Low-Cost Housing by Reclamation of Waste Material and Its Evaluation

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Abstract - *India is one of the developing countries who is facing a shortage of houses to provide its people. Now, it has become a necessity to adopt innovative, cost-effective and environmental-friendly housing techniques to build affordable houses. This study aims to provide a technique which helps to reduce the cost of construction by minimizing the construction waste and will ensure increase in profit. The study defines construction waste and its types and identifies the causative factors responsible for generating waste and its common sources. An estimate of a building understudy was prepared to find out the cost of major construction materials and the percentage of waste generated. The study focuses on the potential to reuse and recycle construction waste and its applicability. The cost saved by recycling and reuse is used to find the deduction in cost of construction waste which makes construction economical.*

Key Words: Construction wastes, Causes of Waste, Construction Waste Management, Reuse, Recycle, etc

1. INTRODUCTION

For healthy living and a good life, it is necessary to have a proper place for living and that place is home. But contrary to this, in India, the people living here don't have adequate type and number of homes available. With an annual population growth rate of 1.64 percent compared to the world population growth rate of 1.23 percent, India has to fulfil a great demand for housing in the coming years. Increased construction activities have resulted in the generation of enormous amounts of construction waste which is dumped illegally. Low-cost housing is a new concept which is focused on effective budgeting and utilization of techniques which result in reducing the cost of construction by the utilization of locally available resources and reusing the construction waste. Substitution of construction waste materials will conserve waning resources and will reduce environmental damages caused by construction. Construction waste materials can be reused or recycled partially or completely to obtain a suitable product. Hence, the purpose is to identify the type and quantity of construction waste generated. Also, to determine the potential of reuse and recycling of construction waste developing a new construction technique which will help to achieve sustainable and affordable housing.

2. CONSTRUCTION WASTE

Paliari (1999) defines construction waste as all resource consumed beyond a predetermined value of reference for one determined period of the construction. According to Freitas, construction waste can be defined as every resource that is spent in excess, further than the strictly necessary to execute a service. According to the new production philosophy, construction waste shall be considered as any inefficiency which would result in excess use of the resources (i.e. equipment, materials, labours, or capital) than the actual quantity required for the production of building.

Fig -1: Construction Waste

2.1 Construction Waste Classification

Construction waste can be classified into two different categories i.e. Physical waste and non-physical waste, also waste can be classified according to the type of resource consumed, nature of waste, control of the waste and the origin of waste.

2.2 Causes of Construction Waste Generation

From studying various researches that covered construction waste generation helped to identify different construction waste sources which may occur during the life cycle of a project which are,

Table -1: Causes of Construction Waste

SOURCES	CAUSES	
DESIGN	Frequent design changes	Slow drawing distribution
	Design errors	Complicated design
	Lack of design information	Inexperience designer
	Poor design quality	
HANDLING	Wrong material storage	Poor quality of materials
	Poor material handling	Equipment failure
	Damage during transport	Delay during delivery
WORKER	Workers mistakes	Lack of experience
	Incompetent worker	Shortage of skilled workers
	Poor attitudes of workers	Inappropriate use of materials
	Damage caused by workers	Poor workmanship
	Insufficient training for workers	Abnormal wear of equipment
MANAGEMENT	Poor planning	Late information flow among parties
	Poor site management	Scarcity of equipment
	Poor controlling	Resources problem
	Inappropriate construction methods	Communication problems
	Lack of coordination among parties	Waiting periods
	Rework	Lack of waste management plans
SITE CONDITIONS	Leftover materials on site	Congestion of the site
	Poor site condition	Lighting problem
	Waste resulting from packaging	Crews interference
PROCUREMENT	Ordering errors	Ignorance of specifications
	Error in shipping	Waiting for replacement
	Mistakes in quantity surveys	

EXTERNAL	Effect of weather	Vandalism
	Accidents	Damages caused by third parties
	Pilferage	Unpredictable local conditions

A questionnaire was conducted to find several factors which have an influence on construction waste generation.

2.3 Questionnaire Design and Analysis

This structured questionnaire was conducted with respondents from the construction site. Questions were asked to the project managers (PM), section in-charge (SI), senior engineers (SE), quality engineers (QE), and the material managers (MM) of the site i.e., the area under study. The respondents were requested to evaluate the potential causes of construction waste by assigning a score to each factor wherever observed. The questionnaire is measured on a 5-point Likert scale where 1 represents "Ineffective", 2 is "Somewhat Effective", 3 is "Moderately Effective", 4 is "Effective" and 5 is "Very Effective". Statistical analysis is carried for deciding the major factors responsible for generating construction waste. For the purpose of identifying the priority and the importance of the factors contributing to waste generation, Relative Importance Index (RII) formula is used. The value of RII mainly lies between (0 to 1). Equation (1) describes the method to calculate the RII for each factor separately, whereas table.4 show the analysis results which is calculated from a questionnaire shown in table.3.

$$RII = \frac{\sum W}{AXN} \tag{1}$$

Where:

W = attached score of each factor and ranges between (1 to 5), (where "1" is "ineffective" and "5" is "very effective")

A = highest score (i.e., 5 in this study)

N = sample size of the questionnaire (i.e., 10 in this study).

