safe disposal of contaminated soil and debris	18, 19, 20

Floods	India (North) Nepal	2013	19,300	Rapid increase in demand for building materials Use of material unfit for shelters: not weather-proof and posing health hazards (a general article) **Main materials used** – Data not available	Improper selection of sites for reconstruction Excessive building material extraction Rapid deterioration of environment due to material extraction to support industries	21, 22
Typhoon Haiyan	Philippines	2013	1,192,000	Insufficient material distribution during reconstruction phase Increase in material prices by suppliers and rapid depletion of stocks (an article on similar disasters) **Main materials used** – Timber, Concrete/Mortar, Steel	Impact of land use changes due to reconstruction Improper shelter site selection and increased climate change vulnerability Potential increase of illegal timber felling Improper handling and disposal of disaster debris Increase in sand and gravel mining from rivers in the Eastern Visayas region	23, 24, 25
Earthquake	Nepal	2015	500,000	Limited affordability and access to modern construction materials Scarcity of optimum quality materials Implied price escalation due to deficiency in material and exchange rate destabilization with higher net imports Significant proportion of disaster aid spent in construction material (72%) **Main materials used** – Timber, Bricks, Cement mortar, CGI sheets	Sand, gravel, boulders and clay over extraction: pollution of water sources, increasing the potential of further hazards, threatening settlements, adverse impacts on air quality, impact on aquatic life, rivers changing course Timber and poles: depletion of forests, increased risk of further hazards, forest fragmentation, loss of habitat, pollution of rivers and streams, pesticide or chemical pollution of water Loss of forest land Stockpiling of disaster debris in urban green areas, and ad hoc disposal impacting urban waterways Some reconstruction work done in unsafe hill slopes	26, 27, 28
Hurricane Maria	Puerto Rico	2017	28,200	Delays in receiving materials due to low and delayed supply Inordinate delays in the recovery and reconstruction projects **Main materials used** – Concrete/mortar, Cement blocks, Timber	Impact of land-use changes Increased climate change vulnerability due to delays in reconstruction	29, 30
California Wildfires	USA	2018	26,200	Shortage of skilled labour and materials Construction material prices increased by 10 to 15 percent, three times more than normal. **Main materials used** – Various	The debris, which contains household hazardous waste, had a significant impact on the reconstruction process Harmful toxins released to the air due to burning of toxins	31, 32, 33,
Cylone Idai	Mozambique	2019	224,000	The cyclone caused a significant increase in the prices of construction materials, particularly CGI The price of cement consistently increased from about 350 to 420 MZM (5.5 USD – 6.50 USD) Poor quality of certain building materials – especially cement blocks Disruption to the supply of certain common building materials **Main materials used** – Clay, Timber, Cement blocks, Thatch	Slow removal of debris from the sites was hampering the recovery process Damage sewage systems and contaminated debris polluting waterways Excessive clay mining in certain localities to repair the vast number of wattle and daub houses destroyed	34, 35, 36, 37, 38,

European Floods	Germany	2021	10,000	Prices were up 77.3% for solid construction timber, 65.1% for roof battens and 61.4% for construction timber compared with the average of the previous year The cost of chipboards, which are typically made from sawmill waste, has increased by 23.0% The industrial producer price index increased by 10.5% annually in 2021 compared to 2020 Delivery delays, raw material shortages, and high demand have impacted the construction sector **Main materials used** – Various	Many oil heating systems leaked in the flood, effectively contaminating houses and upping the overall damage and cost The fast discharge and transport of coarser debris of high gradient valley confined floods produces greater effects on lateral erosion	39, 40, 41, 42,
Turkey–Syria earthquakes	Turkey and Syria	2023	164,000	The steel industry in Turkey will likely face logistical issues and production limitations for a prolonged period. Due to an expected increase in domestic demand, exports of certain building material such as polyvinyl chloride (PVC) will be affected in the medium term. The construction quality is poor due to the use of inadequate steel reinforcement. In order to save on cement costs and boost profits, weak concrete mixes have been utilized. **Main materials used** – Yet be determined	The lack of proper inspection procedures has led to the proliferation of illegal construction activities. The cities built on fertile agricultural lands are often prone to earthquake damage. Debris removal is slow and can last for several more months or years.	43, 44, 45, 46,

