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Incorporating construction and demolition waste into non-load brearing bricks.

Neveen samy Talaat Soliman

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The American University in Cairo

The School of Sciences and Engineering

INCORPORATING CONSTRUCTION AND DEMOLILTION WASTE INTO NON- LOAD BEARING BRICKS

BY:

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B.Sc. Construction Engineering, AUC, 2011

A Thesis submitted in fulfillment of the requirements for the degree of

Master of Science in Engineering

With specialization in

Environmental Engineering

Under the supervision of:

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(Professor and Chair, Construction and Architectural Engineering Department)

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ABSTRACT

Egypt faces serious solid waste management challenges. Currently, waste is either burned or dumped along roads and canals. Not only do these wastes cause health problems, but they also contribute significantly to soil, air, and water pollution. Solid waste can be categorized as residential, industrial, institutional, municipal, manufacturing, and construction and demolition waste (C&DW). The construction industry threatens the environment in three main ways: during the production of raw materials in the process of cement and aggregate production; during the construction process itself due to high consumption of energy; and, in the final stages of the construction process due to demolition waste disposal problems. It is a common practice at the end of the lifecycle of a building in Egypt to demolish it, leaving the construction and demolishing waste without proper waste management. This underscores the unfortunate fact that the concept and practices of adequate recycling are still not applied in Egypt.

This study aims at exploring potential uses for construction waste in feasible applications. More specifically, it targets the possibility of employing construction and demolition waste to produce non-load bearing bricks that is suitable for use in the construction industry. A case study is provided to highlight the socio-economic value of recycling. In addition, a cost and benefit analysis is included in which the feasibility of the proposed bricks is explored. To meet this objective, standard tests, such as compressive strength, flexural strength, water absorption and density, were performed on the bricks.

The results of this study reveal that the final product meets expected properties of standard bricks used in construction. The case study demonstrates that the impact of using bricks made from construction and demolition waste extends beyond the technical and functional to include socio-economic and environmental positive impacts. The cost and benefit analysis pinpoints that applying the recycling concept in this area also offers financial merits; this provides an incentive for the use of such products in future construction projects. Recommendations for future work to further validate the findings of this study are presented.

Keywords (Solid waste management, construction waste, demolition, bricks)

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CHAPTER (1)
INTRODUCTION

1.1 Overview

Solid waste management poses a major problem facing both developed and developing countries. In 1991, the United Nation defined causes of solid waste increase as *“The growth of the world's population, increasing urbanization, rising standards of living, and rapid developments in technology have all contributed to an increase in both the amount and the variety of solid wastes."* In 2009, the Egyptian Environmental Affairs Agency (EEAA), issued a report stating that the amount of solid waste produced in Egypt during that year was 75 million tons, 20 of which were municipal solid waste; moreover, the issue of garbage collection keeps getting worse (Milik, 2011). The daily amount of waste produced by Cairo is 14,000 tons (Viney, 2013), 88 % of which is collected, then thrown in open dumps in urban areas or simply left in the streets (World Bank, 2005). To make matters worse, despite this huge amount of waste produced daily, Egypt still lacks solid waste management laws; what available laws exist are scattered across many legislation (Zaki, 2010). “The lack of awareness in the Egyptian society on conserving the environment has weakened any effort to achieve good results in solid waste management” (Milik, 2011). In 2011, Yousra Loza, founder of the Association for the Protection of the Environment, stated that one of the main reasons why Egypt fails in the management of solid waste is that the status of garbage collectors has not been upgraded. Not only does the municipal solid waste lack effective waste management, but there are also other types of waste streams that lack effective waste management such as construction and demolition waste (C&DW). The construction industry has been developing in the past years worldwide, creating a burden, particularly in developing countries, for waste management (Nagapan, 2012). The daily amount produced in Egypt for C&DW is equal to 10,000 tons (Al Ansary, El Haggar. 2001). While there are abundant data on municipal solid waste, none whatsoever are available concerning construction and demolition waste in Egypt. This chapter will discuss the effects and problems associated with solid wastes in general, and will then focus on certain problems associated with construction and demolition waste (C&DW) in particular. It should also be mentioned that there was difficulty in obtaining data and information on (C&DW) in Egypt.

1.1.1 Solid waste effect on the environment

Nowadays, there are indeed valid concerns about solid waste management, including C&DW. This is due to the fact that if solid wastes are not properly handled, negative impacts occur on the environment. Fig. (1.1) describes the effect of poor solid waste management such as widespread diseases as well as air pollution resulting from gas explosions. Landfill liners can be poorly designed resulting in leachate reaching underground water as well as soil underneath (Landfill, 2013). The effect of this soil and water pollution might extend over many years, endangering public safety (Esin, 2012)

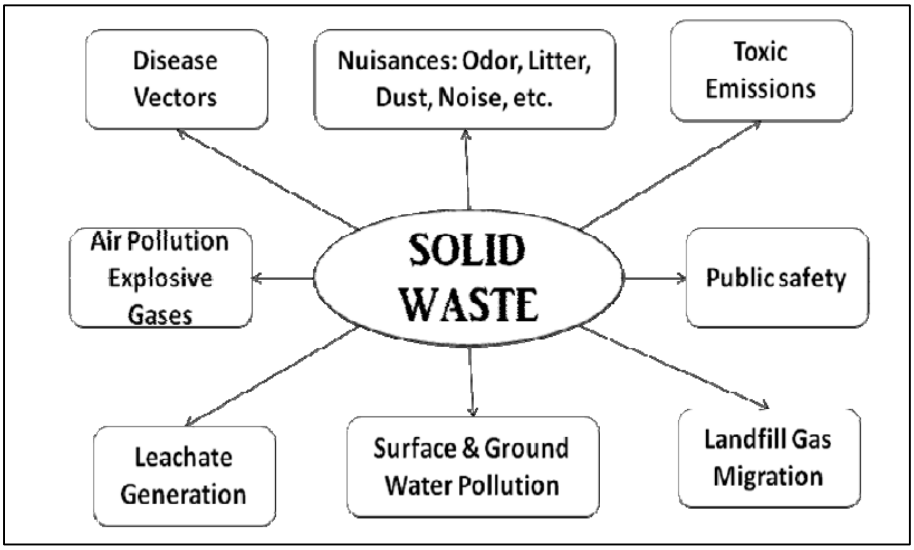


Figure 1.1: Poor solid waste management consequences (Esin, 2012)

1.1.2 Health problems associated with municipal solid waste

There are many living organisms found in solid wastes such as bacteria, protozoa, and fungi. Table (1.1) summarizes the type of living organisms present in each category of waste. Protozoa feed on fungi, both functioning as parasites living off animals and humans. Solid wastes contain thousands of fungi, many of which are pathogenic to humans and animals. Typical infections caused by fungi affect the hair, nails, and skin. Furthermore, bacteria form "spores" in dry seasons to allow them to take in nourishment. Since these spores are easily transported by wind, they may contaminate food eaten by humans with serious, if not fatal, consequences as in severe cases of food poisoning. Other types of bacteria such as "*C. Persringens*" thrive in open wounds, also causing dangerous infections. Solid waste also attracts insects, such as ants and mosquitoes, arthropods (spiders and scorpions) and annelids. Annelids include earthworms and millipede. If these wastes are dumped near forests areas, they might attract wild animals. Herbivores are attracted to hospital wastes (Chandrappa, 2012)

Table 1.1: Major living organisms present in various solid wastes (Chandrappa, 2012)

Waste category	**Fungus**	**Protozoa**	**Bacteria**	**Insect**	**Rodent**
Biomedical waste	√	√	√	√	√
Food waste	√	√	√	√	√
Hazardous waste					
Municipal solid Waste	√	√	√	√	√
Radio Active waste					
WEEE				√	√

1.1.3 Control on Air, Water, and Soil

Solid waste management has both positive and negative impacts on the environment. It is true that one of the positive aspects of waste management is waste removal; however, if these wastes are not properly handled, there can be tremendous consequences for the environment such as air pollution and soil contamination in addition to problems in soil textures. Another hazardous effect concerns living organisms. Positive impacts related to proper waste management are as follows: plant nutrition in the soil is improved by organic matter while air and water pollution is eliminated.

Table (1.2) shows the negative impact on the environment. Even waste management procedures can cause pollution to the environment. In each stage of waste management, there is air, water, soil, or noise pollution. For example, during the waste storage process, dust and fumes are generated. During the collection process, vehicle movement causes noise as well as consumes energy. During transfer and transport of waste, a great deal of noise is generated by the functioning of machines. At the end of the lifecycle, these waste are dumped in the oceans, giving rise to water pollution. This is why attempts to apply the recycling concept might solve this problem by eliminating the need for land filling as well as for waste collection.

Table 1.2: Impact on environment caused from recycling activities (Chandrappa, 2012)

Activity	**Impact**	**Pollution Type**
Storage	Generation of Dust	√*▪
	Generation of fumes	√*▪
	Material Recovery	√*▪□
	Movement of Bins and dropping of waste	√*▪□
Collection	Movement of vehicles	√*▪□
	Material Recovery	√*▪□
	Vehicle maintenance	√*▪□
	Degradation during collection	√*▪
	Activities of waste pickers	√*▪
Transfer and Transport	Machine operation	√*▪□
	Movement of vehicles	√*▪□
	Material Recovery	√*▪□
	Vehicle/machine maintenance	√*▪□
	Housekeeping	√*▪□
Reuse/ Recycle	Machine operation	√*▪□
	Movement of vehicles	√*▪□
	Material Recovery	√*▪□
	Cleaning of recyclable materials	√*▪□
	Composting	√*▪
	Material processing	√*▪□
	Waste to energy	√*▪□
Disposal	Waste dump	√*▪□
	Animal feed	√*▪□
	Thermal conversion	√*▪□
	Land fill	√*▪□
	Geological disposal	√*▪
	Ocean dump	*

Where:

- Air pollution is represented by: “√”
- Water pollution is represented by: “*”
- Soil pollution is represented by: “▪”
- Noise pollution is represented by: “□”

1.1.4 Air Pollution

As illustrated in Table (1.2) air pollution sources can be classified as follows: point sources, fugitive sources, and mobile sources. Uncontrolled landfill gas migration causes problems to human health. Buildup of such uncontrolled gases in landfill may trigger explosions; in addition, landfill gases can cause asphyxiation. The presence of waste pickers itself on disposal sites might cause problems for site operation. Waste pickers themselves endanger safety on site and cause hazards to people working in landfills which reduces productivity. Incineration and open burning also lead to water vapor emissions, carbon dioxide, carbon oxide, salts, and metals, and so forth. The incineration process releases particles with a fine diameter of less than 10, 5, 2.5 microns. Further combustion of such waste leads to dust generation, fly ash, odor and noise. There is evidence that inhalation of these small particles causes' serious diseases such as cardiovascular and respiratory morbidity. Vehicle emissions can also cause serious problems since they include CO, NOx, SO_2, PM and VOCs.

1.1.5 Soil pollution

During the waste disposal process, wastes come into direct contact with the soil. As a result, the soil becomes contaminated and undergoes changes in texture as well as in color. Fig. (1.2) illustrates soil contamination and changes in color and texture as a result of contact with waste.

Figure 1.2: Contaminated soil (Chandrappa, 2012)

1.1.6 Impact on Flora and Fauna

Animals, including birds, are attracted by municipal waste due to its possible food waste content. Remnants of plastic packaging might still be attached to some of these food wastes, resulting in the demise of animals feeding on them. Also, when animals feed on municipal wastes, these wastes indirectly enter the food chain with devastating future health impacts. In addition, animals feeding on these wastes become susceptible to serious diseases that can be later transferred to human beings. The kinds of diseases that can be transferred to humans are called zoonosis. These zoonosis pathogens cause diseases such as diarrhea, leptospirosis, and hepatitis. Fig. (1.3 to 1.10) shows several real life pictures in Egypt due to poor solid waste management. Fig. (1.3) shows how animals feed on the municipal waste in the streets. These wastes are in most cases contaminated, and this contamination is later transferred to human beings feeding on infected animals.

Figure 1.3: Animals feeding on municipal waste (Chandrappa, 2012)

Fig. (1.4) shows how waste is accumulated next to residential areas. This picture was taken in the Mokattam area. Wastes keep accumulating until the waste trucks come and collect them (Purg, 2006). Waste storage areas are located near residential areas. As discussed earlier, these wastes include bacteria as well as other living organisms which can pose serious health hazards to both animals and humans.

Figure 1.4: Solid waste is dumped near residential blocks (Purg, 2006)

Fig. (1.5) shows how waste is dumped on the streets. Once people see any accumulated waste, they think it is a “waste dumping” area, and come to dump their own garbage, thus worsening the problem (Wageeh, 2010).

Figure 1.5: Solid waste management dumped in the streets (Wageeh, 2010)

Fig. (1.6) shows how waste is accumulated along residential areas, with no proper waste collection (Beitiks, 2009)

Figure 1.6: Uncollected solid waste (Beitiks, 2009)

Fig. (1.7) shows uncontrolled waste burning as it is burned in the main streets, creating smoke and high levels of air pollution. To further aggravate the problem, in cases where this waste burning process is not controlled, devastating fires can result, threatening the surrounding buildings and their residents as well as passersby (Nasser, 2012)

Figure 1.7: Uncontrolled waste burning (Nasser, 2012)

Fig. (1.8) depicts burning waste near residential areas. Not only is the waste burned near residential areas, but it is also left to accumulate next to them prior to the actual burning process.

Figure 1.8: Solid waste burning near residential areas (Berman, 2013)

Fig. (1.9) shows that children might be present during the waste burning process. This can have serious negative effects on the respiratory system as well as many other diseases. Fig. (1.9) shows a child on his way to school, a journey he makes every day which necessitates passing by waste burning sites and inhaling harmful smoke generated by them (Egypt’s Garbage, 2013). Serious issues such as these receive little attention, and, most of the time, garbage is burned on main streets and during rush hours when the majority of students are on their way to school or people are heading to work.

Figure 1.9: Children standing near the waste burning (Egypt’s garbage, 2013)

Fig. (1.10) shows a common scene in Cairo: smoke emitted by waste burning covering the whole city as well as the sky (El Dahan, 2011)

Figure 1.10: smoke resulting from solid waste burning (El Dahan, 2011)

1.1.7 Construction and Demolition waste problems

Demolition wastes are defined as mixes of building materials such as aggregate, wood, paper, insulation materials, dirt, and so on. These materials are produced by the demolition of buildings or existing structures, either intentionally by man, or by natural disasters (El Ansary, El Haggar, 2001).

The construction industry produces vast amounts of waste. These wastes are produced throughout the different phases of the construction process starting from the extraction of virgin materials and their manufacturing process to the construction process itself and, finally, the demolition and disposal of the materials in landfills (Pilar, 2010). Some demolition wastes are presented in Fig. (1.11) whose waste includes materials such as bricks, wood, steel, and the like; the type of material found depends on each country's environmental factors.

In order to sustain the sustainable construction concept, therefore, it is necessary to increase the use of recycled materials in addition to decreasing construction and demolition waste during the whole construction process (Pilar, 2010).

Figure 1.11: Demolition waste resulting from demolished buildings (Kartman, 2004)

Construction and demolition waste accounts for a huge percentage of municipal solid waste at approximately 15% to 30%. Due to scarcity of landfill spaces and increasing building costs of the construction process, the need for C&DW has become a priority as well as the management of solid waste, especially in developing countries (Kartman, 2004). Previous studies estimate that, in developed countries, due to C&DW activities, there is total generation of around 500 to 1000 kg of waste per capita per year (Kartman, 2004).

Aggregates of high quality are becoming increasingly difficult to find. In fact, in the past, many aggregates sources were used up, compelling concrete patch plants to use fewer amounts of aggregates. Thus, to extract aggregates from the earth, a huge amount of energy is required, followed by an equally huge percent of energy needed to make these aggregates suitable for use in the concrete manufacturing process. Also, the mining activities have always been the main reason for environmental destruction. Given the above factors, the use of recycled aggregates, or demolition concrete, is becoming an urgent need (Maier, 2012).

According to the World Bank, Fig. (1.12) shows CO_2 emissions from the manufacturing and construction process in million metric tons. As can be seen from the figure, the emissions have been on the increase from 1982 to 2002. In fact, carbon dioxide is a “greenhouse” gas and a main contributor to global warming. Most of this

Co_2 is produced from the high temperature kilns used in the Portland cement plants (Maier, 2012).

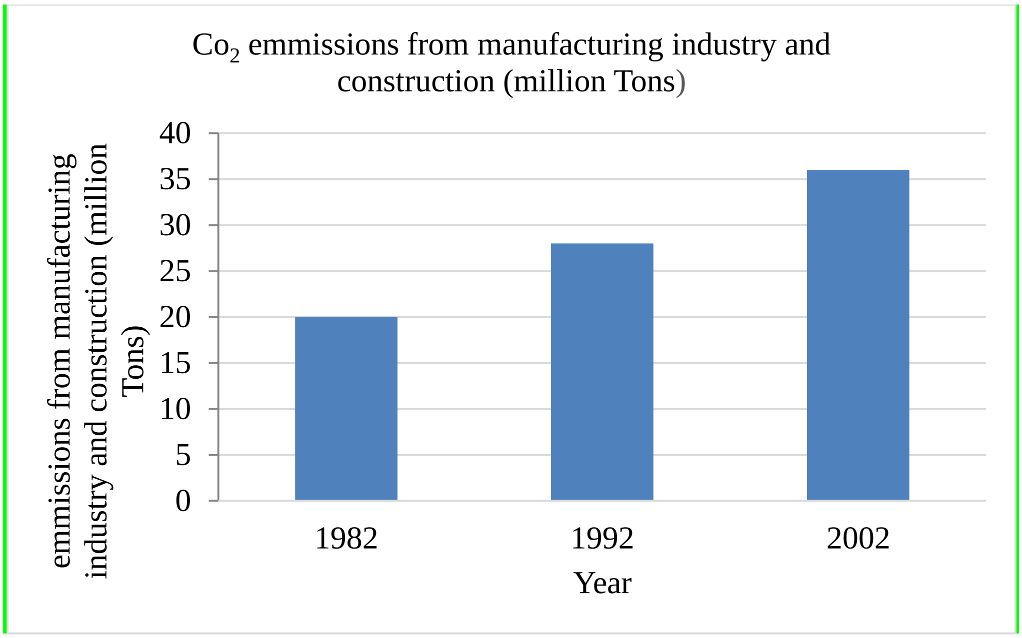


Figure 1.12: CO_2 emissions from the manufacturing and construction industry (World Bank)

It should also be mentioned that the construction process has many negative impacts on the environment throughout all its phases: on rural areas by building construction, at a geological level by extraction and use of materials, on air and water quality by emitting polluted liquid and gases to the environment, and, finally, by consuming vast amounts of energy (Pilar, 2010).

It should also be pointed out that the construction industry consumes huge quantities of raw materials, making it one of the highest environmental polluters. The wastes generated from building activities have the following characteristics (Khairulzan, 2006):

- They might contain high levels of hard to recycle materials, such as asbestos and insulation rated materials.
- They might contain high levels of chemical waste (materials that have a huge percentage of inflammability or taxability).
- Thus, prevention of construction and demolition waste is better than recycling it at the end of its lifecycle, and economically better for stakeholders.

Table (1.3), shows in details some of the construction waste that are considered hazardous. These materials have the following characteristics (Khairulzan, 2006):

- Ignitability (the ability to burn)
- Corrosives, which is the ability to eat human tissues upon contact
- Toxicity, the capacity to poison either in the short or long term
- Reactivity, which is the ability to cause explosions

Table 1.3: Hazardous construction materials (Khairulzan, 2006)

Acetone	Glues
Acetylene gas	Greases
Adhesives	Helium (in cylinders)
Ammonia	Hydraulic brake fluid
Antifreeze	Hydrochloric acid
Asphalt	Insulations
Benzene	Iron
Bleaching agents	Kerosene
Carbon black	Lime
Carbon dioxide (in cylinders)	Lubricating oils
Caulking, sealant agents	Lye
Caustic soda (sodium hydroxide)	Metals
Chromate salts	Methyl ethyl ketone
Chromium	Motor oil additives
Cleaning agents	Paint removers stripper
Coal tar pitch	Paint/lacquers
Coatings	Particle board
Cobalt	Pentachlorophenol
Concrete curing compounds	Polishes for metal Floors
Creosol	Putty
Cutting oil	Resins, epoxies
De-emulsifier for oil	Sealers
Diesel fuel oil	Shellac
Diesel lube oil	Solder, solder flux
Etching agents	Solvents
Ethyl alcohol	Sulfuric acid
Fiberglass, mineral wool	Transit pipe
Foam insulation	Varnishes
Freon	Waterproofing agents

Most of the construction and demolition waste were considered inert - neither interacting nor changing their physical, chemical, or biological characteristics when buried in landfills. However, this concept later proved to be wrong. Table (1.3) shows some of the construction and demolition waste, such as concrete additives, adhesives, glues and sealants, which were shown to decompose and leak chemicals into the environment; which might be extremely dangerous if they reach underground water (Pilar, 2010). Another problem of putting C&DW in landfills is that they occupy too much land area, a problem which results in reduced soil production capacity (Pilar, 2010). Table (1.4) shows an analysis of waste composition: As can be seen, brick (also concrete, tile, dirt) contain the highest percentage of inert residue (99%), as well as glass and metals. This means that these wastes do not decompose after incineration or even landfill; 99% of these wastes do not decompose at any stage. Consequently, this poses a severe threat to the environment. The fact that these waste do not decompose means that they consume a huge landfill area even while the landfill areas keep growing more and more scarce. By analyzing these materials, it is noticed that they all come from the construction industry. Glass, metals, as well as dirt, concrete, and bricks can be found after the demolition of a building. Glass comes from windows, doors, facades, and other decorative elements. Ferrous materials, on the other hand, come from steel reinforcement. Metals come from cladding, frames, rooftops, heating equipment, and other sources. Bricks come from walls while concrete comes from ceilings and floors. According to this analysis, once a building is demolished, the resulting construction and demolishing waste are problematic in terms of landfilling due to their inability to decompose.

