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Sustainable Building Construction with Solid Waste

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The Isra University

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DEDICATION

To my father, my beloved mother, my brothers, my friends

To each person helped me through my studying period,

And especially, to my supervisor Dr. Ayman Abu Hammad

To all of you, I feel honored to dedicate this work.

Bashar Al-Aqtash

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

C&DWM	**Construction and Demolition Waste Management**
CWM	**Construction Waste Management**
LEED	**Leadership in Energy and Environmental Design**
ASCE	**American Society of Civil Engineers**
ISSMGE	**International Society of Soil Mechanics and Geotechnical Engineering**
HDPE	**High-Density Polyethylene**
PET	**Polyethylene Terephthalate.**
R&D	**Research and Development**
LCA	**Life Cycle Assessment**
ASTM	**The American Society for Testing and Materials**
PVC	**Polyvinyl Chloride**
DDAC	**Didecyl Dimethyl Ammonium Chloride**
OPC	**Ordinary Portland Cement**
RPL	**recycled plastic lumber**
CARE	**Carpet America Recovery Effort**
GDP	**Gross Domestic Product**

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ABSTRACT

Prior three decades, numerous global companies, adopted the idea of sustainable buildings using waste management to establish for their facilities and some of their branches in different districts in the world. Here in Hashemite Kingdom of Jordan, many organizations and companies including private and governmental sectors, national and intergovernmental institutions are competing to build such buildings which would achieve sustainability from waste materials. In this work, a house was built via waste construction materials, taking into account the economic feasibility of the new building besides maintaining the same physical and mechanical characteristics of conventional structural materials. After conducting this work, it was found that there are seven major waste materials which can be used in commercial scale achieving economic viability without affecting mechanical and physical features of new construction materials compared to conventional structural materials. Those seven waste materials were: (a) waste glass,

used for partials replacement in exterior wall, (b) waste wood for insulation element in the exterior walls of the house, (c) waste plastic that can be converted and recycled into plastic lumber as an alternative to parquet, (d) construction and demolition waste aggregate that used as an alternative to traditional cement in the slab, (e) waste rubber which was used in interior an part of exterior walls of the house, waste steel bars as an alternative to traditional steel in the house, and (g) cardboard that was used as exterior brick cladding. Also, it was found that utilizing these materials did not change remarkably the mechanical and physical characteristics of traditional material. Alternative hypothesis, 1, was found to be valid and correct whereas null hypothesis ,was not valid, as cost of the house built using waste materials from Jordanian C&D phases was less than conventional construction materials. Additionally, the mechanical and physical characteristics of waste materials were similar to those related to conventional construction materials. A survey was conducted to support the hypothesis of this work. The hypothesis covered managers and engineers from contracting and consulting companies, and found that most of the society surveyed agreed that utilizing waste materials in construction under certain conditions would be more cost effective than conventional construction materials. It is recommended to conduct further analysis on the materials investigated in this work to be more valid and effective in construction industry.

Keywords: Construction Waste Management, Glass, Steel Bar, Rubber, Cardboard, Wood Sawdust, Plastic Waste, Jordan.

Chapter One: INTRODUCTION

This chapter indicates the study background related to waste management in buildings and in the construction industry. Also, this chapter discusses information with respect to the problem statement, purpose, research questions and research significance, and gives details regards to why this work was important and what its contribution was.

1.1 Background

In this section, the definition related to construction and demolition waste management (C&DWM), the global construction status and structural waste management prospects will be addressed.

1.1.1 Definition

Tam and Tam, (2006) defined construction waste as any substance which is created during the structural phase related to small scale buildings or metropolitan infrastructure facilities such as tunnels and bridges, which may affect negatively human health status, life quality, nature sites and animals' health.

C&DW includes wood, concrete, brick, rocks, soil, glass and more. Additionally, Lauritzen, (1998) stated that waste from C&D industry is defined as a massive quantity of waste produced from construction boundlessly when a devastation or nature disasters may occur, causing severe and insecure hazards against human and environment.

1.1.2 Global Construction Status and Structural Waste Management

Currently, construction tasks carried out for building several facilities are highly expanded in the world. Globally, the largest construction countries include those developed and developing counties presented in figure (1-1).

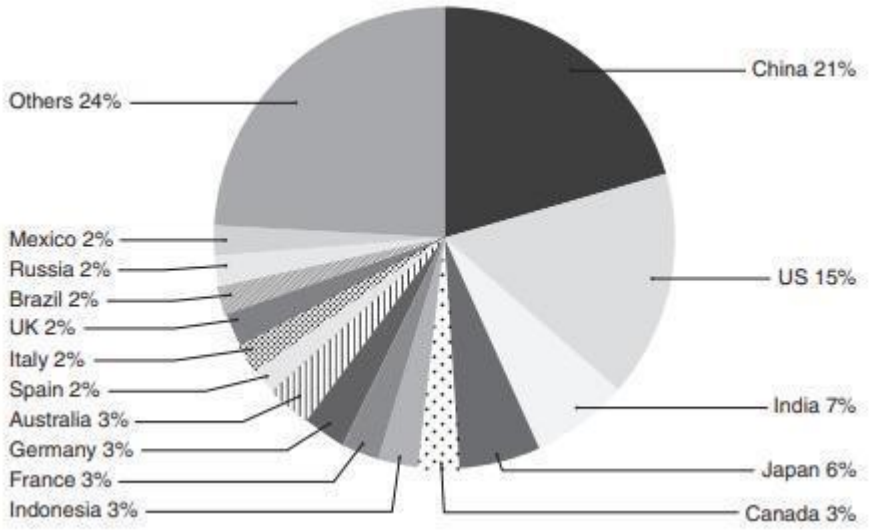


Fig. 1-1 World powerful countries in construction. Source: Ochieng et al., (2013).

Ochieng et al., (2013) stated that the most powerful countries in the construction are China with a rate of 21% followed by the USA with a rate of 15%. India is the third country in this field corresponding to 7%. Other countries, including Canada, Germany, France, Indonesia and other countries have a construction's power rate ranges between 2% and 3%. For this reason, the amount of structural waste generated from those countries is massive relative to other countries in the rest of the world. Waste management has gained much importance because of its higher effective savings and significant economic feasibility for small-scale structures (commercial and public building), and large-scale urban projects (including city infrastructure and services).

David et al., (2019) stated that the amount of world metal waste is 1.3 billion tons annually, and it is predicted to rise up to 27 billion tons in 2050. Yoshizawa et al., (2015) indicated that due to global rapid growth in population, because of economic development and urbanization, the amount of earth resources and materials consumed is so massive, and causes a huge volume of waste from construction processes, causing severe impacts against the environment.