Table A2: Leading building-material-related sustainability assessment tools

Organization and Website	Organization Description	Tool Name	Description	Output / Utility	Medium	Geographical Focus	Disaster Related	Specific To Building Material
BRE Group	BRE is an independent research-based advisory, testing, and training organization, offering guidance and expertise to help clients create products, building, communities, and businesses that are much safer and more sustainable.	BREEAM Family	BREEAM is the world's leading sustainability assessment method for master planning projects, infrastructure, and buildings. BREEAM is an international scheme that provides independent third-party certification of the assessment of the sustainability performance of individual buildings, communities, and infrastructure projects. It provides certifications in the following standards: Communities (Master Planning), Infrastructure (Civil Engineering and Public Realm), New Construction (Homes and Commercial Buildings), In-Use (Commercial Buildings), Refurbishment & Fit-Out (Homes and Commercial Buildings).	Certification and guidance on sustainable construction	Multiple mediums ranging from PDFs to online platforms	Developed countries	Can be used in disaster and reconstruction	Includes building material management
		QSAND	QSAND is a free-to-use sustainability and resilience framework to promote sustainable response and reconstruction activities in the aftermath of disasters.	Returns a sustainability score based on a number of project aspects.	PDFs including an online e-learning tutorial	Developing countries	Specific to disaster and reconstruction	Includes building material management
The University of Melbourne	Melbourne School of Design	EPiC Database	The EPiC Database is a comprehensive open-access Life Cycle Inventory of environmental flow coefficients for building materials; it contains 250+ coefficients that can be incorporated into existing Life Cycle Assessment workflows and processes.	Provides numerical data on embodied energy, carbon footprint and water usage for different common building materials.	Sortable web-based table and PDFs	Global		
UNOPS	United Nations Office for Project Services	UNOPS Peace and Security Cluster (PSC) Information Management & Analysis Team (IMAT)	The Information Management & Analysis Team (IMAT) provides practical, data-driven solutions using cutting-edge geospatial technology, data science, and AI. It designs, delivers, and maintains sustainable and resilient infrastructure by transforming complex data into actionable intelligence, enhancing operational effectiveness, and mitigating risks.	Advanced Data Systems & Operations Predictive Analytics & AI-Driven Risk Assessment Environmental Simulation & Digital Twinning. Automated Infrastructure Redevelopment	Multiple mediums ranging from PDFs to online platforms	Developed countries		

UNHabitat	UNHabitat is the United Nations programme for human settlements and sustainable urban development.	SHERPA	SHERPA is a self-evaluation tool for project managers, communities, and other stakeholders involved in the planning, design, construction and assessment of housing projects.	Provides a sustainability score based on different project aspects.	Web application (mobile-focused)	Developing countries	Can be used in disaster and reconstruction	Includes building material management
		The Housing Value Assessment Methodology (VAM)	The Housing VAM is a rapid and assisted assessment targeted at national housing programmes and large housing projects, with valuable feedback on gaps and potential to shift towards more sustainable construction.	Provides a tailored feedback report with quantitative and qualitative outputs.	Web application	Global	Can be used in disaster and reconstruction	Includes building material management
National Institute of Standards and Technology (NIST)	The National Institute of Standards and Technology is a physical sciences laboratory and a non-regulatory agency of the United States Department of Commerce.	BEES Online 2.1	Building for Environmental and Economic Sustainability (BEES) is a tool developed by the National Institute of Standards and Technology (NIST) to allow designers, builders, product manufacturers, and consumers to select cost-effective, environmentally preferable building products based on consensus standards; it is designed to be practical, flexible, and transparent.	Returns environmental scores on multiple metrics (e.g., Ozone Depletion, Water Use, Land Use, Global Warming Potential, etc.) for a given building material.	Web Application	Global	Can be used in disaster and reconstruction	Specific to building material management
		BIRDS	BIRDS (Building Industry Reporting and Design for Sustainability) allows users to compare the sustainability performance of a new building as the energy efficiency design of that building type changes.	Returns environmental scores on multiple metrics	Online Tool	Global		
Building Transparency	Building Transparency is a non-profit organization that provides open access data and tools that support broad and swift action across the building industry in addressing embodied carbon's role in climate change.	EC3	The Embodied Carbon in Construction Calculator (EC3) tool, is a free and easy to use tool that allows benchmarking, assessment and reductions in embodied carbon, focused on the upfront supply chain emissions of construction materials.	Returns embodied carbon values and related assessment for a project	Web Application	Global	Can be used in disaster and reconstruction	Specific to building material management
Global Infrastructure Basel Foundation (GIB)	Global Infrastructure Basel Foundation (GIB) is an independent, not-for-profit foundation under Swiss law active in the field of sustainable urban infrastructure.	SuRe	SuRe (The Standard for Sustainable and Resilient Infrastructure) is a global voluntary standard which integrates key criteria of sustainability and resilience into infrastructure development and upgrade, through 14 themes covering 61 criteria across governance, social, and environmental factors.	Standards and guidance on sustainable infrastructure development	e-Portal and Documents	Global	Not related to disaster	Includes building material management
Building Transparency (in collaboration with KT Innovations, Thinkstep, and Autodesk)	Building Transparency is a non-profit organization that provides open access data and tools that support broad and swift action across the building industry in addressing embodied carbon's role in climate change.	Tally	The Tally application allows architects and engineers working in Revit® software to quantify the environmental impact of building materials for whole building analysis as well as comparative analyses of design options.	Building design support tool	Autodesk Revit Application	Global	Can be used in disaster and reconstruction	Specific to building material management

