Waste Materials in Construction
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CONSTRUCTION WASTE CHARACTERISATION FOR PRODUCTION OF RECYCLED AGGREGATE – SALVADOR/BRAZIL

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The continuous growth of municipal solid waste generation, especially from construction activities, has been responsible for the appearance of many and efficient municipal solid waste management policies from public authorities. An efficient waste management program can avoid inappropriate waste disposal, which can cause damage to both environmental and public health. Additionally, it may even lead to the development of recycling programmes.
Giving special attention to solid waste from civil construction enterprises, it is important to develop environmentally active practices among construction companies with a view to reduce waste generation, increase reuse and recycling. In order to develop alternatives for construction wastes recycling, it is important to provide efficient solid waste characterization studies.
An experimental study has been carried out in the city of Salvador, Brazil. Currently, 1450 tons daily of construction and demolition (C&D) wastes has been generated in Salvador. Solid waste has variable physical characteristics that depend on the construction sector involved, the techniques employed, the construction phase and the social-economic characteristics present in the urban area in question.
This paper presents the results of an intensive study of construction and demolition wastes from Salvador with the intention of creating alternative methods of increasing environmental protection and generation of low price raw material by recycling solid waste. The principal

procedure used involves the characterisation of solid waste according to its physical characteristics and social-economic aspects.
The results of this characterisation identified priority research lines that will help to maximise recycling of C&D waste produced in Salvador and help develop a local construction material market.

1. INTRODUCTION

The large amount of general waste produced every day is one of the main problems in urban areas. Construction and demolition wastes are one of the key aspects of this subject.
Population growth of and consequent increase in urban construction lies behind a chronic problem, which is the vast production of construction and demolition (C&D) wastes. Thus, the necessity of finding appropriate solutions to C&D waste destination is becoming quite clear and recycling appears as a profitable alternative that will increase the lifetime of landfills and reduce exploration of natural resources.
In many developing countries C&D wastes have often been disposed incorrectly in areas such as vacant urban lots and water streams courses. This behaviour has produced several environmental / health damages with waste materials of high recycling potential. In other countries, to minimize those problems, public authorities have been adopting more restrictive and efficient wastes management policies. Several management policies have been developed with a priority view of reduction, recycling and reuse of waste.
As a matter of fact, the Municipal Waste Management Company of Salvador-Brazil (LIMPURB) has recently created the "C&D Waste Management Program". The main goal of this program is to correct urban disturbances generated by illegal disposal of construction and demolition wastes in Salvador and on its outskirts.
The installation of C&D waste Recycling Plants is also part of this program. These plants will process construction waste, producing low price aggregates to be used as raw construction materials. These recycled materials should be used to provide social benefits in low income areas of Salvador by installing new urban infrastructure (pavements, drainage, etc.) and low cost buildings.
For the success of the C&D waste Management Program, it is necessary to emphasise that C&D waste show quite particular characteristics. The main properties of C&D waste, especially composition and amount, are affected by the great variety of raw construction materials, techniques and methodology usually employed in construction process.
Therefore, the developing stage of local civil construction (labour qualification, construction techniques applied, etc.) influences directly C&D waste composition. In this way the waste characterization is an important step in the study of C&D wastes.
This paper presents the methodology and the results of Salvador's C&D wastes characterization program, including social, material, and operational aspects. This study analyses the potential of Salvador waste recycling in order to produce low cost construction materials. A summary of Salvador's C&D Waste Management Program and some considerations about the use of processed debris as construction materials are also presented.

2. SALVADOR'S C&D WASTE MANAGEMENT PROGRAM

Salvador's C&D waste management program aims at the adoption of an ordering policy which limits environmental degradation by reducing waste generation, increasing C&D waste reuse and recycling and, in general, integrating all the diverse agents involved in the C&D waste management process.

The C&D Waste Management program for Salvador shall promote reduction of municipal waste collecting costs by the minimisation of corrective urban cleaner activities or by the production of low cost recycled materials.

One of the main structuring principals of this project is the decentralisation of C&D waste reception and final disposal. To achieve this, a number of strategically located areas were prepared to receive those materials. They are called C&D Waste Disposal Sites (WDS) and C&D Waste Disposal Bases (WDB).

