Impact of sources on waste production in activities across supply chain: A new approach

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Abstract: Productivity of construction industry is low especially in waste production. To demonstrate how it can be better than this situation, its waste sources should be identified. Whereas sources of waste are different for any material, construction activities across supply chain that use so many kinds of materials have some different sources of waste. In order to respond to the question, "which kind of sources effect on waste production in activities?" 30 questionnaires were distributed between experts. By following question about impact of five top sources on waste in activities, using binominal test, it is observed that sources of waste for any activity are the same as waste sources of materials used in that. Indeed, a category of sources which influence on waste production of some materials are effective on waste in activities that use them.
[Mohamad Reza Parsanejad, Mansor Momeni, Ali Mohaghar. Impact of sources on waste production in activities across supply chain:A new approach. Nature and Science 2011; 9(1):20-28]. (ISSN: 1545-0740).

Keywords: Waste, source of waste, waste in activities, supply chain, dimensional and weight based materials.

1) Introduction

Based on statistics and municipal reports, about 20 million tones of construction waste are produced in Tehran every year. This rate of production along with population increment has created lots of problems in capital and also in other big cities (Report of material section of construction and housing research center, 2008; Report of Tehran municipal recycle organization, 2008; Omrani et al., 2008; Report of environmental committee of consoling Tehran city, 2008).

Amount of waste in construction industry are high in another countries too. We can see these high amounts in some researches (Ekanayake and Ofori, 2004; McDonald and Smithers ,1998; Chun-Li et al., 1997; Kang ,2000; Katz and Baum ,2010; Formoso et al.,1993; Bossink and Brouwers, 1996).

Because of this negative productivity researchers develop some solutions for management and prevention of construction wastes. Among various methodologies of waste management, a categorization is more popular. It classifies waste management solutions to four categories: minimization, reuse, recycle and disposal (Gavilan and Bernaold, 1994; Begum et al., 2007; Silva and Vithana, 2008) Almost all researchers emphasize that minimization and elimination of waste is the best solution between these solutions (Gavilan and Bernold, 1994; Skoyles and Skoyles, 1987; Begum et al., 2006).

Waste minimization cannot be done unless identifying sources of waste and reducing them at its source. There are many researches about this area but in the work of parsanejad et al., (2010) it seems that materials were categorized based on their sources of waste. So impacts of sources on production of waste were illustrated. For more understanding this impact we should illustrate impact of sources on production of waste in activities. In this article we try to know are any relation between impact of sources in material waste production and impact of sources in material waste in activities? Indeed we try to demonstrate that sources of waste in any activity are those sources that are effective in waste production of materials used in that activity. If this happen the categorization of material in two type based on their sources of waste (weight based materials and dimensional materials), will consolidated.

2) Literature review

2-1) Material waste

Construction material wastes refer to materials from construction sites that are unusable for the purpose of construction and have to be discarded for whatever reason (Yahya and Boussabaine, 2006). Material waste can be seen from three views:

1. Construction waste of a specific material as percentage of total construction waste,
2. Construction waste of a specific material as percentage of its total amount,
3. Cost of construction waste of a specific material as percentage of total waste costs (Bossink and Brouwers, 1996).

There are many studies about kinds of material wastes that have so many overlaps. In these studies composition of waste in case studies has calculated (Begum et al., 2006; Yahya and Boussabaine, 2006; Guzman et al., 2009).

2-2) Waste sources

To investigating impact of sources on material waste in activities we should know what are sources of waste. There are many researches about sources of waste.

At first Gavilan and Bernold (1994) grouped the causes of direct and indirect wastes into six categories, including design, procurement, material handling, operation, residual and others such as theft (Silva and Vithana, 2008) .

Then Bossink and Brouwers (1996) worked more detail about elements of this categorization (Ekanayake and Ofori, 2004). in a recent study parsanejad et al., (2010) gathered 32 sources of waste and prioritized them. Some other studies have found sources of waste for any material in case studies (Formoso et al., 2002; Wang et al., 2008; Serpell and Alarcon, 1998).

2-3) Waste in activities

Since the flow of construction waste must be evaluated according to the type of waste and construction activity, the ideal method would be to isolate the different construction activities and monitor the waste generated in the course of each activity. This would probably yield the most accurate information on the waste associated with each activity. This concept is seen in part in the work of Snook et al. (1995).

Thus the purpose of site observation is twofold:

(1) Evaluation of the composition of the waste,

(2) Estimation of construction stage at the time of observation.