Table 1.4: Analysis of waste composition (Chandrappa, 2012)

Waste material	Waste density (kg/m3)	Moisture content (%)	Inert Residue (%)	Calorific Value (Kj/kg)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulfer (%)
Asphalt	680	6 to 12		17100 -18400	83-87	9.9-11	0.2-0.8	0.3-1.1	1-5.4
Cardboard- corrogated paper box	30- 80	4 to 10	3 to 6	16375	44	5.9	44.6	0.3	0.2
Brick/Cement/Tile/dirt	800-1500	6 to 12	99						
Electronic equipment	105	50 - 80	0 to 50.8	14116-45358	38.85-83.10	3.56-14.22	7.46-51.50	0.03-9.95	
food waste	120-480		2 to 8		48	6.4	37.6	2.6	0.4
Garden trimmings	60-235	30 - 80	2 to 6	4785-18563	47	6	38	3.4	0.3
Glass	90-260	1 to 4	99						
Leather	90-450	8 to 12	8 to 20		60	8	11.6	10	
Metal-Ferrous	120-1200	2 to 6	99						
Metal non- ferrous	60-240	2 to 4	99						
Municipal solid waste/ biomedical waste	87-348	15 to 40	6 to 20						
			6 to 20						
Paper	30-130	4 to 10	8 to 20	12216-18540	43.5	6	44	0.3	0.2
Plastic	30-156	1 to 4			60	7.2	22.8		
Rubber	90-200	1 to 4			78	10		2	
Sandust	250-350			20510	49	6			0.1
Textile	30-100	6 to 15	2 to 4		55	6.6	31.2	4.6	0.15
Wood	156-900	15 to 40	1 to 2	14400-17400	49.5	6	42.7	0.2	0.1

1.1.8 Impact of building construction on the environment

In the following paragraphs an analysis of the buildings will be presented just to visualize the impact of buildings and their lifecycle on the environment (Belngini, 2009)

1.1.8.1 Building lifecycle phases analysis

Throughout the entire lifecycle of a building (either in the pre-use, use, or end of life phase) energy is consumed (Belngini, 2009). Table (1.5) explains in detail how each phase consumes energy. The pre-use phase entails: the production of the building material, its transport, and the construction process itself. Then, during the use phase, there is: the use of electricity, fuels for heating, water and lighting. At the end of life, energy is used for the demolition process, after which it is used to recycle aggregates and steel (Belngini, 2009).

Table 1.5: Building lifecycle phases analysis (Belngini, 2009)

Lifecycle phase	Subsystem
Pre-use phase	Building material production
	Transport
	Building Construction (including refurbishment)
Use (operational phase)	Use of electricity and fuels for heating, sanitary, water and lighting
End of life phase	Building demolition
	Aggregate recycling
	Steel recycling

1.1.8.2 Life cycle assessment of a building

A Case Study

The construction industry uses large amounts of raw materials as well as high energy during the production of those raw materials. In general, the materials used for the structure of a building make up more than 50% of the energy consumed in the actual building process itself. For this reason, the use of alternative such as hollow concrete blocks, fly ash, and so forth (instead of reinforced concrete) can save up to 20% of the cumulative energy over a period of 50 years. In addition, the recycling concept of steel and aluminum, for example, would save up to 50% of the energy.

In this case study, the lifecycle assessment of a building will be evaluated. The constituents of each material will be analyzed with a focus on concrete and bricks. In general, these materials proved to consume large amounts of water and energy during their production in addition to contributing to global warming by producing CO_2 emissions. Since all these materials were proven to harm the environment, it is essential to move to the recycling concept (Uson, 2011).

As can be seen in Table (1.6), for an ordinary brick of 1800 kg/m^3, the primary energy demand is 3.56MJ, it produces 0.271 kg of Co_2 and requires 1.890 L/kg. The highest water requirement goes to fiber cement roof slates followed by ceramic tiles. Fiber cement roof slates also account for the highest levels of global warming followed by ceramic tiles. Conversely, the production of light clay bricks decreases global warming effects and is the least one requiring water during its production process.

Table 1.6: LCA results for several types of bricks and tiles (Uson, 2011)

Building product	**Density (kg/m3)**	**Termal conductivity (W/mk)**	**Primary energy demand (MJ-Eq/kg)**	**Global Warming potential (kg CO2-Eq/kg)**	**Water demand (l/kg)**
Ordinary brick	1800	0.95	3.562	0.271	1.89
Light clay brick	1020	0.29	6.265	-0.004	1.415
Sand lime brick	1530	0.7	2.182	0.12	3.009
Ceramic tile	2000	1	15.649	0.857	14.453
Quarry tile	2100	1.5	2.2	0.29	3.009
Ceramic roof tile	2000	1	4.59	0.406	2.456
Concrete roof tile	2380	1.65	2.659	0.27	4.104
Fiber cement roof slate	1800	0.5	11.543	1.392	20.368

Cement and concrete products

As can be seen in Table (1.7), cement is a material that contributes the most to CO_2 emissions, requiring the highest amount of energy during its production and an equally high amount of water (compared to cement mortar, reinforced concrete and concrete).

Table 1.7: LCA results for cement and concrete (Uson, 2011)

Building product	**Density (kg/m3)**	**Termal conductivity (W/mk)**	**Primary energy demand (MJ-Eq/kg)**	**Global Warming potential (kg CO2-Eq/kg)**	**Water demand (l/kg)**
Cement	3150	1.4	4.235	0.819	3.937
Cement mortar	1525	0.7	2.171	0.241	3.329
Reinforced concrete	2546	2.3	1.802	0.179	2.768
Concrete	2380	1.65	1.105	0.137	2.045

1.1.9 Benefits of recycling

C&DW recycling has many advantages to the environment. It enables the reuse of some materials, which would otherwise have been produced from virgin/nonrenewable materials. C&DW recycling also helps reduce the bulk of materials to be disposed of in the landfill, thereby saving land space and protecting surface and underground water from contamination. Recycling also helps providing more job opportunities that would otherwise not have been created. In general, there are two types of recycling techniques (Shen, 2011).

- Open loop recycling: a method in which the material is manufactured to the same product as in concrete into renewed concrete, for example.
- Close loop recycling: in which the material is manufactured into other products (such as crushed concrete into regenerated cement).

Requirements for a successful C&DW recycling operation

For a successful C&DW operation, the following conditions should be satisfied (Chun-Li Peng, 1997).

- Favorable site location
- Suitable equipment
- Sound knowledge of C&DW recycling operations
- Trained employees
- Knowledge of the market
- Financial capacity
- Familiarity with safety regulations

Site location

It is necessary that the site contain enough space for the equipment and the incoming wastes to be treated. The site location should also be adjacent to the construction site it serves in order to reduce transportation costs. (Chun-Li Peng, 1997).

Suitable equipment

Special equipment for C&DW needs to be available on site. This equipment should be capable of handling mixed C&DW. Spare parts for this equipment should also be available on the market in addition to well-trained employees who know how to operate it. If these conditions are not met, there will be losses in time and revenues (Chun-Li Peng, 1997).

Good knowledge of C&DW recycling operations

For the success of a C&DW operation, it is necessary to have knowledge of the manufacturing process of the equipment, quality control issues, and waste separation techniques (Chun-Li Peng, 1997).

Trained employees

Employees should be well-trained in the use of the equipment, even under adverse working conditions. Many types of equipment such as front end loaders, conveyors, screens, and crushers require handling by skilled workmen (Pilar, 2010).

Knowledge of the market

The goal is to maximize benefit by selling the recovered materials to the market. Thus, identifying suitable markets, knowing the market prices, and establishing relationships with customers are crucial (Chun-Li Peng, 1997).

Financial capacity

The C&DW recycling process demands a substantial amount of money for its operation. This money is required for the operation of the equipment, and the startup of the business (Chun-Li Peng, 1997)

Knowing the safety regulations

The C&DW recycling process should be undertaken while protecting the environment from any pollution that might be produced. This includes protecting the surrounding area from air and water contamination. In the U.S, strict penalties have been enforced to protect the environment. Thus, operators should have familiarity with these regulations; otherwise, penalties costs will be very high (Chun-Li Peng, 1997).

Recovery

In order to minimize the production of C&DW, two procedures should be followed:

- The source reduction technique
- Applying waste management strategies

One major product produced from C&DW recycling is aggregates that can be reused in the construction process. This would reduce the use of virgin sources and disposal of used aggregates in landfills (Pilar, 2010).

Acceptance in the Market

One major problem in reusing recycled aggregates is accepting it in the market. Prices of recycled C&DW vary based on several factors, one of which is the purity of the recycled waste itself. Production of a pure, homogenous material from recycled C&DW is expensive, and its costs might not be recoverable (Pilar, 2010).

1.1.10 C&DW recycling

Prior to any kind of demolition, hazardous materials are first removed. This procedure is done by trained laborers who receive the waste and treat it. The recovered materials depend on the type of demolition employed. Allowing individuals to enter the building before the demolition occurs could enable recovery of certain materials. On the other hand, if explosive were used, all the generated types of wastes would be mixed together. These kinds of explosives are used in cases where the target demolition area is crowded and hard to access (Kourmpanis, 2008).

Conventional demolition waste

The conventional demolition waste procedure can be summarized as follows (Kourmpanis, 2008).

- All services are disconnected (such as electricity, water, and drainage)
- A 1m width strip is cut along the demolition line
- Scaffoldings and screens are provided around the building
- A debris gap is provided on each floor (from 2 to $3m^2$)
- A backhoe is placed on the roof
- The beams, columns and slabs on the top floors are first demolished, then the ones on the lower floors
- Pile caps and ground beams are grubbed up
- Rubbish and old materials are collected
- Demolition materials are separated from rubbish for recycling
- Debris is thrown away

Complete and partial selective demolition

The conventional demolition method proved to deliver a low percentage of recovered materials. For this reason, other demolition methods, such as the complete and partial-selective, are used. The difference between the conventional and the selective method is that in the latter method, workers use lightweight tools in the demolition to recover the highest percentage of waste, while in the conventional method, they use heavy equipment and explosives which results in mixed wastes that are difficult to separate and recover (Kourmpanis, 2008).

The complete selective demolition method is mainly divided into phases. In each phase, a different material is recovered. This demolition method is done manually, which takes a longer time compared to the conventional one. The resulting material is free of contaminants and hazardous materials (Kourmpanis, 2008).

Partially selective demolition

This method is a combination of the complete selective and partial demolition methods. In this method, workers use lightweight equipment; however, the resulting wastes might still contain dangerous materials and contaminants (Kourmpanis, 2008).

Location of waste management

Waste management techniques vary widely from simple crushers to fully equipped recycling centers. Therefore, the choice of the waste management location is a critical matter. Waste management can be located either on-site or off-site, both of whose respective advantages and disadvantages are discussed as follows (Kourmpanis, 2008).

Off- site waste management

This includes the recycling centers and large scale treatment plants that feature heavy equipment. This equipment includes metal removal units (for a more intricate process of sorting and sieving) and a washing unit. These recycling centers are capable of handling contaminated and mixed wastes. Fig. (1.13) shows the sorting process in the recycling center.

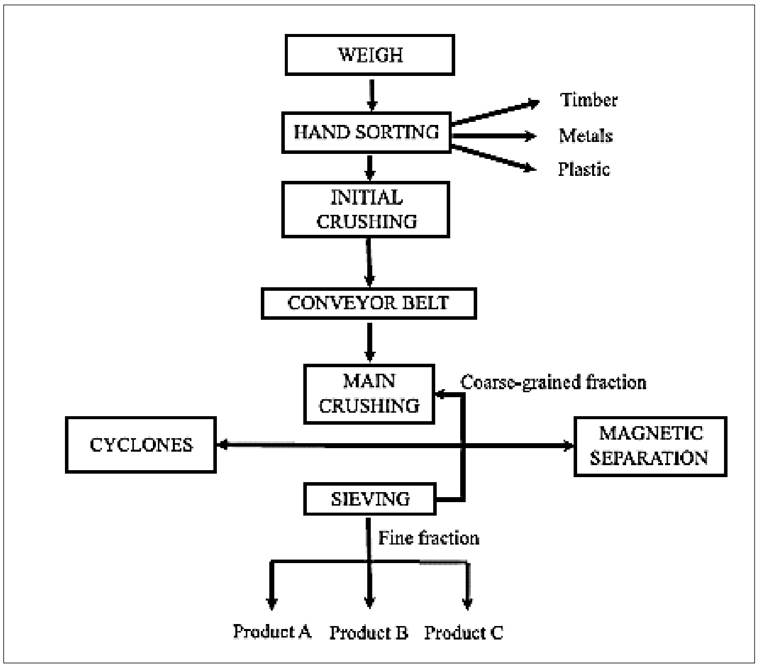


Figure 1.13: Flow chart for recycling centers (Kourmpanis, 2008)

Such recycling centers are common in countries where landfill is prohibited or where landfill fees are very high. For this reason, the only way for solid waste management is to recycle them (Kourmpanis, 2008).

1.1.11 Construction and demolition waste worldwide

C&DW issue from the following sources: waste generated by the demolition of buildings, waste generated by the construction of buildings, materials (such as soil and vegetation) generated by clearing activities (Pilar, 2010). Waste characterization percentages vary from one country to another. In Egypt, the amount of (C&DW) was estimated as 10,000 tons per day, accounting for 4.5 million tons annually (Al-Ansary 2001) .Some of these percentages are presented below in Table (1.8)

Table 1.8: Waste characterization in Spain (Pilar, 2010)

Material	**Percentage**
Bricks, tiles, ceramic materials (masonry)	54%
Concrete	12%
Stone	5%
Sand, gravel, aggregates	4%
Wood	4%
Glass	1.5%
Plastic	1.5%
Metals	2.5%
Gypsum	0.2%
Paper	0.2%
Rubbish	7%
Others	3.1%

- In Spain: 70% of the total waste is C&DW. Production of C&DW grew between the periods of (2001 to 2006), with an average rate of 8.7% annually. Over 50% was discharged without controlling it, more than 30% was sent to landfill or rejected for treatment, and less than 8% was recycled or recovered (Liattas, 2011).

- In the United States, the construction industry is facing a huge problem in finding landfill areas for its C&DW which range from 20kg/m^2 to 30 kg/m^2 for most of the buildings nationwide. C&DW landfill tipping fees range from $8 per ton in New Mexico to $75 per ton in New Jersey while the cost keeps rising. Each year, U.S. builders produce about 31.5 million tons of construction waste, which accounts for more than 25% of the municipal solid waste. Therefore, the motive for reducing construction and demolition waste is purely economic, raising the need to reduce "waste costs money" (Scorpio, 1997).
- In the U.K, annual extraction requires 275 million tons of new construction aggregates: if demand for aggregates in the UK increases annually by 1%, an extra 20 million tons of aggregates would be needed each year. 60% of the extracted aggregates are crushed rock while 40% are sand and gravel. In fact, these materials are essential for both buildings and the infrastructure; however, this extraction causes tremendous impacts to the environment. The British government aims to reduce the demand for primary aggregates by minimizing construction and demolition waste and maximizing the use of alternative materials (Kangkang, 2011).
- Generally speaking, the biggest drain on resources in Europe comes from construction projects; moreover, the single largest waste stream deriving from C&DW generated by construction activities accounts for 82.7% of total waste produced by economic activities and 48% of total waste in the European Union (Liatta, 2011).

Based on the previous analysis, C&DW constitutes one of the largest waste streams within Europe after mining and farming operations. According to data provided by the EU Environment General Directorate, demolition waste totals 180 million tons per year, 55% of which is either reused or recycled (Pilar, 2010).

1.1.12 Laws and regulations

It is known that waste accumulation in the environment occurs more rapidly than natural degradation of the waste itself. For this reason, if a project producing waste is going to be economically successful, its social benefits will be negative due to the large amount of waste produced.

Therefore, while evaluating a project, not only should the economic advantage be taken into consideration, but also the social benefits (Shen. 2011). More environmental policies should be laid down to reduce the cost of construction and demolition waste. These wastes can be categorized as either quantitative or qualitative. Quantitative measures apply mainly to the design phase, where the designer considers ways to reduce the amount of waste generated by demolition, and promote the re-use of materials. On the other hand, qualitative measures depend on reducing the use of dangerous materials in constructing new buildings (Pilar, 2010).

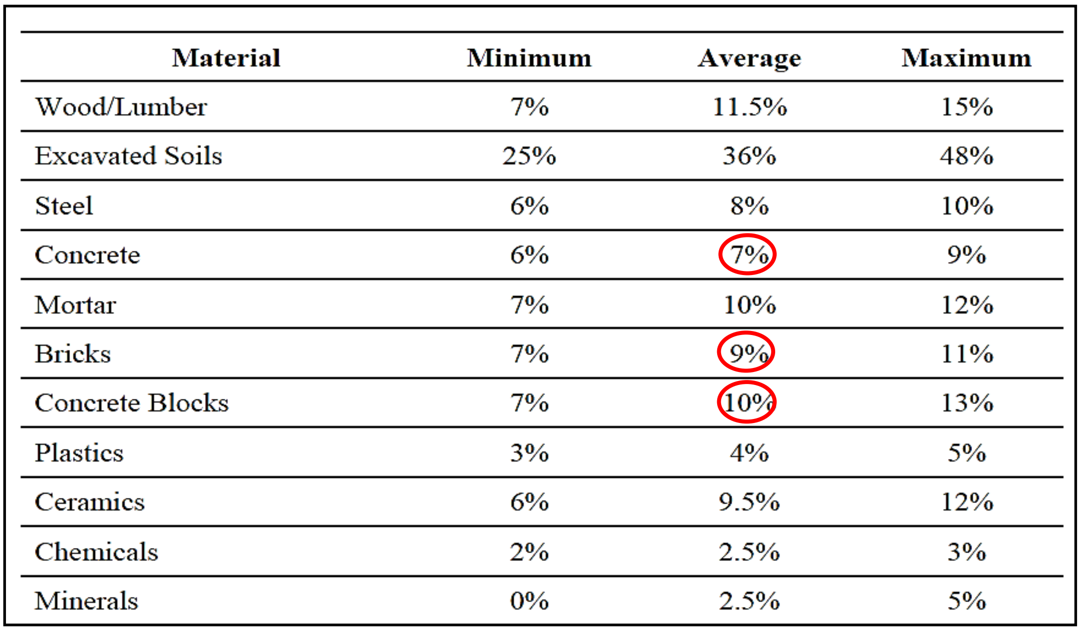
Many rules and regulations have been applied in an attempt to reduce damage of C&DW to the environment. These rules seek to enforce the following (Pilar, 2010):

- Proper management of C&DW
- Application of waste recycling measures by industries
- Increased tipping fees for C&DW

1.1.13 Construction and demolition waste in Egypt

Table (1.9) represents construction and demolition waste composition in Egypt (Al- Ansary, 2001). These figures represent the most recent available data.

Table 1.9: Demolition waste composition in Egypt



Material	Minimum	Average	Maximum
Wood/Lumber	7%	11.5%	15%
Excavated Soils	25%	36%	48%
Steel	6%	8%	10%
Concrete	6%	7%	9%
Mortar	7%	10%	12%
Bricks	7%	9%	11%
Concrete Blocks	7%	10%	13%
Plastics	3%	4%	5%
Ceramics	6%	9.5%	12%
Chemicals	2%	2.5%	3%
Minerals	0%	2.5%	5%

Construction and demolition waste is dumped anywhere, without proper waste management. Most construction and demolition waste is composed of concrete and masonry. It should also be mentioned that the work previously performed in C&DW recycling is extremely limited in addition to many obstacles encountered in obtaining data, information, and prices from the construction industry. Fig. (1.14A and 1.14B) are real pictures that were taken in New Cairo area, where there are many construction sites.

Figure 1.14A: Recent pictures taken in New Cairo (March, 2013)

Figure 1.14B: Recent pictures taken in New Cairo (March, 2013)

CHAPTER (2)
LITTERATURE REVIEW

Introduction

Solid waste management is a critical public issue that affects health as well as the environment. Solid waste is not only limited to waste collection and disposal, but it also includes collection, transportation, sorting, and recycling. Solid waste management is influenced by culture as well as awareness levels. The issue of solid waste management, both traditionally and potentially, poses an ongoing challenge (Milik, 2011.)

In 2003, Egypt adopted a garbage collection system for which the “Zabaleen” assumed responsibility. In this system, the Zabaleen used to recycle 80 to 90% of the garbage they collect. However, due to the Swan Flu, this system failed. Other garbage collection efforts include a project run by private collection companies in which the garbage is crushed and, as a result, cannot be recycled, the only option being to dump it in the streets (Moussa, 2010). In addition, due ever rising population, traditional garbage collection methods of the “Zabaleen” have become ineffective (Mitwally, 2009). This leads to rotting food piling up on the streets, even in affluent districts such as Heliopolis and Zamalek (Mitwally, 2009).

This chapter will discuss two main points: the importance of recycling in developing countries, in general, and will then focus on the importance of recycling in the construction industry, in particular. In developing countries, recycling has a social as well as an economic impact. The “Zabaleen” area in Egypt is an example of “informal waste collection” where waste is recycled and sold, and considered a source of income (Vellis, 2006). With regard to the construction industry, in particular, there is a strong need to “green” this area (Meyer, 2009). As previously discussed, the construction industry consumes a huge amount of energy with equally severe negative effects on the environment. Most of the materials used in this industry are “virgin” materials that are only used once, then either dumped or landfilled at the end of their lifecycle with no possibility of being recycled. This chapter will focus on certain materials that can be recycled in the construction industry as well as the physical and mechanical properties of recycled materials and a comparison with those of virgin ones.

2.1 Recycling in developing countries

Informal waste collection is generally performed by poor people, usually from minority groups, who resort to waste collection for income generation. This is a common practice in urban areas across the developing world. The percentage of such activities is roughly 2% in Asian and Latin American cities. Examples of these informal urban waste collecting sites exist in: Zabaleen (Egypt), Pepenadores, Catroneros and Buscabotes (Mexico), Basuriegos, Cartoneros, Traperos and Chatarreros (Colombia), Chamberos (Ecuador), Buzos (Costa Rica) and Cirujas (Argentina). Fig. (2.1) shows waste pickers at an open dump area (Vellis, 2006).