Twenty-two disposal sites are planned (six in operation at the moment) receiving and transferring C&D waste originating from small generators. Five bases will also receive, reuse and recycle this material. Beyond that, the project intends to implant environmental educational programs, impede clandestine disposals and monitor late illegal disposal sites with the aim of eliminating inappropriate C&D waste dumping. Also foreseen is the stimulation of correct disposal and recuperation of areas degraded by inappropriate disposal of C&D waste. Figure 1 shows the simplified flow chart of Salvador's C&D Waste Management Program.

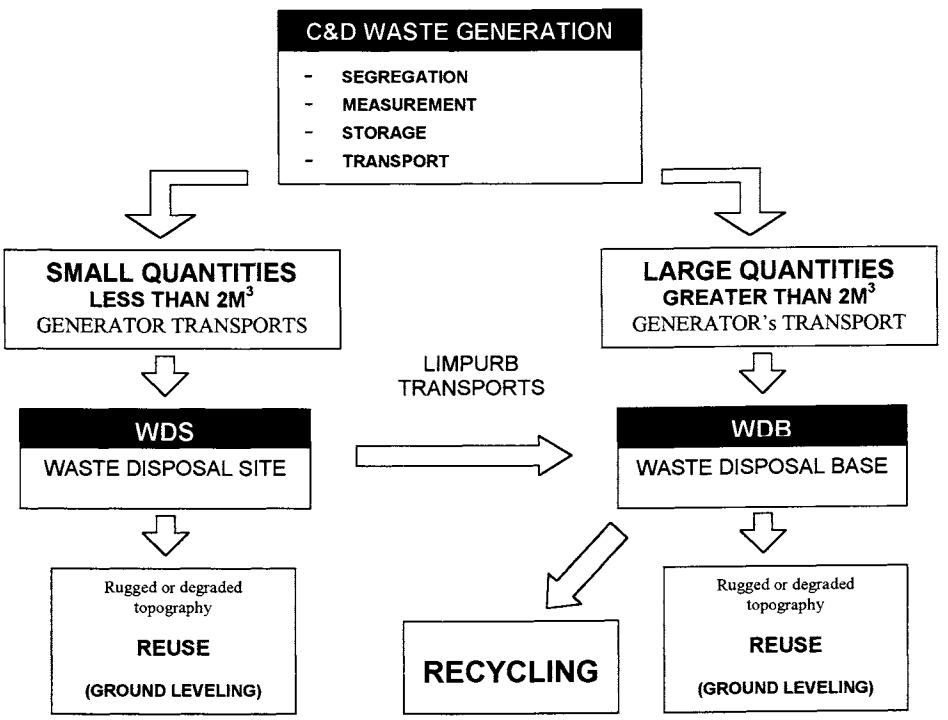

Figure 1 – Simplified flow chart of Salvador's C&D Waste Management Program

This program also aims topographical correction and degraded areas recovery in WDSs and WDBs. The key of this program is the creation of Recycling Plants at the WDBs. Each plant will process (crush and sieve) at least 200 tonnes daily of C&D wastes from Salvador. The processed debris will be commercialised as aggregate and used as social construction materials.

The *Waste Disposal Sites*_will be placed next to C&D waste generating areas. WDSs implantation areas must be chosen preferentially between those that are already used as waste settlings. They will be able to receive by each generator up to $2m^3$ of waste per day. If a generator exceeds this limit, the WDS's staff will indicate the nearest BASE where larger quantities of waste should be delivered. At each WDS's the material will be temporarily stocked and then transported to a Waste Disposal Base where reuse or final disposal will occur.

The *Waste Disposal Bases* will be placed near C&D waste generating centre areas, intending to receive, reuse and recycle large volumes of C&D waste. This material will come from WDSs and generators who produces more than $2m^3$ / day. These areas must be chosen between those with uneven topography or previously degraded areas.