The RII values are transformed into five importance levels as shown in table 2.

Table -2: The Relationship between the RII Values and Importance Levels.

RII Values	Importance Level
1.0 ≥ RII ≥ 0.8	High (H)
0.8 ≥ RII ≥ 0.6	High-Medium (H-M)
0.6 ≥ RII ≥ 0.4	Medium (M)
0.4 ≥ RII ≥ 0.2	Medium-Low (L)
0.2 ≥ RII ≥ 0.0	Low (L)

Table -3: Questionnaire of the Causes of Construction Waste

CAUSES	PM1	PM2	SI	E1	E2	E3	QE1	QE2	MM1	MM2	Σ
Frequent design changes	5	5	4.5	5	4.5	5	4.5	5	4	4	46.5
Design errors	5	4	4	4.5	5	4	4	4	4	4	42.5

Lack of design information	4	4	4	4	3.5	4	4.5	4	4	4	40
Poor design quality	3	3	3	3	3	3.5	3	3	3	3	30.5
Slow drawing distribution	2	2.5	2.5	3	2	2	3	3	2.5	2.5	25
Complicated design	2	1.5	2	2	2.5	2	2	2	2	2	20
Inexperience designer	2	2.5	2	2	3	2	2	2.5	2	2	22
Wrong material storage	5	4.5	4.5	4	4.5	4.5	4	4.5	4.5	4.5	44.5
Poor material handling	5	4.5	5	4.5	4	4	4	4.5	4.5	4	44
Damage during transportation	4.5	4	4.5	4	4	3	4	4	5	5	42
Poor quality of materials	3	3	3	3.5	3	3.5	3.5	3	3.5	3	32
Equipment failure	3	3.5	3	3.5	3.5	3	2.5	3	2.5	2.5	30
Delay during delivery	4	3.5	3	3.5	4	3	3.5	3.5	3.5	3.5	35
Workers' mistakes	4.5	4.5	4.5	4	4	4.5	4	4.5	4	4	42.5
Incompetent worker	4.5	4.5	4	4	4.5	3.5	4.5	4	3.5	4	41
Poor attitudes of workers	4	4	3.5	4	4	4	3.5	4	4	4	39
Damage caused by workers	4.5	4	4	4	4	4	4.5	4	4	4	41
Insufficient training for workers	2	2	2	2.5	2	2.5	2	2	1.5	2	20.5
Lack of experience	4	3.5	3	3	3.5	3.5	3	3.5	3	3	33
Shortage of skilled workers	3	3	3	2.5	2.5	3.5	3	3.5	3	3	30
Inappropriate use of materials	3.5	3.5	3	3	3.5	2.5	3	3	3	3	31
Poor workmanship	3	3.5	3.5	3	3	3.5	3	3.5	3	3	32
Abnormal wear of equipment	2.5	2	2	2.5	2.5	2	2.5	2	2	2	22
Poor planning	4	4	3.5	4.5	4.5	4	4	4.5	3.5	4	40
Poor site management	4.5	4.5	4	4	4.5	4.5	4	4	4	4	42
Poor controlling	4.5	4	4	4	3.5	4	4.5	4	4	3.5	40
Inappropriate construction methods	4	3.5	3	3.5	3	3.5	4	3	3.5	3	34
Lack of coordination among parties	4	4.5	4	4.5	4	4	4	4.5	4	4	40
Rework	4.5	4	4.5	4	3.5	4	4.5	4	4	4	41
Late information flow among parties	3.5	3.5	3	3.5	3	3.5	3.5	3.5	3	3	33
Scarcity of equipment	3	3	3	3.5	3	3.5	3.5	3	3	3	32
Resources problem	3.5	3.5	3.5	3	3	3.5	3	3	3	3	32

