Evaluation of Causes of Construction Waste in Residential Building Projects: A Case Study of Kolkata

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Abstract
Material waste has been recognized as a major problem in the construction industry that hinders the efficiency of the projects and also impacts the environment. With increasing demands in infrastructure projects especially residential projects in India, a large amount of construction and demolition (C&D) waste is being produced. These projects mainly employ conventional construction methods rather than more efficient prefabrication technology. This research focuses on identifying and assessing the main causes of C&D waste in residential projects in Kolkata, India. Twelve major causes noted from literature and case studies were used to develop an analytic network process (ANP) model for further evaluation of their relative share towards waste generation. Twelve industry experts judged the causes and poor management emerged as the main concern followed by design change and use of unfit products. This knowledge may help in framing the recommendation for waste minimization by selecting the best option in various stages of design and construction of residential projects.

Keywords
Analytic network process, Construction waste, Prefabrication, Residential project, Waste minimization.

1. Introduction

Indian construction industry has grown over the last decade with a minor dip during the global economic crisis in 2008 and ranks second as largest contributor to the national GDP (gross domestic product) after agriculture (\Ernst & Young LLP 2014). The industry is dominated by real estate sector with 80% share from housing. It contributed about 6.3% to the GDP in 2013 and is expected to double this value by 2025. Due to unprecedented growth in urban population, demand for housing will be very high as never before. Along with the intense construction activity, comes the inherent issue of construction and demolition (C&D) waste. In a report, CSE (2014) estimates the total amount of C&D waste approximately as 50 million tonne in 2013. This figure may not be the complete picture as a significant chunk of waste which is dumped on roadside or in vacant land are never documented and thus precise waste estimation in India in almost infeasible (Bendi, 2010) . The Union Ministry of Forests and Environment (MoEF) has confessed that there is no systematic database on C&D waste. As landfill tax is not imposed, huge quantities of waste are dumped in landfills every year. MoEF (2016) has recently issued the Construction and Demolition Waste Management Rules in order to handle the issue.

The amount of C&D waste generated at site grossly depends on the outlook and knowledge of the key stakeholders of a construction project (Rocha and Sattler, 2009). Often waste management is excluded from project planning (Su et al., 2007). Compared to other sectors, residential market is highly fragmented, non-standardized and includes numerous architecture, engineering & construction (AEC) agencies. Involvement of the first-time owners in the design or construction phase of a house is not uncommon. As a result, the industry practices for C&D waste minimization are not sound.

The residential building industry is the one where not a single material is used in its raw form (Treolar et al., 2003) and hence any wastage affects the environment. In building projects, 58-60% of the project cost is spent on materials. The true cost of material waste includes the cost of purchase cost, storage, transport and disposal to landfill and the time and resources going into the disposal process. In fact, the cost incurred to mitigate the environmental damage should also be considered for a broader picture. Therefore material waste from construction activity is also huge in monetary terms. Hence, there is an urgent need of optimizing the C&D waste generation in India. In order to capture the issue at its source, causes of C&D waste of housing projects (both traditional and prefab construction) were focused in this research.

2. C&D Waste and Its Causes

Construction waste had been defined and classified in various ways. The Environmental Protection Act 1990 (Parliament of the UK, 1990) defined it as "scrap material or an effluent or other surplus substance arising from the application of any processes". In Hong Kong, it is "the by-products generated and removed from construction, renovation and demolition workplaces or sites of building and civil engineering structures" (Cheung, 1993). MoEF (2016) refers to C&D waste as "waste comprising of building materials, debris and rubble resulting from construction, re-modeling, repair and demolition of any civil structure". C&D waste can be broadly classified as material, labor and machinery, among which material is the most critical one due its non-renewable nature (Ekanayake and Ofori, 2000). For this research only material waste will be considered.

C&D waste mostly comprises of cement, concrete, wood, sand, metals, gypsum wallboard etc. It can be classified into physical and non-physical waste. Physical waste is material loss such as concrete leftover, demolished debris, steel scrap. Non-physical waste in the form of time and cost overrun is caused by poor financial management, wrong construction procedures and lack of supervision.

