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Review Article

STUDYING AND EVALUATING RECYCLED CONSTRUCTION MATERIALS

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ABSTRACT
As a massive amount of urban wastes in developing countries associates to construction activities, recycling these materials can assist for protection from natural resources and environment and can have an economic justification by employing the scientific methods. Surplus exploitation from natural resources to construct roads, produce concrete and brick and other construction materials might be also followed by shortage of natural materials. Unfortunately, recycling construction materials has not a long history in Iran, under which the present research seeks to investigate recycled construction materials and evaluate this issue via a descriptive and analytical nature. Indeed, the main purpose of this research is to examine and classify the existing information in this context at the first stage and create some policies to reuse the construction materials via recycling to other components that are beneficial in construction at the second stage. Legislation and state supports at private sectors and academic centers have been mentioned as the practical approaches regarding necessity of recycling and its effect on environment, economy and its position through the world. Notably, recycling due to dimensional and financial extensiveness at civil projects that financing it has not been undertaken by people and provided by private investors and government can be operationalized in a comprehensive planning, causing creation of revenues followed by exploitation and suitable management of wastes and protection from environment.

Keywords: *Recycling, Construction Materials, Construction, Environment*

INTRODUCTION
A large amount of urban wastes in developing countries pertains to construction activities and construction debris, imposing adverse outcomes on environment in addition to high cost to dispose them. Volume of construction debris is to the extent that currently this issue has been accounted as a social and environmental problem not just in developing countries but also in developed countries (Poon *et al.*, 2002). For this, recycling construction debris can assist for protection from natural resources and environment and can have an economic justification by employing the scientific methods. Surplus exploitation from natural resources to construct roads, produce concrete and brick and other construction materials might be also followed by shortage of natural materials. Volume of construction debris due to destruction of buildings in European countries has been mentioned to a large extent, such that advocates of environment have increasingly concerned about health of community. Over 1 million tons of construction debris in Finland and about 0.7 million tons of concrete in two big cities of Australia have remained from destruction of buildings (Wahlstrom *et al.*, 2002; Nataatmadja and Tan, 2000). Construction debris and recycling materials and unsystematic way to dispose them have raised numerous problems of which it can refer to:
-needing to a place to dispose waste
-creating an unsuitable vision
-environmental problems (Chong and Hermreck, 2010)
-health problems (Yuan *et al.*, 2011)
Economic aspects are of great importance in recycling construction materials that the most important factors for economic justification of recycled construction materials include:
-high cost of early materials
-the cost for carrying debris from production place to disposal place
-the cost for disposal of debris

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Hence, it is obvious that recycling wastes is much more expensive that might not have an economic justification in a short term, yet increasing increase of the cost of early materials and irrecoverable damages to environment in a long term intensify the issue of recycled construction materials (La Cross and Graves, 2000).

Recycled construction materials and its use rely on numerous factors such as volume and composition of debris, waste recycling machines, rate of demand, quality of manufacturing materials, need of civil projects to type of obtained materials and cost of early raw materials. Currently, the materials obtained from recycling can be more likely used at two areas, that is, the first application can be in concrete, that most of volume of debris develops from concrete in European countries, such that numerous studies have been conducted about the possibility of using recycling concrete in new concrete and a variety of methods have been proposed to use recycling concrete (Chi and Dixon, 2006); the second application lies on exploitation from recycling sub-brick to prepare brick and concrete blocks (Akash, 2007). Unfortunately, recycling construction materials has not a long history in Iran, thus access to accurate statistics about rate of production and composition of debris in previous years is much more difficult. For this, the present research seeks to investigate recycled construction materials and evaluate this issue via a descriptive and analytical nature. Indeed, the main purpose of this research is to examine and classify the existing information in this context at the first stage and create some policies to reuse the construction materials via recycling to other components that are beneficial in construction at the second stage, resulting in avoidance from aggregating materials and occupying useful existing spaces and avoidance from environmental pollutions.

