Metabolism of materials by the construction sector in developing countries : Costa Rica as a case study

METABOLISM OF MATERIALS BY THE CONSTRUCTION SECTOR IN DEVELOPING COUNTRIES: COSTA RICA AS CASE STUDY

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Keywords: *industrial metabolism, material flow, construction sector, waste composition, causes*

Abstract

Production practices require large amounts of materials and are not likely to be sustained without large implication for the environment. Materials and energy are put together in order to produce goods and the total of these physical processes have been referred by Ayres and Simons as "Industrial Metabolism", which was defined as "the whole integrated collection of physical processes that convert raw materials, plus labour, into finished products and wastes in a (more or less) steady-state condition". A good understanding of societal metabolism is likely to contribute to more sustainable production and consumption.
The construction industry and its related materials, service, and supply feeder industries are jointly considered to be both the world's largest industrial employer and the largest natural resources consumer as well as a great waste producer.
In developing countries, construction waste is becoming a serious environmental problem due to the continuing growing population and urbanization, which demand material resources, water and energy. Information and data about the sector in those economies is scarce and some of the information found can't be compared with other data.
An assessment has been done in Costa Rica in order to understand how construction materials are metabolised (transformed) by the sector. The study provides an idea of the amount of waste generation and its composition. It also shows the causes, which are related to design, procurement, material handling, operation, residual and others.

1. Introduction

Modern societies extract and metabolise large quantities of raw materials. These flows of resources constitute the basis of the economy, but at the same time, the activities leave a footprint that can't be sustained without large environmental implications.

Materials and energy are put together in order to produce goods and the total of these physical processes have been referred by Ayres and Simons (1994) as Industrial Metabolism, which was defined as "the whole integrated collection of physical processes that convert raw materials, plus labour, into finished products and wastes in a (more or less) steady-state condition" (Lambert, 2008).

Metabolism in the biological context refers to the internal processes of a living organism. The organism needs energy-rich, low entropy materials (food) to provide for its own maintenance and functions, as well as to permit growth of high entropy materials. In analogy with biological metabolism we can consider the metabolism of industrial activities as the total of physical processes that convert or transform raw materials and energy into finished products and wastes (Janssen et al., 2001).

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The purpose of industrial metabolism is to understand the relationship between the system and its environment, focused on the extraction from, and the discharge to the environment of physical flows. It is a modelling method that aims at the investigation of the industrial system and the interchange of physical flows between its subsystems, and between the industrial system and its natural environment. Therefore, this approach can help to examine the inputs, processes and outputs of the construction industry in order to gain insights into resource utilization and waste production, with an eye towards improving resource efficiency (Kibert et al., 2000).

The purpose of the present paper is to report the results of a study performed in the Costa Rican construction sector with the attempt to provide information about quantities, composition and causes of construction waste production while the procurement of buildings.

2. Construction Industry

The construction industry and its related materials, service, and supply feeder industries are jointly considered to be both the world's largest industrial employer and the largest natural resources consumer. As much as 50% of all materials extracted from the earth's crust are transformed into construction materials and products (Environmental Protection Agency U.S, 1995; Arpad, 2004). Building activities based on these materials account for as much as 40% of all energy use. Moreover Mocozoma (2002) indicates that the sector is responsible for 12-16% of fresh water consumption, 25% of the wood harvested and 20-30% of greenhouse emissions. The metabolism (transformation or conversion) of those materials in the construction sector doesn't seem to be efficient. When the waste streams, arriving at the landfill sites, are analysed, a high proportion corresponds to construction and demolition (C&D) wastes. Table 1 presents some percentages described in literature for some developed and developing countries.

