Abstract


The historical importance of the construction industry in the constant improvement of society’s quality of life is undeniable. A major source of employment, it accounts for twenty percent of all U.S. economic activity, and in Brazil, in 2008, it represented 8.9 percent of the GDP; in 2000 it consumed 210 million tons of natural aggregates. These figures express the sector’s strategic need justifying investments in research for its sustainability, which is currently less than 1% from the U.S. government and 6% in Europe. There are thousands of sustainable building techniques and methodologies, as well as those for the treatment and reuse of construction waste in urban centers. This article aims to organize, in a summarized way, these procedures to reduce generation and treat construction waste in Rio de Janeiro, making suggestions for sustainable processes in the idealization, design and implementation phases of a new development and the reverse logistics for treating waste and reintegrating it into the production chain. In chapter two the study suggests the use of the Life Cycle Assessment (ACV) tool during new developments' idealization phases for a broad overview of the environmental impact of their execution, during the use of the developments until their final disposal. Research shows that maintenance costs in a development’s utilization phase represent more than eighty percent of its entire life span. The ACV study qualifies knowledge of sizing, materials specifications and construction techniques, as well as routines for use of developments. It adjusts its viability guiding developments toward sustainable principles, for example, low power consumption settings, minimizing the use of natural resources, parameters for diversity of materials being used, the impact of the use of assembly and/or mounting adhesives that hinder selective disassembly for reuse, and the importance of planning deconstruction ahead of time in order to reuse materials; these factors are crucial in the quest for sustainability in the sector. Chapter three brings an analysis of this waste, its impact potential in urban areas, major generating sources, and a summary of the main Brazilian laws and resolutions regulating its management. By listing the main sources generating waste and scrap in construction, attention is drawn to the selective deconstructions of yesteryear that reused materials. Made viable by the construction techniques used at that time in these buildings that allowed the selective removal of material. Also in chapter three, an example of a current certified demolition in downtown Rio de Janeiro is presented. Finally, it shows the general composition of waste and its classifications according to CONAMA (the National Environment Council) and NBR (Brazilian Technical Standards Association) #10,004. Chapter four provides an overview of construction waste management in large cities, in Rio de Janeiro it is evident that two distinct types of waste generators exist in constructions: the first is the generator in construction works with installed and licensed construction sites, which follow the standards and technical requirements for waste selection.
from generation to transportation under joint liability during the whole process until the final destination, in accordance with CONAMA's resolutions; these generators are monitored throughout the process. Yet the second, the generator in small construction works and renovation without installed construction sites, they do not comply with waste management standards and requirements, they use the same bucket to carry all classes of mixed waste, with no responsibility for the segregation and final disposal. Most often these wastes are dumped in illegal transshipment areas, mostly in protected areas. This widespread practice under the pretext of lack of segregation space in the civil work is endorsed by the lack of an urban policy to empower and require waste segregation at source and its reprocessing. The segment of small generators is responsible for contributing over 50% of waste generated in the city, and for almost all of the total pollution generated by construction waste, due to their crude mixtures that cannot be recycled and untreated transshipments into nature. Thus this study focuses on studying a suggestion for waste segregation logistics and recycling for this second group of generators. Chapter five dissects the formula: (Sustainability = Effective projects + Waste reutilization). Efficient projects, civil works with low waste generation and waste elimination is the way toward sustainability in the sector. In some regions of Brazil, the loss reaches 33% as opposed to the world average of 10%. Several factors rooted in the country’s culture of raw material abundance are mentioned. There is still a lack of sustainable efficiency concern in national projects, of doing more using fewer natural resources, using construction methods to lower the impact on the use and disposal of materials in the process. Some examples of methods that can be used for this purpose are listed below:

- **Foundations with removable stakes and metal structures** – allow stakes to be reused several times. The same apparatus used for crimping the stake is used to remove it. Ideal for small construction works like structural reinforcement, temporary buildings, etc.

- **Hybrid Construction System using timber** – wood is a carbon fixation material in adulthood, and is renewable, biodegradable and reusable. It replaces materials with high energy and natural resource production costs and its energy cost is 21 times smaller than cement production, as shown below in the table comparing steel, concrete and timber.