3. CONSTRUCTION & DEMOLITION WASTE FROM SALVADOR

Currently, the amount of C&D waste collected in Salvador is about 1453 tons / day. This tonnage consists of 41% of the total urban waste collected by LIMPURB in Salvador. Nevertheless, this is only part of the total waste generated. It is estimated that at least 250 tons of waste goes uncollected every day.

The population growth is an important factor that has directly contributed to the increase of the urban waste production. In particular, the high deficit in habitation creates pressure for new housing and the resulting expansion in the number of homes being built increases C&D waste generation notably.

Figure 2 shows the evolution of the C&D waste collection in Salvador for the last 11 years. It shows that between 1996 and 1998 there was a enormous increase in this material collection. This fact is seen as a result of the "C&D waste Management Program", which contributes to the reduction of inadequate and illegal disposal of this kind of waste.

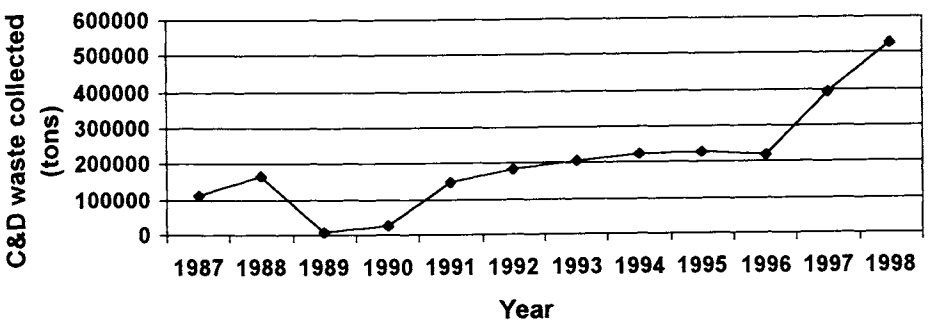

Figure 2 – Evolution of C&D Waste collecting in Salvador (LIMPURB, 1998)

4. CHARACTERISATION METHODOLOGY

C&D wastes characterisation is a fundamental stage in helping to identify alternatives to reduce / reuse and recycle. Precise knowledge of waste properties expands opportunities to maximise its utilisation as recycled construction materials.
In Salvador, the characterization of the C&D waste was done by the partnership between LIMPURB and GEMAC / UFBA (Group of Studies in Construction Materials of the Federal University of Bahia) in September / October 1999. Field studies were carried out at Canabrava landfill site in Salvador.
The methodology used to characterise Salvador's C&D wastes followed the procedures of: sampling, receiving, homogenising, quartering and testing analysis as described below:

4.1. Sampling, Receiving, Homogenising and Quartering

C&D waste samples were collected at both waste disposal sites and Canabrava Landfill. Sixteen C&D waste samples (estimated amount of 142,000 tonnes) were analysed. This tonnage represents 10% of Salvador's daily C&D waste generation, which represents an reliable amount for the statistical work in this study.
The samples were analysed considering aspects related to both delivery site (WSD and landfill) and the income level of generating areas of Salvador's C&D waste (low, medium and high).
The first step was to remove an initial sample between 5 and 10 tonnes from the desired C&D waste and do a first sample reduction. Then, the material was mixed to form homogenous groups, followed by consecutive quartering to obtain a sample weighing about 500 kg. Figure 3 shows the flow chart of this process.

4.2. C&D Characterisation Tests

- Size distribution - The final sample was screened through 50 mm, 25 mm and 4.8 mm sieves. Each retained fraction was weighted. Through this method waste was classified into 4 different sizes. This procedure follows the recommendation of Brazilian Standard NBR 7217.