Athena Sustainable Materials Institute (ASMI)	ASMI is an objective think tank that is working with leading edge construction sector practitioners, product manufacturers, and policy makers in partnership towards the next generation of green buildings.	Athena EcoCalculator (now marked as outdated)	The EcoCalculator is a structured Excel spreadsheet workbook, with worksheet tabs for various categories of structural assemblies (columns and beams, floors, etc.). On each worksheet, find the specific assemblies in your building project and simply enter the total square footage of each.	Returns embodied fossil energy use and several impact measures including global warming potential, acidification potential, eutrophication potential, and smog potential.	Excel spreadsheet workbook	Global	Can be used in disaster and reconstruction	Specific to building material management
		Athena Impact Estimator	The Impact Estimator provides a cradle-to-grave life cycle inventory profile for a whole building. The inventory results comprise the flows from and to nature: energy and raw material flows plus emissions to air, water, and land.	Returns footprint data for the following environmental impact measures consistent with the latest US EPA TRACI methodology: global warming potential, acidification potential, human health respiratory effects potential, ozone depletion potential, smog potential, and eutrophication potential.	Software	Global	Can be used in disaster and reconstruction	Specific to building material management
One Click LCA	One Click LCA is a private company providing Life Cycle Analysis and Environmental Product Declaration software provider for the construction industry.	One Click LCA	Tool that allows users to automate LCA with BIM & BEM integrations to get results that comply with EN & ISO standards, LEED, BREEAM, and 40+ other certifications.	Building design support tool	Software	Global	Can be used in disaster and reconstruction	Includes building material management
U.S. General Service Administration	The General Services Administration is an independent agency of the United States government established in 1949 to help manage and support the basic functioning of federal agencies.	SFTool	SFTool is an interactive website made to meet sustainability planning, designing, and procurement needs while showing users how to build, buy, and operate green.	Sustainability planning tool	Website	Global	Not related to disaster	Not related to building material management
TRANE Technologies	TRANE Technologies is a manufacturer of heating, ventilating and air conditioning systems and building management systems and controls.	TRACE 3D Plus	TRACE 3D Plus allows you to move from project plan to load design to energy and economic analysis all through the same project file and interface. Import 3D models directly from CAD using Green Building XML (gbXML), or import floor plans and trace over using the draw tools.	Building services design support tool	Software	Global	Not related to disaster	Not related to building material management
Ecochain	Environmental Intelligence Platform	Ecochain	Ecochain is an Environmental Intelligence Platform that allows users to get insights into the footprint of their entire portfolio and supply chain, and allow them to reduce the impact where it makes the biggest difference.	Returns carbon emissions and other LCA parameters, and reporting outputs for different products	Web Application (s)	Global	Not related to disaster	Includes building material management