Figure 2.1: Waste Pickers sorting waste at open dump (Vellis, 2006)

In cities featuring formal and municipal waste collection as well as a disposal system, there are at least four categories of informal recycling. These four categories are as follows (Vellis, 2006):

- Itinerant waste buyers: in this category (such as in China and Thailand) collectors go from door to door to collect recyclable materials from households. Collectors then sell this waste to a recycling shop working in the same type of material collected.
- Street waste picking: the secondary raw materials are collected from waste in the streets before collection.
- Municipal waste collection crew: secondary raw materials are collected/recovered from vehicles collecting municipal solid waste.

- Waste picking from dumps: collectors recover raw materials before leaving them in the dumps. This is often done by community members living near dumping areas.

2.1.1 Organization types and the recycling trade hierarchy

Fig. (2.2) depicts and simplifies the waste trade hierarchy as follows: individual waste pickers are at the base of the hierarchy as they are the most vulnerable group lacking resources for proper waste collection and sorting (which is why they have the least valued waste). In contrast, manufacturing industries are placed at the top; since they have sufficient resources for waste collection, they get the most valuable waste. The way informal waste collection is classified affects income generation, working conditions and social status. The less organized the waste collection process is, the less able people are to add value to the raw materials they collect.

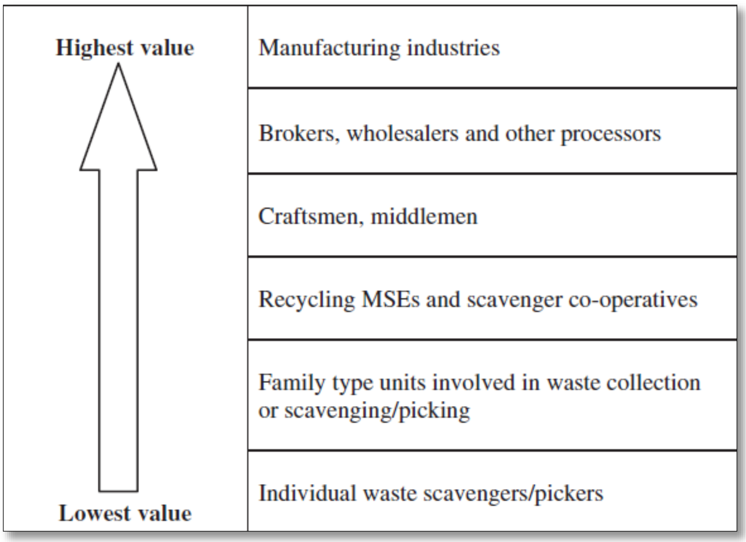


Figure 2.2: Recycling trade hierarchy

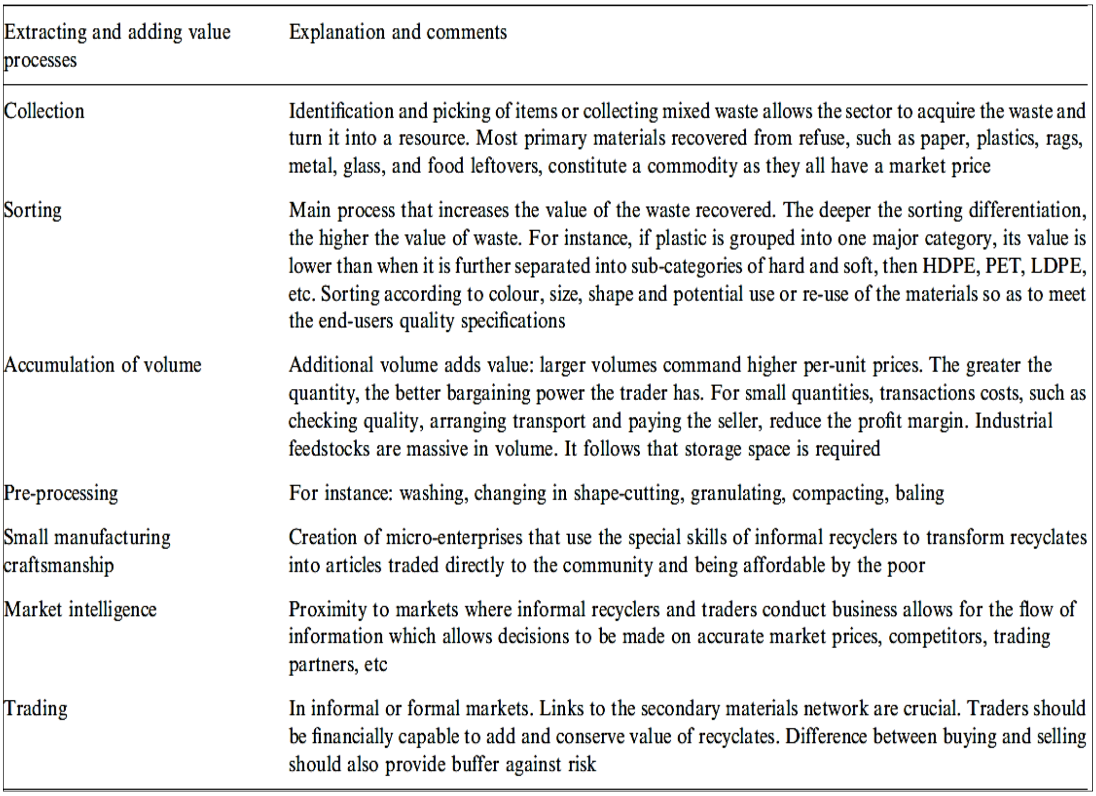
In most cases, the secondary materials collected are traded locally. End users can be industries, craftsmen, or artisans (Vellis, 2006). It should be pointed out, also, that individual waste pickers are the most vulnerable category since they lack a supporting network. Individual waste scavengers/pickers are located at the base of the hierarchy, which explains their low income. Family-based activities are common in the dump scavenging area under the informal collection system. This family system uses vulnerable groups such as children, women, and the elderly. This is considered a disadvantage for children as they are unable to attend school. In addition, scavenging exposes children to health risks. However, training can be provided to maximize earnings by this informal sector so that they can add value to the raw material they sort. To increase the social status of the "waste collectors", moreover, a "Waste Collectors Associations" can be formed to enhance their position in society. In addition, ways should be looked into to integrate efforts of informal waste collection with the formal one – an issue which can be raised in Public Policies (Vellis, 2006).

2.1.2 The economic value of informal recycling

The informal sector is trained to find high-value waste. Discarded waste is taken and value added to using methods such as cleaning, sorting, or changing the physical shape. The potential profit margin is the main criteria for selecting materials targeted for recycling. Commonly recycled materials include plastics, paper, steel, aluminum, cardboard and other materials, and organic waste which is utilized as animal food and in composting. The degree to which a material is recycled depends on various factors such as: income level, existence of a local or international market, prices of virgin material, and the need for secondary raw material. Examples of places that depend on secondary raw materials are China and India. The income of waste pickers is very low due to their position at the base of the trade hierarchy rather than their actual poverty level. These workers are ruthlessly exploited and paid very little for collecting waste material, particularly in cases where dumps are located far away from the city. In some cases, waste collectors have to pay a 'fee' to access the waste itself. It is also worth mentioning that waste collection plays a key role in developed countries due to low economic development. These low wages and service fees create a high profit margin from recycling and collection (Vellis, 2006).

Table (2.1) reveals how "value" is added to collected material. During the collection process, for example, the most important materials picked are: paper, plastics, and rags as they have a high value compared to other materials. In the sorting process, the more rigorously materials are sorted and differentiated into sub- groups, the higher their value becomes as is the case with plastic material. A similar correlation is found with volume and price per unit. The pre-processing phase (such as the washing process, the change in shape, and the compacting and baling process), is especially important. This is because it helps recover the product in its purest form, thus ensuring selling it at a high price. Due to the importance of market intelligence, proximity to areas where informal recyclers work facilitates the flow of information and fixing market prices (Vellis, 2006).

Table 2.1: Ways of extracting and adding value processes (Vellis, 2006)



Extracting and adding value processes	Explanation and comments
Collection	Identification and picking of items or collecting mixed waste allows the sector to acquire the waste and turn it into a resource. Most primary materials recovered from refuse, such as paper, plastics, rags, metal, glass, and food leftovers, constitute a commodity as they all have a market price
Sorting	Main process that increases the value of the waste recovered. The deeper the sorting differentiation, the higher the value of waste. For instance, if plastic is grouped into one major category, its value is lower than when it is further separated into sub-categories of hard and soft, then HDPE, PET, LDPE, etc. Sorting according to colour, size, shape and potential use or re-use of the materials so as to meet the end-users quality specifications
Accumulation of volume	Additional volume adds value: larger volumes command higher per-unit prices. The greater the quantity, the better bargaining power the trader has. For small quantities, transactions costs, such as checking quality, arranging transport and paying the seller, reduce the profit margin. Industrial feedstocks are massive in volume. It follows that storage space is required
Pre-processing	For instance: washing, changing in shape-cutting, granulating, compacting, baling
Small manufacturing craftsmanship	Creation of micro-enterprises that use the special skills of informal recyclers to transform recyclates into articles traded directly to the community and being affordable by the poor
Market intelligence	Proximity to markets where informal recyclers and traders conduct business allows for the flow of information which allows decisions to be made on accurate market prices, competitors, trading partners, etc
Trading	In informal or formal markets. Links to the secondary materials network are crucial. Traders should be financially capable to add and conserve value of recyclates. Difference between buying and selling should also provide buffer against risk

2.1.3 Economic and social issues

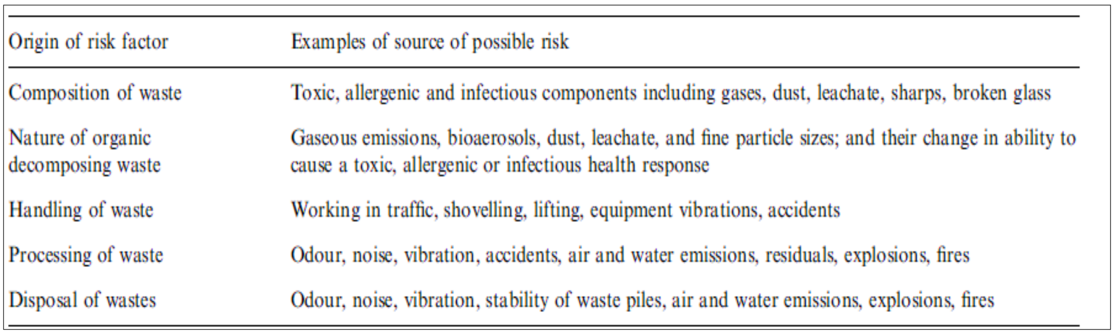
As discussed earlier, the informal recycling system is an important economic incentive in developing countries, most of which are characterized by an abundant workforce and scarce capital. This also encourages the manufacturing of low cost-products. The informal recycling system reduces the cost/burden on the formal recycling system, as it reduces the quantity of waste going to the formal sector, indirectly cutting down on waste and disposal fees. There are also social benefits associated with the informal recycling sector, such as reducing unemployment in countries that suffer from this problem. The scavengers/ waste collectors might not be able to enter the formal sector due to poor education or physical disabilities. The informal recycling system has always been developed by marginalized groups in developing countries such as gypsies, immigrants, and some minor religious groups.

These groups are isolated and it is this isolation that leads scavengers and waste collectors to develop their own customs and traditions for waste collection. Also, as a result of their marginalization, these minorities can be subject to harassment by authorities such as the police. These communities live in poor conditions, and have limited access to clean water and infrastructure, with none at all to social safety networks (Vellis, 2006).

2.1.4 Health impacts of informal recycling

Health and safety factors associated with informal recycling come under two broad categories: first, the health problems potentially caused to waste pickers themselves, and, second, health problems threatening the general public. These health problems are caused during collection, processing or the recycling process, the most serious being during waste collection from open dumps. The case is even worse in developing countries as pickers neglect to wear protective cloth/equipment while handling waste, thus putting themselves into direct contact with the waste. Typical wastes include paper (contaminated with toxic materials), containers (containing chemicals), medical wastes (containing needles and bandages). In addition to these hazards, workers inhale fumes resulting from open dumping which can cause severe respiration problems, eye problems, and lower longevity. The most at risk group is that of women and children since they have maximum exposure to waste collection. (Vellis, 2006). Table (2.2) explains in detail sources of risk and where they come from. The composition of waste itself may cause problems as they might contain toxic materials, broken glass, sharp objects, leachate, and dust. The handling of waste itself might causes risk due to occupational hazard. Waste processing results in odor, noise, vibrations, accidents as well as air and water emissions. In brief, each stage of handling waste may be hazardous to health unless precautions are taken. (Vellis, 2006).

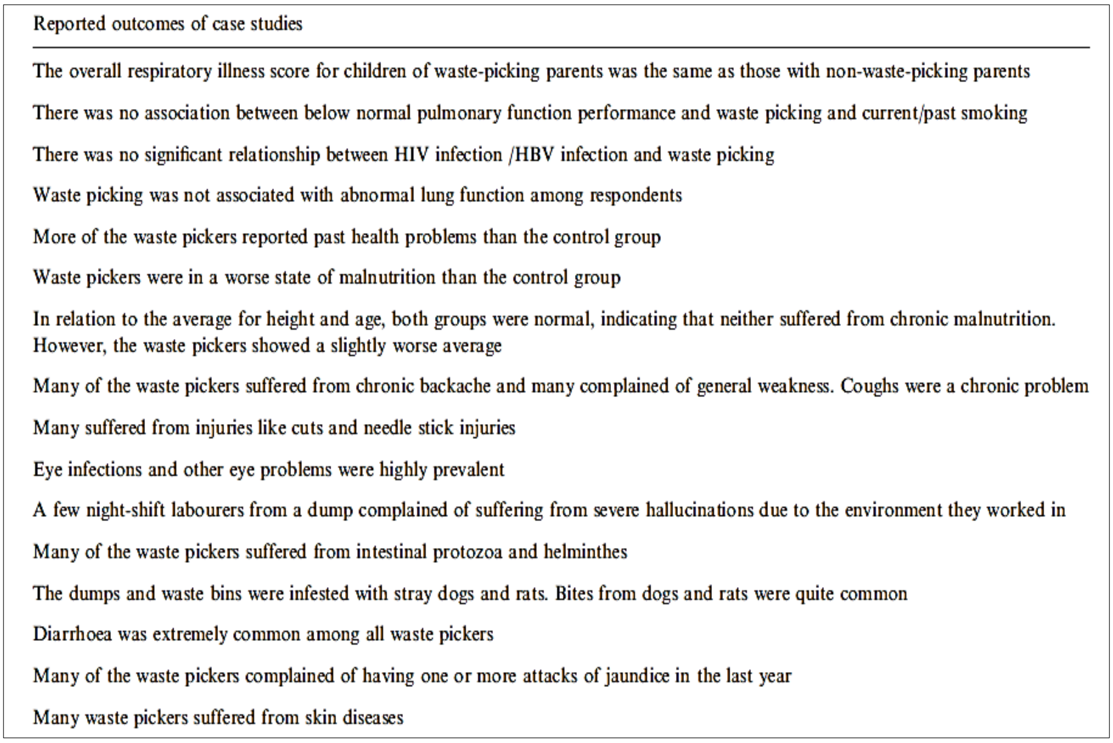
Table 2.2: Risk causing factors related to solid waste management (Vellis, 2006)



Origin of risk factor	Examples of source of possible risk
Composition of waste	Toxic, allergenic and infectious components including gases, dust, leachate, sharps, broken glass
Nature of organic decomposing waste	Gaseous emissions, bioaerosols, dust, leachate, and fine particle sizes; and their change in ability to cause a toxic, allergenic or infectious health response
Handling of waste	Working in traffic, shovelling, lifting, equipment vibrations, accidents
Processing of waste	Odour, noise, vibration, accidents, air and water emissions, residuals, explosions, fires
Disposal of wastes	Odour, noise, vibration, stability of waste piles, air and water emissions, explosions, fires

As previously explained, eye infections were frequently reported in addition to skin diseases (Vellis, 2006). Also reported, were respiratory system problems, for those involved in the waste collection process, and many cases of malnutrition compared to the control group. Many of the waste pickers also suffered from cuts resulting from picking needles as indicated in Table (2.3).

Table 2.3: Health problems associated with waste collection (Vellis, 2006)



Reported outcomes of case studies
The overall respiratory illness score for children of waste-picking parents was the same as those with non-waste-picking parents
There was no association between below normal pulmonary function performance and waste picking and current/past smoking
There was no significant relationship between HIV infection /HBV infection and waste picking
Waste picking was not associated with abnormal lung function among respondents
More of the waste pickers reported past health problems than the control group
Waste pickers were in a worse state of malnutrition than the control group
In relation to the average for height and age, both groups were normal, indicating that neither suffered from chronic malnutrition. However, the waste pickers showed a slightly worse average
Many of the waste pickers suffered from chronic backache and many complained of general weakness. Coughs were a chronic problem
Many suffered from injuries like cuts and needle stick injuries
Eye infections and other eye problems were highly prevalent
A few night-shift labourers from a dump complained of suffering from severe hallucinations due to the environment they worked in
Many of the waste pickers suffered from intestinal protozoa and helminthes
The dumps and waste bins were infested with stray dogs and rats. Bites from dogs and rats were quite common
Diarrhoea was extremely common among all waste pickers
Many of the waste pickers complained of having one or more attacks of jaundice in the last year
Many waste pickers suffered from skin diseases

2.1.5 Success stories: Recycling as a way for learning and earning

The daily amount of waste produced from Cairo is 14, 000 tons (Viney, 2013) . However, authorities cannot cope with the quantity of waste produced. For this reason, Cairo depends on informal waste collectors, although they are not contracted by official agencies. When the Egyptian government in year 2000 contracted multinational waste management firms to set up a centralized waste collection system, the living conditions of informal collectors became threatened (Baraka, 2006). During this time, the consultancy firm Community and Institutional Development (CID), supported by the UNESCO Cairo Office, initiated the Mokattam recycling schools for boys to help lift them out of poverty. Fig. (2.3) shows a scene from one of the Mokattam recycling schools where a boy is working on sorting a piece of plastic comprised of different materials to be recycled later. In fact, these schools play the role of "non-formal basic education" for poor people without access to formal education. Dr. Laila Iskandar, the founder of CID, states that this "non-formal" education links the learning process to work-related contexts". In other words, recycling schools offer flexible hours that enable students to have time later to work with their parents.

Figure 2.3: A child studying in the Mokattam recycling schools (Baraka, 2006)

As a result, informal waste recycling schools have become a place of non-formal learning and skill acquisition for thousands of youth in Cairo. The concept of the recycling school is to integrate "education, work experience, environmental protection, poverty alleviation and earning to create a matrix where one project improves an impoverished community on many levels". The Mokattam School follows an interesting learning program: in the morning, the boys collect empty bottles, for which they are compensated based on the number of bottles they collect. One unexpected benefit of this system is that it requires students to learn reading and writing as well as mathematics. The curriculum of these schools includes the following: "literacy, numeracy, business math, personal and environmental hygiene, income generation and recycling, computer literacy, principles of project management, bookkeeping and simple accounting, along with recreational theatre arts." Fig. (2.4) depicts one of the recycling schools in the "Zabaleen" area. In this school, cloth is sorted according to different materials, and then recycled to create bags or can even to be used in the textile industry (Baraka, 2006). Based on the previous, recycling offers practical ways for improving living conditions in the Egyptian society; not only do they learn how to recycle, but they also learn how to read and write (Baraka, 2006).

Figure 2.4: Cloth recycling in Zabaleen area (Alperye, 2013)

2.2 Recycling in the construction industry

2.2.1 Greening the construction industry

As previously mentioned, the construction industry has represented many negative effects on the environment. For example, concrete production adversely affects the environment for three main reasons; first, numerous natural resources are required for concrete production. It is well known that the Portland cement production releases massive amounts of carbon dioxide into the atmosphere: the production of one ton of cement emits one ton of carbon dioxide to the atmosphere as demonstrated in Fig. (2.5). Second, as exemplified by the production of Portland cement, cement production requires enormous amounts of energy. Finally, the production of concrete requires copious amounts of water, which poses a major problem in places where obtaining water is already difficult, as well as depletion of natural resources. Also, after using concrete in the construction industry and at the end of the lifecycle of buildings, disposal of concrete in landfills is a problematic issue. One way to solve this problem is to substitute Portland cement with other cementation materials. These materials can include Fly ash, Ground granulated blast furnace slag, Silica Fume, Post-consumer Glass, and recycled tires among others (Meyer, 2009).

Figure 2.5: Co_2 produced from the cement industry (Lakshmi, 2010)

2.2.1.1 Fly Ash

Fly ash is an important Pozzolan. It has many advantages compared to ordinary Portland cement. Its heat of hydration is low which makes it perfect for mass structures; however, it cannot be used in applications where early strength is required. It is important to add that fly ash is a by-product of coal combustion, which if not reused requires costly disposal procedures. Fly ash is found in places where there is coal industry and it is less expensive compared to the Portland cement. Fig. (2.6) shows the amount of fly ash produced during the coal production process (Meyer, 2009).

Figure 2.6: Fly ash resulting during the coal industry (Mine reclamation, 2013)

2.2.1.2 Ground granulated blast furnace slag (GGBFS)

Ground granulated blast furnace slag is a by-product of the steel industry. It is a glassy material formed when molten blast furnace slag is rapidly chilled, as by immersion in water. Due to its many advantages, furnace slag is not only used for partial cement replacement, but is also used as aggregates as shown in Fig. (2.7). Optimum cement replacement is estimated at 50% to 80%. It also improves mechanical properties and durability. To give an example, a nine foot thick foundation slab for water treatment was built in New York using 70% slag and 30% Portland cement. It should also be mentioned that the steel industry produces large quantities of slag, most of which is then land-filled or stockpiled. However, such disposal is costly, especially that these materials contain toxic materials that may leak out and contaminate the surrounding soil, or underground water; thus, the most expedient method of getting rid of these materials is re-use (Meyer, 2009).

Figure 2.7: Ground granulated blast furnace slag (GGFS 2013)

2.2.1.3 Silica Fume

Silica fume is a by-product of the semiconductor industry. This material adds more strength and durability to the material. High performance concrete mix designs contain silica fume. Also, due to its fineness, silica fume can be used as filler in many construction applications, as can be seen in Fig. (2.8) (Meyer, 2009).

