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An Optimization Model on Construction and Demolition Waste Quantification from Building

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Abstract

Construction and Demolition (C&D) waste, which constitutes more than 30% of the solid waste stream in India is not given proper attention and loses its recycling potential. Absence of enforcement and negligence on behalf of the authorities has given rise to independent overlords who fight among themselves for the control of waste thereby making it even more difficult to categorize and quantify C&D waste. Re-utilization of Solid Waste is in developmental stage and thus ends up mostly in landfills without taking into consideration the malignant effects on the environment. Elements like Lead, Arsenic, Cadmium and Silica find their way into the soil and are then transported into the ground water (Stefania Butera, 2015). So the directive is to minimize the exploitation on the environment and find a means for recycling the waste into environment friendly building materials. Estimation of CD waste is carried out by making use of Building specific and region specific waste generation rates. An all encompassing model which can successfully predict the total amount of waste generated from a particular project does not exist and this fact is quite evident given the diversity of construction techniques and composition of building materials. Even if such a database were to be compiled, end users would find it hard to comprehend and apply this data into meaningful quantity. The most appealing way of making users more aware of the need to recycle is by offering a perspective where they can perform a cost benefit analysis of the revenue that can be generated from proper optimization and reutilization of CD waste. Contractors can make a prior estimate of the investment for a particular project and order precise quantities of the materials required. This would not only eliminate the additional cost incurred but also reduce waste on site from off cuts and poor handling of surplus materials. Therefore the objective is to propose a model which makes use of easily available data like transportation rates and resale value of recyclable materials which would provide an intuitive and simple optimization model while imbibing the basic principles of Reduce, Reuse and Recycle into action.

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Introduction

Building materials account half of the solid waste generated worldwide. Construction and demolition (C&D) waste have an environmental impact at every step of the building process—extraction of raw materials, processing, manufacturing, transportation, construction and disposal at the end of a building’s useful life. Governments across the world have responded to the need to reduce solid waste with regulation and legislation that have framed a market for building materials and products derived from the (C&D) waste stream.

“Sustainable building” has become a national catchphrase. Construction sites around the world are increasing emphasis on reducing the generation of solid waste both in renovation and new construction. C&D waste are produced directly by construction and demolition industry. This includes Building materials such as bricks, nails, wood, Reinforced Cement Concrete (RCC), lime concrete, mixed earth, electrical wiring and steel bars as well as from site preparation such as dredging material, tree stumps, and rubble. However, C&D waste can also contain lead, asbestos, or other hazardous substances.

Resource depletion coupled with global population growth means that the cost of raw materials, energy, minerals are growing rapidly. Constantly using new materials, results in landfill degradation, deforestation and loss of biodiversity. This is happening at such a rate that two-thirds of world eco-system is in decline. It is predicted that unless actions are taken properly, there could be a shortage of 40% of Global Water Supply by 2030 (United Nations, 2015). Cost of Construction will also increase due to rise of the cost of raw materials.

Literature Review

There is a finite way of looking at CD waste:

- C&D waste management in general
- C&D waste recycling
- C&D waste reduction
- C&D waste generation

Extensive work has been carried out in the course of the last two decades and it has seen a truly international effort to acknowledge the problem and tackle it head on. In an attempt to expound the term, in addition to the solid waste that arises from construction, renovation and demolition activities, Roche and Hegarty (2006) added that C&D waste also includes surplus and damaged products and materials arising in the course of construction work or used temporarily during the course of on-site activities. The term C&D waste is defined as the waste which arises from construction, renovation and demolition activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork, and building renovation. Construction and demolition wastes may also be produced significantly from environmental disasters such as earthquakes, hurricanes, tornadoes, and floodwater (Tansel et al., 1994).

Since the term itself is self explanatory and goes by intuition, one can argue that the need to define CD waste is of subaltern importance.

Going through the Data available on the concentration of CD waste in Solid Waste stream, one finds verisimilitude in the findings presented all over the world.