<table>
<thead>
<tr>
<th>PRODUCTION</th>
<th>Concrete</th>
<th>Steel</th>
<th>Timber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy in MJ/m³</td>
<td>1920</td>
<td>234000</td>
<td>600</td>
</tr>
</tbody>
</table>

Source: Miotto, 2008

Glued laminated wood beams are a very attractive option, which allow the use of low-density timber of lower quality than hardwoods, which should be saved as structural pieces.

The use of timber in construction, when done conscientiously, generates less debris due to reuse of the same material in different sizes in distinct stages of construction; aside from small amounts of waste being disposed it also leads to homogeneous waste. Unfortunately a large part of timber demand in construction
in Brazil is for temporary use, creating even more heterogeneous waste mixed with concrete and masonry.

- **Ventilated Facades**
  External coating is fixed in profiles located 5-8 cm from the building providing a second skin. This method creates an air cushion with upward flow caused by the temperature difference between outside and inside air providing a series of advantages to the building throughout its lifetime.

  1) Thermal and acoustic isolation
  2) Energy savings in air conditioning temperatures
  3) Prevention of moisture on the façade
  4) Weather protection
  5) Completely reusable after deconstruction

- **Waste Reutilization**
  In chapter five it becomes evident that waste segregation at the source is a prerequisite for any efficient recycling process. The large amount of waste generation imposes an urgent need for recycling; the United States of America produce about 136 million tons of waste annually and recycle 25% of the total, while in the Netherlands 90% of the volume of waste is recycled.

  There are countless environmental, economic and social benefits for recycling waste and the replacement and subsequent reduction of consumption of natural aggregates. In Brazil, 210 million tons of gravel were consumed in 2009; aside from the ecological impact of harnessing gravel deposits, the reduction of waste disposal areas is one of the environmental and economic benefits of recycling demonstrated in this chapter. But the main benefit of waste recycling logistics in large cities in developing countries is social, using the collectors’ skilled labor, who currently earn their sustenance working in subhuman conditions rummaging through trash. The social reintegration of these people living below the poverty line is the great legacy of this logistic.

  The main measures necessary for implementing construction waste management are the following:
  - Requiring that a study of the reutilization and final disposal of demolition waste be part of existing projects' designs;
  - Require separation of waste per category at the origin;
  - Create waste collection stations at strategic locations near concentrations of small generators;
  - Establish an efficient waste collection and recycled material replacement infrastructure;
  - Develop ways to encourage the use of recycled material to create a consumer market with permanent support from vendors and all those involved;
  - Educate the population toward a sustainable culture.

"The same management style that large construction works implement when recycling construction waste needs to be implemented in small construction works."

Class A construction waste processing in treatment centers aims to replace gravel and sand with reused material in construction elements that have no
structural function. Production at recycling plants is similar to mining activities in the stages of reduction and belt transport, which determine the movement of materials marking out the operations scripts for the Reception - Selection - Operation - Storage - Shipping phases.

The main products recycled from construction residue are: concrete powder, pebbles, gravel #s 1, 2, 3 and 4, bank gravel, stones, #4 gravel. Studies have shown that the use of recycled aggregate concrete, whose mixture is equal to or greater than 1:7, have the same results in compression and curing tests as concrete using natural aggregate.

Below is a comparative analysis with the natural aggregate consumption volume used for 1:7 concrete in the construction industry in São Paulo; we can see that the volume of recycled aggregate in the region could be fully absorbed, as shown below:

<table>
<thead>
<tr>
<th>Major Gravel Consumption Segments</th>
<th>Recycled potential Segment in total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEGMENT</td>
<td>PARTICIPATION (%)</td>
</tr>
<tr>
<td>Concrete</td>
<td>32%</td>
</tr>
<tr>
<td>Construction</td>
<td>24%</td>
</tr>
<tr>
<td>Prefabricated</td>
<td>14%</td>
</tr>
<tr>
<td>Reseller</td>
<td>10%</td>
</tr>
<tr>
<td>Asphalt plant</td>
<td>9%</td>
</tr>
<tr>
<td>Public agency</td>
<td>7%</td>
</tr>
<tr>
<td>Others</td>
<td>4%</td>
</tr>
<tr>
<td>Source: ANEPAC</td>
<td></td>
</tr>
</tbody>
</table>