Waste management (WM) plan has been emphasized worldwide by various researchers and professionals. Lu and Yuan (2011) developed a framework for understanding C&D WM in terms of ten aspects namely, (1) origin; (2|) amount or volume; (3) impact; (4) regulations; (5) reduce; (6) reuse options; (7) recycling; (8) tools & techniques; (9) human resource and (10) performance measurement. Nagapan et al (2012) conducted a study on the need for sustainable WM which includes environmental, economic and social issues. Tam (2008) studied the effectiveness and difficulties of the WM plan in Hong Kong. Lua et al. (2010) explored the critical success factors for C&D WM for China. Begum et al. (2007) focused on Malaysian construction industry. Arif et al. (2012) suggested reduce, reuse and recycle strategies for C&D waste in India. In almost all studies, the common topic pertaining to C&D waste explored was its causes as discussed next.

2.1 Design

In large complex projects information gap remain unidentified in design phase. They surface up as rework during construction (Li and Taylor, 2011). Design error or more precisely detailing error and change in design or scope are major contributor to rework (Faniran and Caban, 2007; Osmani et al., 2008; Wan et al., 2009). Rework is wasteful due to loss of resources (Hwang et al., 2009) and often is not directly accountable. Hence issues are mainly complex design (CD), detailing error (DE) and design change (DC).

2.2 Procurement

It happens that storage of over-ordered material become difficult at site. Items such as concrete almost remain unutilized if extra amount is procured (Tam and Tam, 2007). On the other hand ordering less may make other related material redundant and finally get wasted (Muhwezi et al., 2012). Similarly procuring from unreliable source may lead to inferior quality work which may need to be demolished after thorough inspection. In brief, procumbent issues are orderings error (OE) and unfit product (UP).

2.3 Material Handling

Several materials such as brick, tiles, glass or stone slabs get damaged during transport mostly due to rough handling and unpacked supply. Ready-mix concrete unless supplied in a proper manner loses its required properties (Tan and Hao, 2014). Unless stored and handled carefully materials get damaged (Nagapan, 2012). Cement is one of the most susceptible items which should be protected from dampness. Similarly, inflammable item must be kept away from any kind of heat source (Das, 2012). Material handling issues can be classified as transport damage (TD) and improper storage (IS).

2.4 Operation

Mistakes during construction include poor performance of the workforce in terms of erroneous application, defective tools, lack of skill etc (Alwi et al., 2002; Wang et al., 2008). Transient workforce is a perennial issue in many construction sites and as a result there is always shortage of skilled workforce. Additionally numerous subcontractors may be problematic unless each of them is competent (Ekanayake and Ofori, 2000). Lack of site management skill and will to monitor and control can be major contributor to the C&D waste (Alwi et al., 2002; Faniran and Caban, 2007) . It is closely associated to contractor's lack of experience. Poor planning and scheduling leads to poor coordination among stakeholders (Llatas, 2011; Wan et al., 2009) which may hinder the information flow from design office to site or among various trades causing rework. Hence, operational error can be broadly classified as laborer error (LE), waste from application (WA) and poor management (PM).

2.5 Others

Inclement weather conditions such as torrential downpour, flood, gusty wind or lightning can dampen stored material, waterlog a site or damage newly completed work (Faniram and Caban, 2007; Wahab and Lawal,.2011) Theft and vandalism is another issue which can be controlled through vigilance to prevent C&D waste.. The stolen or damaged material needs to be replaced. During the finishing stages work from one trade gets damaged by careless operation of another trade or by vandals (Arata, 2006). Hence, the additional causes of C&D waste are bad weather (BW) and theft & vandalism (TV).

3. Methodology

From literature review, the major causes of C&D waste were noted. Next, five residential projects in Kolkata, India were taken as case study to identify any additional information. Project managers of these sites were consulted for this purpose. All of them have more than 10 years of experience and have handled both traditional as well as prefab construction. They commented that the causes of C&D waste are not independent to each other rather interlinked to a certain extent. For example, poor management strategy can be associated with almost all other factors. Similarly design change may lead to procurement and material handling issues. Hence for analyzing the major causes of C&D waste and assessing their relative contribution to the issue is a complex multi -criteria decision making (MCDM) process where various parameters are inter-dependent. For such cases analytic hierarchy process (ANP) has been successfully implemented from the day of its proposal by Saaty (2005).