Construction works were divided into three categories according to the waste generated in each one: structural frame, early finishing and late finishing (Fig.1).In general, the structural frame works produce the least waste for all types of construction materials whether it is made of steel, concrete or wood. Construction materials are supplied to the construction site in accurate amounts with little wastage, small amounts of packing materials are used, and most of the waste is recyclable. The early finishing works (e.g. partition walls, plastering, drywalls, floor tiles, and piping) produce larger quantities of mixed waste that requires more extensive separation treatment before recycling. Waste from the late finishing works are the most difficult to treat and are produced in the largest quantities. Waste from this stage is expected to consist of a mixture of all materials found on the construction site, including significant amounts of packing materials. Foundation and underground activities vary from site to site and were not included.

When monitoring the waste accumulated on a construction site, it is reasonable to assume that waste accumulated during the early stages of the work is related to the structural frame, whereas waste accumulated during the final stages of construction is related to the late finishing works only (Fig. 1). On large construction sites, the time overlap between the stages and activities is greater and ‘‘pure” structural frame works or late finishing works can be found only at the very beginning or very end of the project. In such sites, waste produced during the majority of the project duration is a mixture of waste from all three stages (Katz and Baum, 2010).

A case study about waste minimization in British building sector shows also different wastes in different stages of construction. Observations indicate many waste overlaps and amount of waste in any stage of project life cycle. This study also illustrates many wastes happen in structure stage and fitting that can be seen in the Fig 2 (Jones and Greenwood, 2003).

The waste from construction site activities will vary from one site to another depending on the type of project and its design. It is proven that, project and material specifications contribute to a large extent to waste generation. For example, building construction involves several activities that can be broadly grouped as land clearing, road and sewers, substructure work (excavation and foundation work), superstructure (framing), internal carcassing and service installation (wiring, plumbing, insulation, drywall), finishing work (paint, exterior finishing and roofing), energizing phase prior to handling, landscaping and completion of external works. Each of these activities has a high potential to generate waste from materials such as soil, contaminated soil, wood, metal, concrete, plastics, waste solvents, gypsum, wallboard, cardboard, boxes, paint solvents, bricks, masonry, vinyl, stucco, asphalt shingles and tiles, as shown in Fig 3.

In this study, wastes have been gathered in any activity as below:

Site preparation: soil, wood, vegetation; Excavation: soil, contaminated soil; Foundation work: wood, metal, concrete; Farming: wood; Metal work and wiring: metal; Plumping: metal, plastic, waste solvents; Insulation: metal, plastic, rubber; Drywall: gypsum wallboard, cardboard, boxes; Painting: paint, solvents; Exterior finishing: wood, brick, masonry, vinyl, mortar; Roofing finishing: asphalt, cedar shakes, tiles (Yahya and Boussabaine, 2006).

A debatable point in diversity of material waste is that composition of waste is related to the construction technologies. For example in prefabricated concrete elements, the amount of cement waste is very low (Jaillon et al., 2009).