In Hong Kong, 38% of solid waste comes from the construction Industry (Hong Kong Government – Environmental Protection Department, 2006). According to Construction Materials Recycling Association (2005) and Hendriks & Pietersen (2000), the construction industry generates about 35% of industrial waste in the world. In India, C&D waste and other inert matters contributes to approxiamtely 33% of the Solid Waste stream.
Shedding light in the research on the Classification of C&D waste, the trend is to follow either an atomistic approach or a holistic approach both of which are necessary in sorting out and handling the waste. The European Waste Catalogue (EWC) classifies C&D waste into the following eight categories: (1) concrete, bricks, tiles and ceramics; (2) wood, glass and plastic; (3) bituminous mixtures, coal tar and tarred products; (4) metals (including their alloys), (5) soil (including excavated soil from contaminated sites), stones and dredging spoil; (6) insulation materials and asbestos-containing construction materials; (7) gypsum-based construction material; (8) other construction and demolition waste. In the United Kingdom, SMART Waste TM quantification method is used which recognizes waste up to 13 categories, including ceramic, concrete, wood pallet, etc. Based on the National Methodology (Cochran et al., 2007), Nine types of waste: wood, concrete, block, drywall, asphalt, metal, plastic, ceramic and other debris were categorized from the result of a study to estimate waste generated in construction, rehabilitation and demolition of buildings in Florida according to the constructive technique.

Wen-Ling Huang, Dung-Hung Lin, Ni-Bin Chang, Kuen-Song Lin (2002) in an effort to sort and process C&D waste, simplified the model by categorizing waste into A, B & C streams. Their inferences indicate that the reuse of fine particles generated in product stream A as construction materials in roadbed is highly recommended if the impurities can be removed beforehand. The product stream B could be suitable for reuse in the covering materials in daily operation of sanitary landfills and can also be used as backfill materials in the construction projects if the impurities can be removed in advance. Only does the LA abrasion test support the reuse of product stream C as coarse aggregate or pavement sub base for its new structures.

Calculation of the quantities of C&D waste is carried out by recording the dynamics of collection and flow of materials for construction and demolition activity. The paramount factor in the estimation of C&D waste is the Waste Generation Rate (WGR). WGR can be based on the quantity of material developed from different sources, ranging from unit area of the building to a national average of C&D waste produced.

The final waste is always quantified either in tons (mass) or cubic meter (volume). Lu et al. (2011) and Gheewala & Kofoworola (2009) suggested models on the basis of mass

\[ WGR = \sum m_i / A \]

\[ Q_x = A \times Gav \times P_x \]

\[ (Q_x = \text{quantity in tons}; A = \text{area of activity in } \text{m}^2; Gav = \text{waste generation rate}; P_x = \text{percentage of waste material.}) \]

C. Llatas recognized that C&D waste is of a heterogeneous nature and this mixed waste is not usually separated into work and is removed to landfill in most scenarios. Volume is a valuable marker in this context from which the number and size of containers needed for removal can be estimated. Paola Villoria Sáez et al., used the generic formula

Volume(CD waste) = ix X St,

\[ \text{where } ix \text{ is the indicator value } (\text{m}^3/\text{waste}/\text{m}^2) \text{; and } St \text{ is the total built surface } (\text{m}^2). \text{ This indicator value is different for different stages of the construction or demolition procedure where distinct material is expected to be generated.)} \]

The Spanish Model by Jaime Solís-Guzmán et al., proposed the empirical formula

\[ VAD_i = VAC_i X CT_i = Q_i X CCI_i X CT_i, \]

\[ \text{(where } VAD_i \text{ is the Apparent Demolished Waste Volume for the item” } i \text{” in } \text{m}^3/\text{m}^2, \text{ VAC_i is the Apparent} \]

...
Constructed Volume for the item ‘i’ in $m^3/m^2$, $CT_i$ is the coefficient for the transformation of VAC in VAD (dimensionless), $Q_i$ is the quantity of the item ‘i’ in its specific unit (m, $m^2$, $m^3$, kg or unity)/m², $CC_i$ is the conversion ratio of the amount of the item ‘i’ in VAC in $m^3/Q_i$ specific unit.

Therefore, both these models, in accordance with C. Llatas inference, conform to the accepted norm of quantifying waste based on volume rather than mass. Studies from Poon et al., 2004; Lin, 2006 derived a general WGR by using the volume ($m^3$) or quantity (tons) of waste generated per m² of gross floor area (GFA) without differentiating materials.

Concurring with Weisheng Lu et al., whatever may be the calculation, Waste Generation Rates have two functions, either investigate a specific waste according to its properties and causes, or while treating waste in general, they help predict the total amount of waste generated from a project.

