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Building deconstruction and material recovery in Iran: An analysis of major determinants

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Abstract

The construction industry is one of the main resource consumers and waste generators, which has several environmental, social and economic impacts. Deconstruction of buildings is the careful dismantling of a building so as to make possible the recovery of construction materials and components, promoting reuse and recycling. This idea was emerged as an alternative to demolition in consequence of increasing environmental concerns and rapid increase in the number of demolished buildings. The aim of this study is to investigate the benefits and the main determinants of deconstruction according to current construction practice in Iran, based on analyzing a typical residential building in Tehran. It then gives some practical suggestions for promoting current and future demolition industry in Iran.

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Keywords: construction and demolition waste management; recycling; reuse; deconstruction of buildings ; material recovery; Iran.

1. Introduction

The construction industry is one of the major resource consumers and waste generators, which has several environmental, social and economic impacts [1]. The alternatives (such as recycling and reuse) for reentering building materials and components in the production chain have gained more attention due to the growing international community's concerns about environment [2]. The deconstruction of buildings and dismantling of building materials have emerged as an alternative to demolition. This strategy helps to increase the amounts of components to be reused or materials to be recycled. Thus the share of demolition waste deposited in landfills can be reduced [3]. Ignoring deconstruction means creating a pile of debris that can't be viably reused. Techniques and tools for dismantling the existing structures are under

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development, the research to support the deconstruction is ongoing at the institutions around the world, and government policy is beginning to address the advantages of deconstruction by increasing disposal costs or in some cases, forbidding the disposal if the materials are useful. Designing buildings to build in ease of future deconstruction is beginning to receive attention and architects and other designers are starting to consider this factor for new buildings [4].

In Iran many buildings are demolished each year, mainly due to finishing the useful life span, natural disasters (especially earthquake), low safety standards or demand for more high raised construction. Low quality of construction, poor maintenance, and inability of buildings to adapt with the changes of environmental and users' demands are the factors that reduce lifetime of buildings. Buildings that are demolished in Iran are often made in 1960s or earlier. They are mainly made with the masonry (clay brick) and often demolished manually. Only few limited materials such as bricks, metal, doors and windows are recycled and the rest of them are crushed with sledgehammers and sent to landfills without separating from each other. This demolition method results in over 42000 tons construction and demolition (C&D) waste per day in Tehran (about five times of municipal waste) [5]. On the other hand the growing young population and changes in the lifestyle results in the growing housing demands[a], which have caused a high rate of raw material usage for new construction. However, there is a lack of considering construction standards, recyclability of materials and adaptability of the building in the design and construction procedures. Besides, in our country there is a lack of public tendency and technical knowledge about recycling and reusing construction materials [5].

In this article the necessity of deconstruction and recycling of buildings materials is presented, with regard to current state of Iran's construction industry and then major actions that have to be taken are investigated based on analyzing the demolition waste of a typical residential building in Tehran in two cases of current situation and highest possible recycling rates. This paper will finally suggest some solutions to develop the deconstruction and closing material loop in Iran.

2. The benefits of deconstruction in Iran

2.1. Decreasing Environmental impact

2.1.1. Reducing resource consumption

Each year more than three billion metric tons of raw materials are used to manufacture construction materials and products worldwide [9]. This is about 40–50% of the global economy's total flow. The inclusion of hidden flows b is estimated to more than double the consumption of resources for construction materials [9]. Building phases including construction, operation and demolition use approximately 30–40% of all primary energy utilized worldwide [10], 15% of the world's fresh water resources [11] and produce approximately 40–50% of the global output of greenhouse gases [10]. A report by the World Resources Institute projects a 300% rise in energy and material use as the world's population and economic activity increase over the next 50 years [12].

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[a] Iran has 17.5 million households and there are 16 million housing units, regardless of ownership, which indicates a severe shortage of residential buildings [6].

[b] Hidden flows or indirect flows are materials such as: mining overburden, soil erosion, ore waste, effluents and emissions that are released to land, air, or water that never enter the economy as traded commodities. For many products, these indirect flows are substantially larger than the direct flows [9].

In Iran the rate of steel consumption between the years 2005 to 2009 in the construction sector is estimated to be 14,084,569 ton. Steel consumption rate growth is 7.21% in 2005 to 2009. The rate of cement consumption in the same period was announced to be 8,248,829 ton and its growth is 14.8% [13].