Communication problems	3	3	3	3	3.5	2.5	3.5	2.5	3	3	30
Waiting periods	3	3	3.5	3	3	3	3.5	3	3	3	31
Lack of waste management plans	4.5	4.5	4	4.5	4.5	4	4.5	4.5	4	4	43
Leftover materials on site	4.5	4.5	4.5	4	4	4.5	4	4.5	4	4	42.5
Poor site condition	4	4.5	4	4.5	4	4	4.5	4	4.5	4	42
Waste resulting from packaging	3	3	2.5	3	3	3	2.5	3	3	3	29
Congestion of the site	3	3	3.5	3	3.5	3.5	3.5	3.5	3	3.5	33
Lighting problem	2.5	2.5	2	3	3	2	3	2.5	2.5	2.5	25
Crews interference	1.5	1.5	1.5	1	1.5	1	1.5	1.5	1	1	13
Ordering errors	4.5	4.5	4	4	4.5	4	4.5	4	4.5	4.5	43
Error in shipping	3.5	3	3.5	3	3	3.5	3.5	3	4	3.5	34
Mistakes in quantity surveys	3.5	3.5	3.5	3	3.5	3	3.5	3.5	3	3.5	34
Ignorance of specifications	3	3	3	2.5	3	3	3.5	3	3	3	30
Waiting for replacement	2	2.5	2.5	2	2	2.5	2	2.5	2.5	2.5	23
Effect of weather	4.5	4.5	4.5	4	4.5	4.5	4	4	4.5	4.5	43.5
Accidents	4	4	4	3.5	4	4.5	4	4	4	4	40
Pilferage	3.5	3.5	3	3	3.5	3	3.5	3	3.5	3.5	33
Vandalism	3	2.5	2	3	2.5	2.5	3	2	3	3	27
Damages caused by third parties	1.5	2	1.5	2	2.5	2	2.5	2	2	2	20
Unpredictable local conditions	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	15

Table -4: RII and Rank of Causes of Construction Waste

SOURCES	CAUSES	Σ	RII	Importance Level	Rank
DESIGN	Frequent design changes	46.5	0.93	H	1
	Design errors	42.5	0.85	H	2
	Lack of design information	40	0.8	H-M	3
	Poor design quality	30.5	0.6	M	4
	Slow drawing distribution	25	0.5	M	5
	Complicated design	20	0.4	M-L	6
	Inexperience designer	22	0.44	M	7
HANDLING	Wrong material storage	44.5	0.89	H	1

	Poor material handling	44	0.88	H	2
	Damage during transportation	42	0.84	H	3
	Poor quality of materials	32	0.64	H-M	5
	Equipment failure	30	0.6	M	6
	Delay during delivery	35	0.7	H-M	4
WORKER	Workers' mistakes	42.5	0.85	H	1
	Incompetent worker	41	0.82	H	2
	Poor attitudes of workers	39	0.78	H-M	4
	Damage caused by workers	41	0.82	H	3
	Insufficient training for workers	20.5	0.41	M	10
	Lack of experience	33	0.66	H-M	5
	Shortage of skilled workers	30	0.6	M	8
	Inappropriate use of materials	31	0.62	H-M	7
	Poor workmanship	32	0.64	H-M	6
	Abnormal wear of equipment	22	0.44	M	9
MANAGEMENT	Poor planning	40	0.8	H-M	5
	Poor site management	42	0.84	H	2
	Poor controlling	40	0.8	H-M	4
	Inappropriate construction methods	34	0.68	H-M	7
	Lack of coordination among parties	40	0.8	H-M	6
	Rework	43	0.86	H	3
	Late information flow among parties	33	0.66	H-M	8
	Scarcity of equipment	32	0.64	H-M	9
	Resources problem	32	0.64	H-M	10
	Communication problems	30	0.6	M	12
	Waiting periods	31	0.62	H-M	11
	Lack of waste management plans	43	0.86	H	1
SITE CONDITIONS	Leftover materials on site	42.5	0.85	H	1
	Poor site condition	42	0.84	H	2
	Waste resulting from packaging	29	0.58	M	4

	Congestion of the site	33	0.66	H-M	3
	Lighting problem	25	0.5	M	5
	Crews interference	13	0.26	M-L	6
PROCUREMENT	Ordering errors	43	0.86	H	1
	Error in shipping	34	0.68	H-M	2
	Mistakes in quantity surveys	34	0.68	H-M	3
	Ignorance of specifications	30	0.6	M	4
	Waiting for replacement	23	0.46	M	5
EXTERNAL	Effect of weather	43.5	0.87	H	1
	Accidents	40	0.8	H-M	2
	Pilferage	33	0.66	H-M	3
	Vandalism	27	0.54	M	4
	Damages caused by third parties	20	0.4	M-L	5
	Unpredictable local conditions	15	0.3	M-L	6

2.4 Significant Factors of Construction Waste Generation Based On RII

The results obtained from the analysis of the questionnaire for the sources of the waste generated at construction, the significant factors of construction waste having the highest RII value in their respective sources are frequent design changes, wrong material storage, workers mistakes, waste management plans, ordering errors, effect of weather, and leftover materials on site.

