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ENVIRONMENTALLY RESPONSIBLE SELECTION AND MANAGEMENT OF CONSTRUCTION MATERIALS IN DISASTER RECONSTRUCTION

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Abstract: Disaster reconstruction has become an important component in built environment planning in recent decades as the frequency, scale and intensity of both natural and manmade disasters are increasing globally. Despite the significant improvements in the disaster management sector, disaster recovery and reconstruction, especially in the developing world, faces challenges regarding efficiency and widespread social, economic and environmental impacts. The construction industry is typically engaged in a range of critical activities after a disaster, from provision of immediate temporary shelter to permanent reconstruction of public and private infrastructure. Therefore, sourcing, use and disposal of construction material is an important aspect of disaster reconstruction planning. On the one hand, massive resource shortfalls arise as a result of the new demand created by reconstruction needs, upsetting the markets and usual procurement practices of construction material. On the other, exponential increase of material extraction, transport and disposal can cause significant environmental and social impacts. This paper presents a framework in the form of a matrix which assists the ground-level decision-makers to select construction material in post-disaster reconstruction projects. This framework was developed considering material selection factors such as their relative importance in environmental sustainability, better practices in design, storage, use and disposal. The paper discusses this approach against three major cases of disaster reconstruction in the past decade: Post-Tsunami Reconstruction in Sri Lanka, Post-earthquake reconstruction in Haiti, and Typhoon Haiyan reconstruction in the Philippines.. The paper identifies the challenges that the construction industry faces in unexpected events and highlights better practices to enable efficient and sustainable recovery and a resilient built-environment.

Keywords: Construction Materials; Disaster Reconstruction; Environment; Responsible Procurement; Resilient Built Environment

1. Introduction

The demand for construction material registered a rapid growth in the past two decades in all regions of the world (Escamilla & Habert 2015). Increasing populations, rising urbanization, economic expansion, emergence of new industrial centres and the reconstruction needs after major disasters were among the main driving factors of this growth.

For example, Table 1 depicts the growth in demand for construction aggregates in the world between 2010-2015, where all regions posted solid growth. The Asia/Pacific region registered the largest increases in MCP production and sales (Freedonia, 2016), as construction activity has risen rapidly, particularly in China and India. Eastern Europe and the Africa/Mideast region are also expected to undergo significant growth in MCPs, stimulated by infrastructure development projects and strong growth in general economic activity (Freedonia, 2016). Western Europe, South Korea and Australia will not be as strong as in most industrializing areas

Constant and rapid expansion of the construction industry in any country usually heralds complex environmental and social problems. Issues related to extraction, transport, processing, manufacturing, use and disposal of construction materials and products are critical among these negative social and environmental impacts.

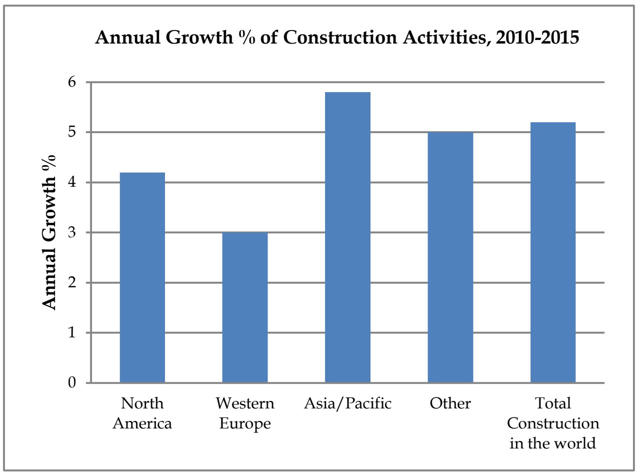

Figure 1: Annual Growth of Demand for Construction Aggregates 2010-2015 (Freedonia, 2016)

A wide array of construction materials is available in different regions of the world. If selected and used in an environmentally responsible manner along with employment of responsible construction technology and practices, future construction needs can be met, while creating a resilient built environment.

This article analyses the anatomy of socio-environmental issues related to construction material and products. It then explores the strategies and paths for sustainable sourcing and use of construction material and products (MCP) to ensure a resilient build environment.

Rest of this article is structured as follows. First it analyses how CMP related issues play out in a generic project cycle. Second, it looks at some specific environmental issues that emerged in sourcing and use of CMPs in post-disaster reconstruction, focusing on three case-studies. Third it draws lessons from examples to formulate key principles and recommendations for sustainable sourcing and use of MCPs in a resilient built-environment.