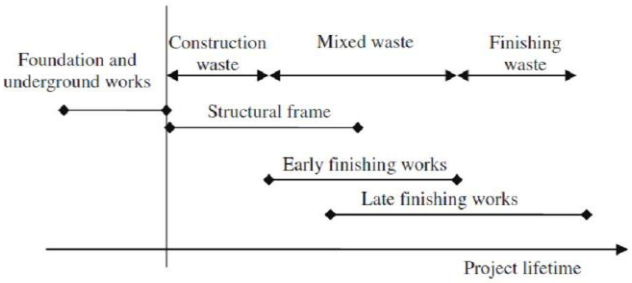

Fig 1: Type of construction works and waste generated during them

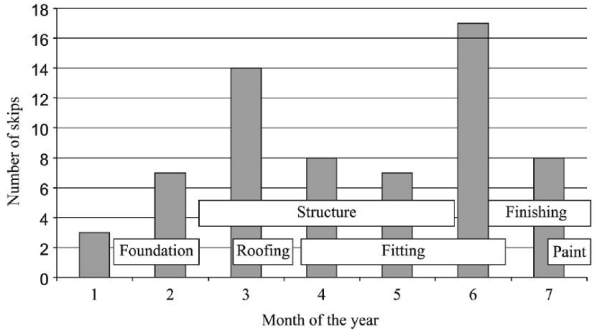

Fig 2: Number of skips in project life cycle

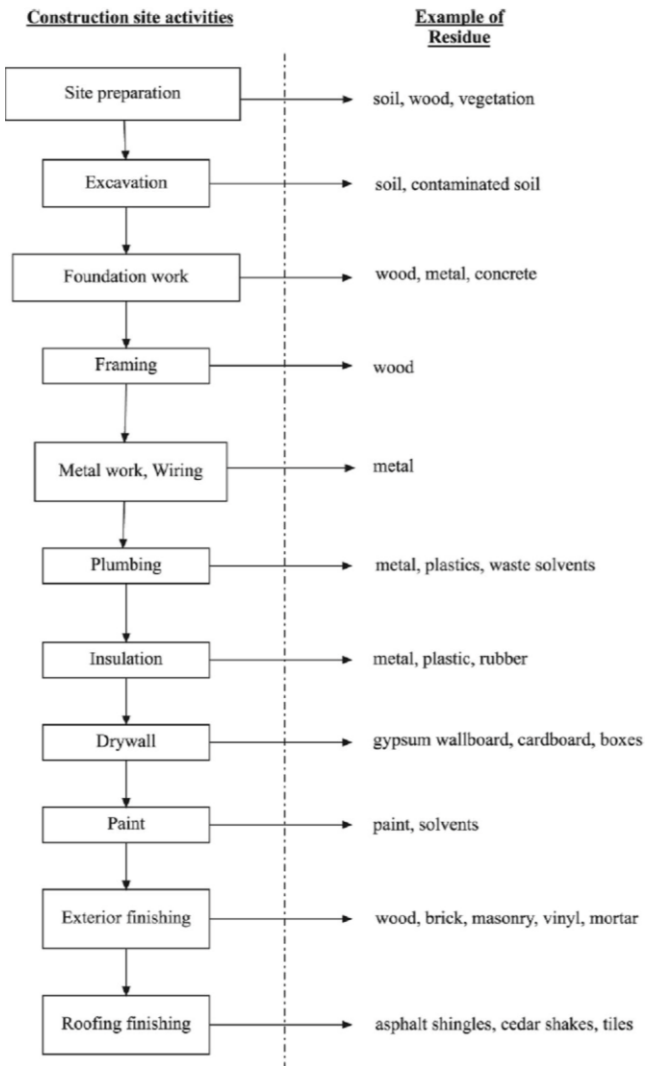

Fig 3: Construction works and material waste generated in that

The impact of new technologies on waste has been investigated in a study in 2007. In this study the amount of waste in buildings with prefabricated and traditional technologies calculated for seven activities. Although wastage levels may vary from different types or natures of project, the wastage levels are believed to be affected by the adoption of conventional in situ and prefabrication construction methods.

A structured survey was conducted to measure the wastage level for the different construction methods. The average wastage level (in per cent) for various construction trades, namely, concreting, rebar fixing, bricklaying, drywall, plastering, screeding and tiling, are measured for the two groups of projects adopting conventional in situ trades and prefabrication denoted as 'A' and 'B'. After measuring the values of (A) and (B), the percentage in waste reduction, (C), is calculated by obtaining the difference between the average wastage level in conventional and prefabrication construction methods (A) and (B) by the ratio of the waste reduction over the average wastage level for the conventional construction method. According to the findings on the average wastage levels for the major construction activities carried out on site, it is noted that the most effective waste reduction trade is plastering, which can have 100% of wastage reduction after adopting prefabrication. It can be explained that plastering can be avoided since the concrete surface of the precast items is smooth and even enough for receiving tile or subsequent finishes. The contractors argued that tiling was directly applied to the concrete surface after formwork striking, while for painting, only a layer of 1–2mm thick skim coat is required instead of 15–20mm plastering. The average wastage level of the conventional construction method is much higher than that of prefabrication in the trades of concreting, rebar fixing, plastering and tiling. This result shows that the wastage levels vary with different trades when prefabricated building components are adopted; therefore, the standardized designs of building can reduce the wastage levels effectively (Tam et al., 2007).

Another classification about wastes in activities is structure waste and finishing waste. Concrete fragments, steel reinforcement, abandoned timber plates and pieces are generated as structure waste during the course of construction. Finishing waste, including a wide range of waste materials, is generated in the finishing stage of the building.

For instances, surplus cement mortar arising from screeding scatters over the floors inside the building. Broken raw materials like mosaic, tiles, ceramics, paints and plastering materials are wasted because of careless use.

Household facilities such as damaged bathtubs, washtubs and window frames are also parts of the finishing wastes (Poon et al., 2001).