Figure 2.8: Silica Fume (Silica fume, 2013)

2.2.1.4 Post-consumer glass

According to Columbia University researchers, post-consumer glass can be used as an aggregate. In fact, it costs New York City taxpayers over 60 million dollars each year to dispose of post-consumer glass in landfills. It should also be mentioned that glass as a material is non-water absorbent, its hardness is high, and has good abrasion resistance as well as a pleasing aesthetic appearance (due to its different colors). Also, the cost of collecting, sorting, and washing glass is low compared to aggregates. Fig. (2.9) shows bricks made from recycled glass. As they have an attractive appearance, they can be used as decorative elements. They also have a lighter weight compared to bricks made with aggregates (Meyer, 2009).

Figure 2.9: Bricks made from Recycled glass (Bricks made from recycled glass, 2013)

2.2.1.5 Recycled tires

Hundreds of tons of tires are produced each year in developed countries, causing serious environmental problems. Dumping causes serious hazardous problems as well as attracting insects. Thus, the most suitable way is to reuse them, even at the end of their lifecycle. Currently, the most common way for getting rid of tires is to burn them in steam and electricity production. In the United States and Europe, the use of alternative tires for energy in cement production is widespread. Scrap tires are used in hot mixed asphalt in asphalt pavements. The most commonly practiced method is to shred the recycled tires into particles to use it in the concrete mix **.**The resulting particles can range from 450mm to powdery ones as small as 75um. However, the use of tires in concrete causes a decrease in compressive and tensile strength, as well as stiffness caused by increasing the percentage of tires. On the other hand, the tires have the effect of reducing the propagation of cracks, which increases strain capacity, ductility, and energy absorption (Meyer, 2009). Fig. (2.10) illustrates recycled tires used as shingles on roofs. These tires have an advantage over concrete as they have more elasticity and water resistance (Green material, 2013)

Figure 2.10: Recycled tires used in shingles (Green material, 2013)

2.2.1.6 Other recycled materials

Many other materials can be recycled and reused for the greening of the construction industry. Rice husk ash resulting from burning rice husks contains proven cementation materials and can therefore be used as supplementary cementation material. The disposal of the ash in landfill areas poses a great problem as ash is considered a hazardous material that contains toxic elements (Meyer, 2009).

All the previous materials discussed above such as Fly ash, Ground granulated blast furnaces slag, Silica fume, Post consumer glass, and recycled tires are some of the materials that can be recycled in the construction industry. However, there are also other materials found in abundance in Egypt that can be recycled. As shown earlier in Table (1.9), the most commonly found materials in Egypt are masonry and concrete. These materials can be recycled and reused in many applications such as recycled aggregates that can be used in many applications. The properties of these recycled aggregates are discussed below.

2.3 Properties of recycled aggregates

2.3.1 Masonry waste

In general, masonry wastes derive from two sources, 60% of which comes from demolition works. Such types of demolition wastes incorporate other components such as bricks, cement mortars and concrete. Also, the type of structure itself plays a major role in determining the properties of these demolished wastes later on (Chun Li Peng, 1997).

Properties of recycled aggregates from masonry waste

Properties of the new aggregates depend on the composition of the waste itself. The properties of aggregates recycled from masonry waste will feature 65% of the main ones. One of the disadvantages of recycled aggregates is that they have more porosity than virgin aggregates, which gives rise to more water absorption. The use of recycled aggregates is not recommended in aggressive environments with acidity values below pH$_7$ (Chun Li Peng, 1997).

Applications for recycled aggregates from masonry waste

Aggregates can be used in the following applications: light concrete, mortars, roofs, concrete blocks and in tiles (Chun Li Peng, 1997).

2.3.2 Properties of concrete made from recycled aggregates

First of all, the method for producing concrete with recycled aggregates is the same if the mixes contain natural aggregates (Chun Li Peng, 1997).

- When recycled aggregates are used with sand, the w/c ratio to reach a required compressive strength for recycled aggregate concrete is the same for the conventional one.
- The sand to aggregate ratio is also the same (as if natural aggregates were used).
- Other trial mixes should be made to know the properties of recycled aggregates, as this depends on the source.

2.3.3 Properties of freshly Recycled Aggregate Concrete

When recycled aggregates replace natural aggregates by more than 50%, the workability of the mix decreases. This is because recycled aggregates tend to absorb more water than natural ones. To solve this problem, recycled aggregates should be used in saturated rather than dry form. The air content of recycled aggregates is higher than natural ones (by 4%to 5.5%) if the replacement is 100%. This is due to the higher porosity of recycled aggregates compared to natural ones. The bulk density of fresh concrete with natural aggregates is in the range of 2400 kg/m^3, while that made with recycled aggregates lies in the range of 2150kg/m^3 (Vellis, 2006).

2.3.4 Properties of hardened Recycled Aggregate Concrete

2.3.4.1 Compressive strength

There are many factors that affect compressive strength. These factors are: the initial compressive strength from which the aggregates were recycled. Also considered are the w/c ratio and the moisture level of the aggregates. The strength of recycled aggregates can be compared to that of the concrete from which they were produced at a replacement level of 75%. However, other research found that the recycled aggregates concrete can be compared to the reference concrete up to a 100% replacement provided that the w/c ratio is higher than 0.55 (Vellis, 2006)

2.3.4.2 Flexural and tensile strength

The ratio of flexural and splitting strength to compressive strength is in the range of 16%-23% and 9%-13% respectively. These values proved to be less than that required by (10% to 15%) (Chun Li Peng, 1997).

2.3.4.3 Bond strength

At a replacement rate of 100%, the bond strength proved to be reduced by 10%.

2.3.4.4 Modulus of elasticity

The modulus of elasticity of recycled aggregate concrete was reported to be in the range of 50%-70% of normal concrete (Chun Li Peng, 1997).

2.3.4.5 Creep and shrinkage

The use of recycled aggregates causes shrinkage since they are more prone to absorbing water than natural ones. Some studies show that in the RAC at 90 days, the shrinkage range can be from 0.55-0.8mm/m, while in normal aggregate concrete the range is 0.30mm/m.

2.3.4.6 Durability

Recycled aggregate concrete proved to be more permeable than natural aggregates; thus, permeability can be improved by adding fly ash and silica fume to ensure complete coverage of pores.

2.3.4.7 Freezing and thawing resistance

Recycled aggregate concrete has shortcomings in terms of resisting freezing and thawing. This is due to the fact that it might contain mortar adhering to it from previously mixed concrete.

2.3.4.8 Mechanical properties and durability of recycled aggregates

Researchers have studied the mechanical properties and durability of recycled aggregates. Properties of recycled aggregates depend on the sources from which they were made and the percentage they form of the total mix. Substituting 30% of the total weight with recycled aggregates proved not to change the strength properties. On the other hand, a 100% substitution causes a decrease in compressive strength by (10 to 20%) (Pilar, 2010).

2.3.5 Objective

According to the previous discussion and keeping in mind that work performed in C&DW in Egypt is rare as well as in the solid waste in general, the objective will be divided into two parts, Descriptive and Experimental. The Descriptive part (discussed earlier) was intended to introduce some of the work conducted worldwide in the area of solid waste in general and C&DW in particular in order to prove that recycled materials can be re-used. Based on previous case studies and analysis (as in the Mokattam Zabaleen recycling schools), recycling can be an incentive for improving living standards in the Egyptian society. When waste collectors recognize the need to know how to read and write in order to count the recycling bottles every day to be rewarded at month end, they are strongly motivated to become literate, a benefit which can spill over into spreading recycling awareness in the Egyptian society. In addition, there are many other materials that can be re-used and recycled in the construction industry, as previously discussed, which can be used in the future.

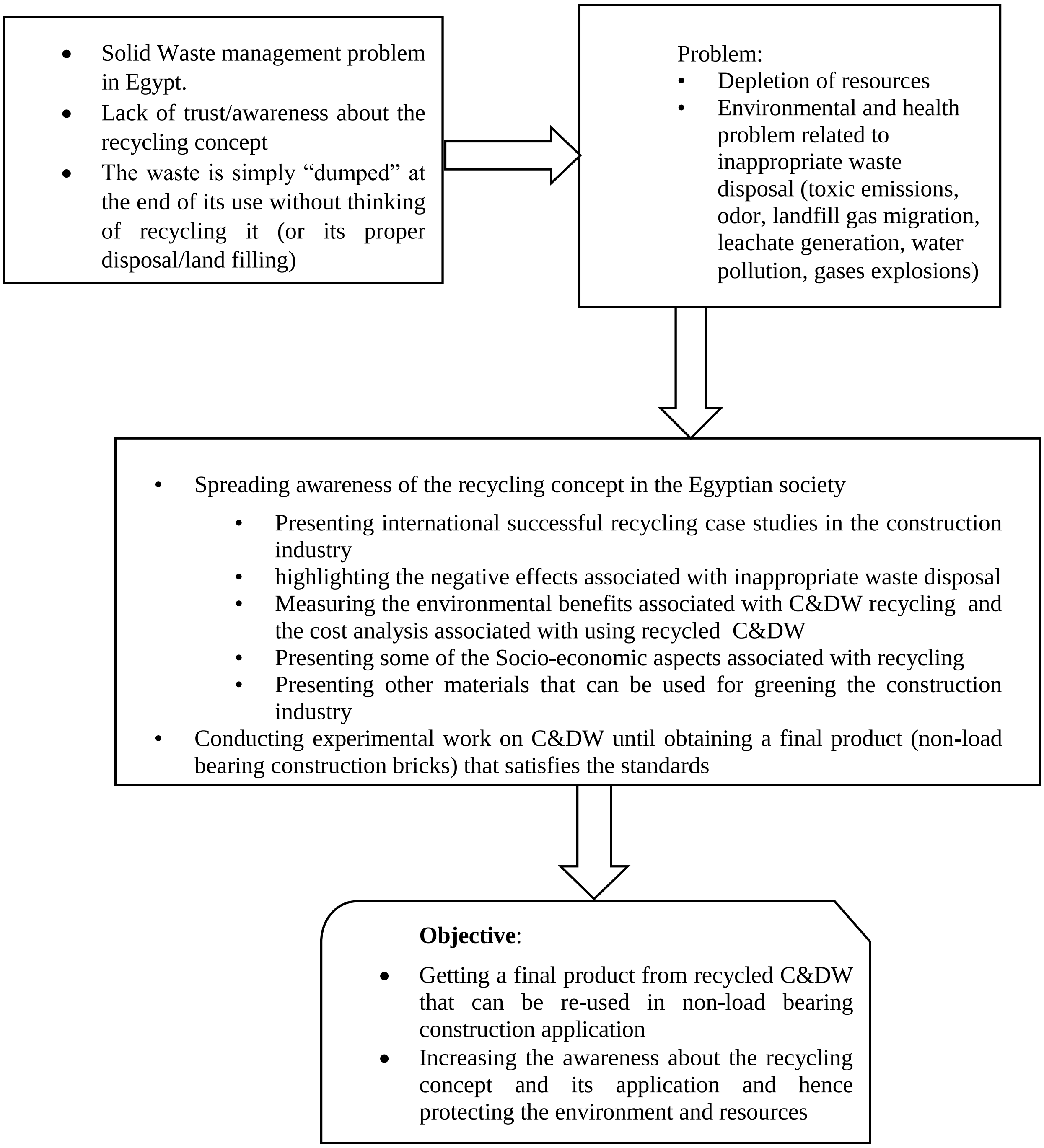
The Experimental part will include: incorporation of recycled materials into non-load bearing brick application that can be used in the construction industry. As practiced in many developed countries, recycled materials can be reused again for creating other useful products instead of being dumped in landfills. These bricks will undergo tests according to ASTM standards. The Scope of work will be limited to materials such as: construction and demolition red bricks as well as construction and demolition concrete (with different particle sizes).

CHAPTER (3)
EXPERIMENTAL WORK

Introduction

Strength of bricks is one of its most important properties. This strength is affected by many factors either during the manufacturing of the specimen or during the curing process. These factors are: the size of the aggregates, the size and the shape of the specimen itself, the mold and its type, the testing procedure, and as the curing process (Lamond, 2006). Accordingly, all the tests in this section were conducted according to ASTM as well as Egyptian standards.

Fig. (3.1) summarizes the current problems existing as well as the objective of our thesis: there is a solid waste management problem in Egypt resulting in many environmental as well as health problems. The objective of the thesis is to obtain a final product from recycled C&DW that can be re-used in non-load bearing construction applications as well as to increase awareness about the recycling concept (shown at the bottom of Fig. (3.1). This can be accomplished by increasing recycling awareness in Egypt (such as presenting some case studies, and so on) as well as doing experimental work on C&DW until reaching a final product that satisfies the standards. This chapter presents the materials, equipment, and methodology for the entire work.



- Solid Waste management problem in Egypt.
- Lack of trust/awareness about the recycling concept
- The waste is simply “dumped” at the end of its use without thinking of recycling it (or its proper disposal/land filling)

Problem:

- Depletion of resources
- Environmental and health problem related to inappropriate waste disposal (toxic emissions, odor, landfill gas migration, leachate generation, water pollution, gases explosions)

- Spreading awareness of the recycling concept in the Egyptian society
    - Presenting international successful recycling case studies in the construction industry
    - highlighting the negative effects associated with inappropriate waste disposal
    - Measuring the environmental benefits associated with C&DW recycling and the cost analysis associated with using recycled C&DW
    - Presenting some of the Socio-economic aspects associated with recycling
    - Presenting other materials that can be used for greening the construction industry
- Conducting experimental work on C&DW until obtaining a final product (non-load bearing construction bricks) that satisfies the standards

Objective:

- Getting a final product from recycled C&DW that can be re-used in non-load bearing construction application
- Increasing the awareness about the recycling concept and its application and hence protecting the environment and resources

Figure 3.1: Summary of current existing problems as well as the objective

3.3.6 Materials and equipment

3.3.6.1 Materials

- Coarse aggregates
    - Demolished concrete collected from construction sites, then crushed and sieved until achieving the required size.
- Fine aggregates:
    - Demolished concrete as well as demolished red bricks also collected from construction sites, then crushed until very fine powder-like articles are obtained. These fine particles act as “fillers” for the mix (instead of sand). The demolished red bricks contained mortar.
    - Mortar calculation: mortar thickness per brick is 0.5 cm. mortar density is 2400 kg/m^3. Total volume of mortar per one brick is 0.00522 m^3 and makes a weight of 12.53 g per brick
- Water:
    - Cairo municipal tap water was used during all stages; such as mixing as well as curing.
- Cement:
    - Oasis Cement CEM II B-L 32, 5 N, a composite Portland Cement that is produced by Helwan and Tourah plants according to the Egyptian Standards ES 4756 / 1-2007 and complies with the European Standard Specifications EN 197/1-2000 (Suez cement, 2013). This type of cement offers excellent performance for the diversified use. It is suitable in general purposes, building works such as masonry mortars, plastering, rendering, pavements and cement products as tiles, bricks and hollow blocks. Compared to the Ordinary Portland Cement, this blend has a better water retaining properties; it enhances the mortar plasticity, cohesion & adhesion to the walls’ supports with lower crack risks (Suez cement, 2013). Physical and mechanical properties of Portland cement used are presented in Table (3.1), while Chemical properties are presented in Table (3.2).

Table 3.1: Physical and mechanical properties of Portland Cement used (Suez Cement, 2013)

Property	**Tourah Cement**	**Standards specification limit**
Fineness (Blain)	3994 cm^2/gm	
Setting time (initial) min	165	75
Expansion (mm)	1	10 max
Compressive strength (2D)		
Compressive strength (7D)	28.9 N/mm^2	16
Compressive strength (28D)	37.9 N/mm^2	32.5 Min

Table 3.2: Chemical properties of Portland Cement used (Suez Cement, 2013)

Analysis	**Tourah Cement**	**Standards specifications limit**
loss on Ignition	8.43%	
Insoluble Residue	1.20%	5%
Sulphate (SO_4)	2.20%	3.50%
Chloride (CL)	0.074	0.1

3.3.6.2 Equipment

Molds for the bricks

Fig. (3.2) presents the molds used; these are wooden molds with the same dimensions as standard bricks (25cm×12cm×6cm). The molds are reusable with non-absorptive and non-reactive materials.

Figure 3.2: Molds used

Crushing machine

Fig. (3.3) presents the crushing machine used. Large concrete or brick particles are inserted through one side, then crushed by the machine, and collected from the other side. A bucket is placed under the exit area of the crushing machine to collect the material crushed. The particles are then taken again to the mechanical sieve, to produce the required sizes for the mix design.

Figure 3.3: Crushing machine

Tow- mixer

Fig. (3.4) presents the Tow-mixer used in the process. In this mixer, the bricks or the concrete particles are inserted, then the cement and water are added, and the mixer starts to mix all the components together.

Figure 3.4: Tow mixer

Mechanical Sieve

Fig. (3.5) presents the mechanical sieve that was used. The purpose of this sieving process was to achieve the required sizes. All the particles are put at the top of the sieve, then the sieve starts to mechanically shake the contents; the particles are then divided among the sieves according to size.

Figure 3.5: Mechanical sieve

Digital Scale

A digital scale was used to weigh the specimen as illustrated in Fig. (3.6). The accuracy of this scale was up to 2 digits.

Figure 3.6: Digital scale used (central Carolina scale, 2006)

3.3.7 Procedure

- Collecting C&DW from construction sites
- Crushing
- Sorting, sieving, and washing
- Batching and mixing
- Pouring into molds
- Curing
- Waiting for 28 days until the mix completely dries
- Testing
- Obtaining a final product

Collecting construction and demolition waste from construction sites

Fig. (3.7) presents construction and demolition waste on construction sites in the New Cairo area. In our case, since it was a small quantity, the waste was manually collected in bags. In other cases, it could be collected in trucks for large-scale usage.

Figure 3.7: Demolition waste on site

Figure 3.8: C&DW collection

As can be seen in Fig. (3.8), the collection process here is at the construction sites to be placed in either bags or trucks according to quantity. This might affect the cost analysis at the end. Due to the fact that this demolition waste might contain various materials such as nails, wood, or rubber as in Fig. (3.9), a sorting process as indicated in Fig. (3.10), is required where workers separate materials other than construction and demolition waste.

Figure 3.9: Other materials in the waste

Figure 3.10: Sorting process (Ma, 2013)

Crushing

Fig. (3.11) presents crushing particles to obtain a suitable size for mixing. The concrete or bricks are inserted from one side of the machine, then crushed, and removed from the other side in smaller volumes. After their removal from this machine, the crushed particles are sieved using the mechanical sieve once again to obtain the desired aggregate sizes.

Figure 3.11: Mechanical crusher

Washing the particles

Since recycled concrete/bricks contain more dust and finer particles than virgin ones, all the particles are washed to ensure that all fine particles are removed, as shown in Fig. (3.12).

Figure 3.12: Washing recycled aggregates (Craven, 2009)

To ensure that they do not absorb water, the particles are used in saturated surface dry conditions as shown in Fig. (3.13). The aggregate is internally saturated with water. By this method, the aggregate itself will not internally absorb any water from the mix.

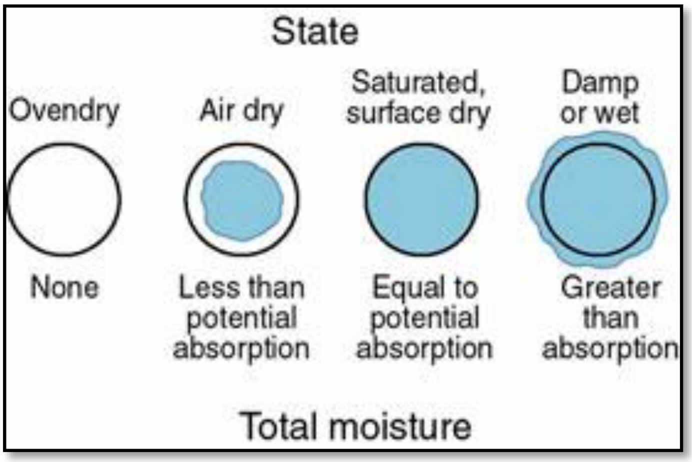


Figure 3.13: Saturated surface dry condition (Concrete Technology, 2013)

To obtain saturated surface dry condition, construction and demolition particles are soaked in water for 24 hours. As in Fig. (3.14), the particles are inserted in the bucket, and water is added until the particles are completely covered.

Figure 3.14: Soaking particles in water

After soaking in water, the particles are left in the sun to dry as illustrated in Fig. (3.15). A plastic cover is put on the floor over which the wet particles are spread.

Figure 3.15: Allowing particles to dry in the sun

Sieving

Demolition concrete will be used in two forms: coarse and fine particles. The purpose of the sieving process is to manage particle size .To ensure that the particles will interlock to each other, two sizes are obtained from the coarse particles and one size from the fine particles. The sieving process was performed mechanically as shown in Fig. (3.16). The crushed concrete is collected from the crusher after being crushed, then put in the mechanical shaker to obtain the required size.

Figure 3.16: Mechanical sieving process

Particle sizes

The different sizes are shown in Fig. (3.17, 3.18 and 3.19). Fig. (3.17) shows the largest particle sizes: particles passing sieve (No. 1) and retained on sieve (No. ¾), which have approximately a size of (19 mm). These are the particles which will increase the strength of the mix design. Those particles have the "largest" size in the mix.

Figure 3.17: particles passing sieve (No. 1) and retained on sieve (No. ¾)

Fig. (3.18) shows particles passing sieve (No. ½) and retained on sieve (No. 3/8); which have approximately a size of 9.5 mm. those particles have a "medium: size compared to the other sizes in the mix.

Figure 3.18: particles passing sieve (No. ½) and retained on sieve (No. 3/8)

Fig. (3.19) shows the smallest size in the mix. Those are passing sieve (No. 8) and retained on sieve (No. 16); they have approximately a size of - 2 mm particles. These particles will play the role of “filler” material (as in sand in the concrete mix design).

Figure 3.19: particles passing sieve (No. 8) and retained on sieve (No. 16)

Mixing and pouring into molds

All the components (bricks, concrete, cement, and water) are mixed together in the mixer until the water is incorporated into the mix as in Fig. (3.20). The concrete particles are put in first, followed by the red bricks, the cement, and, finally, the water, after which all the components are mixed.