Importance of Construction Materials Recycling

With regard to the studies conducted concerning construction debris, it is specified that volume of construction debris is about 13% to 29% among other wastes (Khayati, 2006). Statistics indicate that 136 million tons of building-related materials were generated in the United States, of which 43% and 57% have been related to residential resources and non-residential resources. Further, 48% of the construction wastes include 44% due to reconstruction and 9% due to new construction. Unfortunately, similar estimations for construction debris due to construction of non-residential and commercial centers and physical demolition of centers including concrete structures, steel bridges, road building and cleansing place are not available. With regard to overview of multiple resources, it is estimated that non-building construction debris are 2 pounds per person per day. According to A population of 280 million, non-building construction debris is 100 million tons per year (Tchobanoglous, 2010). Further, the statistics indicate that volume of construction debris for repairing, maintaining and reconstructing roads is about 91 million tons and the recyclable concrete is about 26 to 100 million tons in 1992-1997. Further, 12% of the volumes of landfills develop from wastes in California, a western U.S. state that average weight of construction wastes in this state has reached to over 4 million tons per year (Khayati, 2006). This statistics in Tehran indicate that rate of disposed construction debris has been about 61275196 ton equivalent to 116928033 m^3 construction debris that have been disposed by municipality. Statistics of generation of disposed debris in pits around Tehran have been about 11973947 tons in 2003, that the highest amount of debris has been disposed in Kahrizak and Abali pits (Majedi *et al.*, 2007).

With regard to high volume of construction debris in different parts of building on one hand and high volume of concrete consumption as the most used construction product on the other hand, concerning the fact that the dimensions and number of civil projects keep expanding especially in developing countries, it is obvious that to which extent the process of recycling wastes can be essential in maintaining the existing resources.

Construction Wastes

Construction wastes have appeared due to renovation and demolition of buildings, projects of re-asphalting and paving the roads, repairing bridges and clearing of ruins from natural disasters. In general, construction and demolition wastes include concrete, asphalt, wood, metal, plaster and necessary materials for roofing. In general, components of the debris develop from 40-50% of concrete, asphalt, brick, block and soil, 20% to 30% of wood and related products (pallets, tree roots, branches, logs and

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sand) and 20% to 30% of different wastes (painted or dirty plywood, metal, plaster, glass, asbestos and other insulating materials and plumbing and electrical components) (Tchobanoglous, 2010).

Increasing volume of construction wastes will be followed by extracting more raw materials and more demolition of nature. Natural materials such as sand, gravel, gypsum, limestone and other construction minerals develop during long periods under special conditions in nature, thus such materials have been accounted as renewable resources that surplus use of them will result in shortage of them in future. Although construction wastes are classified to ordinary wastes, since the early 1990s it has been specified that hazardous waste materials such as adhesives, paints and resins in these wastes might raise hazards for the man and environment (Ghafouri, 2005). With regard to lifestyle, industry, composition and demographics, as well as local materials in different countries, composition and percent of these materials differ in wastes. On the other hand, the causing source of these materials is effective in determining composition of wastes. To examine composition and percent of causing materials in composition of waste, overview of different sites, origin of wastes and statistical analysis are required that the sample of resources and a variety of construction wastes have been represented in table 1.

Table 1: Sample of resources and features of construction wastes due to demolition (Tchobanoglous, 2010)