Sphera	Sphera is a provider of Environmental, Social and Governance (ESG) performance and risk management software, data and consulting services with a focus on Environment, Health, Safety & Sustainability (EHS&S), Operational Risk Management and Product Stewardship.	GaBi	GaBi is a tool that combines Life Cycle Assessment (LCA) modelling and reporting software and content databases with intuitive data collection and reporting tools to help users assess every raw material and process in every phase from extraction to end-of-life across your supply chain.	Returns carbon emissions and other LCA parameters, and reporting outputs for different products	Software	Global	Can be used in disaster and reconstruction	
PRé	PRé helps companies turn sustainability strategy into action, through fact-based consulting services, training and software solutions based on life cycle thinking.	SimaPro	The leading life cycle assessment (LCA) software package. Enables its users to dive deep into the LCA calculations of a product.	Returns carbon emissions and other LCA parameters, and reporting outputs for different products	Desktop version with an option to use cloud-based modules	Global	Not related to disaster	Includes building material management
GreenDelta	GreenDelta is an independent sustainability consulting and software company located in Berlin, Germany, founded in 2004 as a capital company.	openLCA	Open-source life cycle assessment (LCA) software.	Returns carbon emissions and other LCA parameters, and reporting outputs for different products	Software	Global		
Shelter Cluster	The Shelter Cluster is an Inter-Agency Standing Committee coordination mechanism that supports people affected by natural disasters and conflicts with the means to live in safe, dignified and appropriate shelter.	Environmental Self-assessment and Action Checklist for Shelter Interventions	An environmental self-assessment checklist is a suggested format to be used by agencies involved in shelter intervention in the Typhoon Yolanda aftermath as an internal document to self-assess the environmental sustainability of the projects.	Binary (Yes or No) checklist points and recommendations for better practices.	PDF	Developing countries		
WoodWorks Carbon Calculator	WoodWorks is a nonprofit ran by architects, structural engineers and construction experts that provides education/tools/technical support for the design, engineering and construction of wood-based buildings	Carbon Calculator	The carbon calculator has 2 parts. The first is a "carbon estimator" that is used for projects without a full plan. The second is a "carbon calculator" that is used for fully developed projects where the volume of wood of each type is known. Both aim to output the carbon benefit of the project and quantify that information, with the "calculator" being much more precise.	Outputs volume of wood used in project and the carbon benefit associated with using wood for the project. Gives analogies for the benefits to qualitatively give a sense of the impact.	Web Application/ Online Tool	Only US. Multiple regions within US are chosen to influence results.	Not related to disaster	Includes building material management
World Wildlife Fund (WWF) and Northwestern University	Jointly developed by World Wildlife Fund (WWF) Environment and Disaster Management (EDM) program and Institute of Sustainability and Energy (ISEN), Northwestern University-USA.	Building Materials Environmental Guide (BMEG)	The Building Material Selection and Use: An Environmental Guide provides guidance on environmentally responsible selection, sourcing, use and disposal of building material. It also outlines the potential environmental and social impacts of different building materials throughout their life cycle. The guide is designed for government agencies, private sector companies, NGOs, and community-based organizations engaged in building construction and post-disaster reconstruction.	Provides specific information on environmental impacts, material properties and construction better practise for 52 common and specialized building materials	PDF	Global	Can be used in disaster and reconstruction	Specific to building material management

World Wildlife Fund (WWF)	World Wildlife Fund (WWF) Environment and Disaster Management (EDM) program. Works with partners to integrate environmental considerations into disaster recovery, reconstruction, and risk reduction programs and policies, and to learn and develop new approaches	Green Recovery and Reconstruction Training Toolkit	The GRRT is a toolkit and training program designed to increase awareness and knowledge of environmentally responsible disaster response approaches. Although disasters wreak havoc, the rebuilding efforts that follow represent a significant and important opportunity to restore communities in a more environmentally and socially responsible way. Humanitarians, conservation practitioners, government officials, local communities, and donor organizations can take steps to ensure communities prepare for disasters and build back safer by actively addressing environmental sustainability, reducing risk and vulnerability to future disasters, and adapting to the effects of our changing climate.	Provide information, policy and planning guidance and decision support tools for better environmental management during post disaster reconstruction.	PDF. Print	Global	Specific to disaster and reconstruction	Includes building material management

Table A3: Commonly used guidelines and policies for post-disaster reconstruction and environmental management

Title of the Guideline/ Policy	Country/ Region	Operating Organisation(s)	Description	Primary Focus	Related to Materials Management	Related to Disaster Management	Related to Environmental Governance	Source
Sendai Framework (UNDRR - 2015)	Global	United Nations	Framework for Disaster Risk Reduction	Disaster Management	None	Aims to achieve the substantial reduction of disaster risk and losses in lives; aims to improve livelihoods and health and the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.	Sendai Framework called for adherence to Rio-Principles and specific action minims environmental degradation and preserving ecosystems under the Priorities 3 and 4.	47
Sphere handbook (Sphere Project - 2018 update)	Global	Sphere Association	Humanitarian response in disasters and conflicts	Disaster Management	Recommends building materials that do not deplete local natural resources or contribute to long-term environmental damage. Salvage and reuse, recycle or repurpose available materials, including debris	The aim is to improve the quality of humanitarian response in situations of disaster and conflict, and to enhance the accountability of humanitarian action to crisis-affected people	Shelter and Settlement Standard 7: Environmental Sustainability. Shelter and settlement assistance minimises any negative programme impact on the natural environment.	48
Global Shelter Cluster/ IFRC: Shelter Related Guidelines	Global	IFRC Global Shelter Cluster (GSC)	A collection of technical and management guidelines on shelter provision	Post-Disaster Reconstruction	Most GSC shelter guideline documents call for material reduction, reuse, recycling and using local materials. Numerous technical resources published by GSC on building material recycling and safe use.	Aligns with Sendai Framework. Calls for integrated practice in shelter provision backed by science and full community engagement	GSC has an Environmental Community of Practice (ECoP) which engages during disaster aftermaths, providing environmental advice. ECoP has issued numerous environmental guidelines, fact sheets and self-assessment checklists for both global use and specific to regions.	49
European Humanitarian Shelter and Settlement Guidelines (EC 2017)	Global	European Commission	Guidelines for Shelter and Settlement	Post-Disaster Reconstruction	Reuse and recycle of material and debris has been identified as an area that needs expertise. Construction/rehabilitation experts will be required for Recycling expertise of salvageable construction materials.	Provides shelter and settlement guidelines mainly for post-disaster, but covers other situations such as conflicts and climate-change-related displacement. Recommends integrated and participatory approach and a balance between disaster resilience and response.	Principle 1 of the guideline emphasises the importance of considering environmental issues and responsible use of natural resources. It also recommends integrating shelter provision closely with the related sectors including environmental management. Environmental Management and Climate Adaptation practices are cited throughout the guideline.	50
Humanitarian Action and Environment: Essential guidance for humanitarian actors (UNOCHA/UNEP)	Global	OCHA, UN, UNEP	How environmental impacts during humanitarian work can be reduced. Not specific to reconstruction	Environmental Management	Addresses material-related aspects such as waste management during relief operations. Recommends green procurement practices.	Addresses disaster management activities across the disaster cycle, including life, health, livelihoods, shelter provisions and security related issues.	Provides overarching guidance on material, water and energy efficiency, green procurement, waste management, sanitation, and pollution control. Also outlines the environmental issues of different disaster management aspects relevant to UN Humanitarian Response Clusters.	51