Waste management has a remarkable contribution to the environment. It has very low impact not only on nature, but also on communities and the global economy. Many consulting and contracting companies relied recently on Leadership in Energy and Environmental Design (LEED) standards, American Society of Civil Engineers (ASCE), and International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) building codes that greatly changed the procedure of the waste management strategy and minimized the amount of waste materials produced midst the construction phase, and hence, saving much of building budget.

Construction waste management comprises effective plans which allow wastes from construction materials, to follow particular recycling processes with a purpose of making them capable to be utilized again. Many construction materials can be sent back to factories in order to be recycled such as wood (covered or plain), aluminum, paper, plastics (including HDPE as well as PET), and concrete.

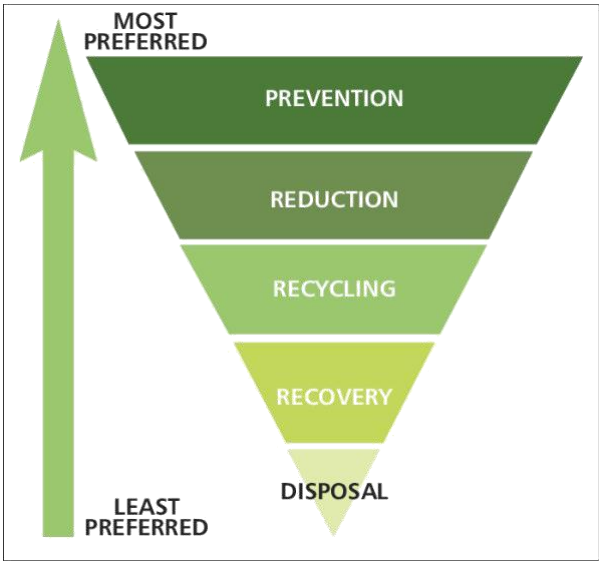


Fig. 1-2 Waste management hierarchy configuration. Source: Komen, (2013)

In this sequence, and as figure (1-2) illustrates, 'Reduce', 'Reuse', 'Recycle', and 'Recover' present major steps which are implemented to cut down the amount of waste generated in construction, utilize the construction materials multiple times instead of throwing them away, generate new products to be utilized from the waste, and convert waste from construction into beneficial materials via special thermal and biological treatments.

Moreover, figure (1-2) presents the backbone of waste management strategy, by which the amount of pollution transferred to the environment can be diminished to a large extent.

C&DW management is highly practical and feasible as it can considerably save natural resources, afford a methodology to recycle construction waste, utilize alternative building substances, and use waste furniture again through recycling. In addition, C&DWM employs sustainable types of paints and colors, exploit waste of glass, wood, plastics, metals, concrete, structural steel and other materials to minimize higher amounts of C&D waste. (Al Rabea, 2016).

1.2 Problem Statement

The amount of waste generated from construction and demolition (C&D) per annum is massive. According to Singh et al., (2014), 1.7 to 1.9 billion tons of global waste was driven to world landfills. Additionally, just 11% of the global waste in 2006 was processed through thermal and waste-to-energy processes, and only 19% of global waste was recycled via different treatment methodologies.

In Jordan, there is also a large amount of waste which is generated from C&D. Furthermore, there is a scarce in implementation of C&DWM in Jordan. Recycling Jordanian C&DW materials such as waste glass, waste metals, waste wood, sawdust, demolition waste aggregate is a very important activity, which can highly minimize these wastes instead of going to landfills.

In this work, a methodology is developed with cost analysis in order to build a house using waste materials from C&D in Jordan. The cost of building a house is relatively higher when it is compared to a house which is built from waste materials. In addition, many researches realized that utilizing waste materials from C&D in construction would highly minimize the cost of the building. At the same time, the same characteristics of mechanical, physical and chemical properties of new materials made out from waste, compared to conventional materials can be achieved. This work is conducted to investigate the price of waste materials used for constructing a house after selecting the proper waste materials in terms of their economic feasibility, cost effectiveness, abundance and availability.

1.3 Significance of the Study

This work comes up with several significances. The major significance of this work is to bring major modifications in building and construction via utilizing C&DWM criteria into Jordanian construction industry.

Additionally, in Jordan, the amount of C&DW is increasing because of a rapid growing population and migration occurred in the last two decades, causing a pressure on the infrastructure as well as construction industry related to residential buildings.

Additionally, many Jordanian towns are having shortage of C&DWM strategy. During the construction phase, different types of C&D wastes are sent to landfills, and they were not subjected to recycling or reduce strategy. This issue causes severe impact on Jordanian green areas and bare lands, and considerable degradation of the agricultural soil.

Furthermore, Jordanian suburbanite areas became so vulnerable to pollution as they are highly close to newly established buildings and urban movement which produce much waste from C&D phases, bringing critical syndromes in residents' respiratory system and unprecedented human diseases related to this case.

In accordance with the preceded discussion, a considerable contribution of this work, is the utilization of waste materials from C&D and minimize the negative impact on Jordanian surrounding environment and nature features.

Moreover, this work will concentrate on managing the efficiency of the house designed to the maximum frontier, by selecting waste materials generated from C&D phases with higher mold resistance, higher capacity of insulation, sufficient resistance to abrasion, and minimized level related to reaction with the atmosphere.

1.4 Research Aim & Objectives

The main aim of this work is to investigate the cost effectiveness and economic feasibility related to waste materials generated from Jordanian C&D phases, through a particular methodology to build a house with minimized cost, and compare this cost with the traditional case which uses conventional construction materials for the same purpose and calculate the quantities of materials used in both cases (case 1: waste materials, and case 2: conventional materials).

Besides these objectives, C&DW generated from Jordanian construction industry must be modified and adjusted to have special mechanical and physical properties, which make them valid and reliable in construction not only in this project, but also in a wider range, such as being robust and having higher thermal insulation capability, besides being environmentally friendly and sustainable. In order to accomplish this aim, four research objectives were formulated and stated through the following:

1. Investigate and overview the status of the waste management strategy around the globe.
2. Explore prospective and possible methodologies utilize waste generated from the construction sector in Jordan.
3. Develop a methodology and a model to waste utilization for building a house.
4. Validate the model by performing project cost estimation and feasibility study.
5. Compare the cost of project to conventional materials used for the same target and also compare the quantity of materials calculated in both cases.

Chapter Two: REVIEW OF THE LITERATURE

2.1 Introduction

This chapter will provide a comprehensive outline regarding the previous research on C&DWM applied in construction industry globally and in Jordan. It discusses the innovations, research and development (R&D) in this field, expressing the major challenges faced by researchers, project managers, and engineers from all disciplines related to C&DWM implementation in several projects.

2.2 Overview of Global Construction Waste Management

From the UK perspective, Lawson et al., (2001) stated that in both England and Wales, 53.5 million tons of C&DW are produced per annum. He indicated that 51% of this waste goes to landfills, whilst 39.6%, (21.2 million tons) of construction waste is utilized for land modeling during the construction phase.