Source	Features
Construction (re-usable materials)	bricks, concrete stones, stone or concrete facades, tile, ceramic, roof tiles, undamaged windows, wooden cabinets, counters, flooring, stairs, construction pipes, home appliances, carpets, insulation and wooden beams
Demolition and Renovation (recyclable materials)	Broken bricks, concrete stones, stone or concrete facades, ceramic and tile roofing, broken or damaged windows, furniture, wooden beams, decorative plaster, trees, metal structural cladding, roofing materials, Aluminium doors and windows
Construction (re-usable materials)	Mixed waste that is not suitable for the separation, Materials that cannot be recovered or reused, asphalt sands, Linoleum flooring, hazardous waste such as asbestos, wood waste including wood, lumber, plywood and wood, painted wood, asbestos or insulation
Physical destruction of facilities including concrete buildings	Concrete (non- metallic strength), Concrete (with strength of metal), bed material (sand), ferrous metals (joists, beams vertically into the wall, pipes), brick, stone, wood products, electrical appliances, electrical wiring and miscellaneous waste
Drilling, paving the ground in heavy constructions	Wood, sand, stone and mixed material found during excavation of mixed waste including wood products, roofing materials, wallboard, insulation materials, ferrous and non -ferrous metals (vertical beams inside walls, pipes, wires, channels) and carpet
Natural disasters (tornado, hurricane, earthquake)	Mixed waste that is not suitable for the separation, Materials that cannot be recovered or reused, asphalt sands, Linoleum flooring, trees, hazardous waste such as asbestos, Concrete (non- metallic strength), Concrete (with strength of metal), bed material (sand), other additional materials from the demolition of buildings that have already been discussed .
Road Construction	Concrete (non- metallic strength), Concrete (with strength of metal), bed material (sand), asphalt and other miscellaneous materials
Cleanup the site	Building materials, plants, soil, steel, broken bricks and other waste(plastic, brick, organic materials)

Construction Waste Problem

Waste implies the residual of any material produced by the man and industrial activities which are useless (Serpelland& Alarcon, 1998). According to Waste Treatment and Disposal Statistics by the

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Environmental Protection Department (2005), it can perceive that 38% of the wastes produced due to C&D activities which are about 6408 tons per year are produced from construction activities. In 2001, it has been indicated that 45.5% with 803190 tons of all the recyclable materials include ferrous metals for about 37.7% and wood and paper for about 665539 tons. Non-ferrous metals include higher recyclable amounts with value of 1000 million (table 2).

Table 2: Value and amount of recyclable materials based on type (Environmental Protection Department, 2002)

Classification of recyclable materials	The price per unit of weight (HK$/tons)	value (HK$ thousand)	Amount(ton)
Non-ferrous metals			
steel Alloy scrap	4382	72171	16470
Cast iron	1086	46667	42970
Steel sheet	1983	1134	572
Other waste	816	606669	743177
Subsection	905	(%27.9)726641	(%45.5)8031190
Nonferrous metals			
Aluminum	4065	693285	17044
Copper and its alloys	6235	296645	47580
Lead	1589	4424	2785
The remaining metal ash	58159	13144	226
Nickel	20206	1273	63
Precious metals	5610137	656386	117
Tin	19500	39	2
Zinc	8859	11251	1270
Subsections	15234	(%40.4)1052447	(%3.9)69087
Plastics			
Polyethylene	1077	124594	115653
Polystyrene and	2606	48076	18445
copolymers	2267	5065	2234
Polyvinyl chloride	1686	120381	71401
Other	1435	(%11.4)298116	(%11.8)207733
Subsections			
Cloth			
Linen	1557	25746	16539
Handmade fiber	5175	295	57
Old fibers, synthetic fibers,	3407	11700	3434
etc.			
Subsections	1884	(%1.4)37741	(%1.1)20030
Wood and Paper			
Paper	742	487785	657336
Wood (including sawdust)	521	4274	8203
Subsections	739	492059	(%37.7)665539

In general, recyclable materials including ferrous metals, non-ferrous metals, wood and paper have been registered about 87% of total recyclable materials. Thus, it requires considering construction waste management in construction operations to reduce the wastes. After identifying the reasons for creation of construction wastes, the important point lies on this fact that the structural strategies for minimization of wastes as the most favorable solution for wastes must be identified. Indeed, waste management plan must

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be issued at all construction companies, and any company must use construction waste management in line with its construction aims. In addition to strategies of waste management, economic issues play a major role in construction waste management in sake of recycling and outcomes of contracts.