There is no optimization model which can easily predict possible value of revenue that can be recovered by recycling of C&D waste. Other proposed model are dependent on waste generation rates, national average and are complicated because of diverse architecture, construction type and construction method used, and there is also paucity of reliable data. A model should be proposed such that it can be calculated with easily available data. If a model can access the maximum revenue that can be recovered through reuse and reutilization it will be very lucrative for common people to recycle C&D waste. This will reduce the exploitation of environment, and also reduce the cost of construction.

Methodology

The research was conducted between May 2015 and August 2015 on 5 ongoing demolition and renovation works in Kolkata, India. An array of Research Methodologies were adopted to critically analyze and develop a model based on current research findings. The exhaustive literature on Construction and Demolition Waste was carefully studied and the research was in harmony with most of the work concluded elsewhere. The categorization of waste was in agreement with the models suggested by agencies such as the European Waste Catalogue and the National Methodology. In an attempt to simplify this categorization, it was concluded that only the constituents contributing to the majority of the waste by volume or mass would be considered and in the case of recyclable materials the items accruing the maximum resale value were accounted for in this study. Similar quantification models proposed to estimate and tackle C&D waste made use of waste generation rates or constants for specific waste materials. Access to such data is not only difficult but varies from one region to another depending on factors such as soil characteristics to construction techniques. To overcome this problem, the major elements contributing to this form of waste were expressed in their relative percentages by nature of the surface to be demolished. This form of data in percentage of surface area to be demolished is intuitive to end users of this model and does not involve pedantic calculation to estimate the quantity of waste generated. The respective Sub Assistant Engineer of the sites were interviewed. From the practical data obtained on the sites, there were five main C&D waste generated from each site, i.e. Steel, Bricks, Plastering Materials and RCC.

We also interviewed experienced engineers and enquired about the reuse percentage of different materials. According to them only bricks are reused efficiently and other materials are disposed off. The percentage of recyclable bricks is dependent on the age of the building as well as on the skill on the labor being employed.

In some sites, the buildings were demolished and in some sites surface drain was demolished to build underground sewerage system and thus the data couldn’t be tallied up.

The sites that we visited were given as follows:

- Regional Housing Estate Ibrahimpur
- LIG Tollyguange Homes
- PaschimBarisha Housing Estate
- RHE Sahapur
- ODRC
We also interviewed local contractors and according to them average volume of truck which carry debris is around 18 Cubic meters. They also stated that these wastes are of minimal use to them. They hand over these wastes to local truck drivers and are paid Rs 200/truck. The local mafias make the most money out of it, mixing garden waste with these materials to increase the volume and selling them at high rates for landfilling.

Discussion of Model

A building in the housing estate of Ibrahimpur consisting of 16 flats with two rooms, one kitchen and one toilet was dismantled. Five types of major waste materials were generated after demolition viz brick, lime, plastering material, RCC and steel. These waste materials were generated from wall & foundation, roof & chajjas and column & lintel. A total 270 cubic meter waste material was evolved in this demolition. 100% Brick and 70% plastering material were generated from wall and foundation while 50% steel, 84% RCC, 30% plastering were generated from roof and Chajja. 100% lime comes from roof. 50% steel and 16% RCC comes from column. 41%, 50% and 9% of the total demolition waste comes from wall & foundation, roof & chajjas and column & lintel respectively.

Among those waste materials, some materials are given to truck drivers for landfilling. Contractor have to bear Rs. 200 per truck to the truck driver or owner for loading and unloading charge, which carries around 18 cubic meter of waste. Recyclable waste material like steel and 60% brick from wall are sold at the rate of Rs. 45000 per ton and Rs. 4 per brick respectively. A mathematical model is built such that the contractor can estimate his maximum revenue from demolition waste of 2200 square foot area.

The following set of variables, and constants are used in the mathematical formulation of the model.

- \( x_{br} \): Quantity of brick in demolition waste
- \( x_{st} \): Quantity of steel in demolition waste
- \( x_{p(tm)} \): Quantity of plastering material in demolition waste
- \( x_{lm} \): Quantity of lime in demolition waste
- \( x_{rcc} \): Quantity of RCC in demolition waste
- \( x_{me} \): Quantity of mixed earth
- \( y_{nrc} \): Payable cost to truck driver for non-recyclable wastes
- \( y_{rc} \): Revenue from recyclable wastes

The objective function of the mathematical model consists of maximizing the revenue.