3.1 Analytic Network Process (ANP) in Brief

Compared to its predecessor method of analytic hierarchy process (AHP), ANP is described by Saaty (2004) as holarchy of supermatrix where constituent elements in the network may not follow a top-down approach but can be otherwise too. The elements are arranged in different levels under a group or cluster – usually decision criteria. ANP allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). The mathematical basis of ANP can be found in works by Saaty (2004, 2005). Here only the application part is described. Expert judgment in a 9-point priority scale (Table 1) is sought for pair-wise comparison for elements in a network for the following questions in order to obtain priority vectors. Judgments with inconsistency ratio $\leq$ 10% are acceptable for drawing a conclusion.

- For a cluster, which element A or B under it has greater influence on the cluster?
- For a cluster, which element A or B is influenced more by the cluster?
- For cluster matrix, for each cluster which of the linked cluster A or B has more influence on it?

Table 1: Fundamental priority scale for pair-wise comparison (Saaty, 2005)

Value	Importance level	Value	Importance level
1	Equal	7	Very strong or demonstrated
3	Moderate	9	Extreme
5	Strong or essential	2,4,6,8	Intermediate values

The priorities derived from the comparison matrices in first two questions are entered as the parts of the columns of a supermatrix known as Unweighted Supermatrix. It represents the influence priority of an element on the left of the matrix on an element at the top of the matrix with respect to a control criterion. The weights of the components are used to weight the blocks of the supermatrix corresponding to the component being influenced. The limiting priorities in each supermatrix are weighted by the priority of the corresponding sub-criterion and the results are synthesized for all the sub-criteria. For an element or a component with no input, the corresponding priority vector is zero.

Multiplying the cluster matrix numbers to their respective blocks in the Unweighted Supermatrix yields the Weighted Supermatrix which is column-stochastic i.e. each column sums up to 1. This is essential to ensure meaningful limiting priorities. Raising this weighted supermatrix to powers gives the Limit Supermatrix that represents all the possible interactions in the system. As Limit Supermatrix is irreducible, it has all columns as same value and thus yields the relative values of network elements. Normalizing these numbers yields the global weights (GW) w.r.t. the given context or goal.

3.2 Development of ANP Model

The 12 causes of C&D waste as identified from literature review and case studies were divided in five clusters and were used to develop an ANP model in Superdecisions software. Clusters and elements were linked based on their interactions. The two-way arrows denote bi-directional influences between clusters i.e. outer dependence. Cluster linked to itself with loop-like arrow represents inner dependence (Figure 1).

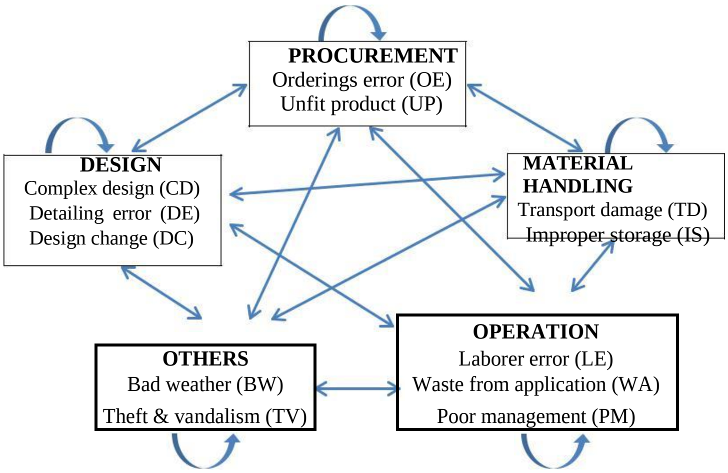

Figure 1: ANP model

3.3 Questionnaire Survey

A structured questionnaire survey was used to collect pair-wise comparison data by interviewing industry experts in Kolkata who has more than 10 years of experience at site for both traditional and prefab construction. First the project managers of the five case-study sites were approached. Another seven experts were contacted through them i.e. snowball sampling method was used.