Figure 3.20: Mixing the components in the Tow-mixer

Pouring the mix into molds:

Once the mix is processed in the tow-mixer, it is poured into wooden molds so that it takes the shape and dimensions of a standard brick as in Fig. (3.21).

Figure 3.21: Pouring the mix into molds

Putting the molds on the vibrator

Once all the components have been mixed together and poured into the molds, they are put on the vibrator to ensure that the mix is evenly distributed in the mold without any voids as in Fig. (3.22).

Figure 3.22: Placing molds on the vibrator

Curing

All the samples were cured as shown in Fig. (3.23) in the curing room. It is also worth mentioning that without curing, some cracks might appear in the brick. Curing the specimen is defined as exposing the specimen to standard conditions of moisture from the time of fabrication to the time of testing. Also noteworthy is that without proper curing, the strength of the specimen can significantly diminish. Curing is conducted in a special curing room at temperatures from (16 to 27 C) for 48 hours (Lamond, 2006).

Figure 3.23: Curing the samples

3.3.8 Testing

ASTM as well as Egyptian standards were applied, both of which are presented below as they feature several differences. Egyptian standards requirements for non load bearing bricks are presented in Table (3.3). However, no standards were found for the flexural strength test that is why they are left blank.

Table 3.3: Egyptian standards requirements for non- load bearing bricks

Type		Compressive strength per brick (N/mm^2)	Density (g/cm^3)	Water absorption	Flexural Strength
Red bricks		2.5	N/A for non-load bearing bricks	not more than 20 % for non-load bearing bricks	
Cement Bricks	lightweight	2	not more than 1.4		
	medium	2	>1.4 to 2		
	heavy	2	more than 2		

The following tests will be conducted on bricks (according to ASTM C129/standard specification for non- load bearing concrete Masonry Units):

- Dimensions (ASTM C129- 11)
    - The overall dimensions (width, height, and length) shall not differ by more than (3.2 mm) of the specified standard dimensions (250mm*120mm*60mm).
- Density (ASTM C129-11)

Table 3.4: Density specification according to ASTM standards

Density classification	oven dry- density of concrete (Average of 3 units)	
	Ib/ft^3	kg/m^3
Lightweight	less than 105	Less than 1680
Medium weight	105 to less than 125	1680 to less than 2000
Normal weight	125 or more	2000 or more

Based on the standards in Table (3.4), the average density of 3 units should be at least 1680 kg/m^3; on the other hand, Egyptian standards specify that the lightweight should be at least 1400 kg/m^3 and medium weight cement bricks from 1400 kg/m^3 to

2000 kg/m^3. As our bricks tend to be very light, Egyptian standards will be considered when testing for density, thus the minimum density considered here is 1400 kg/m^3 rather than 1680 kg/m^3 as in ASTM standards.

Procedure for conducting the density test:

- The weight of the specimen is recorded on a digital balance. The weight of the specimen is taken just before testing it (Lamond, 2006).
- The dimensions of the specimen are carefully recorded (they should have the same dimensions of the wooden molds in which they were poured)
- The weight of the specimen is divided by its volume, where density equals mass/volume.

- Compressive strength test (ASTM C129-11)
  - Based on the standards in Table (3.5), the average compressive strength value for 3 units should be at least 4.14 MPa.

Table 3.5: Compressive strength requirements

Number of Units	Compressive strength	
	psi	MPa
Average of 3 units	600	4.14
Individual unit	500	3.45

The compressive strength machine used is shown in Fig. (3.24). The specimen is inserted and compressed until failure. Once the specimen fails, the machine automatically provides the reading.

Figure 3.24: Compressive strength machine used

The procedure for conducting the compressive strength test was as follow:

- The loading surface area is first cleaned and leveled before putting the specimen
- The specimen is put in the center of the loading area
- The gate of the machine is closed for safety reasons (to avoid scattering of materials during the failure process)
- The machine is put “On”
- The load is gradually applied from the top, until the specimen fails
- Once the specimen fails, the machine automatically stops and gives the failure load

- Flexural strength (ASTM C239)

The test is conducted based on center point loading. The load is applied to the center of the span, and the load at the failure point is recorded. The loading pattern is illustrated in Fig. (3.25). Minimum values for passing flexural strength tests for non-load bearing bricks are not indicated either in ASTM or Egyptian standards.

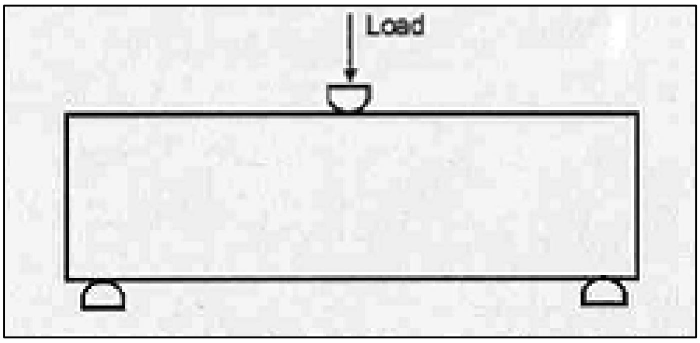


Figure 3.25: Flexural strength test (Concrete in Practice, 2000)

The flexural strength machine that was used is pictured in Fig. (3.26). The specimen is subjected to a load at its middle until its failure. The failure force is then recorded. The machine gives the load in $kg._f$

Figure 3.26: Flexural strength machine used

Procedure for conducting the flexural strength test

- The specimen is loaded on two supports.
- The load is gradually applied from the top, and centered in the middle of the specimen
- Once the specimen fails, the machine automatically gives the failure load

- Water absorption test (ASTM C140)

  Based on the standards, 3 units are going to be tested for water absorption.

The water absorption percentage is calculated according to the following formula: absorption % = $\frac{(ws-wd)}{wd}$

Where:

ws: saturated weight of specimen

wi : immersed weight of specimen

wd: oven dry of specimen

Procedure for water absorption test:

- Specimen should be immersed in water for 24 hours such that the top of the specimen is below water by at least 152 mm as indicated in Fig (3.27)
- The specimen is weighted while suspended by a metal wire and completely submerged in water. The submerged weight is recorded as (ws)

- The specimen is removed from water and allowed to drain. Visible water surrounding the specimen is cleaned with a piece of cloth. The weight is recorded; this is the saturated weight (ws)
- The specimen is dried, then put in the oven for a temperature (100 °C to 115 °C). The weight of the dried specimen is recorded. This is the dried weight (wd)

Figure 3.27: specimen curing in water

Once all the previous tests are performed and the specimen passed all of them (with respect to standards), the final brick is ready to be used in the industry as illustrated in Fig. (3.27). This is the final appearance of the brick after being poured and cured prior to testing it.

Figure 3.28: Red Brick ready to be used in the construction industry

CHAPTER (4)
RESULTS AND ANALYSIS

Introduction

The results presented here were divided into three phases: the first and the second phases were preparatory mixes to introduce the topic (but they should also be mentioned). Then a third phase was performed and its results were recorded and compared to the standards. A recommended mix was selected; this mix passed the following tests: compressive and flexural strength, water absorption as well as density tests .The extent to which percentage variations of coarse aggregates affects the mix design properties under different w/c ratios levels was examined using the “ANOVA” for data analysis (an Excel tool). Also, a case study in Australia was presented at the end of the chapter. This case study studied the cost and benefits associated with using the recycling vs. the non-recycling concept on the environment. It was proved that applying the recycling concept had more benefits than non-applying it. A similar case study will be conducted for Egypt, and the cost and benefits are going to be compared as well.

Phase One: (in this phase, no washing nor sieving was performed):

The purpose of this phase was only to get introduced to the topic. Thus, all the trials performed here were somewhat basic; even the brick dimensions differed from the standards. The materials used here were as follows: concrete (coarse and fine), masonry, gypsum board, foam (coarse and fine), Portland cement, and Tap water. The coarse aggregates sizes were: passing sieve (No. ½) and retained on sieve (No. 3/8); which is approximately a size of 9.5 mm. The fine particles sizes are: passing sieve (No. 8) and retained on sieve (No. 16); or have approximately a size of - 2 mm. In order to avoid wasting the materials, the thickness of the brick was 3 cm instead of 6 cm. At this stage no tests were performed; only visual inspection was conducted. Table (4.1) shows some of the preparatory mixes conducted by weight, with the following code:

* means a high percentage

** means that the percentage was suitable

•means that the highlighted mixes were intended to be compared

For example in Mix#1, the cement weighed a lot which changed the final color of the brick. Moreover, in Mix #2, the coarse particles of the foam caused partial scattering of the brick and inadequate cohesion. The dimensions of the brick used in this phase were as follows: Height = 3cm, Width =12 cm, Length = 25 cm.

Table 4.1: Phase #1 mixes (g)

Mix #	**Concrete**		**Red Brick**	**Foam**		**Gypsum Board**	**Cement**	**Water**
	Coarse	**fine**		**Fine**	**Coarse**			
1	800	170		30		200	*400	400
2	800	500		*100			300	500
3	1200	400					200	300
•4	900	100			5	100	300	300
5	500	500		5		100	200	300
•6		100	900		2	100	200	300
7		500	500	5		100	200	450
•8		500	1000				200	250
•9	500		1000				200	250
10	•500	•300	•500			100	200	300
11	•500	•300	•500			50	200	300
12	300	1000	300				200	300
13	300	300	300				300	**300
14	300	1000	300				300	300
15	500	300	500				200	300
16	500	500		5			200	**300
17	300	1300	0				200	250
18	500	500	500				200	300
19	500	300	500				100	250
•20	500	500	500				100	300
•21	500	300	500				100	**300
•22	300	1000	300				100	300

Fig. (4.1) to Fig. (4.9) show some of the significant outputs. As can be seen in Fig. (4.1), this is the second mix done at a point where there was not much experience. In addition to being full of foam (100g fine foam), the brick was fragile, highly water absorbent, non-uniform and lacking cohesion.

Figure 4.1: Mix #2

Fig. (4.2) depicts the top view of the second mix. As can be seen, the surface is also non-uniform and the particles are scattered.

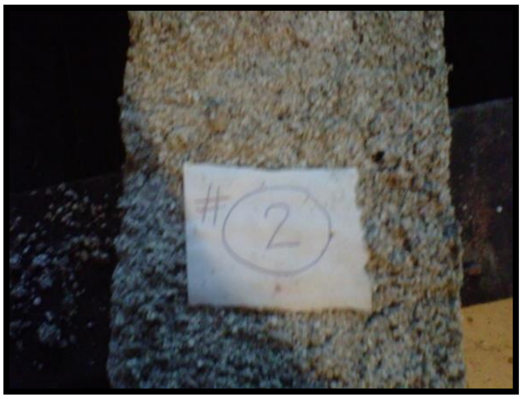


Figure 4.2: Top view for Mix #2

As seen in Fig. (4.3), this was the fifth mix done; it had a very rough, unleveled surface.

Figure 4.3: Mix #5

In Fig. (4.4), the use of the coarse foam was unsuccessful. The brick itself broke into two parts due to brick inelasticity as the coarse particles of the foam did not adhere to the cement particles in the mix. Experience gained from this mix indicates using the foam in very fine powdery particles rather than the coarse/ bubble form used in Mix #6.

Figure 4.4: Mix #6

Fig. (4.5) shows glass waste used in the mix. The type of glass is insulated glazing, coming from a demolished building in New Cairo as well. These glass waste had a particle sizes passing sieve (No. ½) and retained on sieve (No. 3/8); which is approximately a size of 9.5 mm. This mix was done for decoration purposes only. It contained coarse and fine particles of foam, gypsum board, red brick, cement, and water. The foam properties were as follows: it is type is: Styrofoam, with white color and particle sizes of: those are passing sieve (No. 8) and retained on sieve (No. 16); they have approximately a size of - 2 mm particles. The foam was also collected from demolished building, on a construction site, in New Cairo as well. After all these particles were mixed together and before being completely dry, the glass material was added at the top of the brick. In some countries, recycled glass is used to replace the aggregates. As previously mentioned, glass tends to absorb less water compared to aggregates, and gives more strength. Using glass as a replacement for aggregates will give strength as well as reduce water consumption, thus protecting natural resources

Figure 4.5: waste glass used in the mix

Fig. (4.6) shows low cement content, that proved inadequate for binding the brick, as well as insufficient water resulting in segregation and lack of cohesion of particles.

Figure 4.6: insufficient cement in the mix

Fig. (4.7) depicts non-graded particles which do not interlock with each other; this indicates that the mix should be well-graded.

Figure 4.7: Non-graded particles

Fig. (4.8) shows some of the bubbles resulting from water that was not properly dried or absorbed in the mix.

Figure 4.8: Bubbles resulting from water

Fig. (4.9) show lack of fine particles in the mix whose extreme porosity endangers the durability of the brick in the long term.

Figure 4.9: Lack of Fine particles/high porosity

Experience gained from Phase 1:

When the percentage of coarse concrete particles (acting as aggregates) was much greater than the percentage of fine concrete particles, the final mix was highly porous despite having considerable strength. This is due to the fact that all the particles were approximately the same size, so they did not interlock to each other and there were many voids between them. On the other hand, using overly high quantities of fine concrete particles while excluding usage of coarse concrete particles, reduced strength. For this reason, a combination of the two components is required. Adding materials such as gypsum-board or fine foam particles resulted in more water absorption as well as less compressive strength

Phase Two: (no washing or sieving was done, and the materials were limited)

The materials used here were: demolished concrete (coarse and fine particles), demolished red bricks, Portland cement, and Tap water. Successful mixes from Phase #1 were selected. The weight of the cement was kept constant in all the mixes to test the result of varying the other components. The w/c ratio was not calculated and water was added until the mix became workable. More water was added when the percentage of fine particle increased (demolished concrete and red bricks particles). However, the w/c ratio was kept in all cases above 0.55. The mixes done in Phase # 2 are all presented in Table (4.2). The coarse aggregates sizes were: passing sieve (No. ½) and retained on sieve (No. 3/8); which is approximately a size of 9.5 mm. The fine particles sizes are: passing sieve (No. 8) and retained on sieve (No. 16); or have approximately a size of - 2 mm.

Table 4.2: Composition of mixtures (g)

Mix #	Concrete		Red Brick	Cement	Water	Comment	Total weight (added)
	Coarse	Fine					
3	1200	400	0	200	300	successful mix from phase 1	2100
10B	500	300	500	200	300		1800
12	300	1000	300	200	200		2000
13	300	300	300	200	200	Equal components	1300
14	300	1000	300	200	200	Repetition of #12	2000
17	300	1300	0	200	250		2050
20B	500	500	500	200	300	Equal components	2000
21B	500	300	500	200	300		1800
22B	300	1000	300	200	300		2100
*23	0	1500	0	200	250	Fine concrete only	1950
*24	1500	0	0	200	300	Coarse concrete only	2000
*25	0	0	1500	200	400	Red Bricks only	2100
*26	0	1500	0	200	200	Fine concrete only decrease water than #23	1900
**27	1000	500	0	200	200	Eliminating the red bricks and seeing the effect of varying the other components	1900
**28	1200	300	0	200	200		1900
**29	750	750	0	200	200		1900
**30	300	1200	0	200	200		1900
□31	1000	0	500	200	200	Eliminating the fine concrete and seeing the effect of varying the other components	1900
□32	1200	0	300	200	200		1900
□33	750	0	750	200	350		2050
□34	300	0	1200	200	200		1900
•35	1300	200	0	200	200	Eliminating the red bricks and seeing the effect of varying the other components	1900
•36	500	1000	0	200	300		2000
•37	700	800	0	200	250		1950
•38	600	900	0	200	300		2000
39	650	650	200	200	250		1950
40	1100	400	0	200	200	Eliminating the red bricks and seeing the effect of varying the other components	1900
41	not done						N/A
42	200	1300	0	200	200		1900
43	400	1100	0	200	200		1900

Table 4.2: Composition of mixtures (cont.)

Mix #	Concrete		Red Brick	Cement	Water	Comment	Total weight (added)
	Coarse	Fine					
◊69	0	900	500	200	300	Eliminating the coarse concrete and seeing the effect of varying the other components	1900
◊70	0	1000	400	200	300		1900
◊71	0	1100	300	200	300		1900
◊72	0	1200	200	200	300		1900
◊73	0	1300	100	200	300		1900
74	300	600	500	200	300	Fixing the coarse aggregates and seeing the effect of varying the other components: the red bricks are decreased	1900
75	300	700	400	200	300		1900
76	300	800	300	200	300		1900
77	300	900	200	200	300		1900
78	300	1000	100	200	300		1900

Mixes marked with the same signs were intended to be compared, by changing only one criteria and keeping all the other fixed and seeing their effect in the final results. The indented final thickness was 6cm. However, batching the components by weight resulted in final bricks with varying thicknesses (even between different versions from the same sample) as indicated in Table (4.3). Reasons for these variations are unknown. Being exposed on construction sites, contaminants might have reached these wastes, varying their mechanical as well as physical properties later on.

Table 4.3: Different thicknesses

Mix#	Sample#	Thickness (cm)
1	1	6.5
	2	6.7
	3	6.5
1"	1	6.5
	2	6.7
	3	6.6
3	1	5.5
	2	6
	3	6.4
14	1	6.5
	2	6.5
	3	6.5
36	1	5.5
	2	5.5
	3	5.7

*Highlighted results: indicates that the highlighted results are unexpected and inconsistent as compared to the other results. In some cases as highlighted below, when doing 3 samples of the same mix, 2 samples had approximately the same compressive strength and one sample yielded odd results due to unexpected reasons. As can be seen from Table (4.4), three samples were conducted out of each mix. The mass of the samples did not differ much; however, there were noticeable differences in the compressive strength results between the samples of the same mix due to unknown reasons. The average compressive strength was higher than the compressive strength required by the standards. This was due to increasing the percentage of cement (this percentage will be reduced later due to environmental harms and high cost incurred by the cement component).

Table 4.4: Compressive strength as well as mass of some mixes

Mix	Sample (#)	Force (kN)	Compressive Strength (MPa)	Compressive strength	Mass (kg)	Average Mass (kg)
14	1	304.8	10.16	10.34	3.52	3.53
	2	370	12.33		3.58	
	3	256.1	*8.53		3.51	
3	1	372	12.40	14.57	3.53	3.53
	2	550	*18.33		3.52	
	3	390	13.00		3.55	
36	1	180.2	6.00	6.362	2.93	2.93
	2	201.5	6.71		2.94	
13	1	492.3	16.41	15.01	3.03	3.02
	2	452.5	15.08		3.01	
	3	406.4	*13.54		3.03	
28	1	522.3	17.41	16.02	3.04	3.13
	2	511.5	17.05		2.96	
	3	408.1	*13.60		3.4	
29	1	638.4	21.28	19.13	3.08	3.06
	2	604.4	20.14		3.08	
	3	479.2	*15.97		3.04	
39	1	401.4	13.380	11.49	3.44	3.37
	2	382.6	12.753		3.4	
	3	250.2	*8.34		3.29	
40	1	383.8	12.79	12.99	2.96	2.99
	2	317.7	10.59		2.96	
	3	468	*15.60		3.05	

Phase 3: (Batching by mass percentages)

At this stage all the previous errors were corrected. First, the particles were washed and sieved. Then, the mixes were batched by percentages. Out of the coarse aggregates two sizes were chosen while only one size was chosen for the fine particles. Based on Fig. (4.10), this was the first mix to be done with a w/c ratio of 1.7. However, the result was not particularly successful. The amount of water was very high and there were no fine particles to absorb this water. The particles were distantly spaced from each other as shown in Fig. (4.10). Based on the literature review. it was found that recycled aggregate concrete can be compared to reference concrete by up to a 100% replacement provided that the w/c ratio is higher than 0.55; thus, all the following w/c ratios were selected to be higher than 0.55. The w/c ratios that were tried were 0.6, 0.7, 0.8 and the following tests were done on the samples (compressive strength, flexural strength, density and water absorption). Out of each mix and for each w/c ratio, 3 samples were done and the average was recorded.

Figure 4.10: Mix 1 done with w/c ratio of 1.7

Fig. (4.11) shows the extra amount of water used. The water leaked indiscriminately from the mold. Fig. (4.12) depicts the extra amount of water while the brick was being poured in the mold; as can be seen, water is floating on top of the brick.

Figure 4.11: Molds having w/c ratio of 1.7

Figure 4.12: Extra amount of water

Description of the mixes performed (w/c = 0.6, 0.7 and 0.8)

- The percentage of the coarse aggregates was divided into two particle sizes (large and medium) of 19 mm and 9.5 mm respectively (to ensure gradation and interlocking in the mix). In addition, the fine particles was equally divided between concrete and red bricks particles as illustrated in Table (4.5).
- As in Table (4.5), some mixes were intended to contain either fine particles only or coarse particles only (as in mixes 1, 2, 14). The aim here was to compare the effect of having only fine particles in the mix, or coarse particles in the mix.
- The amount of cement was kept constant at 555 g in w/c ratios of 0.6.0.7 and 0.8 to determine the effect of varying the amount of coarse and fine particles on the final properties.

Table 4.5: Amount of coarse and fine aggregates in each mix

Mix	Coarse%	Fine%	Coarse		Fine	
			19 mm	9.5 mm	Concrete (2mm)	Red bricks (2mm)
*1	1	0	1		0	0
*2	1	0	0	1	0	0
3	1	0	0.5	0.5	0	0
4	0.9	0.1	0.45	0.45	0.05	0.05
5	0.8	0.2	0.4	0.4	0.1	0.1
6	0.7	0.3	0.35	0.35	0.15	0.15
7	0.6	0.4	0.3	0.3	0.2	0.2
8	0.5	0.5	0.25	0.25	0.25	0.25
9	0.4	0.6	0.2	0.2	0.3	0.3
10	0.3	0.7	0.15	0.15	0.35	0.35
11	0.2	0.8	0.1	0.1	0.4	0.4
12	0.1	0.9	0.05	0.05	0.45	0.45
13	0	1	0	0	0.5	0.5
*14	0	1	0	0	0	1

The exact amounts for each w/c ratio will be presented in Tables (4.6 to 4.11)

Table 4.6: Components by fraction (w/c = 0.6)

Mix	Components by fraction				
	Coarse	Fine	Cement	Water	Total
	19 mm	9.5 mm			
1	0.76	0	0.15	0.09	1
2	0	0.76	0.15	0.09	1
3	0.76	0	0.15	0.09	1
4	0.68	0.07	0.15	0.09	1
5	0.60	0.15	0.15	0.09	1
6	0.53	0.22	0.15	0.09	1
7	0.45	0.30	0.15	0.09	1
8	0.38	0.38	0.15	0.09	1
9	0.30	0.45	0.15	0.09	1
10	0.22	0.53	0.15	0.09	1
11	0.15	0.60	0.15	0.09	1

Table 4.6: Components by fraction (w/c = 0.6)

12	0.076	0.68	0.15	0.09	1
13	0	0.76	0.15	0.09	1
14	0	0.76	0.15	0.09	1

Table (4.7) provides the masses. The total brick weight is 3700 g, which is 1 or 100 % in table (4.6). The mass of cement is 555 g (0.15 or 15%) and the mass of the water is 333 g (0.09 or 9%). As previously discussed, Mix #1 contains 19 mm particles only, Mix # 2 contains 9.5 mm particles only, and Mix # 14 contains red bricks only; the purpose is to test the effect of each one separately and compare it to the standards.