3) Methodology

Problem of this research is that are any relation between impact of sources in material waste production, and impact of sources in material waste in activities? So for understanding the problem, we should try to demonstrate that sources of waste in any activity that we use some material across it, are those sources that are effective in waste production of materials used in that activity.

Thus we should calculate impact of sources on waste production in activities. Sources of waste that we use are five sources in the study of parsanejad et al., (2010). These sources are the most important sources between 32 sources which prioritize by questionnaire in that study. The results of that research show that the five sources have the highest rank as below:

1) Traditional construction methods,
2) Lack of design commensurate with materials exist in market,
3) Lack of coordination between supply chain,
4) Lack of proportionate material ordering of purchasing section,
5) Lack of production of materials with variant dimensions.

In another hand there are some categorizations of construction activities. But because of acquaintance of Iranian specialists with categorization of Report of adjutancy of planning and inspectorate of president (2008) we use its work breakdown structure (WBS) for this research. Based on this report building activities were categorized in 4 categories and 17 subcategories as below:

- Foundation: leveling concrete, reinforcing, farming, pouring concrete.
- Structure: structure installation
- Hard working: external wall, internal walls.
- Finishings: mechanical installations, electrical installations, door and window framework, indoor work, insulations, tiling, Staircase, installations, Frontage works, Paining.

Then impact of selected sources on waste in these activities can be surveyed. This impact can be calculated by many methods. In this research binominal test are used. Questionnaire also had five options and the question was amount of impact of source on material waste in activities. Options "very low" and "low" impact had been located in a group, and "mediocre", "high" and "very high" impact in another group. Hypothesis had been designed as below:

$$\begin{cases} H0: p \le 0.60 \\ H1: p > 0.60 \end{cases}$$

H0 shows high level of impact and H1 shows that there is no meaningful impact. The calculations had been done by SPSS 15, and with amount of significant validity of questionnaire had been tested.

All questionnaires had sent to 30 specialists and with analysis of impact of source on material waste in activities, effective waste sources for any activities were obtained. Table 1 showes significants and acceptance of assumptions.

4) Results and discussion

Here impact of five below sources on material waste and material waste in activities were analyzed.

Source number1 (S1): lack of design commensurate with materials exist in market,
Source number2 (S2): traditional construction methods
Source number3 (S3): lack of coordination between supply chain
Source number4 (S4): lack of proportionate material ordering of purchasing section
Source number5 (S5): lack of production of material with variant dimensions.

With precision in results from questionnaire about impact of five waste sources in waste produced in activities, some new results were obtained that support analyses of waste in materials.

- First result: it was observed in those activities that materials using along them are type1, effective sources are those sources that are effective in waste production of material type1, and it happen for material type2 too.
- Second result: in those activities that materials using along them are variant and composition of both type1 and 2, all significants are higher than 0.05 except S1 and S3.

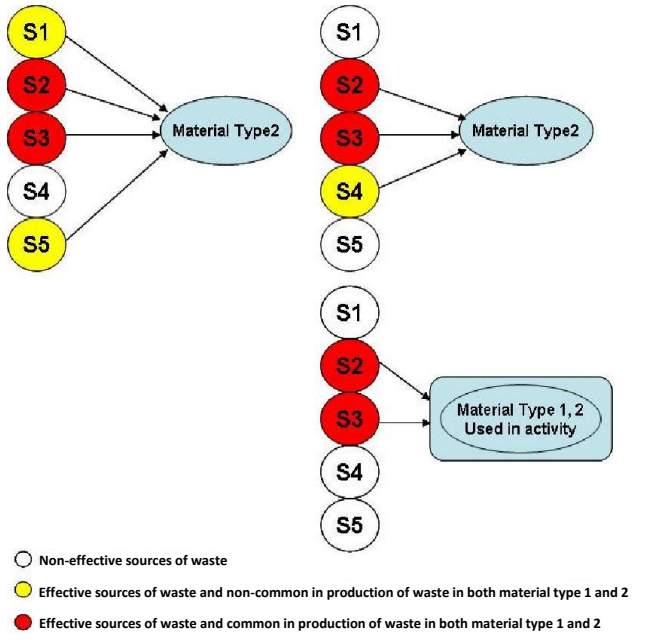

Fig 4: Effectiveness and non-effectiveness of sources on materials waste production in activities.

- Third result: in mechanical installation activity that materials are pipes, waste sources are those that are effective in waste of pipe.
- Forth result: in some activities all five sources are ineffective.
- Fifth result: in framing activity just S2 was effective.