4. Data Analysis and Results

Table 2: Unweighted supermatrix

Clusters	Elements	Design			Procurement		Material Handling		Operation			Others	
		CD	DC	DE	OE	UP	TD	IS	LE	WA	PP	BW	TV
Design	CD	0.0000	0.8730	0.0000	0.2873	0.2500	0.2495	0.2556	0.2387	0.2399	0.2592	0.2495	0.2700
	DC	0.9000	0.0000	1.0000	0.6800	0.6800	0.6813	0.6613	0.6735	0.6723	0.6625	0.6710	0.6700
	DE	0.1000	0.1270	0.0000	0.0327	0.0700	0.0692	0.0831	0.0878	0.0878	0.0783	0.0795	0.0600
Procure-ment	OE	0.2500	0.2438	0.2930	0.0000	1.0000	0.2256	0.2256	0.2500	0.2500	0.1200	0.1300	0.1200
	UP	0.7500	0.7562	0.7070	1.0000	0.0000	0.7744	0.7744	0.7500	0.7500	0.8800	0.8700	0.8800
Material handling	TD	0.6667	0.3333	0.6667	0.6700	0.6700	0.0000	1.0000	0.6700	0.6700	0.6700	0.6700	0.6700
	US	0.3333	0.6667	0.3333	0.3300	0.3300	1.0000	0.0000	0.3300	0.3300	0.3300	0.3300	0.3300
Operation	LE	0.4078	0.4452	0.4030	0.4213	0.4162	0.4224	0.4442	0.0000	0.5622	0.7500	0.3947	0.4032
	WA	0.1544	0.1148	0.1529	0.1404	0.1409	0.1408	0.1540	0.5622	0.0000	0.2500	0.1316	0.1344
	PM	0.4378	0.4400	0.4441	0.4382	0.4429	0.4368	0.4019	0.4378	0.4378	0.0000	0.4737	0.4624
Others	BW	0.6450	0.6194	0.6104	0.6061	0.6404	0.6292	0.6450	0.5868	0.3009	0.8423	0.2857	0.6364
	TV	0.3550	0.3806	0.3896	0.3939	0.3596	0.3708	0.3550	0.4132	0.6991	0.1577	0.7143	0.3636

Table 3: Weighted supermatrix

Clusters	Elements	Design			Procurement		Material Handling		Operation			Others	
		CD	DC	DE	OE	UP	TD	IS	LE	WA	PP	BW	TV
Design	CD	0.0000	0.3495	0.0000	0.0292	0.0254	0.0349	0.0358	0.0670	0.0673	0.0727	0.0508	0.0550
	DC	0.3603	0.0000	0.4003	0.0691	0.0691	0.0954	0.0926	0.1889	0.1886	0.1859	0.1367	0.1365
	DE	0.0400	0.0508	0.0000	0.0033	0.0071	0.0097	0.0116	0.0246	0.0246	0.0220	0.0162	0.0122
Procure-ment	OE	0.0206	0.0201	0.0241	0.0000	0.3825	0.0490	0.0490	0.0325	0.0325	0.0156	0.0346	0.0320
	UP	0.0617	0.0622	0.0582	0.3825	0.0000	0.1683	0.1683	0.0976	0.0976	0.1145	0.2319	0.2345
Material handling	TD	0.0311	0.0155	0.0311	0.2012	0.2012	0.0000	0.3919	0.1163	0.1163	0.1163	0.0514	0.0514
	US	0.0155	0.0311	0.0155	0.0991	0.0991	0.3919	0.0000	0.0573	0.0573	0.0573	0.0253	0.0253
Operation	LE	0.1434	0.1566	0.1418	0.0412	0.0407	0.0737	0.0775	0.0000	0.1900	0.2535	0.0483	0.0493
	WA	0.0543	0.0404	0.0538	0.0137	0.0138	0.0246	0.0269	0.1900	0.0000	0.0845	0.0161	0.0164
	PM	0.1540	0.1547	0.1562	0.0428	0.0433	0.0762	0.0701	0.1480	0.1480	0.0000	0.0580	0.0566
Others	BW	0.0768	0.0737	0.0726	0.0714	0.0754	0.0479	0.0491	0.0456	0.0234	0.0655	0.0945	0.2105
	TV	0.0423	0.0453	0.0464	0.0464	0.0423	0.0282	0.0270	0.0321	0.0544	0.0123	0.2363	0.1203