Adjei et al., (2013) stated that UK C&DW management legislations arranged many policies that contribute to maintaining the environment's protection, natural resources, safety, health and the profitability of projects engaged in the construction process.

European Commission (2005) stated that through the last two decades, European Commission legislated important regulations and instructions that limit the amount of waste produced during the construction phase. In addition, European Union put a scheme to get rid of construction waste with no unfavorable influence on European environment and nature.

Butera et al., (2015) indicated that Denmark has gone a long way through construction and demolition waste management (C&DWM). He stated that transportation presented the most important cause of most waste impact from construction, corresponding to 60% to 95% of this impact on Danish nature. Additionally, as figure (2-1) shows, Denmark has widely adopted C&DWM policy to effectively reduce the waste resulted from road construction.

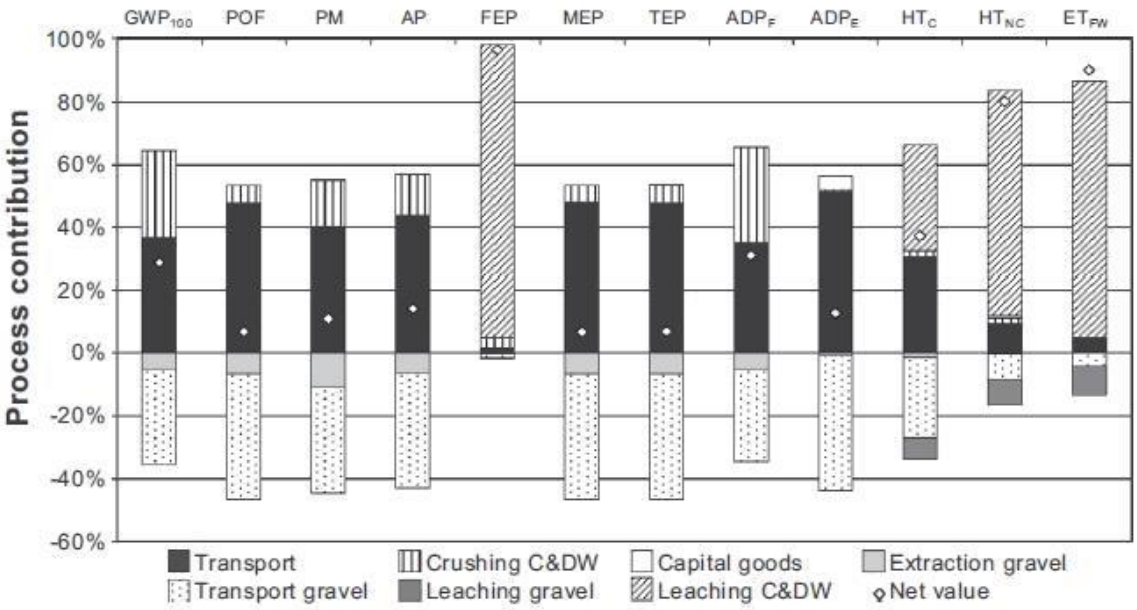


Fig. 2-1 Exploitation of C&DWM in Danish road construction via different scenarios. Source: Butera et al., (2015)

In figure (2-1), many factors and concepts were included. According to Butera et al., (2015), those factors included terrestrial eutrophication potential (TEP), global warming potential (GWP), acidification potential (AP), abiotic resource depletion potential of fossil (ADPF), photochemical ozone formation (POF), Eco toxicity to freshwater (ETFW), particulate matter (PM) and other more vital factors in his work.

Moreover, Nelles et al., (2016) indicates his nation's experience in the process of management for C&DW. He stated that Germany puts a closed-cycle policy for C&DW management, not only to reduce the amount of waste generated from C&DW, but also to make it economical and provide jobs for citizens in waste management in construction.

Nelles et al., (2016) stated that C&DW management utilizes the same principles illustrated in the construction waste management hierarchy. He mentioned that Germany recycles approximately 90% of total C&DW, being the leading European nation in the waste management implementation.

Rawshan et al., (2007) stated that 73% of Malaysian construction waste generated is reused, whereas just 27% is disposed. This makes Malaysia active in practicing C&DWM.

Yeheyis et al., (2012) pointed out that the amount of C&DW generated in Canada is 27% of the total disposed waste in Canada. He stated too, that Canada utilizes C&DWM hierarchy and applies 'reuse', 'recycle', 'recover', and 'reduce' principles for minimizing the amount of waste generated from the construction sector effectively. Yeheyis et al., (2012) stated too, that C&DWM is vital to implement, because approximately 75% of waste generated from structural facilities, and construction industry has a value which can be recovered and employed again by reuse strategy.

Lu and Tam, (2013) stated that C&DWM strategy which was adopted by Hong Kong government, additional to 3R methodology (i.e. reduce, reuse and recycle) and 'polluter pays' system has minimized remarkably the amount of waste resulted from construction. In the last decade, solid construction waste has significantly minimized from about 50 tons to approximately 20 tons per million US$ project.

As figure (2-2) shows, Ratnasabapathy, (2019) stated that the amount of waste resulted from the C&D phases is relatively large. During 2017 and 2018, the Australian GDP from the construction industry alone, which is considered to be the second greatest industrial sector, has a total contribution of 8.10%.

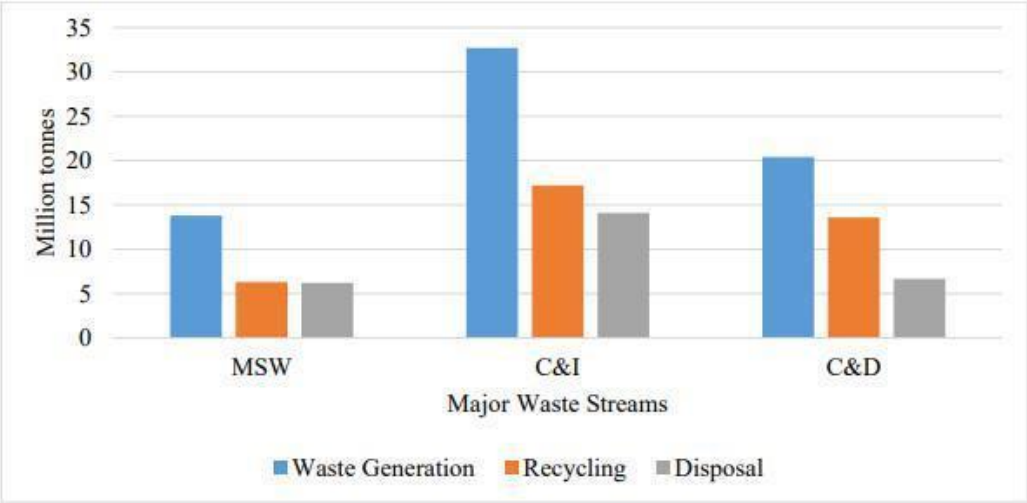


Fig. 2-2 Waste from commercial, industrial, construction and demolition (million tons), in Australia. Source: Ratnasabapathy et al., (2019).