2. CMP and the Construction Project Cycle

Materials (and Products), CMP is a key constraint in a construction project along with equipment, labour, finance and time. Contractors are pressured to source CMPs that fits specifications and standards stipulated in the contract for prices that would not exceed the agreed BOQ rates. Therefore, when time and budgetary pressers creep into projects, social and environmental externalities are often overlooked to maintain quality and price requirements. There are typical CMP related decisions made at each stage of the project

Table 1: Key CMP related decisions at different stages of a project (WWF, 2016)

Stage	Key P&M related decisions and considerations
Inception	Overall project vision and priorities (e.g. traditional building, energy efficiency, disaster resilience)
Feasibility studies	Feasibility of types of structures (e.g earth dam versus concrete dam) Regulation applicable to materials (e.g. building codes, flood proofing requirements) Investigation of potential quarry sites and borrow pits
Design	Architectural / Structural design and selection of M&P Calculation of quantities and preparation of BOQ Estimating and cost comparisons Cost engineering and considering material alternatives
Construction	M&P procurement Site management and storage of M&P Procedures for use of M&P Handling of wastes
Functioning	Selecting and procurement of M&P routine maintenance and repair M&P considerations of minor alterations to the structure
Demolition/ Decommissions	Demolition and removal of material from site Material reuse Disposal of demolition debris

cycle.

Decisions and considerations in Table 1 will determine: 1) what type of CMP will be utilized for the project, 2) in what quantities, 3) how they will be sourced, 4) practices of transport, storage and use, and 5) how the waste or demolished material will be re-purposed or disposed. All such decisions will bear socio-environmental impacts.

3. Material Life Cycle and Environmental Impacts

Material life cycle begins with raw materials, continuous through manufacture, distribution, use and ends with disposal. It is imperative to study the phases of product's lifecycle which harms the environment the most. Table 2 summarizes negative environmental effects caused by CMPs from cradle to grave. Some of the common impacts are discussed.

The environmental impacts associated with extraction, processing, transport, use and disposal of CMPs in a given case may vary both in nature and magnitude according to factors such as: scale of the construction, construction practices and regulations, environmental regulations, local availability of resources, knowledge and skill levels of the construction workers, and environmental awareness among construction industry professionals. However, it can be generally said that CMP related environmental impacts escalate in post disaster situations (WWF & ARC 2010).

In a geographical scale, some of these impacts are extensive or even global (GHG emissions), while others such as water or soil pollution can vary in extent according to the case. Issues such as slope instability usually have local impacts.

In a temporal scale some CMP related impacts such as direct habitat destruction or resource depletion take effect immediately while some such as land degradation may happen gradually over many years. In some cases such as long term discharge of chemicals to soil or gradual soil erosion may cumulate over time and bring sudden and unexpected disasters.

Energy used in extraction and production of CMPs is directly proportionate to GHG emissions and other environmental impacts. Here the concept of "embodied energy" – energy used from extraction to disposal of a CMP, is used as an important indicator. The embodied energy of CMPs varies dramatically. However, none recycled and industrially produced CMPs generally have high embodied energies, while natural, traditional and locally sourced CMPs (e.g. thatching, mud bricks) contain the least embodied energy.

As much as the extraction or production of a CMP, its disposal also bears many environmental impacts. In certain cases the disposal stage may cause the largest impact as it is often the least regulated. Disposal stage becomes more critical during disaster aftermaths because of the massive amount of debris that has to be removed from the damaged buildings.

All these CMP related environmental impacts should be understood in their full complexity in disaster reconstruction projects if sustainability and resilience targets are to be achieved. In the next section we examine how some of these impacts have played out in real disaster. reconstruction cases

4. CMP specific impacts in post-disaster reconstruction

The negative socio-environmental impacts of sourcing and use of CMP are diverse. The impact should be identified both in relation to the project cycle as well as the material life cycle.

Here we analyze the key CMP specific environmental impacts of four major post-disaster re-construction cases globally: 1) Post-tsunami Sri Lanka (2004-2010); 2) Post-earthquake Haiti (2010-2015); 3) Post-cyclone (Haiyan), Phillipines (2013 – present); and 4) Post-earthquake Nepal (2015-present).