3. STUDY AREA

The area under study is a residential project of Goel Ganga Developers, Pvt. Ltd, Pune which is G+11 storied structure of plinth area of 375.57 sq.m. The approximate cost of the building is 5.5 crores and the cost calculated after carrying out the estimate of building is 5,41,41,426 crores Similar to this study multiple other sites are been undertaken to find the relation between them and to obtain standard deviation of percentage of deduction in cost of construction.

3.1 Questionnaire for Average Percentage of Material Wastage

The respondents were requested to assign percentages of waste generated of construction materials depending on their previous experience in implementing construction projects. The respondents had to assign the percentages considering all the stages of the material in construction i.e., from the design stage through purchasing, transportation, storage, and the execution. The kinds of major materials considered are cement, sand, aggregate, brick, steel, wood, tiles and earth.

Table -5: Questionnaire for Average Percentage of Material Wastage

Respondents	Cement	Sand	Aggregate	Brick	Steel	Wood	Tiles	Earth
PM1	5	15	7	7	5	12	9	20
PM2	4	13	6	7	4	14	8	19
SI	6	10	5	5	5	10	9	18
SE1	3.5	12	5	5	7	10	10	25
SE2	4	12	6	8	5	12	9	18

SE3	5	11	4	7	4	15	8	18
QE1	3.5	10	5	6	5	11	8	20
QE2	3	12	5	7	4	8	10	18
MM1	4	12	4	5	4	10	9	20
MM2	4	11	5	5	5	9	9	19
Average	**4.2**	**11.8**	**5.2**	**5.3**	**4.8**	**11.1**	**8.9**	**18.5**

3.2 Actual Quantity and Cost of Construction Materials

The following table summarizes the total approximate quantity of the eight major construction materials & their cost according to the rates as per DSR 2019-20.

Table -6: Actual Quantity and Cost of Construction Materials

Material	Quantity	Units	Rate (INR)	Cost (INR)
Cement	1948.623	MT	4969	96,84,011.04
Sand	1971.59	Cum	1575	30,20,219.8
Aggregates	2342.58	Cum	1050	24,59,709
Brick/Blocks	684.53	Cum	65723	44,99,279
Steel	151.497	MT	43288	65,57,933
Tiles	393.275	Sqm	9099	35,78,521
Wood	502.92	Sqm	4295	2,160,212
Earth	490	Cum	244	1,19,560
			Total	**2,65,99,516**

By using componendo-dividendo formula we can find the cost contributed by major construction materials in the total cost of construction.

$$= \frac{[V1-V2]}{\left[\frac{[V1+V2]}{2}\right]} X100 \qquad (2)$$

$$= \frac{[54141246-26599516]}{\left[\frac{[54141246+26599516]}{2}\right]} X100$$

$$= \frac{[27541730]}{\left[\frac{[80740762]}{2}\right]} X100$$

$$= 0.682226X100$$

$$= 68.22\%$$

Therefore, the expenditure on the purchase of the Major construction materials accounts for 68.22% to the total cost of the building. The quantity of major construction material calculated is in their respective units and can be converted into one specific unit to define the percentage of contribution of these materials to the total quantity of material. So, for that, all the units are converted to one specific unit in terms of weight i.e., in tons.

Table -7: Quantity of Materials in Metric Tons

Material	Quantity	Units	Weight in Kg	Weight in Metric tons
Cement	1948.623	MT	1948622.8	1948.623
Sand	1971.59	Cum	3681791.8	3681.79
Aggregates	2342.58	Cum	3560721.6	3560.72
Brick/Blocks	684.53	Cum	444944.5	444.9
Steel	151.497	MT	151497	151.497
Tiles	393.275	Sqm	9045.3	9.045
Wood	502.92	Sqm	9429.75	9.42
Earth	490	Cum	686000	686
			Total	**10492**

3.3 Actual Quantity and Cost of Construction Materials

The cost of construction material waste can be calculated by multiplying the actual quantity of construction material with the percentage of wastage of the respective material

Actual Quality of Material X Wastage% = Quantity of Waste (3)

Table -8: Amount of Construction Waste Generated and its Cost

Material	Quantity	Units	Wastage %	Waste Generated	Rate (INR)	Cost of waste (INR)
Cement	1948.623	MT	4.2	81.84	4969	4,06,676.8
Sand	1971.59	Cum	11.8	232.64	1575	3,66,408
Aggregates	2342.58	Cum	5.2	121.82	1050	1,27,911
Brick/Blocks	684.53	Cum	5.3	36.28	6573	2,38,461
Steel	151.497	MT	4.8	7.27	43288	3,14,703.7
Tiles	393.275	Sqm	8.9	35.00148	9099	27,534.38
Wood	502.92	Sqm	11.1	55.82	4295	2,39,747
Earth	490	Cum	18.5	90.65	244	22,118.6
					Total	**17,43,560**

3.4 Quantity of Waste Material in Metric Tons

The amount of waste generated is in different units and needs to be converted into one unit so that it would be possible to distinguish the percentage of contribution of all the major waste materials from the total quantity of waste generated.