Data obtained from survey was entered in Superdecisions software. The inconsistency of cluster comparisons is 0.08561 and elements under five clusters ranged between 0.00885 and 0.00945. Values being less than 0.1 all 12 judgments were acceptable. The unweighted supermatrix (Table 2) was constructed from the priorities derived from the pairwise comparison done in survey. The 12 causes (elements or nodes) of C&D waste grouped under 5 clusters constituted the column and row labels of the supermatrix. The column for a particular element contains the pairwise priorities of other elements w.r.t. this element. In Table 2, for example, the elements compared against complex design (CD) are placed in the CD column of the supermatrix and the cells are highlighted with grey.

Comparing the clusters pairwise, their relative priorities were derived and are represented in cluster matrix (Table 4). Values in cells of unweighted supermatrix were multiplied by the corresponding cell i.e. the influencing cell of the cluster matrix to generate weighted supermatrix (Table 3). For example, CD, DC and DD are three factors under the design cluster (relative weight 0.4003 in Table 4). After multiplication, the weighted values for CD, DC and DD are shown in highlighted cells of weighted supermatrix (Table 3). Weighted supermatrix was raised to limiting powers until the weights converge and column–stochastic to derive Limit supermatrix. Since all the columns of this last matrix are the same, only the resulting values of one column are shown in Table 5 along with the ranks.

Table 4: The cluster supermatrix

	Design	Procurement	Material handling	Operation	Others
Design	0.4003	0.1016	0.1400	0.2805	0.2037
Procurement	0.0823	0.3825	0.2174	0.1301	0.2665
Material handling	0.0466	0.3003	0.3919	0.1735	0.0767
Operation	0.3517	0.0978	0.1745	0.3380	0.1224
Others	0.1190	0.1178	0.0762	0.0778	0.3308

Table 5: Limit matrix showing global weight

Cluster	Element	GW	Rank
Design	CD	0.069	5
	DC	0.221	2
	DE	0.022	11
Procurement	OE	0.028	10
	UP	0.109	3
Material handling	TD	0.061	6
	US	0.034	9
Operation	LE	0.039	8
	WA	0.015	12
	PM	0.251	1
Others	BW	0.099	4
	TV	0.053	7

It can be observed from the priorities (Table 5), the top three factors contributing to waste in decreasing order are poor management, design changes and use of unfit products while ordering error, detailing error and waste from application were less significant. This information corroborates the respondents' initial comments that poor management and design changes leads to most of the problems. Poor management sometimes leads to lack of on-site material control, supervision and wrong allocation of resources. The main causes for design variations during construction are last minute client requirements, designers' lack of experience leading to detailing errors, complexity in design. Unfit products are caused due to unclear/unsuitable specification. Procurement errors can be due to ordering items not in compliance with specification, supplier errors and transportation damage during transportation.

Waste from application can be due to materials stored far away from point of application, over preparation or materials handling. For materials supplied in loose form, on-site transportation methods from storage to the point of application, equipment malfunction, off-cuts from length, waste from cutting uneconomical shapes etc. Theft, lack of design information leading to assumptions made at site which result in over-ordering of materials are the other causes of waste.

5. Conclusion

This research focussed on identification of main causes of C&D waste generation in residential projects of Kolkata, India. Opinion was collected from 12 industry experts using an ANP questionnaire. Out of 12 major causes, the most significant factors are poor management, design changes and use of unfit products. This same information was informally communicated buy the respondents while discussing their projects. The ANP model developed here was useful to provide a general framework for the evaluation of the causes of C&D waste in residential building.

These findings can be utilized in a future project while making a decision for design or construction phase. Among various options of design, detailing, material, procurement method, material handling, storage, erection etc, the best alternative can be chosen to minimize C&D waste as much as possible. Otherwise, if any compromise is made, at least it will be made via conscious decision-making process. By knowing the adverse implications and accordingly a contingency plan can be made. Hence, the knowledge elicited from this research can be helpful in improving WM plan for residential projects in India.

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