Table 2: Material Life Cycle and Environmental Impacts

Phase	Impacts	References
Extract	Resource depletion Habitat destruction Land degradation Slope instability GHG emissions Water, air and soil pollution Ground water depletion Noise and vibration Livelihood impacts Direct human health impacts	(UNEP & SKAT,2007), (Schneider 2012), (WWF 2016)
Transport	GHG emissions' Water and air pollution Noise Damage to rural roads	(Caimi et al. 2013), (Escamilla & Habert 2015), (Morel et al. 2001), (Schneider 2012), (UNEP & SKAT 2007)
Process/Treat / Manufacture	Water, air and soil pollution Noise GHG emissions Direct human health impacts	(Schneider 2012), (UNEP & SKAT 2007)
Storage	Water, air and soil pollution Direct human health impacts	(WWF & ARC 2010), (Schneider 2012)
Use	Water, air and soil pollution Noise and vibration Direct human health impacts	(Morel et al., 2001), (WWF and ARC 2010), (Schneider, 2012), (Tucker et al., 2014)
Demolish	Water, air and soil pollution Noise and vibration Direct human health impacts	(Blanco-Lion et al. 2011), (Schneider 2012), (UNEP & SKAT 2007)
Dispose	Water, air and soil pollution Habitat destruction Land degradation Direct human health impacts	(WWF & ARC 2010) , (WWF 2016)

Each of these cases were the largest reconstruction efforts during the given periods. Though all are cases in developing countries, there were many social, political-economic and ecological differences among them, which affected the reconstruction programs.

Table 2 discusses a key CMP related issue in each of these cases and their environmental impacts. Table 3 identifies certain steps that could or could have alleviated these impacts and improved the sustainability of the reconstruction process.

All three cases had significant CMP specific environmental issues. Yet, how they played out in different cases was diverse and complex.

In Sri Lanka the demand for fine aggregate created by the reconstruction projects, exerted additional pressure on the river systems already over exploited for river sand.

There, 1) exploring alternatives for river-sand, 2) encouraging sand efficient design and practices, and 3) enforcing regulations

Table 3: CMP related issues and impact in the cases

Case	Issue	Impact
Sri Lanka	Sudden increase in the demand for river-sand	Acute over extraction of river-sand for reconstruction projects, caused unprecedented degradation of major river systems.
Haiti	Rubble in the sites of collapsed building	Delays in removing rubble from the sites, hampered the entire reconstruction process, causing social discontent. Arbitrary disposal of rubble caused serious impacts to waterways and coastal environments in some places.
The Philippines	Coconut trees fallen in the cyclone	Millions of coconut trees fallen in the cyclone, posed the threat of insect infestation to other good trees in plantations.
Nepal	Burnt bricks needed for housing reconstruction in the Kathmandu valley	Potential increase in demand for burnt bricks in the valley may cause severe air pollution and over extraction in clay.

in river-sand mining and transport would have helped to alleviate the impacts.

In Haiti, the problem was the opposite to that of Sri Lanka. Rubble that heaped up due to collapsed building was a major barrier to the reconstruction process. If left in the sites, it caused health and social issues. If disposed improperly it caused acute environmental problems. At the same time, aggregate for reconstruction projects were being sourced from rivers and hill-slopes in very harmful ways, while rubble had the potential to be reused as a low quality aggregate in construction: 1) proper rubble reprocessing and reuse plan, 2) designs and practices that encourage rubble re-use 3) Safe disposal plan for excess rubble.

The case of Philippines was somewhat similar to that of Haiti, where millions of coconut trees lay fallen in the plantations, which was huge threat to the industry. It did not pose direct obstacle to reconstruction. However, the fallen trees offered a high quality material that could almost entirely alleviate the projected pressure on timber resources locally and globally due to reconstruction demand. The Philippines was a country with a long history of using coconut timber in housing construction and a well regulated coconut industry. There the key steps were to: 1) effective plan collect, process, treat and store the fallen trees, 2) designs and practices that encourage coco-timber use in reconstruction, and 3) proper disposal of cut offs from timber processing.

Socio-environmental impacts related to CMP don't have to be necessarily negative. In any region of the including there is a wealth of construction material and products, which if sourced and used in an environmentally responsible manner can bring in many social and environmental benefits.