Revenue from selling non-recyclable wastes for landfilling can be expressed as

\[
y_{nrc} = \frac{x_{rec} + x_{lm} + x_{p(tm)} + \frac{40}{100} x_{br}}{7} \times \text{(Cost of Transportation)}
\]

Similarly, revenue from selling recyclable wastes can be expressed as

\[
y_{rc} = (\text{Resale value of Steel per ton}) \times x_{st} + \frac{60}{100} \times (\text{Resale Value of Bricks per meter cube}) \times x_{br}
\]

Constraint on loading and unloading the recyclable waste are expressed as

\[
y_{rc} \leq \frac{y_{rc}}{50}
\]

Constraint on waste material generated from wall & foundation, roof & chajjas and column & lintel are respectively

\[
\frac{100}{100} x_{br} + \frac{70}{100} x_{p(tm)} + \frac{41}{100} x_{me} = \frac{41}{100} \times (\text{Total Waste Evolved}),
\]

\[
\frac{50}{100} x_{st} + \frac{84}{100} x_{rcc} + \frac{30}{100} x_{p(tm)} + \frac{50}{100} x_{lm} = \frac{50}{100} \times (\text{Total Waste Evolved})
\]
\[
\frac{50}{100} x_{st} + \frac{16}{100} x_{rcc} = \frac{9}{100} \times (Total \ Waste \ Evolved). \tag{4}
\]

Fig. 1. Demolition waste from different section of building

N.B. Mixed earth is generally reused for covering the foundation up to ground level. Therefore, contractor can’t expect any revenue back from this waste material. Hence, we exclude mixed earth from the optimization model which estimates maximum revenue from demolition waste.

Minimize \[ y_{nrc} = \frac{x_{rcc} + x_{lm} + x_{pim} + \frac{40}{100} x_{br}}{\text{volume of truck}} \times (Cost \ of \ Transportantion) \] \tag{5}

Maximize \[ y_{r} = (\text{Resale value of Steel per ton}) x_{st} + \frac{60}{100} \times (\text{Resale value of Bricks per meter cube}) x_{br} \] \tag{6}

Subject to \[ y_{nrc} \leq \frac{y_{rcc}}{50} \]
\[ \frac{100}{100} x_{br} + \frac{70}{100} x_{pim} \leq \frac{41}{100} \times (Total \ Waste \ Evolved), \]
\[ \frac{50}{100} x_{st} + \frac{84}{100} x_{rcc} + \frac{30}{100} x_{pim} + \frac{100}{100} x_{lm} = \frac{50}{100} \times (Total \ Waste \ Evolved) \]
\[ \frac{50}{100} x_{rcc} + x_{im} + x_{pim} + x_{br} + x_{st} > 0. \]

**Study and Results**

The observations from the Regional Housing Estate, Ibrahimpur are tabulated below.
The following are the results from the Mathematical Modelling:

The optimization model is a multi-objective linear programming problem with two inequality and two equality constraints. A multi-objective problem is often solved by combining its multiple objectives into one single-objective function. This approach is generally known as the additive method. Following that technique, the multi-objective programming problem can be written as

Maximize Total revenue\(= \frac{x_{rcc} + x_{lm} + x_{pim} + \frac{40}{100} x_{br}}{Volume\ of\ Truck} \times (\text{Cost of Transportation}) + (\text{Resale value of Steel per ton}) x_{st} + \frac{60}{100} \times (\text{Resale Value of Bricks}) x_{br}
\)

Subject to \(y_{nrc} \leq \frac{y_{rcc}}{50}\)

\(\frac{100}{100} x_{br} + \frac{70}{100} x_{pim} \leq \frac{41}{100} \times (\text{Total Waste Evolved}),\)

\(\frac{50}{100} x_{st} + \frac{84}{100} x_{rcc} + \frac{30}{100} x_{pim} + x_{lm} = \frac{50}{100} \times (\text{Total Waste Evolved})\) and

\(\frac{50}{100} x_{st} + \frac{16}{100} x_{rcc} = \frac{9}{100} \times (\text{Total Waste Evolved}).\)

\(x_{rcc}, x_{lm}, x_{pim}, x_{br}, x_{st} > 0.\)

The following values were used to compute the optimized solution:

Solving this model in LINGO-11.0, optimal amount of waste materials along with optimal revenue are listed in Table-2. The non-recyclable items are expected to handover to the truck driver at 200 Rs. per truck. Therefore, we don’t expect so much non-recyclable waste materials which also give maximum revenue to the contractor. That is why, a suitable range of those waste materials are used to find optimal amount of C&D waste materials with optimal revenue.