Table 4.7: Actual components by mass (w/c) = 0.6

Mix	Components by mass (g) (w/c) = 0.6			
	Coarse		Fine	
	19 mm	9.5 mm	Concrete (2mm)	Red bricks (2mm)
1	2812	0	0	0
2	0	2812	0	0
3	1406	1406	0	0
4	1265.4	1265.4	140.6	140.6
5	1124.8	1124.8	281.2	281.2
6	984.2	984.2	421.8	421.8
7	843.6	843.6	562.4	562.4
8	703	703	703	703
9	562.4	562.4	843.6	843.6
10	421.8	421.8	984.2	984.2
11	281.2	281.2	1124.8	1124.8
12	140.6	140.6	1265.4	1265.4
13	0	0	1406	1406
14	0	0	0	2812

Fig. (4.13, 4.14) represents some of the mixes done with no particle gradation; they were composed solely of coarse aggregates 19 mm in size.

Figure 4.13: Large particles with no gradation

Fig. (4.14) shows coarse particles in the process of being placed in the molds. As can be seen, the particle are scattered around the mold because there was no gradation in the mix so that the particles can interlock with each other.

Figure 4.14: Placing the large particle sizes in the molds

Fig. (4.15) shows only fine particles of (concrete and bricks). No coarse aggregates were added to the mix. This mix absorbed abundant water.

Figure 4.15: Fine particles (concrete and bricks) only

Fig. (4.16) shows red bricks only in the tow mixer. This mix was done as a reference mix to compare the effect of having red bricks only and seeing the effect on the final properties of the mix.

Figure 4.16: Red bricks only

Fig. (4.17) shows red bricks after being poured in the mold

Figure 4.17: Red bricks in molds

All the samples were put on the vibrator while pouring them in the molds, to ensure uniform distribution of the mix in the mold with no voids as was previously shown in Fig. (3.22). As was previously shown in Fig. (3.28), this figure depicted the final appearance of red bricks for w/c = 0.6 (after curing and before testing). This brick comprises only red bricks particles.

Fig. (4.18) shows red bricks with w/c ratio of 0.8 (insignificant difference in appearance compared to those with w/c of 0.7).

Figure 4.18: Red bricks with w/c = 0.8

Table 4.8: Particles gradation by percentage (w/c) = 0.7

Mix	Components by fraction						
	Coarse		Fine		Cement	Water	Total
	19 mm	9.5 mm	Concrete (2mm)	Red bricks (2mm)			
1	0.75	0	0	0	0.15	0.11	1
2	0	0.75	0	0	0.15	0.11	1
3	0.37	0.37	0	0	0.15	0.11	1
4	0.34	0.34	0.04	0.04	0.15	0.11	1
5	0.3	0.3	0.07	0.07	0.15	0.11	1
6	0.26	0.26	0.11	0.11	0.15	0.11	1
7	0.22	0.22	0.15	0.15	0.15	0.11	1
8	0.19	0.19	0.19	0.19	0.15	0.11	1
9	0.15	0.15	0.22	0.22	0.15	0.11	1
10	0.11	0.11	0.26	0.26	0.15	0.11	1
11	0.07	0.07	0.3	0.3	0.15	0.11	1

Table 4.8: Particles gradation by percentage (w/c) = 0.7 (cont.)

12	0.04	0.04	0.34	0.34	0.15	0.11	1
13	0	0	0.37	0.37	0.15	0.11	1
14	0	0	0	0.75	0.15	0.11	1

Table (4.9) gives the mass of each component. The amount of cement was kept the same in all the w/c ratios at 555 g (as varying the amount of cement affects the final strength). The mass of water here is 388.5 g.

Table 4.9: Particle gradation by mass (w/c) =0.7

Mix	Components by mass (g) (w/c)=0.7			
	Coarse		Fine	
	19 mm	9.5 mm	Concrete (2mm)	Red bricks (2mm)
1	2756	0	0	0
2	0	2756	0	0
3	1378	1378	0	0
4	1240	1240	137.8	137.8
5	1102	1102	275.6	275.6
6	964.7	964.7	413.4	413.4
7	826.9	826.9	551.3	551.3
8	689.1	689.1	689.1	689.1
9	551.3	551.3	826.9	826.9
10	413.4	413.4	964.7	964.7
11	275.6	275.6	1102	1102
12	137.8	137.8	1240	1240
13	0	0	1378	1378
14	0	0	0	2756

Table 4.10: Particle gradation by percentage (w/c) = 0.8

Mix	Components by fraction						
	Coarse		Fine		Cement	Water	Total
	19 mm	9.5 mm	Concrete (2mm)	Red bricks (2mm)			
1	0.73	0.00	0.00	0.00	0.15	0.12	1
2	0.00	0.73	0.00	0.00	0.15	0.12	1
3	0.37	0.37	0.00	0.00	0.15	0.12	1

Table 4.10: Particles gradation by percentage (w/c) = 0.8 (cont.)

4	0.33	0.33	0.04	0.04	0.15	0.12	1
5	0.29	0.29	0.07	0.07	0.15	0.12	1
6	0.26	0.26	0.11	0.11	0.15	0.12	1
7	0.22	0.22	0.15	0.15	0.15	0.12	1
8	0.18	0.18	0.18	0.18	0.15	0.12	1
9	0.15	0.15	0.22	0.22	0.15	0.12	1
10	0.11	0.11	0.26	0.26	0.15	0.12	1
11	0.07	0.07	0.29	0.29	0.15	0.12	1
12	0.04	0.04	0.33	0.33	0.15	0.12	1
13	0	0	0.37	0.37	0.15	0.12	1
14	0	0	0	0.73	0.15	0.12	1

The same concept will be applied here in Table (4.11). The amount of cement will be kept at 555g or 15 % of the total weight. The mass of the water here will be 444 g.

Table 4.71: Particles gradation by mass (w/c) =0.8

Mix	Components by mass (g) (w/c) = 0.8			
	Coarse		Fine	
	19mm	9.5mm	Concrete 2mm	Red bricks (2mm)
1	2701	0	0	0
2	0	2701	0	0
3	1350	1350	0	0
4	1215	1215	135	135
5	1080	1080	270.1	270.1
6	945.3	945.3	405.1	405.1
7	810.3	810.3	540.2	540.2
8	675.2	675.2	675.2	675.2
9	540.2	540.2	810.3	810.3
10	405.1	405.1	945.3	945.3
11	270.1	270.1	1080	1080
12	135	135	1215	1215
13	0	0	1350	1350
14	0	0	0	2701

The results are as follows in Tables (4.12, 4.13, and 4.14) for different w/c ratio. For the compressive strength to satisfy the standards, the average results of 3 units has to be at least 4.14 MPa.

- The Net area compressive strength load (MPa) = P_{max}/A_n
  - P_{max} =maximum compressive load (N)
  - A_n = average net area of the specimen (mm^2)

The w/c ratio of 0.6 gave the highest compressive as well as flexural strength. This is consistent with the literature review.

Table 4.82: Compressive and flexural results for mixes (w/c = 0.6)

Mix Number	w/c = 0.6	
	Compressive Strength (MPa)	Flexural strength (kg.f)
1	9.95	360
2	8.2	343
3	7.82	320
4	7.1	285
5	7.05	280.1
6	6.5	279
7	6.3	275
8	5.31	273.4
9	5	270.2
10	4.8	269
11	4.65	268.6
12	4.2	260
13	4	263
14	3.93	198

Table 4.93: Compressive and flexural results for mixes (w/c = 0.7)

Mix Number	w/c = 0.7	
	Compressive Strength (MPa)	Flexural Strength (kg.f)
1	8.6	330
2	7.5	310
3	7	290
4	6.95	265
5	6.5	263.8
6	6.2	260.1
7	6	257
8	5.1	255
9	4.8	250
10	4.6	246
11	4.3	242
12	3.95	240
13	3.8	245
14	3.5	180

Table 4.14: Compressive and flexural strength results for mixes (w/c =0.8)

Mix Number	w/c = 0.8	
	Compressive Strength (MPa)	Flexural Strength (kg.f)
1	7.5	300
2	7	293
3	6.8	260
4	6.65	258
5	6.3	256.8
6	6	255
7	5.8	251.6
8	4.9	250
9	4.6	246

Table 4.104: Compressive and flexural strength results for mixes (w/c =0.8) (cont.)

10	4.3	243.6
11	4.1	239
12	3.71	238.5
13	3.4	236
14	3.42	184

Data interpretation:

Here the interpretation will focus on studying the effects of changing the percentage of coarse and fine aggregates on the final properties of the mix (as well as changing the percentage of w/c) .The following is the notation to be used:

Mix I.D notation ($m^{c}/_{f}$)

- Notation: for (m100/0) for example:
    - “m” abbreviation for “mix”
    - The first number refers to coarse aggregates percentage, for example, “100” means that this mix contains 100 % coarse aggregates
    - The second number refers to fine aggregates percentage, for example, “0” means that this mix contains 0 % fine aggregates.
- Other mixes are:
    - m100c/0= 100% particle size of 19.5 mm
    - m100m/0 = 100% particle size of 9.5 mm
    - m100R/0 = 100% red bricks
    - The previous mixes m100c/0, m100m/0, and m100R/0 were intended to know the properties of only having particles sizes of 9.5 mm, 19 mm and red bricks in the mix design.

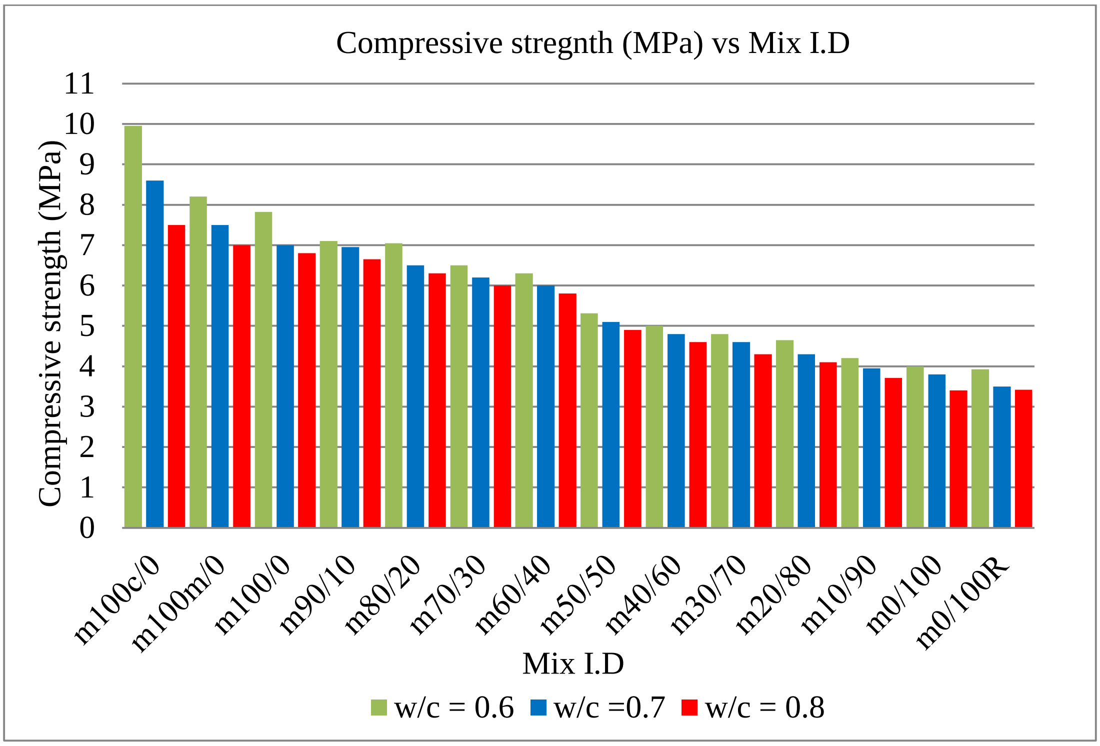


Figure 4.19: Compressive strength value vs. Mix I.D

As can be seen in Fig. (4.21), increasing the water content decreases the compressive strength; this is the same case when increasing the percentage of fine aggregates. These results are consistent with the literature review.

As indicated in Fig. (4.21) and according to the standards, the average of 3 units should be no less than 4.14 MPa.

Table (4.15) indicates the mixes that passed the compressive strength test. The red bricks mix did not pass it. This might be due to the fact that red bricks absorb a large amount of water which decreases the value of the compressive strength.

Table 4.15: Mixes passing the compressive strength test

Mix I.D	w/c = 0.6	w/c = 0.7	w/c = 0.8
m0/100R	Not passing	Not passing	Not passing
m0/100	Not passing	Not passing	Not passing
m10/90	√	Not passing	Not passing
m20/80	√	√	√
m30/70	√	√	√
m40/60	√	√	√

Table 4.15: Mixes passing the compressive strength test (cont.)

m50/50	√	√	√
m60/40	√	√	√
m70/30	√	√	√
m80/20	√	√	√
m90/10	√	√	√
m100/0	√	√	√
m100m/0	√	√	√
m100c/0	√	√	√

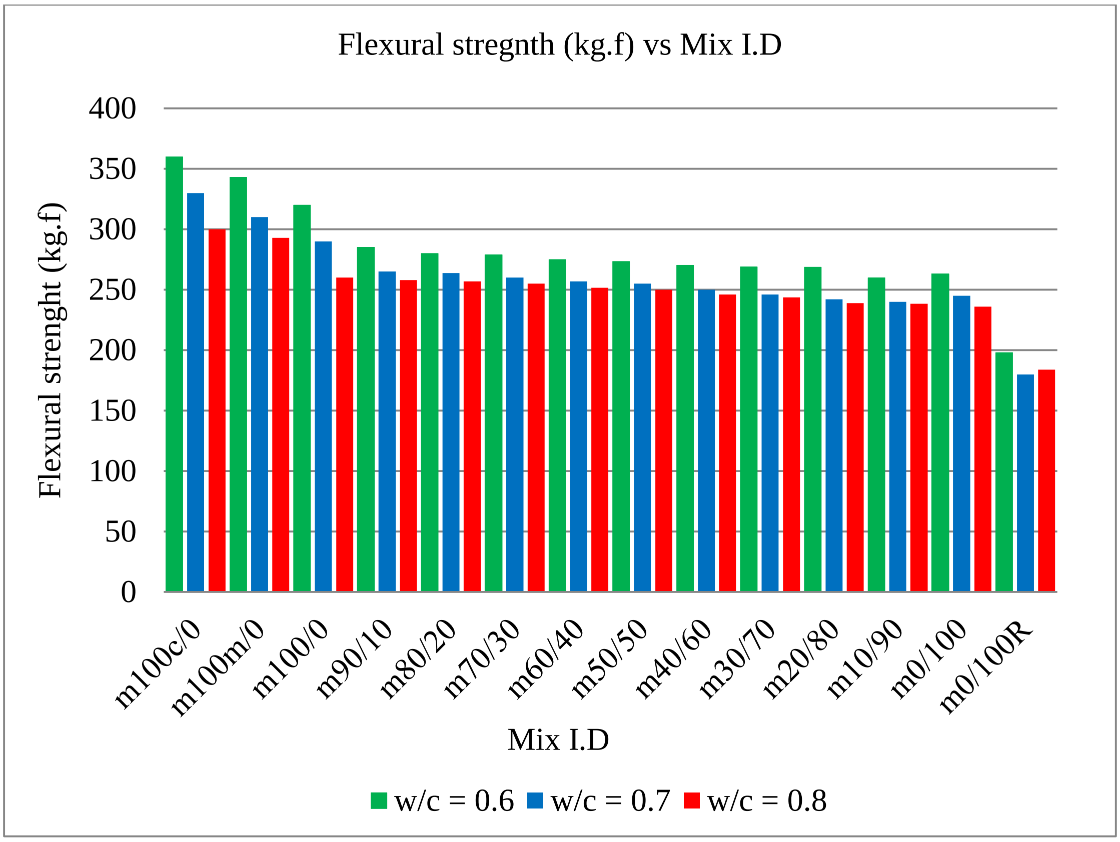


Figure 4.20: Flexural strength value vs. Mix I.D

Also as indicated in Fig. (4.20), increasing the water percentage decreases the flexural strength. Once again, these results are consistent with the literature review. However, no data existed on the flexural strength standards for non-structural bricks.

- The flexural strength test was conducted according to ASTM C239, using the following formula (flexural strength using center point loading method). However, the flexural strength standard for bricks was not found either in the

ASTM or in the Egyptian standards. The following formula was used to calculate the flexural strength values:

- $R = 3PL/2bd^2$
  - P: is the load applied to the specimen
  - L: length of the brick
  - b: width of the brick
  - d: depth of the brick
  - R: flexural strength

Tables (4.16, 4.17, and 4.18) show the density as well as the percentage of water absorption for w/c ratios of 0.6, 0.7 and 0.8 respectively. As discussed previously, density decreases in parallel with increasing the fine particles. The percentage of water absorption increases also in parallel with increasing the percentage of fine aggregates as they tend to absorb water and swell compared to coarse aggregates. This is consistent with the literature review.

Table 4.16: Density and water absorption for mixes (w/c = 0.6)

Mix Number	Results for w/c = 0.6			
	Average Weight (kg)	Density (kg/m^3)	Weight after soaking in water (kg)	Water Absorption (%)
1	2.96	1644	3.2	7.98
2	3.08	1711	3.34	8.22
3	3.02	1677	3.28	8.5
4	3	1666	3.27	8.9
5	2.98	1655	3.25	9.2
6	2.91	1616	3.19	9.35
7	2.9	1611	3.19	9.7
8	2.89	1605	3.19	10.1
9	2.84	1577	3.14	10.4
10	2.82	1566	3.13	10.81
11	2.96	1644	3.3	11.3
12	2.75	1527	3.07	11.7
13	2.79	1550	3.12	11.83
14	2.5	1388	2.5	12.1

Table 4.17: Density and waster absorption for mixes (w/c = 0.7)

Mix Number	Results for w/c = 0.7			
	Average Weight (kg)	Density (kg/m^3)	Weight after soaking in water (kg)	Water Absorption (%)
1	2.94	1633	3.14	7
2	3.01	1672	3.25	8.1
3	3	1666	3.25	8.4
4	2.98	1655	3.23	8.7
5	2.94	1633	3.2	8.9
6	2.89	1605	3.15	9
7	2.87	1594	3.13	9.2
8	2.86	1588	3.14	9.9
9	2.8	1555	3.08	10
10	2.79	1550	3.07	10.2
11	2.76	1533	3.05	10.7
12	2.75	1527	3.04	10.8
13	2.7	1500	2.99	11
14	2.34	1300	2.6	11.4

Table 4.18: Density and water absorption for mixes (w/c =0.8)

Mix Number	Results for w/c = 0.8			
	Average weight (kg)	Density (kg/m^3)	Weight after soaking in water (kg)	Water Absorption (%)
1	2.9	1611	3.08	6.5
2	3	1666	3.21	7.3
3	2.98	1655	3.2	7.7
4	2.95	1638	3.18	8
5	2.94	1633	3.18	8.3

Table 4.18: Density and water absorption for mixes (w/c = 0.8) (cont.)