As illustrated in figure (2-2), national Australian waste report (for 2018), stated that the quantity of C&D waste generated in this year amounted to just over 20 million tons. Less than 15 million tons of waste has been recycled. In the same year, over 5 million tons of C&D waste has been disposed. Ratnasabapathy et al., (2019) pointed out that block chain platform technology is utilized by Australian government connected with the C&DWM strategy by providing a decentralized database to enhance the quality and efficiency of this strategy to manage waste from a variety of sectors.

Clark et al., (2006) mentioned that the USA has a significant construction industry and real estate businesses, inspiring a real consideration to C&D waste management, which comprises a

collection of leachates, controlling the quality of groundwater, monitoring the location constraints, and running the lining method of landfills.

EPA report, (2017) stated that approximately 569 million tons of debris generated from C&D were reported in 2017 for the whole states of the US. Clark, (2006) stated though, the regulations of C&D waste management vary from state to state.

Fraile-Garcia et al., (2018) investigated utilizing rubber in construction as a filler material of conventional hollow brick. He stated that thermal conductivity of hollow brick after filling it with disposed of rubber and other construction materials such as slabs and joists has been minimized. Fraile-Garcia et al., (2018) utilized several mixing percentages of rubber including 0, 10, and 20 percent in these three construction elements. They subjected the latter into a number of heating and cooling tests with specific time intervals and recorded the resulting temperature values.

Fraile-Garcia et al., (2018) found that the thermal insulation of these construction materials corresponds directly to the amount of rubber doped inside these materials. The temperature difference was remarkable (5.6 percent), when the largest amount of rubber (i.e. 20 percent) was doped inside different concrete components, including bricks, slabs and joists.

2.3 Overview of Construction Waste Management in Jordan

Al-Rifai and Amoudi, (2016) investigated the status and prospects of waste materials from construction industry in Jordan. They stated that these wastes have unfavorable impact on the performance and efficiency of Jordanian construction industry. In order to investigate the factors, which cause large impact against Jordanian environment, they conducted a survey that utilized semi-structured interview, which help collect more information from construction professionals concerning the causes of C&DW in Jordan. They found that there are many waste materials would be generated from construction industry sector in Jordan. These are presented in table (2-1).

Table 2-1 Waste generated from construction.

#	Building Material					Range of Actual Waste (%)
1		< 2%	2%–5%	5% - 10%	> 10%	
2	Concrete	20	80	0	0	2-12
3	Steel	80	20	0	0	2-10
4	Formwork	0	0	20	80	10-40
5	Sand and Aggregates	20	80	0	0	3-15
6	Cement	20	80	0	0	3-20
7	Bricks	0	40	40	20	5-10
8	Stone	10	50	20	20	5-20
9	Tiles	0	80	20	0	3-11
10	Ceramic	0	60	40	0	3-11
11	Pipes	80	20	0	0	3-7
12	Paint	60	20	20	0	3-7

In their findings, Al-Rifai and Amoudi, (2016) stated that the most significant factors which have contributed, to a large extent, to waste from Jordanian construction industry were two. The first one is the factors which are related to the quality of management system, and the second one is the factors which are related to the workforce. Al-Rifai and Amoudi, (2016) stated that decision makers can benefit from their research results in building effective strategies, which in case applied by professionals, would highly minimize the amount of waste generated from construction sector in Jordan. Yakhlef, (2020) stated that Jordan does not include clear management policy for waste generated from construction. In addition, Jordanian sustainable development needs a planned methodology by which each stakeholder who is correspondent with waste generated from construction must be engaged. Environmental affairs related to C&D waste management must be also considered and thoroughly investigated. Yakhlef, (2020) investigated the problems related to C&D waste in Jordan with analyzing four factors. Those factors, which are: (A) regulations, (B) technology, (C) policy, (D) guidelines, were investigated synchronously with project life time and the three R-principle (i.e. reduce, reuse and recycle). Yakhlef, (2020) found that residential construction projects generate around 22 kg/m^2 of waste from construction, while demolition generates around 630 kg/m^2 of waste. Moreover, non-residential construction generates 20 kg/m^2 from construction, while 780 kg/m^2 are generated from demolition. Yakhlef, (2020) suggested that modern construction and building standards, and Building Information Modeling (BIM) must be utilized for efficient management generated from C&D waste. Bekr, (2014) investigated the reasons of waste generated from C&D phases in Jordan, and the amount of those wastes produced in construction sites in Jordan. In order to achieve the target of the research, the researcher conducted a survey to predict the percentage of waste generated from construction sites in Jordan, and the reasons, why they are produced with the current magnitude. The researcher's questionnaire society included 240 individuals (contractors, consultants and customers). Bekr, (2014) found that

there are several reasons which cause waste from construction sites in Jordan. Those reasons include: (A) client's decisions to change the design, (B) workers' mistakes which cause rework, (C) shortage of materials storage, (D) lack of strategy of waste management, (E) shortage in experience and skilled worders, (F) materials damage caused by transportation, (G) inappropriate site conditions, (H) materials vandalism and robbery, (I) faults related to materials' quantity survey. Moreover, it was found that 15% to 20% of waste is generated from construction sites in Jordan. Bekr, (2014) recommended to enhance the standards related to contracts' documents, to avoid wastes which may generated from a change in the design, or poor documentations. He suggested to prepare promoted storage place near the construction sites, hire high experienced-engineers and supervisors, and implement C&DWM strategies by contractors. Aldayyat, (2019) stated that Jordan construction waste resources are concentrated in the northern and middle of the region, i.e. Irbid and Amman, respectively. The reason is due to the higher population centralization in those regions, which was generated through the migration of about 1.4 million Syrians, 650,000 of them are refugees, which cause a heavy burden on construction waste management infrastructure in Jordan. Those several migrations resulted in much pressure on infrastructure and the amount of waste generated from C&D phases. Figure (2-3) represents the types of waste in Jordan that was generated in 2014.