Draft Emergency Shelter Policy with Regards to Environmental Issues (ProAct & Care, Shelter Cluster, UNHCR)	Global	ProAct and CARE International	Key environment-related policies which should be incorporated into relief and recovery in the shelter sector following a disaster.	Environmental Management	Deals with building-material-related environmental issues. Provides policy guidelines on material use, material efficiency and recycling.	Mainly addresses the reconstruction phase of the disaster management cycle, with focus on shelter provision.	Addresses multiple environmental and social issues related to shelter reconstruction. Provides environmental reference points and policy guidelines for better environmental management of shelter projects.	52
Disaster Waste Management Guideline UNEP/UNOCHA	Global	OCHA, UNEP & MSB	Guidelines in disaster waste management	Disaster Waste Management	Focus on solid waste management. Typical building and infrastructure waste is the focus for recycling materials such as concrete, steel, and timber.	Addresses disaster response and reconstruction phases. Various intersecting points between disaster waste and disaster management activities such as health and safety, environment, livelihoods, and reconstruction are considered.	Addresses environmental issues emerging from disaster wastes and provides guidance for managing them. Specific guidance on reuse, recycling, and environmentally safe disposal of disaster waste.	53
Rapid Environmental Assessment in Disasters (REA) Guidelines	Global	USAID, UNEP/ UNOCHA Joint Env. Unit	Guidelines for rapid Environmental Impact Assessment in disasters	Environment	Guidance on waste management and implementation of waste management plans.	Focuses on the disaster response and reconstruction stages. However, it addresses Disaster Risk Reduction as part of recovery and reconstruction processes.	Presents a framework to assess the environmental impacts and risks in a disaster aftermath and also to identify the negative environmental consequences of response and reconstruction activities. Provides guidelines for assessment at both organisational and community levels.	54
Green Recovery and Reconstruction Training Toolkit (WWF/AmCross)	Global	WWF and American Red Cross	Toolkit to inform practitioners on environmental concerns of disaster recovery and reconstruction	Environment	Takes a holistic approach to sustainable sourcing of building material and their safer use in construction, including reuse, recycling and disposal. The 10-part Toolkit includes a dedicated module on building materials.	Mainly addresses post-disaster reconstruction. Follows an integrated approach to disaster management aligning with the Hyogo framework. Highlights social inclusion, community engagement and a multi-disciplinary approach.	Addresses different environmental issues in the post-disaster reconstruction stage. Recommends environmental interventions based on the construction project cycle, including: environmentally responsible project planning, resource efficiency, minimising ecosystem impacts, waste management, supply chain greening, and water and sanitation.	55
Standard Operating Procedures for Post Disaster Rubble Management 2025	Lebanon/ Global	UNDP	Standard Operating Procedures	Post Disaster Reconstruction	The "Standard Operating Procedures for Post Disaster Rubble Management" (2025) outlines key procedures designed to systematically address the management of debris resulting from natural disasters and conflicts in Lebanon.	Covers Debris Pre-Processing Measures, Debris Processing, and Quarry Rehabilitation. Volume 1 focuses on safety protocols and assessments for risks like unexploded ordnance and hazardous materials. Volume 2 details standards for the segregation, transportation, storage, recycling, and disposal of debris, ensuring compliance with environmental regulations. Volume 3 establishes methods for the safe and sustainable rehabilitation of quarry sites through the utilization of non-recoverable/non-reusable components.	Collectively, the SOPs aim to enhance resource efficiency, support ecological restoration, and promote sustainable practices in post-disaster recovery efforts.	56