The above examples demonstrate that, on the one hand, some common factors have

Table 4: Issues and impacts according to the project and life cycle stages

Issue	Steps that could have improved CMP sustainability	
	Relevant Project Cycle stages	Relevant Life Cycle stages
Sri Lanka: River-sand sourcing	*Design:* Using alternatives to river sand or sand efficient design. *Construction:* Where river-sand is the only option procure from sustainable and legal sources. Store and use properly minimize waste	*Extraction:* Legal mechanisms to control over-extraction. *Transport:* Enforce regulations on safe sand transport.
Haiti: Rubble management and reuse for reconstruction	*Feasibility and planning:* A community base rubble removal and reuse program. *Design :* Design non-load bearing building components with crushed rubble *Construction:* Employ skilled staff and small scale crushing plants to source aggregate from rubble.	*Extraction*: Safe crushing and removal/ storage of rubble Use: Use crushed rubble for permitted purposes. Safe handling without generating excess dust. *Disposal*: Proper disposal of excess rubble
The Philippines: Management of fallen coconut trees and sourcing for reconstruction	*Feasibility and planning*: Effective plan source fallen coconut trees as timber. *Design*: Designs that can use coconut timber effectively *Construction:* Employ skilled carpenters with experience in using coconut timber	*Extraction*: Sustainable collection of fallen coconut trees *Processing*: Proper milling and treatment of coconut timber for long durability. *Disposal*: Proper disposal of cut-offs for fallen trees.

Figure 2: Primary, secondary and tertiary impacts of river sand mining in Sri Lanka – **A.** ecosystem destruction due to mechanized mining, **B** bank erosion and damage to infrastructure, **C** long term ecosystem degradation

lead to these specific CMP related issues. On the other, there were common steps that can be taken at different stages of the construction project cycle and the material life cycle, which can improve the sustainability of construction and overall resilience of the built environment.

Therefore it is very important to identify the negative and positive social-environmental impacts related to CMPs and develop both general principles and specific tools mitigate the negatives while enhancing the positives.

5. Responsible selection and use of CMP: Key Concepts

The first step towards a framework of environmentally responsible sourcing and use of CMPs is to comprehensively identify their environmental impacts and develop better practices for extraction, processing, sourcing/procurement, use and disposal. These better practices should apply to all stages of Project Cycle (Table 1)and Material Life Cycle (Table 2). Some international agencies have developed initial guidelines and tools to address this need. Environmental Procurement Practice Guide (UNDP), Green Recovery and Reconstruction Toolkit (WWF & ARC, 2010), Debris Management: The Door to Development (UNDP, 2015) and Construction Materials Selection and Use: An Environmental Guide (WWF, 2016) are some examples.

Key principles stipulated by all these documents are as follows.

- Think through the whole supply chain:
- Only support sound and legal sourcing of materials
- Design to use fewer materials and reduce waste
- Use local sources – where this can be done in a sustainable way
- Use disaster debris as a reconstruction material
- Use materials with recycled content and recycle

The most environmentally sustainable option for resourcing construction projects is the reuse of waste building materials in their existing state without downgrading and reprocessing into new products. Massive amounts of materials can come from disaster debris and demolition sites. The potential for using these materials is enormous; they mitigate the need to buy new materials and prevent the consumption of energy in moving debris to landfill areas.

CMP related decisions can substantially impact the cost of construction and project management. It is prudent to make such decisions very early in the project cycle (inception or feasibility stages). However it is never easy to convince time and resource stressed project managers and investors on purely on environmental merits. Thus, further research is needed on how to calculate environmental costs and benefits related to CMPs and integrate them to project cost evaluations.

Where such costs (or benefits) remain external to the projects, it becomes the responsibility for construction industry regulatory agencies to seek ways to internalize those externalities.

However, critical gap in terms of practically achieving responsible CMP practice is lack of specific and user-friendly guidelines, tools, standards and regulations to guide the decision makers at different levels.

6 Conclusions and Recommendations

Socio-environmental impacts due to unsuitable and irresponsible practices in selection, sourcing and use of CMPs in post-disaster re-construction are diverse and alarming. Comprehensive steps need to be taken both through government policy and construction industry regulatory and professional bodies to establish a responsible CMP practice in all aspects of construction: design, procurement, costing and estimating, project management, construction, maintenance, demolition and disposal. Following are some recommended strategic and policy actions towards this goal based on the experiences of the above cases:

1. Construction industry regulatory bodies to develop and publish detailed and user-friendly guidelines to assist engineers, architects and technical officers to select CMPs in a responsible manner.
2. Construction industry regulatory bodies to develop and publish detailed and

user-friendly technical guidelines for responsible use of different types of CMPs.

3. Construction industry regulatory bodies and Environmental Agencies (along with other regulators) to work collaboratively to identify the CMPs that cause most critical socio-environmental impacts in Sri Lanka (river sand, clay, quarry products, timber) and develop special regulatory instruments for them.
4. Revise the existing construction specifications to include environmentally responsible practices in terms of selection and use of CMPs.
5. Professional bodies to include "Responsible selection and use of CMP" as a critical component of their continuous processional development (CPD) programs and curricular.
6. Universities and technical institutes to revise curricular of construction and design related to modules to introduce the CMP related environmental impacts and better practices for their responsible use.

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