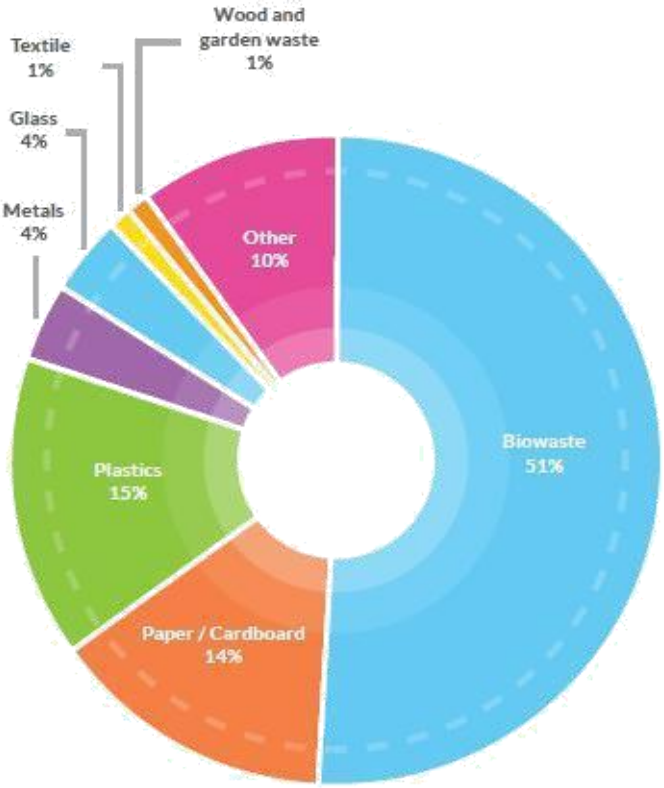


Fig. 2-3 Commonalty waste sorts generated in Jordan in 2014. Source: Saidan and Abu Drias, (2016).

It can be indicated that construction waste components, including paper or cardboard (14%), plastics (15%), metals (4%), glass (4%), wood (1%), and textile (1%) present overall 39% of total municipal waste in Jordan. Additionally, Saidan and Abu Drias, (2016) reported, from a database in the Jordanian green building council Report in 2016, that the quantity of construction waste differs from province to province based on the urbanization index corresponding to the zone. Table (2-2) presents these preceded facts.

Table 2-2 C&D waste composition based on the urbanization index. Source: Saidan and Abu Drias, (2016).

Waste Category	C&D Waste Composition (%) based on urbanization index		
	0-50	51–75	76 - 100
Paper and cardboard	9	13	15
Plastics	9	13	15
Metals	2	3	4
Glass	2	3	4
Wood	5	2	1
Governorates	Mafraq, Tafila	Jerash, Madaba, Balqa, Ma'an, Karak	Amman, Zarqa, Irbid, Ajloun, Aqaba

It can be shown that provinces such as Amman, Zarqa, Irbid, Ajloun, and Aqaba have the highest urbanization index; that range between 76 and 100%, generates the largest amount of structural waste. Amman is the major capital of Jordan, while Aqaba presents the economical metropolis of Jordan. Irbid and Zarqa have the highest population density after Amman. Additionally, Saidan and Abu Drias, (2016) mentioned that major debris substances from C&D and excavation are dumped down the side of the streets. However, the structural steel and wood were highly recovered. Structural steel rods are utilized directly again, or reused after subjected to further processing. Moreover, most of Jordanian wood employed in construction is recovered as a fuel, or sold to Jordanian chicken's farms. The recoverable items resulted from C&D phases are recovered and sent to

second-hand trading. These items include wooden and Aluminum frames, windows glass, doors and carpentry accessories.

2.4 Waste Construction Materials from Structural Waste - Review

In his article Hamoush et al., (2011) described a unique artificial stone was produced boosting the characteristics and quality of the stone by integrating a variety of materials into a single material (yet consisting of two layers). The first layer is external, modified for accepted scenery, and designed with enhanced durability and strength.

On the other hand, the internal/ back layer has a lightweight and higher resistivity coefficient. This feature was achieved for the internal layer by utilizing construction waste from recycled rubber. Rubber improves material's toughness and ductility, and, it reduces the material's conductivity allowing energy saving fulfillment due to the insulation purpose. Table (2-3) presents the water absorption percentage of new material made from recycled rubber from scrap compared to other conventional structural materials.

Table 2-3 Rate of water absorption by several construction materials. Source: Hamoush et al., (2011)

Material	Face Layer	Internal Layer	Limestone	Sandstone	Clay brick
Absorption (%)	0.21	0.38	0.53	1.51	8.15

As table (2-3) shows, the new modified material made of scrap rubber has the least absorption rate of water, making it beneficial for humidity and mold resistance in cold and humid weather conditions. Hamoush, (2011) stated too, that the compressive strength measured on new material is lower than the compressive strength of hard limestone (approximately 97 MPa – face layer and 7.4 – internal layer) vs (235 MPa). Yet, the hard limestone is more brittle than manufactured stone.

On the other hand, in his work, Kaosol, (2010) created a hollow concrete block utilizing the sludge processed from wastewater. This in turn increased the value of wastewater exploitation. Kaosol, (2010) found that 10% and 20% of treated sludge from waste water can minimize the cost of each block by 0.021 and 0.034 US$, respectively. Figure (2-4) illustrates the result of the compressive strength test, a test that was conducted through several days (till about a month) in order to predict the strength profile of a hollow concrete block that was made from wastewater sludge [part (a)].

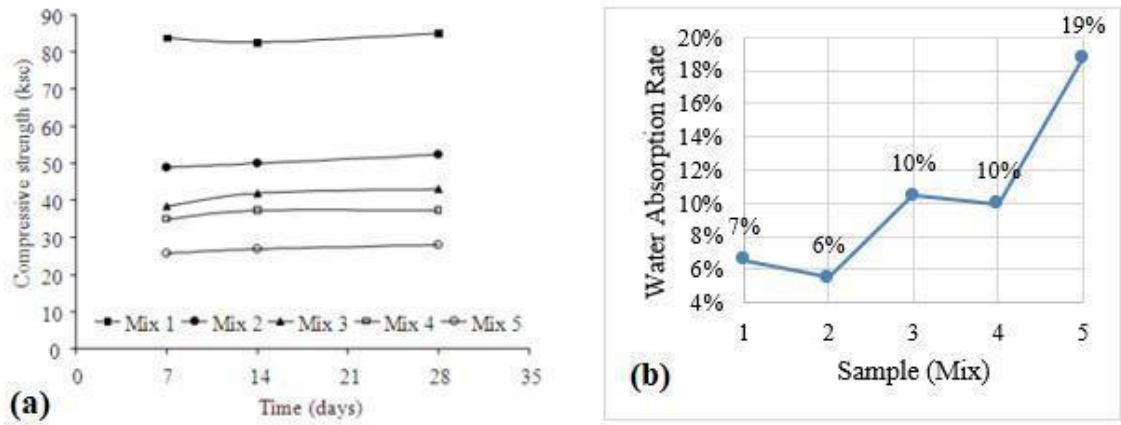


Fig. 2-4 (a) Compressive strength of hollow concrete block with water treatment sludge. (b) Water absorption of concrete block made of sludge. Source: Kaosol, (2010).