Supplementary References

1. Rizvi, A. (2006), "The challenge of holistic development: tailoring environment to the post-tsunami response in Sri Lanka", CARE International, Available at: cmsdata.iucn.org/downloads/the_challenge_of_holistic_development_post_tsunami_response_in_sri_lanka.pdf (Accessed on 30th January 2019).

2. United Nations Office for the Coordination of Humanitarian Affairs (2004), "Tsunami disaster - Sri Lanka Summary situation report 26 - 31 Dec 2004", Reliefweb, Available at: reliefweb.int/report/sri-lanka/tsunami-disaster-sri-lanka-summary-situation-report-26-31-dec-2004 (Accessed on 30th January 2019).

3. World Bank (2014), "Lessons Learned from the Sri Lanka's Tsunami Reconstruction", World Bank.

4. Brown, P. (2005), "Tsunami cost Aceh a generation and $4.4bn", The Guardian, Available at: www.theguardian.com/world/2005/jan/22/tsunami2004.internationalaidanddevelopment.

5. O'Brien, D., Ahmed, I., and Hes, D. (2008), "Housing reconstruction in Aceh: relationships between house type and environmental sustainability", in B*uilding Abroad: Procurement of Construction and Reconstruction Projects in the International Context*.

6. Spaling, H. and Vroom, B. (2007), "Environmental assessment after the 2004 tsunami: A case study, lessons and prospects", *Impact Assessment and Project Appraisal*, Vol. 25, pp. 43–52.

7. United Nations Resident and Humanitarian Coordinator for Indonesia (2005), "Indonesia earthquake and tsunami: situation report No. 38", Reliefweb, Available at: reliefweb.int/report/indonesia/indonesia-earthquake-and-tsunami-situation-report-no-38 (Accessed on 30th January 2019).

8. Institute of Medicine (US) Roundtable on Environmental Health Sciences (2007), "Environmental public health impacts of disasters: Hurricane Katrina: workshop summary", National Academies Press (US).

9. Reible, D. (2019), "Hurricane Katrina: environmental hazards in the disaster area", *Cityscape*, Vol. 9, pp. 53–68.

10. India Today (2015), "2005 Kashmir earthquake: all you need to know about one of the deadliest earthquakes", India Today, Available at: indiatoday.in/education-today/gk-current-affairs/story/kashmir-earthquake-267053-2015-10-08.

11. Rossetto, T. and Peiris, N. (2009), "Observations of damage due to the Kashmir earthquake of October 8, 2005 and study of current seismic provisions for buildings in Pakistan", *Bulletin of Earthquake Engineering*, Vol. 7, pp. 681–699.

12. Chang, Y., Wilkinson, S., Potangaroa, R., and Seville, E. (2011), "Identifying factors affecting resource availability for post-disaster reconstruction: a case study in China", *Construction Management and Economics*, Vol. 29, pp. 37–48.

13. United Nations Centre for Regional Development (UNCRD) (2009), *Report on 2008 Great Sichuan Earthquake*, UNCRD.

14. UNICEF (2009), *Sichuan Earthquake: One Year Report*, UNICEF, Available at: unicef.cn/en/reports/sichuan-earthquake-one-year-report.

15. Reid, K. (2018), "2010 Haiti earthquake: facts, FAQs, and how to help", *World Vision*.

16. Scientific American (2010), "Haiti's legacy of environmental devastation compounded by earthquake", *Scientific American*.

17. United Nations Environment Programme (UNEP) (2011), "UNEP in Haiti: 2010 year in review", UNEP.

18. Kajitani, Y. and Tatano, H. (2014), "Estimation of Production Capacity Loss Rate after the Great East Japan Earthquake and Tsunami in 2011", *Economic Systems Research*, Vol. 26, No. 1, pp. 13-38, Available at: tandfonline.com/doi/abs/10.1080/09535314.2013.872081.

19. Motosaka, M. and Mitsuji, K. (2012), "Building damage during the 2011 off the Pacific coast of Tohoku Earthquake", *Soils and Foundations*, Vol. 52, No. 5, pp. 929-944, Available at: sciencedirect.com/science/article/pii/S0038080612001035.