Natural resources for some materials are of sufficient quality and quantity to meet the demand for building materials at a moderate cost. This fact reduces motivation to obtain these materials through recycling [7] (e.g., large areas in our country are covered by alluvial soil that is the main resource for sand and gravel. This reduces the tendency to process concrete debris to obtain gravel.)

The deconstruction creates the possibility of reusing the materials while maintaining the internal energy (Embodied Energy) and prevents the arrival of a new internal energy and raw materials in processing or further production of construction material.

2.1.2. Reducing land use

Raw material extraction and C&D waste disposal change the existing ecosystem and environment of undeveloped natural lands.

Generally, C&D waste generation in Iran is much higher than in most other countries, especially developed countries. For example the average C&D waste generation in the United States is 0.77 kg *per capita* per day[c] [14] while this proportion is 4.64 kg *per capita* per day in Tehran based on reports from Tehran Municipality Waste Management[d]. In spite of the importance of this crisis, detailed quantitative data regarding C&D waste produced in Iran are still much reduced. Nevertheless, in recent years some limited studies and experiences have been done in this field (See [5,7,8]). Demolition waste in Tehran is generated at a rate about 1.3 to 1.61 tons per square meter of construction [7]. Table 1 presents the result of a recent study which tried to quantify the amounts of demolition waste for typical residential buildings in Tehran that has been carried out by the Building & Housing Research Centre of Iran [14,15].

Since there are vast undeveloped lands outside cities in Iran that can be used as a place for disposing C&D waste for many years, less attention has been paid to the this crisis. However, it should be noted that the land is limited. Furthermore, construction wastes in disposal sites have undesirable physical and chemical impacts on the environment. If dealing with this crisis is postponed until large areas of lands are covered with building disposals, it may be impossible to fix the damages.

2.1.3. Reducing pollutants

Environmental pollutants are produced in different stages of a building's lifecycle (i.e. materials' extraction, transportation, production, construction, operation, maintenance, demolition and disposal.) and released to land, water, and air [17].

Table 1. Demolition waste in 8 typical residential buildings in Tehran [7]

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[c] This is the average of reported *per capita* C&D generation rates in the United States based on recent waste characterization studies. There is a considerable difference in the generation rates presented in this report due to a combination of what is and is not reported as C&D (In some cases total recycled plus disposed materials are included, in other instances materials recovered for recycling are excluded. Moreover, soil generated from land cleaning and excavation is excluded in some databases.); geographic differences (fast and slow growing areas of the country); and differences in the year in which the data were gathered (thus differences in economic conditions) [14].

[d] According to the 2009 annual report of Tehran Municipality Waste Management, the daily C&D waste generation in Tehran is 46,655 m^3 which includes recycled materials and soil generated from land cleaning and excavation. The average weight of C&D waste is around 863 kg per m^3 [15]. Dividing the total daily C&D waste generation (40.26 million tons) by the population of Tehran in 2009 (8.67 million [16]) yielded a *per capita* C&D waste generation rate of 4.64 kg per day.

Building number	Structure	Area *(m^2)*	Weight *(ton)*	Volume *(m^3)*	Weight *(ton/m3)*
1	Steel	635	851.04	416	1.34
2	Steel	390	557.08	283	1.43
3	Concrete	800	1188	581.31	1.49
4	Mixed	400	645	360	1.61
5	Mixed	290	421.77	240	1.45
6	Mixed	435	465.95	236.51	1.39
7	Mixed	433	696	341	1.61
8	Masonry	290	438.08	232.47	1.51

2.1.4. Reducing sound pollution

Sound pollution is also produced in all stages of material procurement, building construction and demolition and has harmful effects on human health.

2.2. Social and economic benefits:

In our country, the construction industry is highly relevant, whether in terms of the employment it provides or the part it plays in our economy. According to available statistics, the construction sector share in national economy's total flow has never been less than 59% [7].

Although, the environmental benefits of deconstruction is discussed a lot in the literatures [4,17]; the more socio-economic benefits for buildings' deconstruction are recognised, the more motivation among governments, investors, designers, contractors, and owners for advancing this idea is provided.

As a rule of thumb, deconstruction and secondary construction material market increase employment opportunities and reduce construction costs.