In [part (b)] of figure (2-4), it can be indicated that sample number five has the maximum rate of water absorption with a percentage of 19%. The reason goes back to the composition of each sample. For instance, sample number five has the minimum amount of sand mixture and crushed stone dust mixture, with a rate of 15% and 15%, respectively.

Abdul and Mohajerani, (2011) stated that recycling cigarette butts (CBs) to fired clay bricks is totally economical feasible. Every year, there are trillions of cigarettes are produced around the world, resulting in several millions of tons of severe poisonous waste taking several years to decay.

They added too, that the major component of cigarettes is much purified cellulose fiber made out of wood pulp via acetylation process.

Four specimens with the distinguished volume of CBs were selected with a CBs' content of 2.5%, 5%, 7.5%, and 10% compared to a fifth specimen with 0% of CBs as a control and modification purpose. Figure (2-5) provide some details of the experiment's procedure.

Fig. 2-5 Soil and water mixture of cigarette butts, soil, and water in laboratory. Source: Abdul and Mohajerani, (2011).

After conducting the investigation, they found that the compressive strength for of these specimens (with 1% CB) was 19.53 MPa, knowing that the average compressive strength of conventional structural brick amounts to 5.7 MPa, which is relatively a satisfying result. At the same time, Abdul and Mohajerani, (2011) found that bricks with CB content greater than 5% will not possibly accepted in many construction fields, due to the compressive strength value which runs lower than 3.0 MPa.

Moreover, gas emitted from the combustion of two of these engineered bricks (0% and 5% of CB), varies depending on the specimen composition. For instance, the amount of carbon dioxide, carbon monoxide (CO), nitrogen oxide (NO), hydrogen cyanide (HCN), and chlorine were highly

diminished with the brick of % CB. Additionally, the four specimens (compared to the fifth) varied in the value of resistivity (i.e. Thermal conductivity) between 0.4 and 1.2 W/m.K, as shown in figure (2-6).

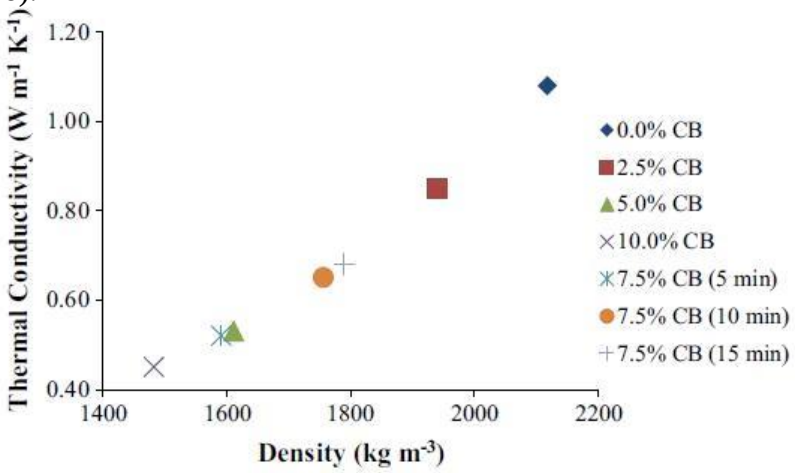


Fig. 2-6 Five brick engineered specimens' thermal conductivity and their density. Source: Abdul and Mohajerani, (2011).

As it can be noted from figure (2-6), the most convenient brick, which can be used for construction purposes effectively is the one which contains 10% of CBs, as it has the least value of thermal conductivity. Finally, Abdul and Mohajerani, (2011) proposed the utilization of the specimen with a CBs rate of 1% as the most preferable structural brick to be utilized or construction purposes. The latter is highly professional to provide quite similar characteristics to the conventional bricks (i.e. Bricks with no CB substances).

Gu and Togay, (2016) has reported 84 previous studies, which discussed the employment of plastics, plastic fibers (PF), and plastic aggregates (PA) in manufacturing sustainable concrete from construction waste.

They reported that the amount of plastics production worldwide reached more than 288 million tons in 2012, approximately 25 million tons of that run down to the garbage stream, which caused serious environmental issues as plastics take decades to completely decay.

Gu and Togay, (2016) reported too, that the direct mechanical recycling process would lead to a lower density of plastics, whilst melting methodology would lead to a higher density of plastics. Furthermore, Gu and Togay, (2016) listed six specimens comprising a different amount of expanded polystyrene (EPS) employed to compare the amount of strength and strain for the newly manufactured bricks as shown in figure (2-7).

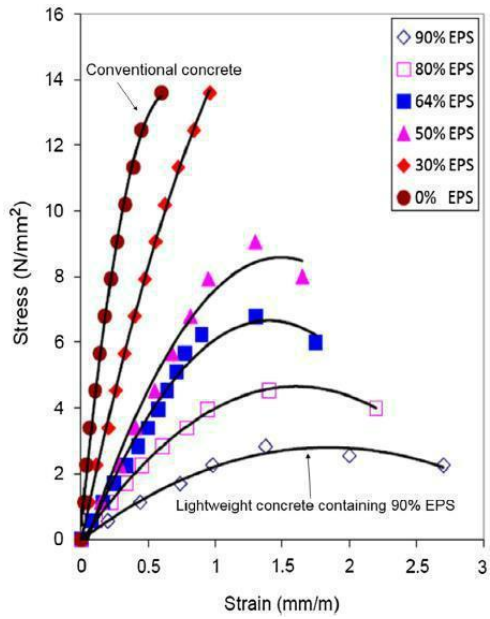


Fig. 2-7 Strength-Strain curve for different bricks with particular EPS. Source: Gu and Togay, (2016)

From figure (2-7), it can be noted that concrete mixed with EPS has highly different mechanical properties compared to conventional concrete. For instance, conventional concrete can reach maximum strength value of 14 N/mm^2; however, as the percentage of EPS increase in the concrete, it will be able to absorb more energy, becoming more ductile comparing to conventional concrete that is brittle. Additionally, concrete with 90% and 80% EPS have a definite yield point that allows much strain hardening, and higher plastic deformation.

Additional to the preceded literature review, Bolden et al., (2013) stated that there are several components utilized in the manufacturing of concrete as well as asphalt made of recycled solid waste. Figure (2-8) present these materials.