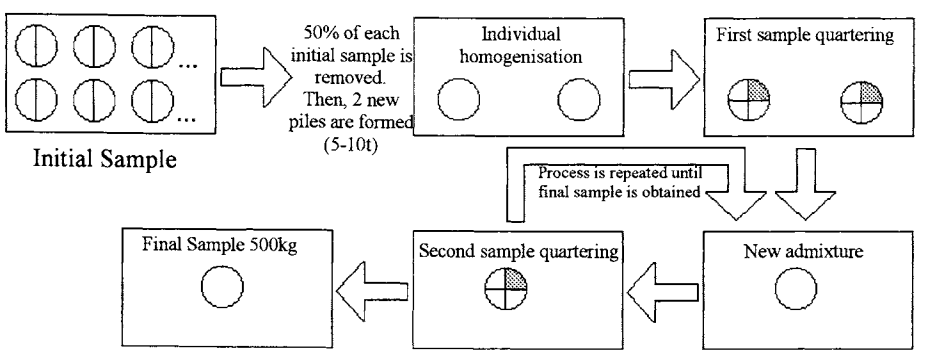

Figure 3 – Flow chart of Salvador's C&D waste sampling process

- Gravimetric composition - The waste's gravimetric composition was determined by classifying the material types of each fraction of the screening process. Those elements composed by more than one kind of material were classified according to predominance. The materials classification was done following the groups below:

1 – soil and sand	6 - stone	11 - plastic and rubber
2 – white ceramic	7 – reinforced concrete	12 - paper
3 – red ceramic	8 – metals	13 - timber
4 – asphalt	9 – gypsum	14 - other material
5 – concrete and mortar	10 – leather and fabrics	

5. RESULTS

According to the methodology presented, figure 4 shows the size distribution and figure 5 the main components analysis of Salvador's C&D waste.

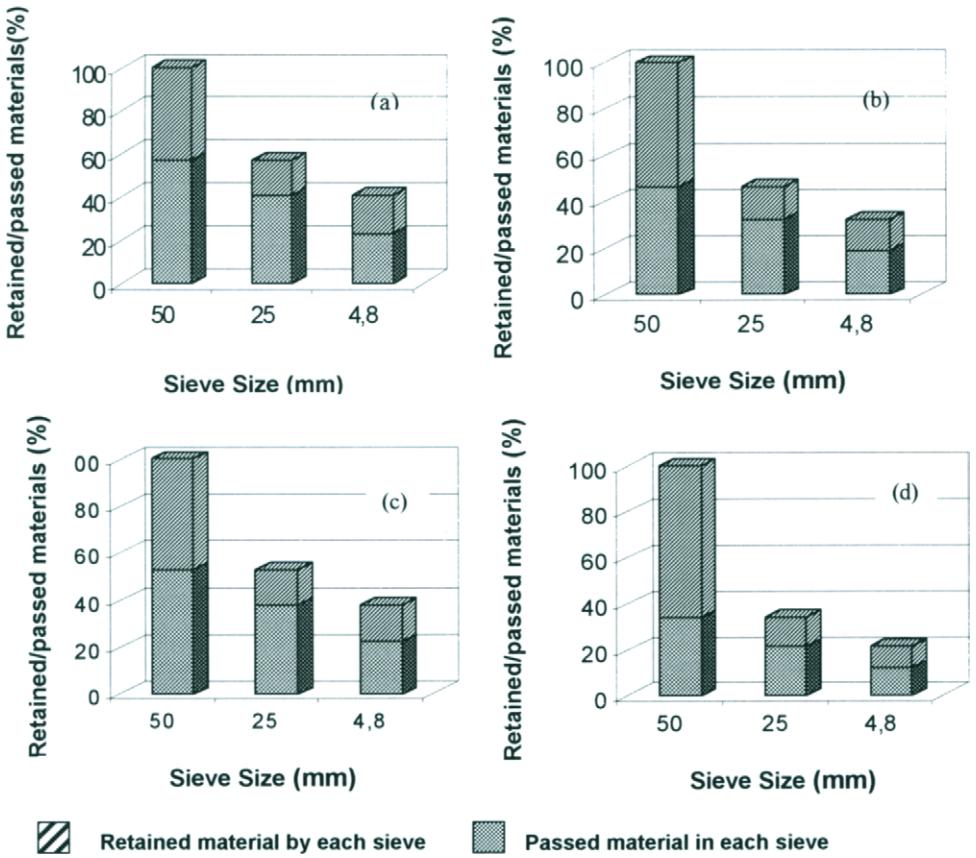

Figure 4 –Size distribution of Salvador's C&D wastes
(a) WDS; (b) Delivered at landfill; (c) Low & medium income areas; (d) High income areas