Construction Waste Management

Construction waste management increases the power for executive performance in construction operations, e.g. if the cost for demolition of construction wastes consists of 5% of sum of construction costs, ultimate benefit will be maintained by controlling production of this waste to 5% of total waste. In addition, reduction in production of construction wastes can reduce the need to purchase of raw materials, as a result sum of costs of control and disposal of production wasts will reduce to a large extent by optimal use of construction wastes and recycling them. By removal of the purchased raw construction materials, double cost must be paid, i.e. firstly an amount of money is paid to purchase the raw materials and then an amount of money is paid to get rid of these wastes and carry them to recycling centers or waste disposal sites. Hence, finding a way to use useful raw construction materials is much easier than finding a way to dispose them. Studies have shown this reality that 80%-85% of the construction wastes are recyclable (Coelho & Brito, 2013).

In general, three methods in line with construction waste management have been used in recent years:

1- Source reduction: source reduction implies reduction of the amount of materials used through more accurate estimation so as not to produce waste. Increasing the costs pertaining to disposal of construction wastes through disposal at waste disposal site as the result of new rules raises a motivation to reduce amount of waste.

2- Reuse: a variety of reusable or without use materials are found in each of demolition projects, of which it can refer to timbers in various sizes, plywood, sand and asphalt, insulation, paint, thermal channel and pipe. In addition, other wastes such as broken concrete stones and brick can be found in some applications, e.g. chalk and board can be used. According to what mentioned here, changing the pattern is required, because it causes reusing the materials. Fortunately, most of the countries have useful information on opportunities for reusing the materials. In addition, most of countries have special plans for recycling materials.

3-the opportunities for reusing and recycling construction wastes rely on the necessary ability for processing the solid waste at a container. The materials which are recycled from construction wastes include concrete, wood, asphalt sands, gypsum boards, metal and dirt (Tchobanoglous, 2010).

Recycling Construction Materials

Reprocessing is applied on reduced materials transforming them to new materials. In addition to disposal cost, there are several other reasons to increase attention to the issue of recycling construction wastes. Reduction in reuse of resources with high quality to produce construction materials is the most important reason to pay attention to the issue of recycling construction wastes. In the most cases, there is a huge gap between intact and untouched materials and the project execution site, that the transport costs allow the contractors to search a local alternative source.

Another advantage in use of stone materials lies on this fact that value of stone materials obtained from intact stones goes beyond assuming less important applications for them such as earth-filling. In these cases, use of demolished stone materials can be a suitable alternative (Yuan *et al.*, 2011).

In recycling operations on construction materials, the rate of resources and equipment are considered regarding what mentioned in following:

-Recycling in the construction site (to reduce freight)
-Recycling in place to isolate and prepare
-Recycling in a base station
-Recycling in a remote unit (over 200 miles)

Table 3 represents amounts of recycling a variety of materials such as paper, plastic, metals and glass in Hong Kong, Australia, Japan, United States of America, Germany and the UK.

The highest rate of recycling has been seen in Germany compared to other countries that 169%, 108%, 105% and 88% of amount of recycling have been pertained to paper, plastic, metals and glass. Recycling

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practices has lagged behind in Hong Kong in comparison with other countries. A large amount of construction wastes are disposed at waste disposal sites that there are huge opportunities to minimize them (CIRIA, 1993). There are the opportunities to increase lifetime of waste disposal sites and minimize use of transport devices and reduce energy and mineral materials.

Table 3: Amount of recovery and recycling of waste materials (EPD, 2005)

Site	year	Glass (percent)	Metal (percent)	Plastic (percent)	Paper (percent)
Hong Kong	2001	3	89	38	58
Australia	1995	42	65	30	51
Japan	2000	78	75	14	58
United States of America	1999	23	35	6	42
Germany	1999	88	105	108	169
UK	1998	22	43	3	38

**percents more than 100 imply the recycled amount for more than one time.*

Practical Practices in Recycling Construction Wastes

Although there are numerous recommendations in different plans to recycle construction materials, just several practices are used. With regard to the recyclable materials, three areas must be considered in recycling the materials (Mindess *et al.*, 2003).