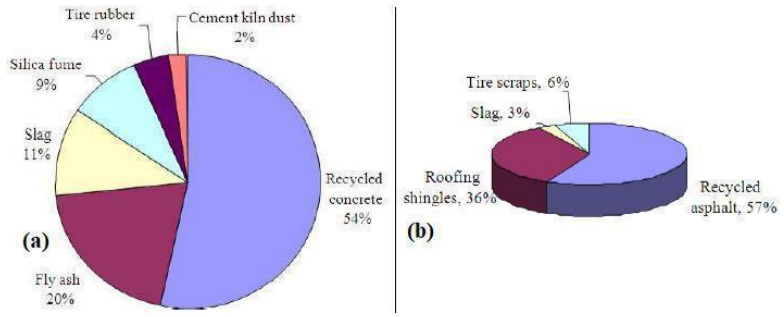


Fig. 2-8 Prevalently recycled substances used for: (a) concrete, (b) paving asphalt. Source: Bolden et al., (2013).

It can be found that the major recycled materials from waste utilized in making concrete are rubber from tires (4%), slag (11%), fly ash (20%), silica fume (9%), besides the recycled concrete itself (with a rate of 54%). For paving asphalt, tire scraps (6%), slag (3%), roofing shingles (36%), and recycled asphalt itself are employed.

Sas, (2018) stated that in 2015 approximately 1.6 billion kilograms of carpet were disposed of in the whole US. According to (CARE annual report, 2018), total consumers' carpet amounted to 0.4 kg per US capita in 2018. Greenhouse emissions that were saved in this year were roughly 160,000 million tons of carbon dioxide.

According to EPA, equalizes removing 34,087 cars from the road, saving about 372,000 barrels of crude oil, and providing electricity for 19,225 houses in a one-year interval. Sas, (2018) stated too, that recycled carpets from the garbage and landfills were disassembled into several categories

including mainly nylon and plastics, besides the fabrics such as cotton and silk from traditional carpets.

2.5 Limitations and Challenges related to Structural Waste Management

Bolden et al., (2013) stated that there are some variables and factors that significantly affected the process of implementing waste management storage within construction effectively. This depends largely on the budget of the project, its sustainability as well as whether there are environmental considerations towards nature or not. Figure (2-9) shows the major factors of this case.

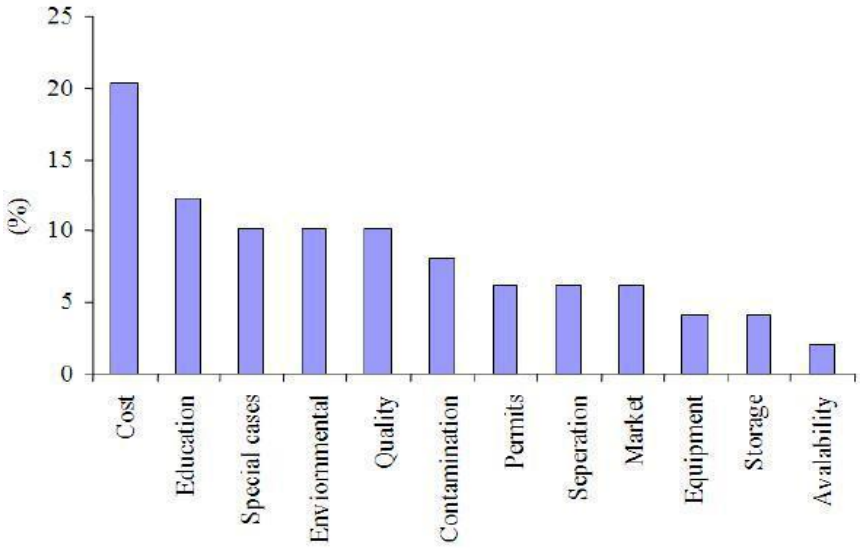


Fig. 2-9 The restrictions of CWM implementation in real and practical case. Source: Bolden et al., (2013).

It can be noted from figure (2-9) that the influencing factor which controls or limits the application of waste management in the construction sector is the cost with a rate of 20%. Moreover, the financial status of the company and the availability of funds for waste management plays a key role in allowing the utilization of waste management criteria. Bolden et al., (2013) mentioned that in case, a consulting

or contracting company intends to recycle its construction waste, this affair must be considered during the analysis of the project's budget.

The second influencing factor that affects the capability to apply waste management criteria in construction is education. Other factors that may affect this strategy include whether the country is taking environmental issues into the account in building and construction or not, market status, availability, permits to utilize this methodology and storage.

2.6 Summary

According to the researches discussed above, it can be shown that there are considerable contributions concerning sustainable strategies related to C&DWM, which started for about thirty years, covering wide range of materials which are generated from C&DWM. Table (2-4) presents the amount of C&D waste generated from different countries.

Table 2-4 Generated C&D waste from different nations. Source: Jalaei et al., (2019)

China/ Shanghai	842 (kilogram per capita per annum)
Thailand	18 (kilogram per capita per annum)
USA/ Florida	471 (kilogram per capita per annum)
Portugal	400 (kilogram per capita per annum)
Kuwait	800 (kilogram per capita per annum)
Greece	191 (kilogram per capita per annum)
Taiwan	110 (kilogram per capita per annum)

Table (2-4) shows that the quantity of waste generated from developing countries such as Kuwait and from other Middle East countries is approximately double or triple that quantity generated in the first and second world countries. This goes back to the fact that there is high awareness towards

environmental protection and nature safety from individuals and governments of developed countries compared to the developing countries. Additionally, Bolden et al., (2013) reported that most materials that companies are aware of to recycle and recover are gypsum (6%), metals (6%), steel (2%), flounder sand (5%), silica fume (5%), and furthermore presented in figure (2-10).

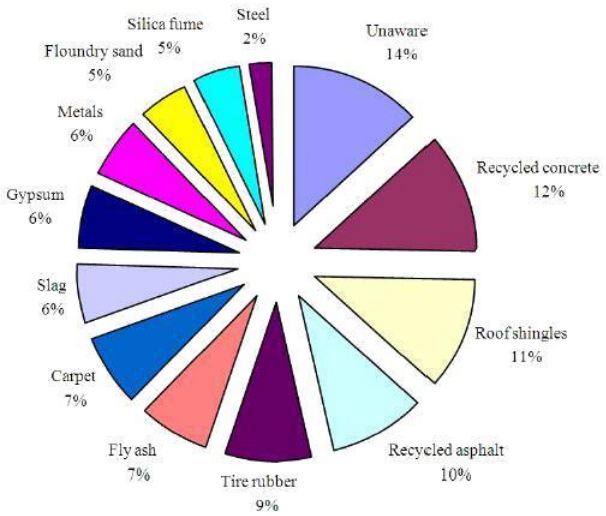


Fig. 2-10 Major substances which is recycled, and recovered by construction. Source: Bolden et al., (2013).

The survey of Bolden et al., (2013) was conducted in North Carolina, USA, yet after discussing the literature, it can be found that not only the USA is aware of C&DWM, but also several nations such as European Union, China, and more.

Appendix (A) presents a summary for the findings of the previous researches regards to C&DWM.