Table -9: Amount of Construction Waste Generated and its Cost

Material	Quantity	Units	Weight in Kg	Weight in Metric tons	Wastage %	Weight of Wastage in Metric tons
Cement	1948.623	MT	1948622.8	1948.623	4.2	81.84
Sand	1971.59	Cum	3681791.8	3681.79	11.8	434.45
Aggregates	2342.58	Cum	3560721.6	3560.72	5.2	185.157
Brick/Blocks	684.53	Cum	444944.5	444.9	5.3	23.57
Steel	151.497	MT	151497	151.497	4.8	7.27
Tiles	393.275	Sqm	9045.3	9.045	8.9	0.805
Wood	502.92	Sqm	9429.75	9.42	11.1	1.045
Earth	490	Cum	686000	686	18.5	126.91
			Total	**10492**		**861.047**

4. DISPOSAL OF WASTE GENERATED

The disposal cost primarily consists of two costs that are handling Cost and transportation cost. The necessary resource to be considered for disposal of waste are labors, tipper truck, equipment's for handling etc. So, assuming that the tipper truck used is a light tipper truck of capacity 10 tons, the labor required is 6 in numbers.

Handling Cost - It takes about 15 minutes to gather and fill the waste of 1 ton by 6 labors, therefore it would take 2.5 hours to fill the tipper of capacity 10 tons. However, these values may vary on the kind of waste material produced at the site. Contractors rarely consider the cost of handling in their total waste management cost.

Transportation Cost - The transportation cost includes ownership cost, loading capacity, speed of the vehicle, the distance of transport, number of trips per day of 8 hours working, labor cost of loading and unloading, consumption of fuel. The transportation cost is calculated by following DSR 2019-20 considering the working hours of 8 hours, disposal site is 2 km away from the construction site, the rate of tipper truck is taken as 2882 INR per day & 493 INR are to be paid to 6 labors, cost of fuel is 68 INR, cost of machine oil is 58 INR.

So, here it is important to calculate the factors involved in handling and transportation like no of trips, cost of handling which includes loading and unloading, and cost per trip which will contribute to finding the cost of waste disposal. These factors can be found by referring to the guidelines and formulas given in the DSR 2019-20. The number of trips which are possible by a tipper truck on 10 tons as per the ideal conditions and by following the formula for calculating trips by DSR is,

$$\text{No of Trips (N)} = \left[\frac{8}{\frac{2L}{S}+1}\right] \tag{4}$$

Where,

L = Lead in Km

S = Average Speed

N = No of Trips

$$\text{No of Trips (N)} = \left[\frac{8}{\frac{2X2}{17}+1}\right]$$

$$\text{No of Trips (N)} = 6.48$$

$$\text{No of Trips (N)} = 7$$

The other factor involved handling and transportation is the cost of loading or unloading which includes different cost like the cost for diesel, machine oil, truck charges per day, and labor charges.

Cost of loading and unloading = D+M+L+T (5)

Where,

D = Cost of diesel i.e., 68 INR

M = Cost of Machine oil for 2 km i.e., 58 INR

L = Cost to be paid for 6 labors i.e., 493 INR

T = Hire charges of a truck per day 2882 INR

Therefore,

Cost of loading and unloading = 68+58+(6X493)+2882

Cost of loading and unloading = 5966 INR

The cost of handling and transportation includes some additional charges which are about 10 percent.

Cost of handling and transportation = Cost of loading and unloading + overhead charges 10% (6)

Cost of handling and transportation = 5966 + 596.6

Cost of handling and transportation = 6562.6 INR

So, to calculate the cost of disposal it is important to calculate the cost for a single trip which can be calculated by dividing the cost of handling and transportation by no of trips possible.

$$\text{Cost per trip} = \frac{6562.6}{7}$$

Cost per trip = 938 INR

So, to find out the actual number of trips required to dispose of the construction material waste generated and the cost associated with can be calculated by dividing the waste generated by the waste which can be disposed of in one day i.e., 3 truckloads of 8 working hour a day. Therefore, 30 tons of material can be transported in day.

$$\text{Total number of trips required} = \frac{\text{Total waste generated}}{\text{Waste generated per day}} \quad (7)$$

$$\text{Total number of trips required} = \frac{861.047}{30}$$

Total number of trips required = 29

Now we can calculate the total cost associated with the transportation of waste i.e., the cost of disposal in 29 trips by multiplying it with cost per trip.

Cost of disposal = 29 X 938

Cost of disposal = 27,202 INR

Therefore, the total cost of wastage is the summation of cost of waste and the disposal cost.