20. Hrabrin (2015), "March 2011 earthquake, tsunami and Fukushima nuclear accident impacts on Japanese agri-food sector", *Munich Personal RePEc Archive*, Available at: mpra.ub.uni-muenchen.de/61499/1/MPRA_paper_61499.pdf.

21. India's National Institute of Disaster Management (NIDM) (2014), *India Disaster Report 2013*, NIDM, Available at: nidm.gov.in/PDF/pubs/India%20Disaster%20Report%202013.pdf.

22. World Society for Protection of Animals (WSPA) (2013), *WSPA disaster assessment and needs analysis, Uttarakandh flash floods – 2013 India, WSPA, Sphere India*, Available at: reliefweb.int/report/india/wspa-disaster-assessment-and-needs-analysis-uttarakhand-flash-flood-june-2013.

23. Santos, C.T., Toda, L., Orduña, J.R., Santos, F.D., and Ferrão, J. (2016), "The impacts of Typhoon Haiyan in the Philippines: implications to land use planning", *Climate and Development*, Vol. 1, pp. 58–67.

24. The World Bank Group, Government of the Philippines, Global Facility for Disaster Reduction and Recovery (2014), *Recovery and reconstruction planning in the aftermath of Typhoon Haiyan (Yolanda)*, International Bank for Reconstruction and Development.

25. Hernandez Jr, J.Y., Aquino, R.E., Pacheco, B., and Cruz, E.C. (2015), "Damage caused by Typhoon Haiyan in the Philippines, review of structural regulations and practice, and research developments in wind engineering", *Wind Engineering*, Vol. 40, pp. 270–274.

26. Karnik, M. (2015), "The economic damage from the Nepal earthquake is almost half of the country's GDP", *Quartz India*, Available at: qz.com/india/409484/the-economic-damage-from-the-nepal-earthquake-is-almost-half-of-the-countrys-gdp/ (Accessed on 30th January 2019).

27. National Planning Commission of Government of Nepal (2015), *Nepal earthquake 2015: post disaster needs assessment*, Kathmandu Government of Nepal.

28. Ojha, H., Baldry, E., and Shrestha, K. (2017), "Two years after the earthquake, why has Nepal failed to recover?", *The Conversation*, Available at: theconversation.com/two-years-after-the-earthquake-why-has-nepal-failed-to-recover-77552 (Accessed on 30th January 2019).

29. Barclay, E., Campbell, A., and Irfan, U. (2018), "Hurricane Maria: 4 ways the storm changed Puerto Rico and the rest of America", *Vox*.

30. Boose, E. and Serrano, M. (2004), "Landscape and regional impacts of hurricanes in Puerto Rico", *Ecological Monographs*, Vol. 74, pp. 335–352

31. CBS News (2018), "Wildfires worsen California's construction labor shortage", Available at: cbsnews.com/news/wildfires-worsen-californias-construction-labor-shortage/.

32. Environmental Health Department, "Debris removal and cleanup work plan" (NEVADA COUNTY), Available at: nevadacountyca.gov/DocumentCenter/View/44152/Structure-Fire-Debris-Removal-and-Cleanup-Work-Plan.

33. Drabble, C. (2018), "The Challenges of Rebuilding A Community After A Wildfire", *CapRadio*, Sacramento, CA, Available at: capradio.org/news/insight/2018/12/12/the-challenges-of-rebuilding-a-community-after-a-wildfire/.

34. Schofield, H. and Deprez, S. (2019), "Supporting urban recovery after Cyclone Idai Beira, Mozambique", *CARE International Secretariat*, Available at: urban-response.org/system/files/content/resource/files/main/CARE%20-%20Supporting%20urban%20recovery%20-%20Beira.pdf.

35. Chatiza, K. (2019), "Cyclone Idai in Zimbabwe: An analysis of policy implications for post-disaster institutional development to strengthen disaster risk management", *Oxfam International*, Available at: policy-practice.oxfam.org/resources/cyclone-idai-in-zimbabwe-an-analysis-of-policy-620892/.

36. Yaxley, C., Holmes à Court, P., and Turner, V. (2019), "Cyclone Idai survivors struggle to rebuild devastated communities", *Platform of Disaster Displacement hosted by UNOPS*, Available at: disasterdisplacement.org/blog/2019/04/03/cyclone-idai-survivors-struggle-to-rebuild-devastated-communities/.

37. Kelly, C. (WWF Environment and Disaster Management Program), "Initial Environmental Issues – Cyclone Idai", Available at: envirodm.org/wp-content/uploads/2022/03/Enviromnent-Summary-Idai-Mar-22-2019.pdf.

38. Macamo, C. (2021), "After Idai: Insights from Mozambique for Climate Resilient Coastal Infrastructure", *South African Institute of International Affairs*, Available at: saiia.org.za/wp-content/uploads/2021/07/Policy-Insights-110-macamo.pdf.