Table 1 Percentage of waste that corresponds to C&D activities at different landfill sites

Country	C&D waste (% by weight)	Reference
Netherlands	26	Bossink & Brouwers, 1996
Hong Kong	44	Hong Kong EPD, 2000
England and Wales	42.2	Lawson & Douglas, 2001
Kuwait	15-30	Kartam et al., 2004
Taiwan	15-20	Taiwan EPA, 1999
USA	20-29	Apotheker, 1990; Mincks, 1994; Peng et al,1994; Rogoff & Williams, 1994; Bossink,& Brouwers, 1996
Australia	20-30	Craven et al, 1994
Germany	19	Brooks et al., 1994
Finland	13-15	Heino, 1994
Japan/Tokyo	57	Kennedy et al., 2007
Worldwide	13-29	Bossink & Brouwers, 1996

Construction waste is becoming a serious environmental problem in many large cities in the developing world, due to the fact that the activity generates lots of pollution, which causes significant impacts on the environment and arise growing concern in the population at the local context. Based on the impacts, the industry has for some time been seriously challenged to become more environmentally friendly and promote sustainability (Shen et al., 2000; Smallwood, 2000; Poon et al., 2001; Tam et al., 2004 and Begum et al., 2006)

3. Construction Industry in Costa Rica

Costa Rica is situated in Central America. It has 4.5 million inhabitants, with a developing economy and a construction activity growing very rapidly. The construction industry contributes a significant amount to the country's economy (The Economist Intelligence Unit, 2006) and the rate of growth has been one of the most dynamic in the past five years, surpassing the rate of Gross Domestic Product growth (Costa Rican Construction Chamber (CCC), 2007).

In developing countries there are very few data available in relation to the construction sector and waste generation. The literature review indicated that the availability of data on the Costa Rican construction sector related to waste production (quantity and composition) is very scarce and variable, e.g. Villalobos (1995) reported as an indicator of construction waste generation between 11-25 kg/m^2 while Ramirez (1995) presented a value between 300-700

kg/m^2. A study done by Leandro (2006) showed that the projects investigated generated a roughly average of 115 kg/m^2.

These data suggest that the access to more precise information could reveal opportunities for waste reduction strategies at its source, being the most economical way to "treat" construction waste (Gavilan, 1994).

4. Research objective and methodology

This study aimed to provide a baseline understanding related to the generation of construction waste in Costa Rica, its quantities, composition and causes. It is part of a more comprehensive research, which attempts to model the procurement of buildings to predict waste generation and construction practices in a newly starting industrialized setting.

Sites visits were planned and a questionnaire was prepared and applied to 419 companies in the central valley that represented 96% of the total of construction companies of the database provided by the Federation of Engineers and Architects. The answers were obtained from 29 complete questionnaires. The results were discussed with a Group of Experts coming from the companies that participated in the survey as well as members of the universities and other professionals working in the construction sector.

5. Survey results and analysis

The size of the company was defined, for this study, by the number of employees working for it during the survey. Those numbers may fluctuate in time since the companies can hire and fire personnel relatively easy due to the fact that most of the employees working at the construction sites have temporary contracts.

Table 2. Company size

No. Employees	Label	No. Firms
< 25	Small	11
25 - 100	Medium	9
> 100	Large	9
TOTAL		29

5.1. Quantity of construction waste

From the literature review, the following waste generation figures were found.

Leandro (2005): 115 kg/m^2

Villalobos (1995): 11-25 kg/m^2

Cartín (1995): 0,97 m^3/m^2 (300-700 kg/m^2)

This baseline analysis didn't consider an on site material flow analysis but the questionnaire had questions related to the knowledge the interviewee had of their construction waste generation. The survey revealed values ranging from 7 to 170 kg/m^2.

Most of the waste generation values found in the literature for different countries provided a total value per year. In Costa Rica it was not possible to find such a value but an estimation was done using the value of construction that took place in the private sector in the last 5 years, and an average indicator obtained by Leandro (2005). These values are presented in Table 3.