Total cost of waste = Cost of waste + Disposal cost (8)

Total cost of waste = 17,43,560 + 27,202

Total cost of waste = 17,70,762 INR

5. POTENTIAL OF CONSTRUCTION WASTE TO BE REUSED AND RECYCLED

Reusing and recycling waste can reduce the volume of waste material to be disposed of to the landfills or discharged into the environment. Direct reuse of construction waste materials in its original form or slightly altered form which involves the processing of the waste material into new material. Reusing and recycling construction waste material is the best option to be chosen to reduce waste and cost of construction. The reuse and recycling potential of various construction materials will vary, so it is important to focus on the main construction materials which generate a high volume of wastage. The following is the suggested list of the main materials and its potential to reuse and recycle:

- Earth – high potential for reuse either on or off-site as the infrastructure for reuse already exists to grade excavated soil. Earth has a low potential of recycling on-site as it involves the processing of the material.
- Concrete – high potential for recycling, as the recycled product obtained has a variety of uses in unbound aggregate applications as well as concrete aggregate. Concrete has a low potential for reuse on-site due to potential problems of deterioration and component sizes for new build situations.
- Brick/Blocks – high potential for reuse as bricks in cement mortar can be cleaned by carrying out some on-site processes and can be reused and has vast applications, also bricks have a high potential for recycling as crushed aggregate from brick and block in unbound applications.
- Wood – the low potential for recycling generally for the manufacture of chipboard or MDF type products; high potential to reuse as wood can be used for a different purpose and also as a source of energy. Wood materials which are contaminated by lead-based coatings and treatments are major risks.
- Steel – high potential for recycling as the material has 100% recyclability in manufacturing of steel and aluminum. Steel has a low potential for reuse as the material obtained from structural members are generally deteriorated or corroded.
- Tiles – Low potential of reuse as the waste material cannot be reused without any processing and has very fewer applications of reuse. Tiles have a high potential of recycling as the products generated from waste tiles can be used for different purposes and are in different forms.

6. LAWS IN INDIA ON REUSE AND RECYCLING OF CONSTRUCTION WASTE

The Government of India has notified “Construction and Demolition Waste Management Rules, 2016”. It is an initiative to tackle the issues of waste management and pollution created by C&D waste. The rules specify duties to be followed by waste generators which are as follows,

- Every waste generator has to segregate waste produced from construction and demolition and deposit it at the collection center or has to handover it to the authorized processing facilities.
- The waste generator needs to ensure that there isn’t any littering from the waste or any deposition while transportation so as to prevent obstruction to the public or the traffic.
- Large generators (i.e., companies generating 20 tons or more in one day or companies generating 300 tons per project in a month) have to submit their waste management plan for the project and will have get approvals from the local authority prior to starting construction work or demolition work or remodeling work.
- Large generators need to have an EMP i.e., Environment Management Plan so that they can address the environmental issues from construction work, demolition work, storage, transportation process and disposal/reuse of Construction & Demolition Waste.
- Large generators need to segregate the waste before its disposal into major streams such as soil, concrete, steel, wood and plastics, bricks and mortar.
- Large generators are obligated to pay relevant charges for transportation, collection, processing and disposal as informed by the concerned local authorities.

Similar to this, the Government has also notified duties for the service providers and contractors, duties of government and local authorities, duties of CPCB (Central Pollution Control Board) and SPCB (State Pollution Control Board), duties for central ministries, standards for products of construction and demolition waste, duties of a recycling facility, and applicability of the rule.

7. FEASIBILITY ANALYSIS OF RECYCLING OF CONSTRUCTION WASTE

Feasibility analysis has to be carried out considering the amount of wastage to be sent to the recycling plant to produce recycled material from waste generated from construction sites like concrete, wood, steel, tiles, earth & bricks.

For recycling to be feasible the location of the recycling plant should be so chosen that there is,

a. Availability of feedstock.

b. The market for the recycled product.

c. It is difficult to dispose of the waste by other means.

d. The distance of the recycling plant.

Also, the feasibility of recycling depends on some other factors like,

a. Cost of transportation of the waste material from the construction site to recycling plant.

b. The labor charges involved for loading and unloading the waste.

c. The cost of recycling i.e., the cost required for the process of recycling the waste product.

Considering the fact that the recycling plant is located in Chickhali, Pimpri-Chinchwad area which is approximately at a distance of 30 km from the construction site. So, it would not be feasible to use the recycled product which is generated from the construction waste from the site itself. As all the factors mentioned above are not applicable in this case and will include certain charges, so it would be infeasible to carry out recycling of the waste. Also, a major inhibitor in construction waste recycling is the tax levied on recycled waste material, which could be higher than the old material in some products. To overcome this drawback of recycling and to reduce the transportation impacts of a project, use of on-situ crushers can be made. The three possible options that can be explored in Construction and Demolition waste recycling are,

a. Mobile C&D waste recycling crusher.

b. Semi-Mobile C&D waste recycling crusher.

c. Stationary plant C&D waste recycling crusher.