39. Xinhua (2023), "Germany reports record increase of building material prices", Available at: english.news.cn/europe/20220210/6f4d5e1719654e089470edb666faf903/c.html.

40. Press (Statistisches Bundesamt) (2022), "Construction material prices rose sharply in 2021", Available at: destatis.de/EN/Press/2022/02/PE22_N006_61.html.

41. Muller, N. (2021), "After the flood: rebuild or relocate?", *Deutsche Welle (DW)*, Available at: dw.com/en/climate-change-flooding-germany-dernau-rebuilding-homes/a-59640272.

42. Lehmkuhl, F., Schüttrumpf, H., Schwarzbauer, J., et al. (2022), "Assessment of the 2021 summer flood in Central Europe", *Environmental Science and Pollution Research*, Vol. 34, Article 107. DOI: 10.1186/s12302-022-00685-1.

43. Kumar, R. (2023), "Impacts of the Turkey-Syria earthquake across sectors", *Procurement Strategy*, Available at: procurementmag.com/articles/impacts-of-the-turkey-syria-earthquake-across-sectors.

44. Ahmed, I. (2023), "Key Building Design and Construction Lessons from the 2023 Türkiye–Syria Earthquakes", *Architecture*, Vol. 3, Issue 1, pp. 104-106. DOI: 10.3390/architecture3010007.

45. Chousein, B.C. (2023), "Reports largely reveal poor ground conditions and material weaknesses in Turkey-Syria earthquake", *Turkey Architecture News*, Available at: worldarchitecture.org/architecture-news/enncn/reports-largely-reveal-poor-ground-conditions-and-material-weaknesses-in-turkey-syria-earthquake.html.

46. Keskinocak, P. (2023), "Earthquake Debris Could Create an Environmental Catastrophe in Türkiye and Syria", *Scientific American*, Available at: scientificamerican.com/article/earthquake-debris-could-create-an-environmental-catastrophe-in-tuerkiye-and-syria/.

47. United Nations Office for Disaster Risk Reduction (UNDRR) (2015), *Sendai framework for disaster risk reduction 2015-2030*, UNDRR, Available at: undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030.

48. Sphere Association (2018), *The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response, 4th Edition*, Sphere Association, Geneva, Switzerland, Available at: pherestandards.org/handbook.

49. International Federation of Red Cross and Red Crescent Societies (IFRC) Global Shelter Cluster (GSC), *Global Shelter Related Guidelines*, IFRC, Available at: sheltercluster.org/global.

50. European Civil Protection and Humanitarian Aid Operations (European Commission) (2017), *European humanitarian shelter and settlement guidelines*, Available at: ec.europa.eu/echo/files/policies/sectoral/shelter_and_settlement_guidelines.pdf.

51. United Nations Office for Coordination of Humanitarian Affairs (UNOCHA) and United Nations Environmental Program (UNEP) (2007), *Humanitarian action and environment: essential guidance for humanitarian actors*, UNOCHA, UNEP, Available at: interagencystandingcommittee.org/system/files/legacy_files/IASC_leaflet.pdf.

52. ProAct, Care, Global Shelter Cluster, United Nations High Commission for Refugees (UNHCR) (2008), "Draft emergency shelter policy with regards to environmental issues. global shelter cluster", ProAct, Available at: sheltercluster.org/resources/documents/draft-emergency-shelter-policy-regards-environmental-issues-2008-revison-1.

53. Joint United Nations Environment Programme (UNEP) / United Office for the Coordination of Humanitarian Affairs (OCHA) Environment Unit (2013), *Disaster waste management guideline*, Joint UNEP/OCHA Environment Unit, Available at: wedocs.unep.org/bitstream/handle/20.500.11822/27291/DisaterWM_guidelines.pdf?sequence=1&.

54. Moritz, H., Kelly, C. (2018), "Guidelines for rapid environmental impact assessment in disasters, 5th Edition", United States Agency for International Development, Available at: reliefweb.int/report/world/guidelines-rapid-environmental-impact-assessment-disasters-version-5-2018.

55. World Wildlife Fund (WWF) and American Red Cross (2010), G*reen Recovery and Reconstruction Training Toolkit for Humanitarian Assistance*, WWF, Washington, DC, Available at: envirodm.org.

56. Ministry of Environment, Lebenon and United Nation Developemental Program (UNDP) (2025). Standard Operation Procedures for Post Disaster Rubble Management, Ministry of Environment. Beirut, Lebanon. Available at: undp.org/lebanon/publications/standard-operating-procedures-post-disaster-rubble-management-2025