Table 3. Amount of construction waste potentially produced in Costa Rica

Year	Construction (million m^2)	Estimated amount of waste (kton)
2002	1,3	130
2003	1,8	180
2004	3,3	330
2005	3,7	370
2006	6,0	595

Source: CCC, 2007

The answers to these waste generating questions showed that companies are not aware and do not keep track of the total amount of waste they produce. Four of the five on-site visits illustrated that fact. The interviews with the supervisors clearly showed unawareness in topics related to environmental matters related to the sector and lack of information. This lack of awareness in itself is already a cause of waste generation since unaware companies are not likely to take action against polluting activities that they do not even know exist.

5.2. Composition of construction waste

The type of waste produced is wood, steel, concrete, soil, piping materials, corrugated roof sheets, wires, packaging materials (paper, plastic and cardboard), cement, blocks, paints and debris. The amounts (either by volume or by weight) of these streams are unknown since the majority of the companies don't keep track of these data.

Analysing the waste streams showed that a considerable part of it consisted of recyclable materials. Therefore recycling can contribute to diminish the need for landfills or disposal sites, diminishing environmental pressure and increasing revenues. One construction company in Costa Rica that participated in the survey had performed a material flow analysis and proved that a recycling rate of 80% is feasible (Chinchilla, 2007). Some of the respondents also mentioned that some of the waste produced in their projects is already reused, mostly on-site, and some via recycling companies.

To try to make a correlation between the waste streams and the company's environmental behaviour, an indicator was prepared, and here defined as "environmental performance". It is based on questions related to some good environmental practices used by the organizations. They were: if the company monitors the amount of waste produced and which indicators are used, if it has a waste management plan or someone in charge of environmental topics for the construction sites, if the company had any environmental friendly technologies to decrease the environmental impact of construction in the last two years and questions related to separation and reuse of waste.

That is an indication that the waste streams, as such, cannot be prevented given the current technological and organisational characteristics of the Costa Rican construction sector. Maybe attention to environmental measures can decrease the magnitude of the waste streams.

Table 4. Environmental performance, statistical analysis

Environmental score	No. Companies	% Companies
Low	11	36,7
Medium	15	50,0
High	3	10,0
Total	29	96,7
Missing	1	3,3

5.3. Environmental impact

The pollution of the site and its surroundings is the principal manifestation of environmental effects created during the construction works. The impacts can be to the air, water and soil. Pollution to the air is mainly due to the dust produced and the common practice of burning the combustible waste to reduce its volume. The surface and ground waters are affected by surface runoff and infiltration during heavy rains (2000-4000 mm/year) that may transport fuels, oils and paints that are improperly stored. Besides construction waste is sometimes dumped in the ocean or onto the riverbeds. The soils are affected as well, by the practice of leaving waste in the ground that often is covered with vegetation at the end of the projects.

Another impact on the environment is the abundant use of wood as a casing material, which results in an extra pressure on forests that are already under stress.

5.4 Causes of waste generation

The empirical findings revealed that the causes of waste generation are mainly related to legislation and law enforcement, awareness, and technical aspects as: material sizes, material handling and revenues.

Legislation and law enforcement

The country has plenty of laws and regulations to protect the natural resources but the enforcement is weak, the fines to be paid in case of non-compliances are very low and there are no policies that can help the sector towards sustainability.

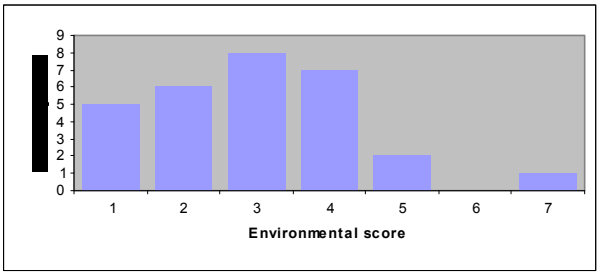
Awareness

The awareness concept meant as “the importance that the company gives to the protection of the natural resources or the environment in general”, was assessed during the survey. Awareness of environmental problems is one of the most important precursors for environmental benign developments.