Mobile recycling units can be more economical and cost savings considering the size of this project and the semi-mobile and stationary plant crusher can be used for bigger scale projects.

Mobile crushers- Mainly it consists of crushing and screening equipment. Mobile crushers are ideal for on-site treatment of C&D waste. They can be easily transported by using hook lift lorry and are ready to operate in a short time. Before using mobile crusher, it is important to remove certain materials such as wood or metal manually before feeding the waste into the crusher. Materials that can be fed into a screening section designed as per crusher feed size are concrete, stones, kerb-stones, marble, paving slabs, tiles, blocks, brick and mortar and mixed construction and demolition waste. The materials which are bigger should be resized by rock breakers or by hammering before feeding. Based on what kind of waste is feed into the crusher, either recycled concrete aggregate or recycled (mixed) aggregate would be obtained.

8. REUSE AND RECYCLING OF CONSTRUCTION WASTE

The construction and demolition waste management rule, 2016 proposes to practice minimum disposal of construction waste to the landfill. There is no specific figure to be followed for the dumping waste to the landfills. To achieve economical construction, a practice of no more than 20% of construction waste to be disposed to the landfills could be followed, so about 80% of waste can be recycled and reused. As per the Construction and Demolition Waste Management Rules 2016 rule (9) sub-rule (4) which highlights “procurement and utilization of construction and demolition waste recycled products up to 10-20%”. Therefore, 60% of the construction waste can be reused and 20% of the waste can be recycled in-situ. This practice will encourage recycling and reuse rather than disposal.

8.1 The Cost Saved by Reuse of Construction Waste

The cost of construction can be reduced by reusing the construction waste that is available on-site. The percentage of reuse is decided by the potential of the construction waste material and its volume of waste generated. The quantity of the waste to be reused will be multiplied by the rate of product and by considering the type in which it could be used so the rates may vary as per the situations. The following table summarizes the cost which can be saved be reusing waste:

Table -10: Cost Saved by Reuse of Construction Waste Material

Material	Weight of Wastage in Metric Tons	Quantity	Unit	Reuse %	Quantity to Reuse	Rate (INR)	Cost Saved by Reuse (INR)
Concrete	701.44	292.26	Cum	40	116.9	400	46,761.6
Bricks	23.57	36.26	Cum	60	21.75	6,573	1,42,958.4
Steel	7.27	7.27	MT	20	1.45	43,288	62,767.6
Tiles	0.805	35	Sqm	40	14	9,099	1,27,389.92
Wood	1.045	55.73	Sqm	60	33.43	4,295	1,43,581.85
Earth	126.91	90.65	Cum	70	88.837	244	21,676.22
						Total	**5,45,135.59**

8.2 The Cost Saved by Recycling of Construction Waste

In addition to reusing construction waste, the construction waste materials can be recycled too. Here in this case mobile crusher are used to recycle the waste material, wood and earth cannot be feed into the crusher and they are needed to be removed manually from the mixed waste also the oversized waste material needs to be broken down to the desired side before feeding. Therefore, only concrete, bricks, and tiles can be feed to the crusher. For recycling waste steel, the material can be sold at the scrap value. Steel is a material which has high recycling potential therefore all the steel waste can be sold at the scrap value. The table below summarizes the cost saved by recycling construction material:

Table -11: Cost Saved by Recycling of Construction Waste Material

Material	Weight of Wastage in Metric Tons	Quantity	Unit	Recycle %	Quantity to Recycle	Rate (INR)	Cost Saved by Recycle (INR)
Concrete	701.44	292.26	Cum	25	73.065	1,050	76,718
Bricks	23.57	36.26	Cum	20	7.252	1,050	7,615
Tiles	0.805	35	Sqm	20	7	1,050	7,350
Steel	7.27	7.27	MT	80	5.816	18	1,30,860
						Total	**2,22,543**

The process of recycling construction waste material by mobile crusher includes mobile crusher hiring charges, fuel charges and labor charges. Therefore, the cost that is saved by recycling the waste material would be after minimizing these additional costs. The cost of hiring a mobile crusher will be depending on the size of the crusher. In this case the amount of waste generated is 861.047 tons so therefore using a mobile crusher of capacity 10-15 tph (tons per hour) is sufficient, which can take feed of maximum input size of 150-180 mm and obtaining the recycled product of size 0-20 mm, 20-50 mm. The hiring charges for mobile crusher of capacity 10-15 tph is 700 Rs/hour. Also, two labors and one operator are sufficient to carry out the crushing work.