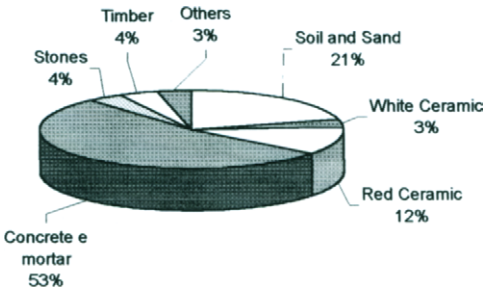

Figure 5 – Main components of Salvador's C&D wastes

The analysis of figure 4 indicates:

- Parts greater than 50mm occupy the majority of C&D waste in Salvador. Whereas the remaining particle sizes were well distributed on the other sieves.
- The C&D wastes size distribution found in high-income areas is similar to the one delivered at landfill. Both distributions have a low amount of small materials (passed through 4,8mm sieve) and high percentage of large pieces (up to 66% of the material was retained in 50mm sieve). This similarity is quite understandable, as the C&D waste sent to landfill came from high-income areas. People in these areas can afford the delivery costs and most construction companies concentrate their building activities in high-income areas.
- On the other hand, the size distribution of C&D waste from low/medium income areas of Salvador is similar to the ones collected at WDSs. This similarity establishes the main strategy of the WDSs, which collect waste from auto-construction activities and small house repairs (typical activities of low/medium income population on the Salvador area). Due to the high transportation cost to official the landfill sites, these wastes typically found there way onto vacant urban lots and into watercourses. In 1996 there were 420 illegal C&D waste disposal sites identified in Salvador. With the creation of the Waste Delivery Sites and stronger policing of uncontrolled sites there was a significant reduction in illegal dumping (140 sites in 1998).

The analysis of figure 5 indicates:

- Concrete and mortars represents the major portion of Salvador's C&D wastes (53%). It is also significant the amount of ceramic materials (15%). These two groups, together with stones (4%) represent 72% of the samples studied. Those materials when processed (crushed and sieved) produce an aggregate with high potential for use on road construction and non-structural concretes.
- Soil and sand (21%) are also a significant part of Salvador's C&D wastes. The quantities of this materials will increase when larger pieces of debris are crushed in the recycling plants. Looking forward, some applications that use this fraction of the C&D waste should be studied. The Federal University of Bahia (UFBA), supported by Caixa Econômica Federal (Federal Bank for Urban Infra Structure and Habitation), is

carrying out studies to promote the use of these alternative construction materials as base and sub-base for roads as well as to produce soil-cement blocks and mortars. These applications should contribute to reduce the cost of construction in some areas of Brazil.

- Timber represents 4% of the waste under study, so it is possible to conclude that 21000 tonnes of high potential recycling material has been thrown away every year. In the C&D waste recycling plant, timber will be sorted at an early stage of the process and commercialised.
- Other materials (metals, paper, plastic, rubber, asphalt, gypsum, leathers, fabric, etc.) represent only 3% of Salvador's C&D waste. However, some components (such as gypsum, asphalt, clay, some paints and timber), even in small amounts, may cause damage to concretes and mortars if included as part of the aggregate (GEHO, 1997).

The composition of C&D waste will normally differ depending on the generation area / country, type of raw material used, construction techniques and other factors. Furthermore, the methodology used to characterise the waste may change the results considerably. Table 1 shows the main components of C&D wastes produced in different cities/countries. This table indicates the immense variation of the main components found in C&D waste.

Table 1
The main components of C&D waste of several cities / countries (% of weight)

MATERIAL	ORIGIN SITES						
	United Kingdom[1]	Hong Kong[2]	*Salvador**	São Paulo*[3]	São Paulo*[4]	São Carlos*[5]	Ribeirão Preto*[6]
Concrete and mortar	9	8	*53*	63	11	69	89
Soil and sand	75**	19	*21*	-	83**	-	18
Ceramic	5	12	*15*	29	3	30	23
Stones	-	23	*4*	-	-	1	-
Others	11	38	*7*	8	3	-	-