4-1) Result 1:

These results support categorization of material in two types. It shows that sources of waste will related to the type of material. In this section activities like: leveling concrete, pouring concrete, isolation, and painting are among category 1 and reinforcing and door and window framework installations are in second category.

4-2) Result 2:

This section includes activities such as structure installation, external walls, internal walls, indoor work, tiling, Staircase and Frontage works. An introduction is necessary here. Because of these seven activities use both materials type 1 and 2, respondents have not achieved to a consensus unless in S2 and S3. The reason is that these two reasons are common in effective sources of both material type 1and 2.Thus activities in those both two type materials were used S1 and S2 ,are effective and other sources cannot take consensus of respondent because they are not between this sharing. This concept can be seen in Fig 4.

Now with above introduction it can be analyzed result of these seven activities that both two types of materials are used in them.

Structure installation can be from steel or concrete. Concrete structures itself are a composition of materials like reinforcement, cement, sand and water that are both type 1 and 2. Thus respondents that were steel structure in their minds selected some sources and others that concrete structure were in their minds select some others. And thus there is no consensus about sources except in S2 and S3.

In external walls there are so many materials type 1 and 2 such as brick, adobe and block, with composition of cement, sand and water.

Table 1: Questionnaires results about Impact of selected sources on waste production in activities
When Sig >0.05

sources	leveling concrete		Reinforcing		Framing for concreting		pouring concrete		Structure installation		External walls		Internal walls		Mechanical installations		Electrical installations		Door and window framework installations		Indoor works		Insulations		Tiling		Staircase		Installations		Frontage works		Paining	
S1	.002		.000	√	.006		.000		.097		.285		.175		.001	√	.000	–	.003	√	.097		.044		.175		.175		.000	–	.291		.002	
S2	.001	√	.003	√	.000	√	.001	√	.008	√	.001	√	.003	√	.044		.000	–	.021	√	.003	√	.048	√	.008	√	.001	√	.000	–	.003	√	.008	√
S3	.003	√	.008	√	.002		.008	√	.021	√	.003	√	.048	√	.003	√	.000	–	.008	√	.008	√	.008	√	.003	√	.003	√	.002	–	.001	√	.001	√
S4	.008	√	.002		.002		.003	√	.422		.176		.291		.008	√	.002	–	.044		.578		.001	√	.422		.431		.006	–	.097		.003	√
S5	.006		.001	√	.017		.002		.175		.094		.176		.021	√	.000	–	.001	√	.176		.006		.094		.422		.000	–	.094		.044	
Effective sources	*2,3,4*		*1,2,3,5*		*2*		*2,3,4*		*2,3*		*2,3*		*2,3*		*1,3,4,5*		–		*1,2,3,5*		*2,3*		*2,3,4*		*2,3*		*2,3*		–		*2,3*		*2,3,4*	
Non Effective sources	–		–		–		–		*1,4,5*		*1,4,5*		*1,4,5*		–		–		–		*1,4,5*		–		*1,4,5*		*1,4,5*		–		*1,4,5*		–	
Material type	*Type1*		*Type2*		*Non consuming*		*Type1*		*Type1,2*		*Type1 ,2*		*Type1 ,2*		*Type1 ,2*		*low waste*		*Type2*		*Type1 ,2*		*Type1*		*Type1 ,2*		*Type1 ,2*		*low waste*		*Type1 ,2*		*Type1*	

In internal walls those materials using in external walls are used too.

In indoor workings there are two methods, traditional and industrialized. First method is producing Mortar with mixing materials such as gypsum, soil and water in construction site and doing indoor work in traditional method by traditional workers.

Second method is producing gypsum boards in great dimensions in factory and installation of them on walls. It is obvious that first way is traditional with material type1, and second way is industrial with material type2.

In tiling activities tiles and ceramics (material type2) should be conjunct to surfaces with a mortar that is composite of cement, sand and water. Thus both type 1 and 2 materials are used.

In Staircase there are a collection if materials such as ceramic, stone, gypsum, gypsum board, cement, sand, water and so on. Some of them are type1 and others are type2.

In Frontage works there are same events that happen in indoor workings. We mention three methods here:

1. Cementing with materials such as cement, gypsum, soil and water in traditional way.
2. Conjunction of bricks or stones with using material such as cement, sand and water in traditional way.
3. Installing cement boards instead of cementing in industrial way.

In another word about impact of S2 and S3, there are proper consensuses between respondents. Consensus about S2 is because of changing production and construction paradigm. Consensus about S3 is because of generality of it over S1, S4 and S5. However there is no Consensus about these three sources but there are about S3.