6	2.9	1611	3.14	8.45
7	2.86	1588	3.1	8.7
8	2.83	1572	3.08	9.1
9	2.82	1566	3.08	9.5
10	2.78	1544	3.05	9.8
11	2.75	1527	3.02	10
12	2.72	1511	2.99	10.1
13	2.68	1488	2.95	10.3
14	2.3	1277	2.54	10.7

Plotting charts for results:

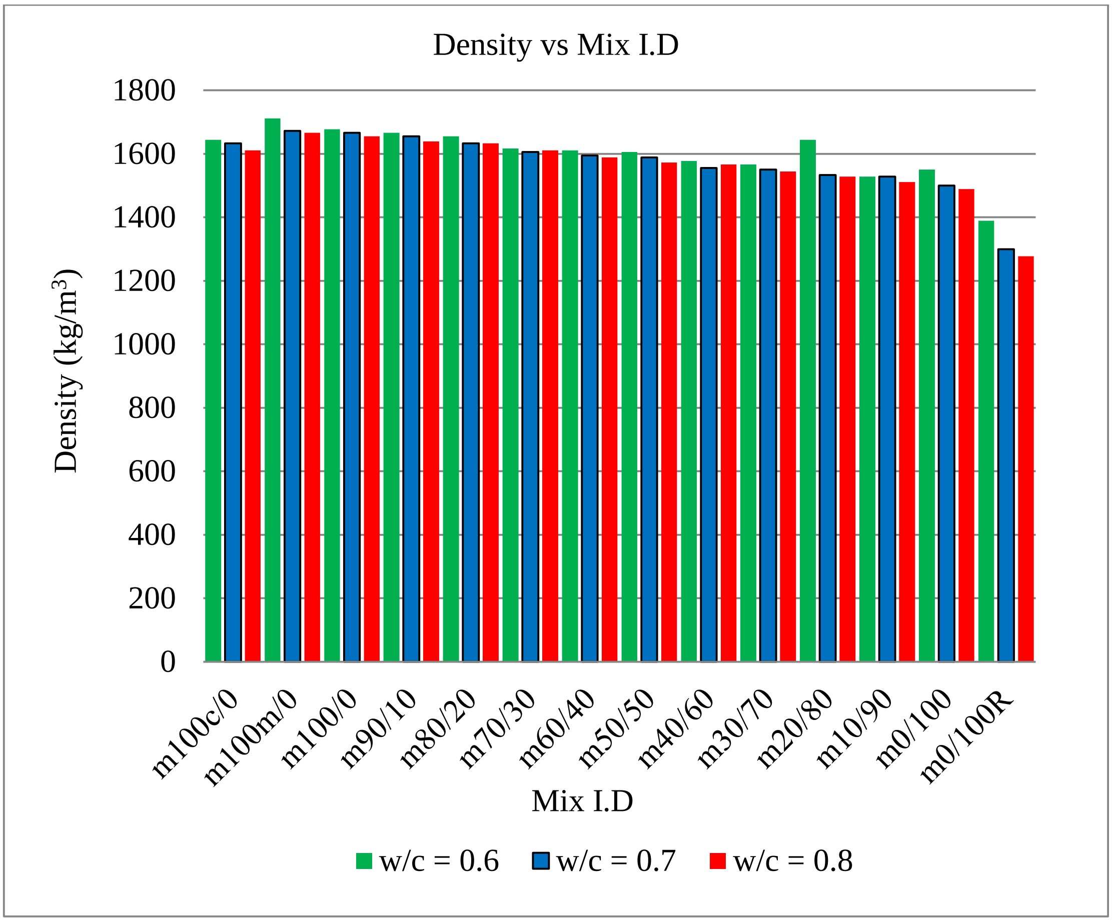


Figure 4.21: Density vs. Mix I.D

- As indicated in Fig. (4.21), increasing the percentage of the fine aggregates decreases the density. Negligible density differences between the different mixes were revealed. These results were also consistent with the literature review as the density of the fine aggregates are lighter compared to the coarse ones. Therefore, when their percentage increase, the overall density of the mix decreases. The minimum value for the density (according to the Egyptian standards as discussed earlier) is 1400 kg/m$^{3.}$
- As indicated in Fig. (4.21) and based on the standards, the density should be not less than 1400 kg/m^{3}. All the mixes passed the density test, except for m0/100R (mix containing red bricks) under w/c ratios of 0.6, 0.7 and 0.8
- For the water absorption test, all the mixes passed it with no exception.

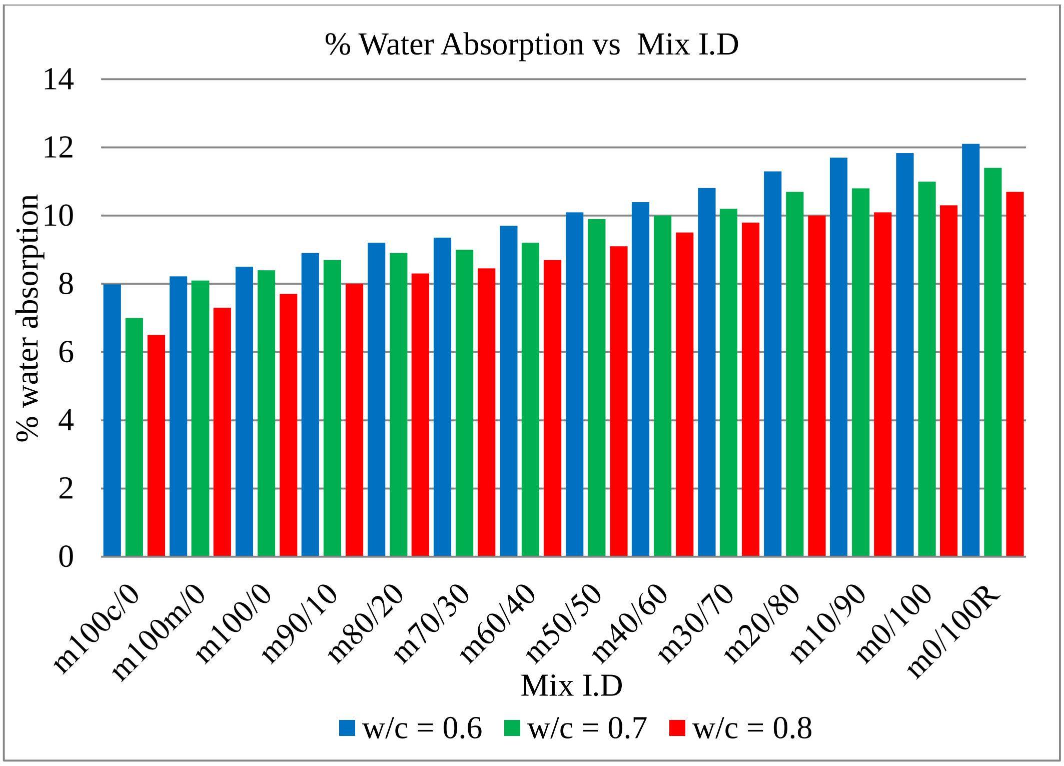


Figure 4.22: %water absorption vs. Mix I.D

- All the previous graphs were expected according to the literature review. However, the recommended mix design should feature the following:
  - Compressive and flexural strength passing the standards as well as the water absorption and the density tests

Data interpretation using the ANOVA (an Excel tool)

The goal here was to determine whether variations in the percentage of coarse aggregates had an effect on the final compressive strength value for the mixes at different levels (here w/c ratios). The Null Hypothesis in Excel is that all the means are equal (H_0: Mean1 = Mean 2 =Mean 3). The alternative hypothesis is that at least one of them is different, H_a= at least one of the means is different. The significance level used here is 0.05 (or a confidence level of 95 %). If the P value calculated from the ANOVA was less than 0.05, this entails rejecting the Null Hypothesis (meaning rejecting H0, and that the means are not equal), and accepting Ha (at least one of the means is different). In case of accepting Ha, this means that varying the percentage of the coarse aggregates has an effect on final compressive strength values under different w/c ratios. Notation for Table (4.21): the group number refers to the percentage of coarse aggregates in the mix; for example, group “100” means that this mix contains 100% coarse aggregates, 90% means that this mix contains 90% coarse aggregates and 10% fine aggregates. The mixes that only have coarse aggregates of 19mm and 9.5 mm or only red bricks, were removed from the list to avoid confusion. The effect of changing the w/c ratio on the compressive strength is discussed with the input data presented in Table (4.19).

Table 4.19: Input data for ANOVA

% Coarse Aggregates	w/c = 0.6	w/c = 0.7	w/c= 0.8
100	7.82	7	6.8
90	7.1	6.95	6.65
80	7.05	6.5	6.3
70	6.5	6.2	6
60	6.3	6	5.8
50	5.31	5.1	4.9
40	5	4.8	4.6
30	4.8	4.6	4.3
20	4.65	4.3	4.1
10	4.2	3.95	3.71
0	4	3.8	3.4

Table 4.20: ANOVA output

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	45.61	10	4.56	50.25	8.24E-13	2.29
Within Groups	1.99	22	0.090			
Total	47.61	32				

Based on Table (4.20), the P value < 0.05 indicates that there is a strong relation between changing the percentage of coarse aggregates and final values of compressive strength under different w/c ratios

Table 4.21: Input data for Density values to ANOVA

% Coarse Aggregates	w/c = 0.6	w/c = 0.7	w/c= 0.8
100			
90	1677	1666	1655
80	1666	1655	1638
70	1655	1633	1633
60	1616	1605	1611
50	1611	1594	1588
40	1605	1588	1572
30	1577	1555	1566
20	1566	1550	1544
10	1644	1533	1527
0	1527	1527	1511
	1550	1500	1488

Table 4.22: Output data for density from ANOVA

Source of Variation	SS	df.	MS	F	P-value	F crit.
Between Groups	77615	10	7761.5	12.80	5.16E-07	2.29
Within Groups	13333.3	22	606.061			
Total	90948.4	32				

Based on Table (4.22), the P value here is < 0.05, indicating that there is a strong relation between changing the percentage of coarse aggregates and the variation in the density value

Table 4.23: Input data for water absorption

% Coarse Aggregates	w/c= 0.6	w/c = 0.7	w/c= 0.8
100	8.5	8.4	7.7
90	8.9	8.7	8
80	9.2	8.9	8.3
70	9.35	9	8.45
60	9.7	9.2	8.7
50	10.1	9.9	9.1
40	10.4	10	9.5
30	10.81	10.2	9.8
20	11.3	10.7	10
10	11.7	10.8	10.1
0	11.83	11	10.3

Table 4.24: Output data for water absorption from ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit.
Between Groups	29.19	10	2.91	9.24	8.36E-06	2.29
Within Groups	6.94	22	0.31			
Total	36.14	32				

Based on Table (4.24), there is a strong relation between changing the percentage of coarse aggregates and water absorption value.

However, to select the best mix, a weighted average will be given to each criterion according to its importance, whose sum should be equal to 100% or “1”. The recommended mix will be evaluated based on the following factors:

- Compressive strength (weight of 50%)
- Water absorption (weight of 25%)
- Density (weight of 25%)

As compressive strength is the most important criterion, it was given a weight of 50%, followed by equal weights for density and water absorption (as indicators that the mix includes fine particles). The lighter the density, the higher the percentage of fine particles, and the higher the water absorption is. It should be mentioned here that the recommended mix must include a combination of fine and coarse particles as the use of only coarse aggregates creates a very rough surface that might cause problems later in the finishing process. Here the cost will not be included as the material is collected for free. The formula used is as follows:

0.5 (compressive strength) + 0.25 (density) + 0.25 (1/water absorption) = Total

The maximum total weight here will be selected. It should be noted that the mixes that did not pass the compressive strength test were removed from the analysis since using them would be unsafe, excluding the need to keep them in the selection process.

Table 4.25: Recommended mix based on weighted average (w/c = 0.6)

Mix I.D	w/c = 0.6						
	Compressive strength (MPa)	weight	Density (kg/m^3)	weight	Water Absorption (%)	weight	Total
m100c/0	9.95	0.5	1644	0.25	7.98	0.25	416.1
m100m/0	8.2	0.5	1711	0.25	8.22	0.25	431.9
m100/0	7.82	0.5	1677	0.25	8.5	0.25	423.3
m90/10	7.1	0.5	1666	0.25	8.9	0.25	420.2
m80/20	7.05	0.5	1655	0.25	9.2	0.25	417.4
m70/30	6.5	0.5	1616	0.25	9.35	0.25	407.4
m60/40	6.3	0.5	1611	0.25	9.7	0.25	405.9
m50/50	5.31	0.5	1605	0.25	10.1	0.25	404.0
m40/60	5	0.5	1577	0.25	10.4	0.25	396.9
m30/70	4.8	0.5	1566	0.25	10.81	0.25	394.0
m20/80	4.65	0.5	1644	0.25	11.3	0.25	413.4
m10/90	4.2	0.5	1527	0.25	11.7	0.25	384.0

As was calculated in Table (4.25), the recommended mix would be Mix# 2, but again this mix would not contain any fine particles and might thus cause problems later on in the finishing process. Mix # 4 (or $m_{90/10}$), therefore, will be selected as the recommended mix (as it has fine particles)

Table 4.26: Recommended mix based on weighted average (w/c = 0.7)

Mix I.D	w/c = 0.7						
	Compressive strength (MPa)	weight	Density (kg/m3)	weight	Water Absorption (%)	weight	Total
m100c/0	8.6	0.5	1633	0.25	7	0.25	412.6
m100m/0	7.5	0.5	1672	0.25	8.1	0.25	421.8
m100/0	7	0.5	1666	0.25	8.4	0.25	420.1
m90/10	6.95	0.5	1655	0.25	8.7	0.25	417.3
m80/20	6.5	0.5	1633	0.25	8.9	0.25	411.6
m70/30	6.2	0.5	1605	0.25	9	0.25	404.5
m60/40	6	0.5	1594	0.25	9.2	0.25	401.6
m50/50	5.1	0.5	1588	0.25	9.9	0.25	399.7
m40/60	4.8	0.5	1555	0.25	10	0.25	391.3
m30/70	4.6	0.5	1550	0.25	10.2	0.25	389.8
m20/80	4.3	0.5	1533	0.25	10.7	0.25	385.5

The same concept used in Table (4.25) will be used in Table (4.26); thus, the recommended mix to be used is Mix # 4 (or $m_{90/10}$)

Table 4.27: Recommended mix based on weighted average (w/c= 0.8)

Mix I.D	w/c = 0.8						
	Compressive strength (MPa)	weight	Density (kg/m3)	weight	Water Absorption (%)	weight	Total
m100c/0	7.5	0.5	1611	0.25	6.5	0.25	406.5
m100m/0	7	0.5	1666	0.25	7.3	0.25	420.2
m100/0	6.8	0.5	1655	0.25	7.7	0.25	417.3
m90/10	6.65	0.5	1638	0.25	8	0.25	413.0
m80/20	6.3	0.5	1633	0.25	8.3	0.25	411.5

Table 4.27: Recommended mix based on weighted average (w/c= 0.8) (cont.)

m70/30	6	0.5	1611	0.25	8.45	0.25	405.8
m60/40	5.8	0.5	1588	0.25	8.7	0.25	400.1
m50/50	4.9	0.5	1572	0.25	9.1	0.25	395.5
m40/60	4.6	0.5	1566	0.25	9.5	0.25	393.9
m30/70	4.3	0.5	1544	0.25	9.8	0.25	388.2

The recommended mix here is also Mix # 4; however, selection depends on the actual application (whether or not brick gradation is important).

4.2 Cost Analysis

4.2.1 Introduction

In order to determine whether it is better to use recycled or virgin aggregates, the cost analysis should be calculated. In this analysis, the cost of harming the environment should also be calculated. Using recycled aggregates means that the environment is protected and landfill areas are not consumed. The opposite is true when recycled aggregates are not used: the environment is polluted and landfill areas are consumed. This cost analysis was first applied in Australia; the same method will be applied in Egypt, after which the results will be compared to determine the differences.

4.2.2 A Case study in Australia

In order to find out and investigate the costs and benefits of concrete recycling, three construction and demolition companies were visited; these comprised of four recycling plants and two landfills in Queensland, Australia (Tam, 2008). Two options will be presented for aggregate production: the recycling option, and the option of using virgin aggregates. Based on the interviews conducted, it was found that the average demolition waste generated from each construction site was 115,200 t while the recycling plant had a capacity of 110,000 t/year and an expected life of 10 years. Recycling is more beneficial than using virgin aggregates for the following reasons: the latter consumes energy to dump the waste and produce new materials. Therefore, the concrete here will be sent to recycling plants for crushing in order to save energy on dumping it and producing new materials. This method also involves putting the concrete through a closed-loop recycling process. Tables (4.28, 4.29) show detailed data released by the Environmental Protection Agency as well as an estimation of pollution released into the environment. Calculations based on these estimates were not made public. Pollution and energy consumption per landfill space charge was estimated as follows: 16.5% air pollution, 17.7% noise pollution and 23% energy consumption.

The terminologies used are as follows:

- Stripping: the stage where rocks are cleared and leveled
- Blasting: the stage where blasting equipment is used
- Stockpiling: the stage where one laborer is used at a rate of 18/h
- Sorting: the stage where equipment such as excavators is used
- Crushing process: this includes a primary crushing, magnetic separation, and secondary crushing process. It involves the following equipment: primary equipment, secondary equipment and a crusher
- The washing, screening or air sitting process: the stage involving fuel and recycled waste

Table 4.28: Current method used with No recycling (Tam, 2008)

	cost (1000/year)	benefit		
construction waste				
landfill dumping charge	6566.4		57	$per t
landfill space saved by not dumping waste	18777.6			
transportation	576		5	per t
Air pollution	3136.3		16.5	of landfillspace charge
Gas emission	3267.3		17.4	of landfillspace charge
Energy consumption	4318.9		23	of landfillspace charge
Noise pollution	3323.6		17.7	of landfillspace charge
stripping				
equipment	145		1450000	buldozer equipment cost
labor	45.8		45760	cost of 1 person per year ($)
fuel	17.2			
fixed overhead	40.6			
blasting				
capital	137.8		1378000	blasting equipment cost
working capital	19.4		19930	per unit per year (15% variable operating cost)
Equipment maintenance	30.1			
labor	124.8		45760	2 people at about 45,760 per person per year
fuel	15.9			
fixed overhead	40.6			
stockpiling	37.4		37550	per 1 person per person per year
sorting process				
Capital	168.4		1,684,000	excavator equipment costs
working capital	19.4		15%	variable operating cost of 19,350 per unit per year
Equipment maintenance	35.2			
labor	45.8		45,760	per 1 person per year
fuel	7.8			
fixed overhead	40.6			

Table 4.28: Current method used with No recycling (cont.) (Tam, 2008)

crushing process				
primary crushing				
equipment	165.1		1651000	primary crusher equipment
working capital	18.9	10.2	18930	15% of variable operating cost per primary crusher per year
equipment maintenance	30.1			
labor	45.8		45760	per 1 person per year
fuel	9.8			
fixed costs	40.6			
secondary crushing				
equipment	168		1680000	cost of secondary crusher equipment
working capital	19.3	10.1	19260	15% of variable operating cost per secondary crusher per year
Equipment maintainence	32.2			
labor	45.8		45760	per 1 person per year
fuel	9.9			
fixed overhead	40.6			
shaper				
Equipment	90		900000	shaper equipment cost
working capital	17.6		17630	15% of variable operating cost per shaper per year
equipment maintenance	22.3			
fuel	8.9			
fixed overhead	40.6			
labor	45.8		45,760	per 1 person per year
washing screening or air-sitting				
water	0.6		0.005	($) per t
fuel	7.8			
Total (without agg inclusion)	41797.6	20.3		
finished graded materials				
20mm aggregates	550		23000	t/y of 25$ per t
10mm aggregates	1000		40000	t/y of 25$ per t
7 mm aggregates	270		18000	t/y of 15$ per t
75 mm aggregates	480		29000	t/y of 16$ per t
Total	**44097.16**	**20.3**		

Here in the current method (No recycling is used) as indicated in Table (4.28), the cost was 44,097.16 ($1000/year) and the benefit was: 20.3 ($1000/year). Thus the net benefit here was: -44,076.84 ($1000/year); which is a loss. In this case study, the costs are more than the benefits because there is air pollution, gas emission, energy consumption as well as noise pollution. The financial costs associated with them were added to the “costs” side and not to the “benefit”. In the next lines, the recycling method will be used and the final results are going to be compared

Table 4.29: Recycling method used (Tam, 2008)

	COST	BENEFIT		
construction waste				
dumping charge from recycling plants	2914.6		25.3	per t
landfill dumping charge		6,554.40	57	per t
landfill space saved by not dumping waste		18,777.60		
transportation		576	5	per t
Air pollution		3,136.60	16.5	of landfillspace charge
Gas emission		3,267.30	17.4	of landfillspace charge
Energy consumption		4.318.9	23	of landfillspace charge
Noise pollution		3,323.60	17.7	of landfillspace charge
Stockpilling				
labor	37.4		37.44	per 1 person per year
sorting process				
capital	168.4		1,684,000	pulveiser equipment cost
working capital	19.4		19,350	15% variable operating cost per excavator per year
Equipment maintenance	35.2			
labor	45.8		45,760	per 1 person per year
fuel	7.8			
fixed overhead	40.6			
			37,550	1 person per person per year
excavation				
equipment	156.2		1,562,000	excavation equipment cost
working capital	19.4		19,350	15% variable operating cost per excavator per year
Equipment maintenance	34.9			
labor	45.8		45,760	per 1 person per year
fuel	7.8			
fixed overhead	40.6			
crushing process				
primary crushing				
equipment	163.2		1,632,000	primary crusher equipment cost
working capital	20.5		20,450	per primary crusher per year
Equipment maintenance	40.2			
labor	45.8		45,760	per 1 person per year
fuel	9.8			
fixed overhead	40.6			

Table 4.29: Recycling method used (cont.) (Tam, 2008)

magnetic separation				
equipment	120.8		1,207,900	magnetic separator equipment cost
working capital	16.6		16640	per magnetic separator per year
crushing process				
primary crushing				
equipment	165.1		1,651,000	primary crusher equipment
working capital	18.9		18,930	15% of variable operating cost per primary crusher per year
equipment maintenance	15.9			
labor	45.9		45,760	per 1 person per year
fuel	8.7			
fixed overhead	40.6			
revenue from selling scrap (mainly steel)		187.2		
secondary crushing				
equipment	166.6		1,666,000	cost of secondary crusher equipment
working capital	20.8		20,780	15% of variable operating cost per secondary crusher per year
Equipment maintainence	42.3			
labor	45.8		45,760	per 1 person per year
fuel	9.9			
fixed overhead	40.6			
shaper				
Equipment			900,000	shaper equipment cost
working capital			17,630	15% of variable operating cost per shaper per year
manual removing of remaining contaminants				
labor	37.4		37,440	per 1 person per year
removal of large pieces of wood,paper,plastics to landfill	190		3328	per ton per year for 57/t
washing,screening, or air sitting				
water	0.6		0.005	per t
fuel	7.8			
Total (without agg inclusion)	4888.3	35,822.70		
finished graded materials				
20mm aggregates	506	45	23,000	t/y of 22$ per t
10mm aggregates	800	200.00	40,000	t/y of 20$ per t
7 mm aggregates	266.4	3.6	18,000	t/y of 14.8$ per t
75 mm aggregates	462	33.4	29,000	t/y of 15.4$ per t
Total	**6738.06**	**37,654.61**		

Based on Table (4.29) and using the recycling method, the cost here was 6738.06 ($1000/year) while the net benefit was 37,654.61 ($1000/year) making a net benefit of 30,916.55 ($1000/year). The difference between the recycling and the non-recycling method is that the former method considers protecting the environment from air pollution, gas emission, noise pollution, and energy consumption in addition to saving on landfill space by not dumping waste. This is why there was a positive net benefit here compared to the other method.