3. Analyzed building

In order to find the main bottlenecks of deconstruction in Iran a typical building is analyzed to assess the maximum potential recycling rate with current technologies and current recycling rate (See table 2). The case study is a typical two story residential building in Tehran with a basement level that has steel structure. The walls and ceilings are made from brick. More detailed information about the building is presented in appendix A. The mass of each material is assessed by quantitative analyzes of detailed plan of the building. In the case that area or volume of the material is assessed in quantitative analyzes; their mass is calculated according to its density. The comparison between amounts of waste generated in current recycling state and highest potential rate of recycling with available technologies indicates a 68.81% improvement. This result can be analyzed as followed:

Table 2. Weight, Percentage, and type of recovery of materials in a typical residential building demolition in Tehran

Material	Mass (kg)	Potential recycling	Current recycling
Metal			
Structural steel	22556.48	Recycle/Reuse	Recycle

Bar	5909.03	Recycle	Partly Recycled
Window	2372.67	Recycle/Reuse	Recycle/Reuse
Aluminium (Door/Window)	550.2	Reuse	Recycle/Reuse
Concrete			
Lean Concrete	13639	Recycle	Landfill
Foundation	62280	Recycle	Landfill
Brick			
Clay brick wall	303744.62	Reuse	Partly Reused/Recycled
Facade brick	8397.58	Reuse	Partly Recycled
Clay brick roofing	65025.6	Reuse	Landfill
Wood			
Door	15678.9	Reuse	Reuse
Glass			
Window	5516.48	Reuse/Recycle	Partly Reused
Stone			
Foundation isolation	124414.54	Reuse/Recycle	reuse
Finishing	4527.75	Recycle	Landfill
Flooring			
Ceramic	236.95	Landfill	Landfill
Tile	994.63	Landfill	Landfill
Terrazzo	16417.4	Landfill	Landfill
Finishing			
Plaster	24281.02	Landfill	Landfill
Cement coat	18955.33	Landfill	Landfill
Total Recovered (ton)		634.61	156.10
Total Waste (ton)		60.89	539.4
Recovery Percentage		91.25	22.44
Waste (ton/m^2)		0.16	1.45

- The total construction area is 372 m^2.
- Material damage during the recycling process is neglected in assessing the total recovery in potential recycling rate.
- Waste generation *(ton/m^2)*, in current recycling practice is the average of the range presented in section 2.1.2. Other factors (e.g., total waste) are assessed based on this factor and the total construction area of the building.

3.1. Short-term actions:

The mentioned difference illustrates the lack of accuracy in demolition phase, because a higher rate acquisition is possible with current technologies. If the buildings were demolished in more appropriate manner, the amount of generated waste would be decreased considerably. Currently there is a significant drop in the quality of recycled materials and excluding some few cases, they are used in infrastructures. For example, 54.23% of materials that are used in this case study are bricks that have low recycling costs. Currently recovered bricks are used in foundations and infrastructures but it can be reused in non-structural walls of a building and it does not affect safety and quality of construction. Cheap labour in Iran, as a developing country, is one of the opportunities to develop high quality manual deconstruction.

3.2. Mid-term actions:

In Iran, buildings are conventionally constructed with a reinforced concrete or steel structure, plastered and painted masonry walls and steel fenestration. Floor finishes are terrazzo or ceramic tiles, while plumbing pipes and conduits for electric wiring are embedded in masonry walls. Buildings constructed with such materials are not easy to deconstruct; while the type and amount of recoverable building components is limited. The joints and mortar that are used in structural and non-structural connections are major reasons for the failure in appropriate deconstruction and severe drop in quality of recycled materials. The use of cement mortar in many of non-structural joints is a reason for impossibility of recycling stones, tiles, bricks, and etc. A revision in current practice of construction methods should be made to solve this problem by using simple methods that are possible according to national capabilities. For instance, using dry joints in building facades and floorings and passing pipes through the false ceiling and shafts instead of passing them through mortars in walls and floors. Applying these simple construction methods not only increases deconstruction ease and quality, but also extends life span of buildings by developing possibilities of building maintenance and lowering materials damages caused by their contact.

3.3. Long-term actions:

Considering recycling potential of all building components in the design phase and investigating creative methods for design for deconstruction is the most efficient solution to promote deconstruction and recycling quality and quantity. General principles of design for deconstruction are available in the literature [18,19,20]. Local capabilities and vernacular architecture should be considered in these studies, since they have advantages such as environmental friendly design, accessibility to materials, environmental compatibility of materials, localization of construction techniques, local employment, and less construction costs [23].