Gravel Production in the Greater São Paulo Area, 2009

<table>
<thead>
<tr>
<th>YEAR</th>
<th>PRODUCTION (t)</th>
<th>Estimated recycled demand (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>25,753,933.00</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>26,975,988.00</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>29,764,948.00</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>35,158,412.00</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>37,619,501.00</td>
<td>21% 8,054,335.16</td>
</tr>
</tbody>
</table>

Comparison between waste generation and demand in São Paulo - 2009

<table>
<thead>
<tr>
<th>annual waste production (t)</th>
<th>recyclable index</th>
<th>recycled aggregate (t)</th>
<th>recycled gravel demand (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,292,600.00</td>
<td>63%</td>
<td>3,964,338.00</td>
<td>8,054,335.16</td>
</tr>
</tbody>
</table>

We see above that there is a strong market for recycled aggregate usage, ensuring economic viability for mineral waste recycling. In Rio de Janeiro, recycled aggregate appears as an item within the City Hall's SCO (Construction Works and Engineering Services Costs) Index, used to prepare municipal public works budgets.

Class B residues (Paper, Cardboard, Glass, Metal, Plastic, Timber) are not a problem for recycling, they can be easily reinserted into the production chain and have an enormous number of interested companies.
Class C and D residues, when segregated at source, are collected by authorized companies to be chemically reprocessed into a blend for use as raw material in other industries or for final disposal.

Chapter six proposes a path for construction waste recycling logistics in Rio de Janeiro.

Most of the construction works with sites are designed to segregate waste and process those that are Class A on-site for reuse or forward it to treatment plants, where they are well-accepted due to their segregation quality, resulting in a clean and homogenized mixture. However, waste generated by small construction works without sites is transported in buckets without segregation, creating a crude mixture which is not accepted by private waste recycling stations, so they are transshipped into landfills without subsequent processing, often inappropriately, causing great environmental impact due to pollutant mixtures they represent.

We must transform this linear industrial segment process into a circular process, implementing a reverse logistics in order to reuse waste and reintegrate recycled material into the production chain, as illustrated in the chart shown below:

<table>
<thead>
<tr>
<th>Image:</th>
</tr>
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</table>

<table>
<thead>
<tr>
<th>MATÉRIA PRIMA</th>
<th>Material Industrializado</th>
<th>Material de Construção</th>
<th>Geradores</th>
<th>Reformas e pequenas obras</th>
<th>Obra com canteiro</th>
<th>Demolições</th>
<th>RCC classe A</th>
<th>RCC classes B, C, D</th>
<th>CTRCC especial</th>
<th>ECOPONTOs</th>
<th>Centros de tratamento e reciclagem específicos</th>
<th>Reprocessamento ou reutilização</th>
<th>Disposição final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Material</td>
<td>Industrialized Material</td>
<td>Construction Material</td>
<td>Generators</td>
<td>Small construction works</td>
<td>Construction with construction site</td>
<td>Demolitions</td>
<td>Class A</td>
<td>Classes B, C, D</td>
<td>Specific CTRCC (RCC Treatment Station)</td>
<td>ECOPONTs</td>
<td>Specific recycling and treatment stations</td>
<td>Reprocessing or reuse</td>
<td>Final disposal</td>
</tr>
</tbody>
</table>
Implementation of construction waste recycling logistics in a city is a daily task for all of its inhabitants; a communication campaign about its social and environmental importance is required in order to build awareness and mobilization, and an oversight and feasibility infrastructure needs to be provided by the public sector. Without these prerequisites, it will not be maintainable. Society's awareness of this logistic's social and environmental value, using labor from underprivileged sectors for reintegration into society, reducing the exploration of deposits and disposal of waste into natural environments, is essential for this sustainable policy to solidify.