Questions used to analyse this concept were related to the incorporation of environmental practices in terms of: including the environment into their accounting, personnel promoting environmental practices within the company, environmental criteria when choosing the suppliers or sub-contractors, knowledge of where the waste is disposed of, recycling activities, information required and technical assistance related to sustainable construction, environmental certifications, measures to save input materials and waste management plans. The outcomes showed a low level of awareness related to environmental matters and particularly of construction waste (Table 5). Based on the “responding firms”’ scores on individual questions an overall score depicting the environmental performance is devised.

Table 5. Environmental performance distribution

Score	No. companies	% of companies
Low < 2,5	13	45
Average 2,5 - 5	15	52
High > 5	1	3
Total	29	100



The need for information and technological assistance is also an indicator for awareness. The survey demonstrated that most of the information required is related to legislation and few of the companies look for information or technology related to sustainable construction which shows that they are looking for a way to reduce their environmental pressure, whether motivated by economical or ecological reasons.

Technical aspects

Knowledge of the causes of waste generation from the technical point of view is essential and it was analysed based on the information provided by the study of Bossink and Brouwers (1994) and the additional information provided by the respondents. The results showed that incompatible standard sizes of construction materials are causing major problems related to waste generation. More than 50% of the companies experience this problem in more than half of their projects. Incompatible standard sizes also have the highest number of companies experiencing this problem “on all projects”. Table 6 shows already reported aspects that contribute to the generation of waste from former studies, but it also includes newly reported during the present one. The table also provides information on the link between the source or part of the construction activity and the aspect that influences the production of waste.

It is important to highlight the fact that one of the major material suppliers for buildings are companies from United States of America that use the Imperial System of measurement (British), which is not compatible with the SI-measures used by Costa Rica. Besides the sector has to deal with a colonial heritage, which is the unit ‘vara’ used to measure wood during its colonial Spanish period, therefore extra waste is generated to fit all the pieces together.

Another common practice within the builders is to request future owners to buy more materials than actual needed. This is profitable for the contractor who can benefit from increased turnover and convenient for the construction workers. They do not have to work meticulously in order to get the most useful sections out of a piece of wood or a steel bar. Obviously, this practice generates waste. Sometimes, leftovers are used to construct ladders, sieves and scaffoldings. However, when the construction is completed, these materials turn into waste. A useful practice is an unknown amount of informal recycling by construction workers.

Table 6. Waste generation influencing aspects

Aspects	Source
Choices about specifications of products	Design
Incompatible standard sizes available on the market	Design
Lack of influence of contractors and lack of knowledge about construction	Design
Changes made to the design while construction is in progress	Design
Designers unfamiliarity with alternative products	Design
Incomplete contract documents at the beginning of the project	Design
Errors in contract document	Design
Selection of low quality products	Design
Complexity of detailing on the drawings	Design
Ordering errors (too much, too little)	Procurement
Lack of possibilities to order smaller quantities	Procurement
Use of products that don't fit	Material handling
Materials supplied in loose form	Material handling
Unpacked supply	Material handling
Damages during transportation	Material handling
Inappropriate storage leading to damage or deterioration	Material handling
Throwaway packaging	Material handling
Use of incorrect material, thus requiring replacement	Operation
Damage to work done caused by subsequent subcontractors	Operation
Bad weather	Operation
Required quantity unclear due to improper planning	Operation
Delays in passing of information to the contractor on types and sizes of products to be used	Operation
Accidents on the construction site	Operation
Errors by tradespersons or labourers	Operation
Equipment malfunctioning	Operation
Conversion waste from cutting uneconomical shapes	Residual
Purchased products that do not comply with specifications	Residual
Off cuts from cutting materials to length	Residual
Waste from application process	Residual
Packaging	Residual
Environmental unfriendly attitude of project team and labourers	Other
Criminal waste due to damage or theft	Other
Lack of on site materials control and waste management plans	Other
Natural disasters	Other

6. Conclusions

The literature related to the quantity and composition of the construction waste in Costa Rica is very limited and the existing one has discrepancies. The most important waste categories are wood, concrete, piping materials and roof sheets. Often, the waste is mixed and only 50% of the companies indicated that they separate the waste to some extent. The most used fractions for waste separation are wood, metals and mixed waste.