-Economic
-Compatibility with other materials
-Properties of materials

Reducing and recycling C&D materials will be acceptable from economic perspective when the recycling product can be competed with natural resources in sake of pressure and amount. Recyclable materials in the areas where there is shortage of raw materials and there is no landfill will be competitive. With regard to high consumption of concrete in construction activities as well as favorable production of recycling materials, specifically the discussions below will be considered:

Recycling Construction Materials in Concrete Construction

Using wastes from construction materials and recycling them are of great importance in concrete construction, of which it can refer to following:

-the first advantage lies in protection from environmental resources that are renewable in most of industries or can be renewed during long periods.

Nowadays, concrete is considered as the most used construction material, indicating high volume of using different resources such as Iron, cement, aggregate and water to produce concrete. Some products such as protective materials and curing concrete and spacers indirectly cause maintenance of these resources in an indirect way through increasing durability of structures.

-reducing final waste and environmental pollution is another advantage of concrete construction through recyclable materials.

With regard to high volume of construction wastes, use of a part of these wastes in concrete construction raises reduction of wastes and problems due to lack of recycling these wastes.

-recycling construction materials and constructing concrete via these materials based on the requirements in allocation of human resources at different stages such as research, separation and waste transportation can raise job opportunities.

Further, this process will be followed by numerous economic benefits. Liberalization of prices, elimination of government subsidies, the current sanctions on Iran's economy, increasing costs of production and transportation, recycling wastes especially construction materials such as cement, aggregate, fittings, chemicals and so forth can raise suitable economic benefits in sake of protection from natural resources and rise of the possibility for exporting or in sake of recycling wastes for investors.

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Recycling Construction Materials to Construct Concrete

Environmental values must be taken into account in recycling construction materials to construct concrete, that recycling most of construction wastes is considered to construct concrete (Majedi *et al.*, 2007).

The materials that can be recycled to construct concrete include:

- A variety of plastic and rubber materials: UPVC doors and windows, plicae pipe, types of flooring, polymer wall and ceiling covers, plastic packaging materials and other products.
- A variety of stones: Stones used for flooring and façade
-a variety of destructive concretes: a variety of concretes are used in foundations, slabs, columns, shear walls, beams, landscaping and flooring, different kinds of structures, reservoirs, power plants, bridges, factories and so forth
- a variety of metals: Doors and windows, horseshoe ports, skeletons, fittings, Valves, fences, etc.
- Ceramic and tile: ceramic and tile used in bathroom, kitchen and flooring rooms
-Glass: all kinds of glass doors and windows, etc.
-Clay bricks: traditional walls and partitions, ceiling blocks and so forth
-Asphalt: Asphalt in roads, landscaping and roofs.
-Plaster materials: Joinery and partitions.
- Types of petroleum-based materials
-Types of sealing coatings such as asphalt, bitumen & Roofing

Recycling the aforementioned materials can be used as follow:

-glass: studies indicate that adding powdered recycled glass in using cement or aggregate in new concrete will improve electrical resistance and reduce permeability in addition to maintenance of compressive resistance. Further, use of powdered glass in artificial concrete stones can increase wear quality and beauty (Abbasi *et al.*, 2012).

Aggregate: in most of cases, recycling concrete materials can be used in new concrete by recognition of properties and potential of concrete. If crushed concrete is used as coarse grain, it will have no effect on resistance and other properties of concrete will not be subjected to change. Hence, if crushed concrete is replaced with fine grain, some of the properties such as modulus of elasticity, compressive strength, tensile strength and shrinkage dependant on the rate of displacement can raise improvement to the rate of 15 % (Majedi *et al.*, 2007). Further, displacement of recyclable stone materials with crushed concrete causes reducing weight of concrete to about 2100 kg (Mostofi nejad & Eftekhar, 2010).

Brick powder on concrete: the results from studies indicate that adding brick powder instead of cement in concrete has raised an acceptable extent of reduction in compressive strength and abrasion resistance, being used in concretes with ordinary resistance and concretes which do not need high abrasion resistance (Byat *et al.*, 2010).