The implementation of this new logistics does not change the “actors” currently participating; rather, it is the methodology and objectives that will be changed to a new organization and criteria, into their respective new roles:

- **Public Power**
  - Legal regulation and oversight
  - Implementation of operational and physical infrastructure
  - Encourage consumer market for recycled products

- **Generators**
  - Notify of waste generation
  - Segregate to transport
  - Transport small quantities free of charge to an Eco Point

- **Waste collection companies**
  - Transport only legalized buckets
  - Transport waste to a CTRCC
  - Pay differentiated prices for transshipment

- **Collectors associations**
  - Perform recycling work
  - Selection and provision of labor

- **Waste treatment stations**
  - Reception and treatment of waste
  - Sale of recycled material

- **Existing Landfill**
  - Licensed to receive as final destination

- **Universities**
  - Surveys in CTRCCs
  - Academic course on waste management

- **Class Councils: CREAS (Engineering and Architecture Regional Council), IAB (Brazil Architects Institute), etc...**
  - Mobilize and communicate relevance to professionals.

The operation of the new logistics is based on waste segregation at the source.

The generator has the option to take small amounts of materials to the closest point of capture (Eco Point) or hire a collection company, depositing segregated waste into buckets separated by class. The waste collection points, here called ECO points, will receive materials from generators and store them in containers or their equivalent to be transported by Comlurb (the municipal urban sanitation company) to treatment stations.
Treatment stations whose function is to select and treat waste for reinsertion into the industrial process should be installed at strategic points in the city, plant locations should take into account availability, processing type, production volume and transportation cost for recycled product sale at competitive prices. The objectives of treatment plants are formalization of the sector’s labor, reuse of waste in order to replace natural resources, and prevention of environmental degradation at disposal sites.

A careful study of neighborhood impact is critical to installation and operation success within the city’s urban network, these impacts must be addressed with effective measures, some listed in this paper, for a perfect harmony with the population.

The choice of equipment, which can be fixed or semi-mobile, depends on the amount of RCC to recycle, the dimensions of the blocks present in the RCC, and the grain size required in the final recycled aggregate according to its use (SALVADOR, 1999).

Very often old equipment is used, coming from mining plants, the main ones are:

- Jaw crushers
- Impact crushers
- Hammer mills

There is a great variety of techniques mentioned in this paper that can be used to improve the recycled aggregate quality and reduce the fine and light (or porous) organic material proportions.

This logistics’ major demand for financial investment will be in the implementation phase that should be left to the public sector and private initiative, but as previously mentioned, the value and demand for natural aggregate reassure the financial return for recycled aggregate use.

Despite the difficulty in ascertaining the current cost of the city’s construction waste collecting logistics we can do comparison by tasks. Currently “impure” waste collection uses trucks and/or private bucket companies at points around the city. The proposed new logistics will continue with the same cost standard for the generator who pays the collection to private companies, or use Comlurb free collection, the gratuity is maintained when delivered to the nearest Eco point for amounts not exceeding 1 m³ per day.

Private collector companies will continue to pay for transshipment as they currently do. Buckets in the recycling centers will pay different prices according to the impurity degree in the residue segregation.

Waste transport from ECO points to the recycling stations should be done by Comlurb, which in turn will not collect free of charge in homes as it does today, exempting the standard, pre-packed, point to point transported payment.

Plant operation will be the responsibility from the collectors' cooperatives who already work in the industry.

To stimulate demand for recycled aggregates the public sector, SOEs, should encourage State working contractors to use recycled aggregate in poor traits (1:7 concrete or higher) through the public tenders, this procedure does not change final product quality, as seen in previous chapter.
Conclusion

Elimination of “in nature” (untreated) civil construction waste dumping is a goal to be continuously pursued by all of society as a commitment to future generations. The path suggested here is to make use of preventive actions in design and implementation phases to reduce its generation and waste, and planning ahead for material recycling after deconstruction.

The recycling of almost all the waste in the city of Rio de Janeiro depends on the implementation of a logistics plan for the segregated collection of small works generators and waste treatment for reinsertion into the production chain. These are actions that follow the criteria for segregation, transportation and transshipment procedures under the new waste management law.

Keywords

Construction Waste; Construction Waste Recycling; Construction Waste Management; Construction Waste Policy.