The survey helped to find the causes of waste generation, which are not only related to technical aspects but also to the lack of governmental motivation and enforcement of the existing legislation. There are no policies aimed at the reduction of the environmental pressure of the construction sector.

There is a general lack of awareness on environmental issues among the construction sector. Additionally a lack of information, technologies and governmental or market incentives to use those technologies frustrate the efforts of those trying to improve their environmental response.

At a company level, the most significant cause for waste generation is unawareness. This results in low interest in sustainable ways of construction and is thus a barrier to decrease the environmental pressure. The respondents also indicated that even though the profit margins are very high, the companies don't dedicate part of the revenues to environmentally sound technologies and this shows also the unawareness of the potential profitability by applying

those technologies. But since the profits in the sector are very high this will not be a very important motivator.

Builders can improve their operations through a better understanding of their activity in an integral way, taking into account not only the cost, quality and schedule of the projects but also the environment.

Further research should be done in order to assess the performance of the production system by means of Material Flow Analysis (MFA) as a way to unravel the “industrial metabolism” of material flows through the construction system, in order to understand the complex interaction between this economic activity and the environment, which can help to point out the main causes of inefficiency allowing areas of potential improvement.

Probably no sector has more potential to contribute to the achievement of sustainable development than construction and most attention has to be devoted to analyse the proper management of the materials that enter in the production process, and future research should continue in this line.

References

Apotheker, S. 1990, Construction and demolition debris-The invisible waste stream. *Resource Recycling*, 9, pp. 66-74.

Arpad, H. 2004, Construction materials and the environment, Annu. *Rev. Environmental. Resources*, 29, pp. 181–204.

Ayres, R.U. and Simonis, U.E. (eds) 1994, *Industrial metabolism – Restructuring for sustainable development*. Tokyo: United Nations University Press.

Begum, R. A., Siwar, C., Pereira, J. J. and Jaafar, A. H. 2006, Benefit–cost analysis on the economic feasibility of construction waste minimisation: The case of Malaysia, *Resources, Conservation and Recycling*, 48(1), pp 86-98.

Bossink, B.A.G. and Brouwers, H.J.H. 1996, Construction waste: quantification and source evaluation, *Journal of Construction Engineering and Management*, 122(1), pp. 55-60.

Brooks, K.A., Adams, C., and Demsetz, L.A. 1994, Germany's construction and demolition debris recycling infrastructure: What lessons does it have for the US? Sustainable Construction In Proceedings First Conference of CIB TG 16, Gainesville Fla., 647-656.

CCC, Camara Costarricense de la Construccion, January 2007.

Craven, E.J., Okraglik, H.M., and Eilenberg, I.M. 1994, Construction waste and a new design methodology In Proceedings First Conference of CIB TG 16, Gainesville Fla., pp. 89-98.

Environmental Protection Agency U.S. 1995, Residential construction waste management demonstration and evaluation, Office of Solid Waste, NAHB Group.

Gavilan, R.M. and Bernold, L.E. 1994, Source evaluation of solid waste in building construction, *Journal of Construction Engineering and Management*, 122(1), pp. 55-60.

Heino, E. 1994, Recycling of construction waste Sustainable Construction In Proceedings First Conference of CIB TG 16, Gainesville Fla., pp. 565-572.