4. Suggestions

The following suggestions can help to achieve a practical approach to short-term, mid-term and long-term actions to promote deconstruction and material recovery:

4.1. Policy, legislations and guidelines

An array of legislative, fiscal and policy framework affecting the demolition industry is needed [21]. As mentioned in section 3.1 and 3.2, short-term responses requires frameworks that are supported by the current skills and technologies. Longer term solutions need to be incorporated into today's construction. This is where design for deconstruction and innovative solutions are vital keys.

Sectoral and detailed legislations on waste management need to be formulated and promulgated to ensure effective management and compliance with the Waste Management Acte (WMA). Legislation relating specifically to C&D waste should discourage the abuse of natural resources, illegal dumping, promote C&D waste minimization, and secondary material use.

Policy and legislations should motivate the following trends by strategies like funding, tipping reduction, tax reduction, funding, and faster granting construction license:

- Promoting design for deconstruction and material recovery by applying simple methods that increase possibility and quality of deconstruction
- Promoting using recycled material
- Promoting separation of C&D waste which is sent to landfills
- Promoting private sectors and universities to investigate innovative methods for construction technologies especially studies about joints and mortars.
- Promoting contractors to embed their waste management strategy in contract documents
- Promoting contractors to embed their waste management strategy in contract documents

High tipping costs on illegal dumping and waste generating, is pointed out in the literatures as a positive factor for the adequate management of C&D waste and promoting recycling [22,23]. However, it should be noted that tipping and taxes tend to further weaken the reuse and recycling of C&D waste once there is a lack of fulfilment of such regulation, control over the illegal disposal, and application of penalties. According to similar experiences in our country and other developing countries, this context makes illegal disposal, an attractive option, from an economical point of view. Furthermore, these kinds of taxes directly affect real estate prices, especially in housing sector.

Guidelines are necessary to initiate a practical approach to deconstruction. They should support decision for the selecting adequate demolition techniques. Therefore advantages and disadvantages of different demolition techniques should be analyzed according to economic, environmental and other aspects. They also should inform about building elements which could contain harmful substances and advices should be given on which procedure to be carried out before the demolition of buildings containing the mentioned elements [3].

4.2. Government support

The government is probably one of the most important stakeholders in the establishment of the secondary construction materials market. The government should visibly support this national target by promoting the use of secondary materials and discouraging the unnecessary use of primary materials. They can have effective role in promoting deconstruction by financial supports and strictly enforcing the passed legislations.

4.3. Increasing public awareness

Financial support must be given to the secondary construction materials market, but more importantly, the level of public awareness needs to be raised. Firstly, people need to realize that “secondary” does not

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[e] In the Waste Management Act (WMA) that is enacted in 2004, waste is divided into five categories: general, medical, specific, agricultural, industrial. C&D waste is classified as general waste. This act has emphasized on reducing waste production, facilitating the recycling, promoting secondary material use, and allocating parts of recycling costs to products’ producers. It also has emphasized on the role of public media and institutions in increasing public awareness. Waste overproducers penalties have been set, but these penalties do not depend on the amount of waste that is produced. In the executive regulations of WMA, which was enacted in 2005, all the stakeholders in construction industry are obliged to obey the rules of waste management [6].

necessarily mean "inferior" and secondly, the environmental benefits of using secondary materials need to be emphasized [22]. Increasing public awareness about necessity and benefits of deconstruction will motivate the public to participate and invest in this market. The effective public media role in promoting public awareness in other experiences (e.g. reducing energy consumption) indicates its importance to promote public awareness of deconstruction necessity and advantages.

4.4. National secondary material administrative system

In order to make waste management more effective, a national C&D waste exchange service is needed. This service will be useful for waste generators and secondary material consumers by providing information on available and required waste material for secondary applications by type, source, location, and available quantities.

In some studies, it is suggested to use the web to provide such a system [1,22]. This suggestion will be very efficient with regard to the development of communication technologies in recent years; however, it is not currently applicable in all of the regions in our country, since there may be the lack of internet access or computer driving skills.

5. Conclusion

Future development of demolition industry in a constant, sustainable, efficient and prosperous manner, that material and component reuse is one of its essential aspects, requires a considerable investment in terms of time, money, skills, tools, technologies, standards, and risk. Although this process may not seem profitable at the beginning, a look at the changes in Iran's metropolises (e.g., Tehran) and their surroundings in the recent decades illustrates the extent of damages to the environment caused by construction industry. These impacts are such fast that, if planning and investment are postponed, it may be late to compensate damages in the future. Thus, it is quite urgent to change this trend and ensure the preservation of environment and resources and contribute towards sustainable development.