Table (4.30) compares the recycling vs. the non recycling method with and without including costs/ gain from aggregates. As can be seen, whether aggregates are included or not, not much difference exists on final results. This is due to the fact that there is loss decrease (Which is considered gain) of 88 % as well as gain increase of 99 % when using the recycling method. These gains already outweigh any other benefits from selling aggregates. However, this case study chose to sell its produced recycled bricks with less prices than bricks produced from virgin materials. Table (4.31) compares recycled vs. virgin bricks prices. There is a decrease of 12%, 20%, 1.33%, 3.75% in aggregates with particles sizes 20 mm, 10 mm, 7 mm, and 75 mm respectively

Table 4.30: Comparing recycling vs. non recycling methods with and without aggregates inclusion

Status	Non recycling		Recycling		loss decrease	gain increase
	cost	benefit	cost	benefit		
without aggregates	41797.6	20.3	4888.3	35822.7	0.88	0.999
with aggregates	**44097.16**	**20.3**	**6738.06**	**37,654.61**	0.85	0.999

Table 4.31: recycled bricks prices vs. virgin bricks prices

size	non-recycling	recycling	% decrease
20 mm	25	22	12
10 mm	25	20	20
7 mm	15	14.8	1.33
75 mm	16	15.4	3.75

4.2.3 Cost analysis in Egypt

Here the cost analysis will use the same method used in Australia, but at Egyptian rates. Cost of materials and labor as well as miscellaneous rates will also differ.

The costs in the Egyptian market are as follows:

- Water used = LE10 /m^3 (water density = 1000 kg/m^3)
    - 1 ton = LE10
- 1 \$ = LE7.3
- Cost of transportation = LE350/t (for a density of 2500 kg/m^3)
- Landfill dumping charge: No data were available, so it was estimated at LE150/ton (as the landfill dumping charge for municipal solid waste ranges from LE100 to LE 110/ton, thus C&DW should have a higher rate)
- Overhead cost will be calculated at 45% of running costs
- As per most recent C&D waste data in Egypt, C&D waste was estimated at 4500000 t/year.
- Based on the Egyptian market value, scrap metal selling price was estimated as L.E 2000/ ton. The amount of metal found in the demolished in Egypt, was estimated as 8%.
- Cost of fuel will be calculated using the following equation for each piece of equipment (Source: Caterpillar manual)
    - Fuel consumption per liter per hour× cost of fuel per liter× number of operational hours per day.
    - Consumption rate was estimated as “high” as this is the one that goes with ditching, filling, and spreading of base and other materials (source: Caterpillar Manual)
    - Number of working days per week will be estimated at 6 days per week with one day off. Working days per year = 312 days per year. Other data used are presented in Table (4.32)

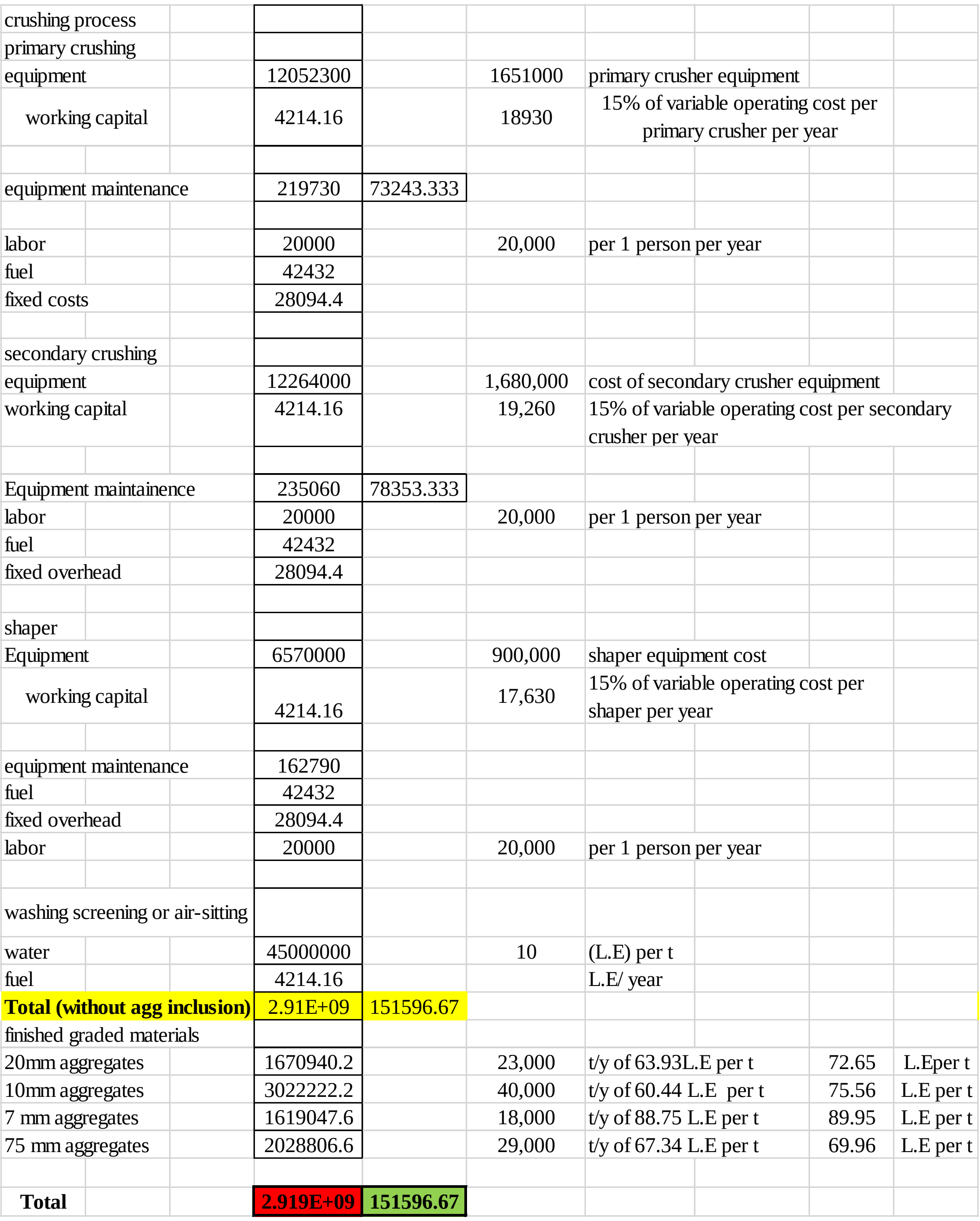
Table 4.32: Data used in cost analysis

Name	Amount	Unit
Construction waste generated	4,500,000	t
Recycling plant production capacity	110,000	t/year
Expected life of the plant	10	years
Landfill space	220	L.E/t
Cost of 1 person per year	20000	L.E
Dollar value	7.3	L.E
Fixed overhead	45	%
Fuel cost	1	L.E/l
Working hours per day	8	hrs/day
Working days per year	312	days/year
Fuel consumption per hour	17	l/h
Landfill dumping charge	150	L.E/t
Transportation for C&D waste	350	L.E/t
Dumping charge from recycling plants	150	L.E/t
Water consumption	10	L.E/t
Scrap Metal selling price	2000	L.E/ton
Metal %	8	%

Table 4.33: Non-recycling method used in Egypt (Excel snapshot)

	COST	Benefit		
construction waste				
dumping charge from recycling plants	225000000		50	L.E per t
landfill dumping charge		675,000,000.00	150	L.E per t
landfill space saved by not dumping waste		18,777.60		
transportation		1575000000	350	L.E per t
Air pollution		111,375,000.00	16.5	of landfillspace charge
Gas emission		117,450,000.00	17.4	of landfillspace charge
Energy consumption		155,250,000.00	23	of landfillspace charge
Noise pollution		119,475,000.00	17.7	of landfillspace charge
Stockpilling				
labor	20,000.00		20,000.00	per 1 person per year
sorting process				
capital	12293200		1,684,000	pulveiser equipment cost
working capital	2867.2515			15% variable operating cost per excavator per year
blasting				
capital	10059400		1,378,000	blasting equipment cost
working capital	2867.2515			per unit per year (15% variable operating cost)
Equipment maintenance	256960			
labor	20000		20,000	per 1 person per year
fuel	42432			
fixed overhead	28094.4			
excavation				
equipment	11402600		1,562,000	excavation equipment cost
working capital	2867.2515			15% variable operating cost per excavator per year
Equipment maintenance	254.77			
labor	20000		20,000	per 1 person per year
fuel	42432			
fixed overhead	28094.4			
crushing process				
primary crushing				
equipment	11913600		1,632,000	primary crusher equipment cost
working capital	149285		20,450	per primary crusher per year
Equipment maintenance	293460			
labor	20000		20,000	per 1 person per year
fuel	42432			
fixed overhead	28094.4			

Table 4.33: Non-recycling method used in Egypt (Excel snapshot) (cont.)



crushing process						
primary crushing						
equipment	12052300		1651000	primary crusher equipment		
working capital	4214.16		18930	15% of variable operating cost per primary crusher per year		
equipment maintenance	219730	73243.333				
labor	20000		20,000	per 1 person per year		
fuel	42432					
fixed costs	28094.4					
secondary crushing						
equipment	12264000		1,680,000	cost of secondary crusher equipment		
working capital	4214.16		19,260	15% of variable operating cost per secondary crusher per year		
Equipment maintainence	235060	78353.333				
labor	20000		20,000	per 1 person per year		
fuel	42432					
fixed overhead	28094.4					
shaper						
Equipment	6570000		900,000	shaper equipment cost		
working capital	4214.16		17,630	15% of variable operating cost per shaper per year		
equipment maintenance	162790					
fuel	42432					
fixed overhead	28094.4					
labor	20000		20,000	per 1 person per year		
washing screening or air-sitting						
water	45000000		10	(L.E) per t		
fuel	4214.16			L.E/ year		
Total (without agg inclusion)	2.91E+09	151596.67				
finished graded materials						
20mm aggregates	1670940.2		23,000	t/y of 63.93L.E per t	72.65	L.Eper t
10mm aggregates	3022222.2		40,000	t/y of 60.44 L.E per t	75.56	L.E per t
7 mm aggregates	1619047.6		18,000	t/y of 88.75 L.E per t	89.95	L.E per t
75 mm aggregates	2028806.6		29,000	t/y of 67.34 L.E per t	69.96	L.E per t
Total	**2.919E+09**	**151596.67**				

Based on Table (4.33), and the Excel analysis sheet, total cost was LE 151596.667 and the benefit was LE 2.9×10^9 resulting in a loss of LE 2.9×10^9.This loss was due to high environmental pollution (air, land, and noise). That is, the costs outweigh the benefits because there is air pollution, gas emission, energy consumption as well as noise pollution. Financial costs associated with them were added to the “costs” side and not to the “benefit.”

Table 4.34: Cost and benefit analysis of using the Recycling technique

	COST	Benefit		
construction waste				
dumping charge from recycling plants	675000000		150	L.E per t
landfill dumping charge		675,000,000.00	150	L.E per t
landfill space saved by not dumping waste		18,777.60		
transportation		1575000000	350	L.E per t
Air pollution		111,375,000.00	16.5	of landfillspace charge
Gas emission		117,450,000.00	17.4	of landfillspace charge
Energy consumption		155,250,000.00	23	of landfillspace charge
Noise pollution		119,475,000.00	17.7	of landfillspace charge
Stockpilling				
labor	20,000.00		20,000.00	per 1 person per year
sorting process				
capital	12293200		1,684,000	pulveiser equipment cost
working capital	2867.2515			15% variable operating cost per excavator per year
blasting				
capital	10059400		1,378,000	blasting equipment cost
working capital	2867.2515			per unit per year (15% variable operating cost)
Equipment maintenance	256960			
labor	20000		20,000	per 1 person per year
fuel	42432			
fixed overhead	28094.4			
excavation				
equipment	11402600		1,562,000	excavation equipment cost
working capital	2867.2515			15% variable operating cost per excavator per year
Equipment maintenance	254.77			
labor	20000		20,000	per 1 person per year
fuel	42432			
fixed overhead	28094.4			
crushing process				
primary crushing				
equipment	11913600		1,632,000	primary crusher equipment cost
working capital	149285		20,450	per primary crusher per year
Equipment maintenance	293460			
labor	20000		20,000	per 1 person per year
fuel	42432			
fixed overhead	28094.4			

Table 4.34: Cost and benefit analysis of using the Recycling technique (cont.)

magnetic separation						
equipment	8817670		1,207,900	magnetic separator equipment cost		
working capital	121180		16640	per magnetic separator per year		
crushing process						
primary crushing						
equipment	12052300		1,651,000	primary crusher equipment		
working capital	1807845		18,930	15% of variable operating cost per primary crusher per year		
equipment maintenance	116070					
labor	20000		20,000	per 1 person per year		
fuel	42432					
fixed overhead	28094.4					
revenue from selling scrap (mainly steel)		720000000				
secondary crushing						
equipment	1216180		1,666,000	cost of secondary crusher equipment		
working capital			20,780	15% of variable operating cost per secondary crusher per year		
Equipment maintainence	308790					
labor	20000		20,000	per 1 person per year		
fuel	42432					
fixed overhead	28094.4					
shaper						
Equipment			900,000	shaper equipment cost		
working capital			17,630	15% of variable operating cost per shaper per year		
manual removing of remaining contaminants						
labor	20000		20,000	per 1 person per year		
removal of large pieces of wood,paper,plastics to landfill	225000000		3328	per ton per year for 50 L.E/t		
washing,screening, or air sitting						
water		45000000	10	L.E per t		
fuel	42432					
Total (without agg inclusion)	971352461	3518568778				
finished graded materials						
20mm aggregates	32349401.7		23,000	t/y of 2.8 L.Eper t	63.93	L.Eper t
10mm aggregates	48355555.6		40,000	t/y of 2.8 L.E per t	60.44	L.E per t
7 mm aggregates	23642412.7		18,000	t/y of 6.11 L.E per t	88.75	L.E per t
75 mm aggregates	31108950.6		29,000	t/y of 0.4 L.E per t	67.34	L.E per t
Total						
	1106808781	**3518568778**				

Based on Table (4.34), the cost here was LE 1.1× 10^9 and the benefit was LE 3.52×10^9 which translates into a net benefit of LE 2.41×10^9. In the recycling method technique, the benefits outweighed the cost due to the ability to resell the scrap material collected. This method also avoids pollution (air or land), thereby allowing the cost to be added to the benefit. What can be concluded from this cost analysis is that environmental costs should also be calculated. Protecting the environment from pollution is considered a benefit, while environmental harm should be calculated as a loss. Comparing between the two case studies in Egypt and Australia reveals differences in the overhead rate as well as wages. Costs of equipment were the same in both countries.

Tables (4.33) and (4.34) compared the recycling vs. the non recycling method in Egyptian market with and without including costs/ gain from aggregates. As can be seen, whether aggregates are included or not, no much difference exists on final results. This is due to the fact that there is loss decrease (Which is considered gain) of 63% to 67 % % as well as gain increase of 99 % when using the recycling method as indicated in Table (4.37). These gains already outweigh any other benefits from selling aggregates. However, to encourage the use of recycled bricks, their prices will be less compared to virgin ones as presented in Table (4.36).

Table 4.35: Comparing recycling vs. non recycling methods with and without aggregates inclusion

Status	Non recycling(Egypt)		Recycling (Egypt)		loss decrease	gain increase
	cost	benefit	cost	benefit		
without aggregates	2910296907	151596.7	9.71E+08	3518568777.60	0.67	0.999
with aggregates	**2984670887**	**151596.7**	**1.11E+09**	**3518568778**	0.63	0.999

Prices per tons that were previously used in Tables (4.33) and (4.34) are indicated in Table (4.38) and will be explained as follows: the same amount of price reduction in recycled bricks compared to virgin ones that was used in the Australian case study will be applied in Egypt as well. Assuming that non- recycled bricks are sold in the Egyptian market with L.E480 per 1000 bricks; on particle sizes 20 mm, 10 mm , 7 mm and 75 mm, the decrease will be 12%, 20 %, 1.33 % and 3. 75% respectively leading to the following prices: L.422.4, L.E384, L.E473.60, and L.E462 per 1000 bricks for particle sizes of 20 mm, 10 mm, 7 mm and 75 mm respectively. Given the density for each particle sizes, the selling price per ton can be calculated.

Table (4.36): Prices of recycled vs. non recycled brick in Egyptian market per ton as well as per 1000 Bricks for different particle sizes

size	% decrease	Egyptian market price after % decrease	density (kg/m^3)	weight per 1.8 m^3	Recycled price per ton	Non recycled price per ton
20 mm	12	422.4	2600	4680	90.26	102.56
10 mm	20	384	2500	4500	85.33	106.67
7 mm	1.33	473.60	2100	3780	125.29	126.98
75 mm	3.75	462	2700	4860	95.06	98.77

CHAPTER (5)
CONCLUSION AND RECOMMENDATIONS

Based on the results discussed in Chapter 4, the findings, conclusions and recommendations are presented herein. Such conclusions and recommendations are derived based on the materials, procedures, and other parameters associated with this work.

5.1 CONCLUSION

In Egypt, accumulated C&D waste are estimated in millions of tons, none of which is utilized. As discussed before, the daily amount produced in Egypt for C&D waste is equal to 10,000 tons. Despite this significant number, not much data, as well as laws are available concerning C&D waste in Egypt. It is also worth mentioning that no construction companies in Egypt care for proper C&D waste management as well as disposal.

5.1.1 Effect on the Construction level

- On the whole, the results obtained were consistent with the Literature Review; compressive strength as well as flexural strength decreased by increasing both the water content and the percentage of fine aggregates. Also, density decreased by increasing the percentage of fine aggregates. The water absorption percentage increased in parallel with increasing the percentage of fine aggregates.
- The recommended mixes were selected based on the following criteria: their compressive strength conformed to the ASTM standards as well as the National standards. Also smoothness of their surface as well as their external finishing should also be considered as these factors will influence the construction as well as the finishing process later on.
- The use of w/c ratios of 0.6, 0.7, and 0.8 proved to be a good selection. Below this range, the workability is difficult, and above this range the water becomes abundant in mixes and leaks out of molds.
- For the compressive strength test, at a percentage of 20 % coarse aggregates and 80 % fine aggregates (or $m_{20/80}$), as well as with increasing the coarse aggregates percentage above 20%, the effect of w/c ratio becomes negligible and all the mixes passes the compressive strength test.

- For the density test, mixes containing red bricks only, and under w/c ratios of 0.6, 0.7, and 0.8, did not pass the test. On the other hand, mixes containing only coarse aggregates of 19 mm and 9.5 mm, and under similar w/c ratios, passed the test. This proves that red bricks are more prone to water absorption than aggregates produced from recycled C&D waste. This is also consistent with the literature review.
- As per the standards, the use of aggregates produced from C&D waste proved to be successful. Therefore, the recycled materials are suitable for re-use. Bearing in mind the tremendous pollution impacts created by the construction industry, there is no other way except recycling.
- The use of crushed glass, in the first phase, did not affect the final mechanical properties of the brick. This proves that glass can be used in mix design with negligible effect on final mix design mechanical properties, such as compressive strength as well as flexural strength.
- Based on the previous results, the use of aggregates produced from C&D waste was shown to lead to a decrease in compressive strength in comparison to the use of virgin materials. Therefore, the use of aggregates produced from C&D waste should be limited to non-structural applications such as pavements, interlocks, as well as non- load bearing bricks as in this work.
- Unexpected results occurring in the first phase might be due to contaminants leaching the construction and demolition waste, thereby changing their final properties.
- As previously discussed, construction players should handle construction materials in a proper manner. Proper construction design should contribute to minimizing leftovers; which, in turn, translates into fewer materials going to landfills.

5.1.2 Effect related to costs and benefits

- When conducting the cost and benefit analysis, it is of paramount importance to include the environmental costs. Protecting the environment from pollution is a positive undertaking that should be included in the benefits. Not only is this a matter of calculating material costs, but it also concerns the environmental costs. This agrees with the Australian case study, which estimated the environmental costs as follows: air pollution, noise pollution, and energy consumption as 16.5 %, 17.7%, and 23% respectively of the value of the landfill space charge.

- Costs and benefits for the environment can be classified as direct and indirect costs. The direct ones were mentioned in terms of waste accumulation. The indirect ones are related to environmental pollution, public health, as well as conserving the natural resources according to sustainability principles

5.1.3 Effect on the Environmental level

- Recycled glass is utilized as replacement for aggregates. As previously explained, the fact that glass tends to absorb less water in comparison to aggregates, gives more strength to the final mix design. Therefore, using glass will reduce water consumption, in turn, conserving the natural resources.
- As previously discussed, lack of proper C&D waste leads to health problems as well as air, water, and soil pollution
- The use of aggregates produced from recycled C&D waste is no longer optional rather than a must to conserve natural resources and protect the environment. Due to a continuous increase in population as well as depletion of resources, the use of aggregates produced from recycled C&D waste is becoming an urgent need.

5.1.4 RECOMMENDATIONS FOR FUTURE WORK

- Since the weight of each brick is heavy (3 kg), future work might focus on using lighter materials in the mix design.
- Recommendations for future work should focus on trying w/c ratio of 0.5; this might include putting other materials in the mix design to increase the workability.
- Future research should also focus on utilizing construction and demolished red bricks. These red bricks have already used lots of energy during their manufacturing process. Thus re-utilizing them, should save energy that, otherwise, would have been used to produce new red bricks.
- Recommendations for future work might include studying the properties of the aggregates used in the mix design, such as fineness modulus and gradation curve, and reconciling them with the final properties of the mix design.

- Recommendations for future work could focus on materials such as silica fume, fly ash and alike. Since these materials can save considerable energy, re-using them has the two-fold benefit of conserving the environment and greening the construction industry.
- One major obstacle for recycling is lack of awareness as well as lack of standards, particularly in Egypt where government does not encourage the use of recycled materials.
- As discussed before, Egypt still lack C&D waste management laws. Therefore more laws and regulations focusing on C&D waste should be enforced.
- As mentioned earlier, more awareness campaigns should be organized to encourage recycling. This movement should initially start at a local level prior to moving up to the national level. Citizens need to develop awareness of the importance of existing resources, and realize that even those that remain will, over time, never be able to accommodate the huge increase in population.
- Future work should focus on recycling, as a “way of life” in society; as previously discussed, a great number of people earn their living through recycling. Actually, it was through using the recycling technique that many students in Mokattam acquired reading, writing and mathematical skills. This proves that recycling, not only provides more job opportunities, but has also a “social” role in society. Given the fact that recycling is a job that does not require any special training or qualifications, a factor that particularly matches the needs of developing countries where most of the populations are illiterate, this might be one of the best jobs for Egyptian citizens

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