In this mathematical formulation, emphasis is given on revenue of contractor. From the table, we can say that contractor can get maximum revenue back if demolition wastes are as per the table.
Table 2: Optimal values of waste materials and revenue back to contractor

<table>
<thead>
<tr>
<th>Optimal amount of waste material</th>
<th>Total optimal revenue (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastering Materials</td>
<td>36.00 m³</td>
</tr>
<tr>
<td>Lime Concrete Terracing</td>
<td>22.00 m³</td>
</tr>
<tr>
<td>RCC</td>
<td>114.55 m³</td>
</tr>
<tr>
<td>Masonry</td>
<td>85.50 m³</td>
</tr>
<tr>
<td>Steel</td>
<td>11.94 ton</td>
</tr>
<tr>
<td></td>
<td>622624</td>
</tr>
</tbody>
</table>

A comparison of the Observed and Calculated values are presented as follows:

N.B. : RCC , Masonry , Plastering Materials and Lime are in m³.

The following discrepancies can be explained:

- RCC – The difference can be attributed to the contamination of RCC by Mixed earth and other foreign debris.
- Masonary – The anomaly is due to the level of skill being employed for demolition.
- Plastering Materials – No Appreciable difference was found that warrants an explanation.
- Lime – The observed and predicted values were identical.
- Steel – The minor dissimilarity can be accounted to the type and grade of steel used and due to rusting.

Wood, sanitary pipes, electrical fire and fittings are not considered in this optimization model because these materials are generally auctioned by the authority. Around 10%-15% and 5%-6% of the present market value are recovered by auctioning wood and sanitary fittings respectively.

Conclusion

There has been extensive demolition in Indian cities and the number of construction projects is increasing. It is imperative that these wastes generated from these sites are managed efficiently before we run out of space for landfilling. Moreover, leachate from the landfills pose a heavy threat to human habitat. Authorities must respond to these alarming findings and act accordingly to tackle the situation.
The 5 demolition and renovation works on which the research was conducted, gave us valuable insight ranging from the components to be included in the mathematical model to the evident causes of waste produced on site.

Research on the categorization of CD waste yielded the following conclusions.
- Non-Recyclable materials– RCC, Bricks (Damaged), Plastering materials and lime concreting (Major), Mixed Earth (Minor).
- Recyclable materials– Steel and Bricks (Major), wood, sanitary pipes, Glass (Minor).

Only the major components were included in the optimization model to avoid lengthening and unnecessary complications.

The common causes of waste on site were identified as:
- Off-Cuts of materials such as tiles and plasterboard.
- Damage to materials e.g. through inappropriate handling or inadequate storage.
- Inaccurate or surplus ordering of materials.
- Rework due to errors, poor workmanship or defective site processes.
- Inefficient use of materials e.g. use of temporary materials such as hoardings.

The comparative values between Practical and Mathematical values proved satisfactory. The minor discrepancies between the values arose due to rusting, efflorescence and adulteration of mixed earth with RCC. Skilled labour and proper handling played an important role in demolition which directly impacted the quantity of usable building waste such as bricks.

The model was deliberately based on revenue generation to engage contractors in the practice of recycling waste. Enabling them to accurately estimate the investment and quantity of raw materials is not only in the best interest of contractors and municipal corporations but would directly benefit the environment.

Benefits of CD waste recycling:
- It’s an alternative to landfill disposal. Less waste needs to be put into the earth, and landfill space is conserved.
- It’s economically attractive.
- Recycling and using recycled content promote sustainability.
- Check in ground water contamination.

Minimizing the exploitation due to excavation of raw materials can also be stymied. The C&D waste produced can be reutilized as new components in building materials.

References
5) Latas, C., 2011, A model for quantifying construction waste in projects according to the European waste list.