The aim of this study was to investigate the major determinants of deconstruction and material reuse in Iran. The main suggestions were categorized in short-term, midterm, and long-term actions as follows: demolishing buildings in more accurate and appropriate manner, revision in current practice of construction methods with regard to simple alternative methods that are possible according to national construction industry capabilities, and encouraging design for deconstruction with considering the potentials of vernacular architecture. The main tools for reaching these aims can be: adopting encouraging and disincentive legislations, government support, increasing public awareness, establishing a National secondary material administrative system, and encouraging researches on innovative construction methods in ease of future deconstruction with regard to local capabilities and vernacular architecture.

Further research is necessary to develop pragmatic and quantitative studies to assess the extent and implications of analyzed factors and also to investigate new methods of construction.

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Appendix A. Documents of the case study

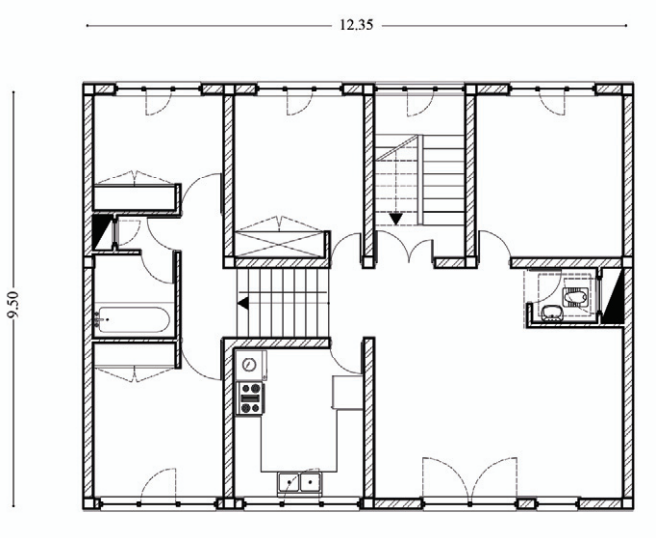

Fig. 1. First and second floor plan

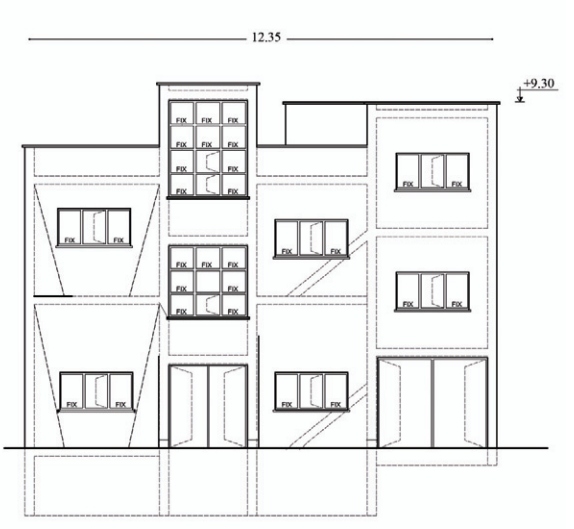

Fig. 2. North Elevation

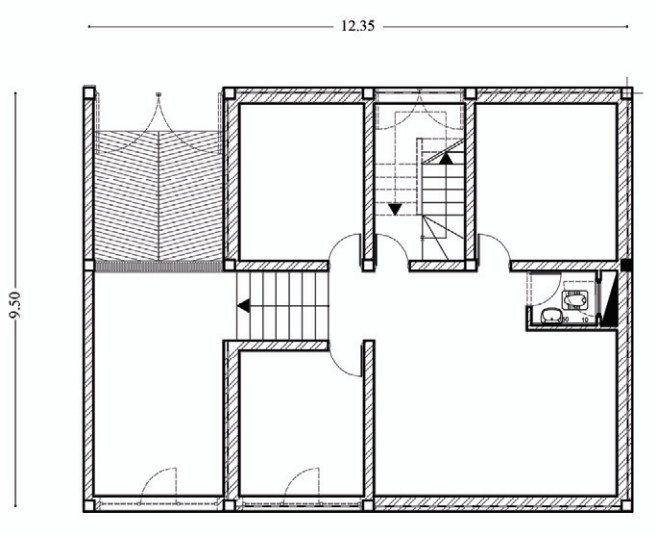

Fig. 3. Basement plan