8.3 Quantity of Waste to Feed into The Mobile Crusher

Table -12: Quantity of Waste to Feed into Mobile Crusher

Material	Quantity	Units	Tons
Concrete	73.065	Cum	175.36
Bricks	7.252	Cum	4.714
Tiles	7	Cum	0.616
		Total	**180.235**

$$\text{Time required for crushing} = \frac{\text{Amount of waste}}{\text{Capacity of crusher}} \quad (9)$$

$$\text{Time required for crushing} = \frac{180.235}{10}$$

Time required for crushing = 18 Hours

Cost of crushing per hour = Hiring charges + Fuel charges + 3 Labor charges (10)

Cost of crushing per hour = 700 + 68 + 180

Cost of crushing per hour = 948 INR

Cost of crushing = 948 X 18

Cost of crushing = 17,064 INR

Actual cost saved by recycling = Cost saved by recycling - cost of crushing (12)

Actual cost saved by recycling = 2,22,543 - 17,064

Actual cost saved by recycling = 2,05,479 INR

8.4 Cost Saved Reuse and Recycling of Construction Waste

Cost saved by reuse of construction waste = 5,45,135.59 INR

Cost saved by recycling of construction waste = 2,05,479 INR

Total cost saved = Cost saved by reuse + Cost saved by recycling (13)

Total cost saved = 5,45,135.59 + 2,05,479

Total cost saved = 7,50,641.59 INR

8.5 Percentage of Deduction in Cost of Construction Waste

Cost of construction waste = 17,70,762 INR

Deduction in cost of construction waste = Cost of construction waste - Total cost saved (14)

Deduction in cost of construction waste = 17,70,762 - 7,50,641.59

Deduction in cost of construction waste = 10,20,147.41 INR

$$\text{Percentage of deduction in cost of construction waste} = \frac{10,20,147.41}{17,70,762} \text{X } 100$$

Percentage of deduction in cost of construction waste = 57.61%

9. CONCLUSIONS

The construction industry is a significant factor in the world economy. It is observed that when the construction industry increases, the waste generated from these activities also increases with the same increasing intensity. As established at the beginning of this study, the objectives of this study are to identify the most frequent waste sources and causes generating the most amount of waste in this residential project. The study helps to identify sources and causes generating construction waste by referring to different case studies, papers and carrying out questionnaire and RII to find out the most significant cause from the different sources of waste generation. The most significant factors causing construction waste are frequent design changes, wrong material storage, Workers' mistakes, waste management plans, Procurement, the effect of weather, Site conditions other than these major factors, vandalism, pilferage, rework, Communication problem, resource problem, waiting periods, etc. such other minor factors contribute in generation of construction waste.
The results and findings contributed to improved estimation of the actual cost of building which was approximately 5.41 crores. For the estimation the quantity and the cost of major construction material are calculated which accounts for about 68.22% of the total cost of construction. The major construction material considered in this study is earth, cement, sand, aggregates, steel, bricks, and tiles. By conducting a questionnaire, the allowable and actual percentage of the construction waste materials were found and from these percentages, the quantity and cost of construction are calculated. The

quantities are converted into tons, the waste generated in this project is 861.047 tons considering on the major construction material and cost of these waste materials is 17,70,762 INR. After studying different research works and technologies on construction waste utilization it is concluded that construction waste recycling and reusing has great business potential. In this study, the major construction waste materials were reused and recycled depending on their potential to reuse and recycle. The laws notified by the government of India are considered in the study. Construction and Demolition Waste Management Rule,2016 highlights procurement and utilization of construction waste materials up to 10-20 %. The percentage to reuse the construction waste is decided following the rules and from the potential of the particular material and the cost is calculated considering the resources required for reuse and rate of the material reused. To carryout recycling the on-site recycling technology is used i.e. mobile crusher to reduce the transportation impacts on the project. Mobile crusher is a viable solution for economical and cost saving construction. In this study the cost saved by reuse and recycling is 7,50,641.59 INR. The obtained percentage of deduction in cost of construction waste is 57.61 %.

10. RECOMMENDATIONS FOR FUTURE STUDIES

The following recommendations for future studies are relevant and related with this research:

1) Conduct a similar study with wider sample sizes and compare the results and findings with the results of this research.
2) Apply the concepts and the recommendations established in this study to other residential projects to verify the impact of them in the reduction of construction waste and the cost of construction waste.
3) Conduct a similar study with other segments of construction industry that is in commercial projects, industrial projects, and institutional projects to figure out which waste sources are most affecting the cost in respective projects, the types of waste occurring in these sources and its causes, then recommend actions to reduce waste and cost.

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