WaterStop: use of polymers recovered from debris to construct WaterStop bands to seal concrete expansion joints.

Use of the recycled rubber and plastics materials as additives in concrete: use of rubber can improve some features in new concretes, such as increasing elasticity, tensile strength, impact resistance (Mostofi & Eftekhar, 2005; Hajati & Poor, 2011).

Fittings: this product can be recycled from all irons extracted of construction debris in melting and casting factory. This recycling is without change in type of recycled product from waste.

-use of recycled tile in concrete: numerous studies have been conducted in the context of use of recycled tile and ceramic in decorative flooring, that some countries including Denmark have been engaging in producing the flooring (Majedi *et al.*, 2007).

- concrete fibers: a variety of fibers that can be used in concrete in two type of plastic and metal have the ability to produce from recycling a variety of plastic and metal materials in debris. These fibers create the features such as reduction of thermal fractures in concrete and increase of tensile strength, flexural and compressive strength of concrete.

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- Armature holders: Plastic spacers can be recycled from a variety of polymeric materials in construction debris such as plastic products and PVC.

Concrete with with recycled materials via mix design is applied:

- Polymeric materials recycled from construction debris are used as adhesive materials in concrete for special consumptions such as fillers-repair mortars repair or grout alternative materials such as polymer concrete

-with regard to suitable curing in quality and durability of concrete and diversity in the existing methods, use of recycling materials via creation of films that keep moisture from polymeric materials such as plastic sheets can be drawn into attention in process of recycling polymer and bitumen materials.

-to protect and seal concrete surface, recycling bitumen or polymer materials through transforming them to protective cover which controls the permeability of concrete is used.

-recycling a variety of metals is used for formatting. The recycling appears as recycling without change in nature of waste (Majedi *et al.*, 2007).

Conclusion

Since production of wastes due to consumption has been inevitable on one hand and the individuals' health and environment have been threatened due to adverse environmental effects of wastes on the other hand, thus disposal of these materials at suburbs are not an efficient solution, such that reuse of the wastes in construction activities can be the best solution about construction debris. This solution in addition to resolving the problems and reducing negative effects will be economically effective. Further, with regard to necessity of recycling and its effect on environment and economy, it requires paying attention to states aids at private sectors and scientific centers by legislation.

With regard to dimensional and financial diversity in civil projects that financing them has not been undertaken by people and financed by private investors and state, these projects can be operationalized in a comprehensive planning, causing rise of economic revenues after suitable management of wastes and protection from environment. Experiences of countries throughout the world indicate that the approaches below have been effective in development of recycling from construction materials:

- Taxation and restrictions on the extraction of natural sand from riverbeds
- Taxes on construction debris
- Full control of debris and increase of the cost of their disposal
- Add criteria to encourage and develop recycling in road and building regulations (Abdoli, 2008).

With regard to this fact, the approaches below are suggested to recycle construction materials used in concrete:

-firstly, practical and operational approaches must be considered to recycle wastes and transform new materials. It should be noted that such approaches can work out effectively in development of recycling products in transforming to new materials. This idea has been being executing in most of development countries such as Germany, Australia, U.S, Canada and so forth regarding heavy restriction on disposal of wastes.

-currently, some courses are held in most of developed countries by associated organizations, that the courses are based on use of materials with more recycling capability, how to recycle and use of a variety of recycling materials in design, construction and demolition sectors. This can widely facilitate the problems pertaining to practicability of this process.

-currently, in most of countries throughout the world, several standards and agenda to recycle construction debris have been given to the practitioners. Thus, the qualitative and executive control standards for recycling wastes and transforming them to construction materials must be formulated.

-recycling rest of construction debris and materials must come to realize by the investment and research by domestic researchers. Yet, this has been being fulfilled concerning recycling of stone materials in some disposal sites such as AbAli Tehran station that requires expansion in diversity, size and extension.

-Financing projects is the most important issue that can have positive outcomes in research and recycling sectors by governmental resources or municipalities.

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