[1] Industry and Environment, 1996
[2] Hong Kong Polytechnic, 1993
[3] Pinto, 1994 (sample collect construction site)
[4] Castro, 1998
[5] Pinto, 1989
[6] Zordan e Paulon, 1997

* Brazil
** Soil, sand and stones

6. SOME APPLICATIONS FOR SALVADOR'S PROCESSED DEBRIS

Recycling and reusing C&D processed debris as an alternative construction material appears to be an interesting solution for the problems caused by its inadequate disposal. Some priority R&D fields were identified for Salvador C&D waste:

6.1. Production of Soil-Cement Blocks using processed debris

The use of processed debris to produce blocks with soil-cement is clearly a good alternative solution for this environmental problem and it also has the benefit of producing a low-cost construction material.

The possibility of making soil-cement blocks with processed construction waste presents several economic advantages: the production unit occupies little space, it requires few investments in industrial equipment and causes no environmental damage.

GEMAC/UFBA is studying the influence of the construction waste's composition in the production of blocks with soil-cement including how effects differ with partial or total substitution of soil by waste. The results obtained in this investigation should provide an appropriate solution for developing low cost housing.

6.2. Application of processed debris in base and sub-base of roads

One of the most widespread ways to use recycled debris is both in base and sub-base layers. Using debris in the flexible-granular bases and sub-bases of roads presents many advantages; firstly, this kind of recycling requires very simple technology and secondly it uses large amounts of material.

Moreover, previous researches show that the use of processed debris in various layers of roads is viable (HENDRIKS, 1998). However, debris may present significant differences of characteristics, according to each region. This makes research into local material necessary to establish technical and economic viability for the use of each region's waste material.

GEMAC/UFBA is developing studies of the behaviour of Salvador's processed debris behaviour in flexible-granular base and sub-base layers of urban roads. The results obtained will allow a maximum use of debris and will help persuade local contractors to accept processed debris as secondary raw materials in the road construction.

6.3. Production of Mortar and Concrete using additions of processed debris

Mortar and concrete can be produced using the waste material processed by a recycling plant. The equipment crushes the debris so that it can be used to replace part of the aggregates in the production of mortars and non-structural concretes.

The addiction of processed debris may increase compressive strength of mortars and concretes. This is caused by the natural pozzolanic effect of crushed debris, which also causes a tendency to reduce the consumption of clusters in relation to conventional dosages (LEVY & HELENE, 1998). This way, use of processed debris shows economic advantages both lower cost of recycled aggregates and reduction of conventional clusters consumption. On the other hand, mortars produced with processed waste may develop fissures, probably caused by the large quantity of fine particles found in this material.

GEMAC/UFBA is analysing different dosages of processed debris in mortar and non-structural concrete. The studies of final product behaviour consider workability, durability, strength and others. Finally, its economic viability is also verified.

7. CONCLUSIONS

- Salvador's C&D waste characterisation was a fundamental stage in the studying and planning of ways to reduce, reuse and recycle this material. This study has helped to identify ways to maximize the utilization of Salvador's C&D waste as recycled aggregate.
- This study has shown that Salvador C&D waste is a high potential recycling material for the production of aggregates. The recycling of this waste will reduce environmental damages caused by incorrect disposal, extend the useful life of landfills and preserve finite natural resources.
- The characterisation of Salvador's C&D wastes will continue to be done systematically by LIMPURB and GEMAC/UFBA, in order to analyse the variation of properties found over time and in different seasons of the year.
- At the present time, GEMAC/UFBA is studying the complete characterisation of the processed C&D waste of Salvador. This study analyses physical / chemical properties of the processed debris as aggregates for construction materials and the environmental risk it presents during the entire life cycle of the material.

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ACKNOWLEDGEMENTS

- To Caixa Econômica Federal (Federal Bank for Urban Infra Structure and Habitation) and CNPq (National Council for Research) for their financial support.
- To LIMPURB (Municipal Waste Management Company) for its essential partnership in this work.
- To Edvaldo Carneiro, Sean Bradley and Ana Carolina Castilho for their collaboration in writing this paper.

This paper is dedicated in memory of
Prof. José C. Cassa – 1st Coordinator of GEMAC