Hong Kong Environmental Protection Department (Hong Kong EPD). 2000, "Statistics Data". http://www.epd.gov.hk/epd Hong Kong EPD, Hong Kong SAR Government, Hong Kong

Hovarth, A. 2004, Construction materials and the environment, *Annu. Rev. Environmental Resources*, 29, pp. 181-204.

Janssen M.A., Bergh, J.C.J.M. van den Beukering, P.J.H. van and Hoekstra, R. 2001, Changing Industrial Metabolism Methods for Analysis. *Population and Environment*, 23(2), pp. 139-156.

Kartam, N., Al-Mutairi, N., Al-Ghusain, I., and Al-Humoud, J. 2004, Environmental management of construction and demolition waste in Kuwait, *Waste Management*, 24, pp. 1049-1059.

Kennedy, C., Cuddihy, J. and Engel-Yan, J. 2007, The changing metabolism of cities, *J. of Industrial Ecology,* 11(2), pp. 43-59.

Kibert, C.J., Sendzimir, J. and Guy, B. 2000, Construction ecology and metabolism: natural system analogues for a sustainable built environment, *Construction Management and Economics*, 18, pp. 903-916.

Lambert A.J.D. 2008, Industrial Metabolism: Roots and Basic Principles. In: Gupta S.M. and Lambert A.J.D. (eds), Environment Conscious Manufacturing, CRC Press, Florida, pp. 1-33.

Lawson, N., and Douglas, I. 2001, Recycling construction and demolition waste – A UK perspective. *Environmental Management Health*, 12(2), pp. 146-157.

Leandro, A.G. (2006), Researcher Costa Rica Institute of Technology, Personal communication.

Mincks, W.R. 1994, The construction contractor's waste management plan: optimizing control and cost, Sustainable construction In Proceedings First Conference of CIB TG 16, Gainesville Fla., pp. 765-774.

Mocozoma, D. 2002, International Report on Construction Site Waste Management and Minimisation, International Council for Research and Innovation in Building and Construction.

Peng, C.-L., Grosskopt, K.R., and Kibert, C.J. 1994, Construction waste management and recycling strategies in the United States. Sustainable Construction. In Proceedings First Conference of CIB TG 16, Gainesville, Fla., pp. 689-696.

Poon, C.S., Yu, A.T.W. and Ng, L.H. 2001, On-site sorting of construction and demolition waste in Hong Kong, Resources, *Conservation and Recycling*, 32(2), pp 157-172.

Poon, C.S. 2007, Reducing construction waste, *Waste Management*, 27, pp. 1715-1716,

Ramírez, M. 1995, Impacto fisico y financiero de la generacion de desechos solidos en la construccion de dos proyectos hoteleros, Lic. Dissertation, Universidad de Costa Rica, Costa Rica.

Rogoff, M.J., and Williams, J.F. 1994, Approaches to implementing solid waste recycling facilities, Noyes Publication, Park Ridge, N.J.

Shen, L.Y., Tam, V.W.Y. 2000, Material wastage in construction activities-a Hong Kong survey. In: Proceedings of the first CIB-W107 International Conference: creating sustainable construction industry in developing countries, pp 125-131.

Smallwood, J.J. 2000, Construction and the environment-general contractor (GC) perceptions and practices. In: Proceedings of the first CIB-W107 International Conference: creating sustainable construction industry in developing countries, pp 155-164.

Taiwan Environmental Protection Agency (Taiwan EPA), (1999) Environmental Protection Agency Annual Reporton disposal of solid and liquid wastes, Report, Taiwan EPA, Taiwan

Tam, V.W.Y., Tam, C.M. and Zeng, S.X. 2004, Comparison of environmental performance assessment (EPA) for construction in Hong Kong and the Mainland China, University of Hong Kong.

The Economist Intelligence Unit, June 2006, London.

Villalobos, A.J. 1995, Estudio de Generación de Desechos en la Construcción de Viviendas de Mampostería, Lic. Dissertation, Universidad de Costa Rica, Costa Rica.