4-3) Result 3:

In mechanical installations both material type1 and 2 are used (branch and loop pipes). But, there are no great variant and complexity in comparison with activities in result 2.

Therefore, respondent can reach to consensus in effectiveness of S1, S2 and S4. Because of clear condition and no great variation in using material there are no significant higher than 0.05.

4-4) Result 4:

In some activities such as electrical installation and installations ,all five sources are not effective. The reason is that these activities have not significant waste.

4-5) Result 5:

In framing in foundation just S2 is the source of waste. In traditional methods of framing, bricks were used Today's this method has no tendency between contractors. Some new industrial methods like big steel frames are used in many cases. This material is not consuming and does not have any waste. Thus if contractor apply traditional methods, it will be the single source of waste.

Results 1 to 5 are shown in Table 2 to 6.

5) Conclusions

We know materials inherent properties are methods of usage, important parameters when use, how to supply and how to maintain, measurement units. These properties impact on process of row material conversion to final product and therefore impact on methods that wastes produced in any material in activities.

And also, in weight based materials, that their weight is important in their usage, some sources are effective in their waste that relate to amount of purchasing.

Dimensional materials are those materials which their dimensions in their usage are important and so, some sources are effective in their waste that relate to building design.

Questionnaires Results intensively support the Results of categorization of materials to two categories. Everywhere material used in activities are type1, their waste sources are waste sources of material type1. This happen for material type 2 too. In those activities that materials used in them are composition of type 1 and type2 materials, respondents have Consensus about effectiveness of traditional construction methods and lack of coordination between supply chain, and in another sources there are no consensus.

Another conclusion of these five results is that the categorization of construction materials by their source of waste to two categories (weight based materials and dimensional materials) is true, because it describes waste production very well.

Moreover, this categorization is an appropriate way to recognition of waste production process in construction industry and it helps us to act with any kind of material based on their type and their inherent properties to minimize their waste and then increase the total performance of construction supply chain.

Acknowledgements

We like to thank Mapsa Company and all practitioners that helped us in the research process.

We also gratefully thank the comments from Dr.Ahmad Jafarnejad, Ahmad Ganaatian and Mohamad Mehdi Tohidi for their reformative comments.

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Table 2: Types of construction works that use materials type 1 and 2, and their wastes

No	Activity	Effective sources	Materials used in activity	Types of material used in Activity
1	Structure installation	2,3	Steel, Reinforcement steel/ Cement, sand and water	Type 1,2
2	External walls	2,3	Brick, adobe , block/ Cement, sand and water	Type 1,2
3	Internal walls	2,3	Brick, adobe , block/ Cement, sand and water	Type 1,2
4	Indoor finishing	2,3	Gypsum board/ Gypsum, paint, water	Type 1,2
5	Tiling	2,3	Tile, ceramic/ Cement, sand and water	Type 1,2
6	Staircase	2,3	Stone, ceramic/ Cement, sand and water	Type 1,2
7	Frontage works	2,3	Cement, sand, cement board, stone, brick, sand and water	Type 1,2

Table 3: Types of construction works that use materials type 1 or 2, and their wastes

No	Activity	Effective sources	Materials used in activity	Types of material used in activity
1	leveling concrete	2,3,4	Cement, sand and water	Type1
2	Pouring concrete	2,3,4	Cement, sand and water	Type1
3	Insulations	2,3,4	Liquid and solid insulation	Type1
4	Paining	2,3,4	Paint , toner , water	Type1
5	Reinforcing	1,2,3,5	Reinforcement steel	Type2
6	Door and window framework installations	1,2,3,5	Steel and wood	Type2

Table 4: mechanical installations that use both materials type 1 and 2, and its wastes

No	Activity	Effective sources	Materials used in activity	Types of material used in activity
1	Mechanical installations	1,3,4,5	Looped and branch pipes	Type 1,2

Table 5: Types of construction works that have low wastes generation

No	Activity	Effective sources	Materials used in activity	Types of material used in activity
1	Electrical installations	-	Wire, lighting fixtures	Low waste
2	Installations	-	Cooling and heating installation, bolt and nut, cabinet, UPVC, faucet, plumbing fixture, and other fixtures	Low waste

Table 6: Type of construction works that is not consumable

No	Activity	Effective sources	Materials used in activity	Types of material used in activity
1	Framing	2	Steel and wooden frames	Non-consumable

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12/5/2010