Chapter Three: MATERIALS AND METHODS

3.1 Introduction

In this chapter, the materials and methods utilized to execute this work are illustrated.

3.2 Alternative Materials Selection Methodology

In this work, an innovative methodology (shown in figure (3-1)) was executed to select the proper materials for building the house. The reason why this methodology was chosen, goes back to the fact that it interprets and explains the steps desired to select correctly the waste materials generated from Jordanian construction industry according to their abundance and cheapness. Firstly, literature review is conducted related to waste materials which are highly abundant, available, low-priced and can be recycled with no complex processes that add extra cost.

Secondly, some of waste materials which were investigated in step number 1, will be selected to be utilized in this work, in which a house is built by waste materials generated from Jordanian C&DW.

Thirdly, in order to allow those chosen waste materials to be utilized safely in this project with no side effects such as mechanical or technical failure caused by replacing some fractions of conventional construction materials, modifications and justifications on the physical and mechanical characteristics are performed.

Fourthly, results will be obtained and further revisions and amendments will be carried out to guarantee that these waste materials from C&DW can be effectively and widely exploited not only in this project, but also for large and commercial scales in Jordan.

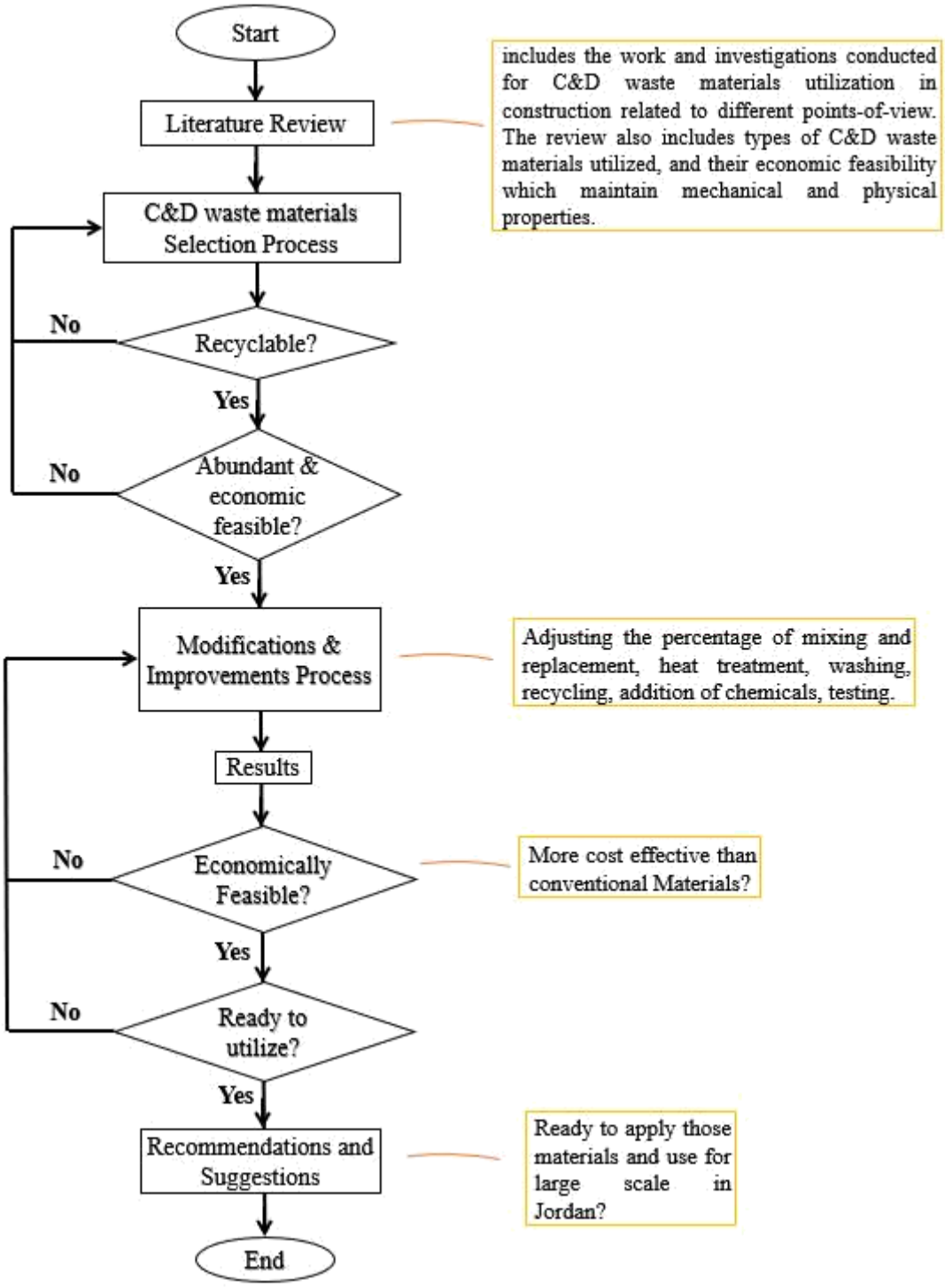


Fig. 3-1 Waste material selection methodology to build a house from C&D.

This work will investigate the utilization of several materials generated from C&DW phases in Jordan; including cardboard, glass, structural aggregate, plastic, and sawdust. This work will assume two hypotheses, one of them will be correct and valid. Those hypotheses are presented in the following:

(A) **Null Hypothesis ( ),** which assumes that waste materials generated from C&D phases in Jordan, are not cost competitive compared to conventional construction materials, and their mechanical and physical properties are not sufficient enough to be utilized in construction industry in Jordan, especially to build a house through this work.

(B) **Alternative Hypothesis ( ),** which states that waste materials generated from C&D phases in Jordan, are more economically feasible than conventional construction materials, and their mechanical and physical properties are sufficient to be utilized in construction industry in Jordan, especially to build a house through this work.

In this work, investigations will be performed to predict whether those preceded materials (i.e. cardboard, glass, structural aggregate, plastic, and sawdust) provide alternative state-of-the-art construction materials that are more economic feasible than conventional construction materials in Jordan, considering the minimization of harmful impact on environment. The following sections illustrate in details waste materials which are utilized for building the house in Amman, Jordan.

3.2.1 Waste Glass

Waste glass is utilized as aggregate replacement to house's concrete walls with a replacement percentage of (60%). Du and Tan, (2014) investigated the glass utilization in manufacturing concrete as a replacement of cement. They exploited glass aggregate waste with 0, 15, 30, 45, and

60 percent of the weighted mixture for manufacturing concrete. After 28 days of compressive strength validation, the replacement of cement into glass particles inside concrete did not make a remarkable change in the mechanical compressive strength of the concrete, in case the replacement amount did not exceed 30 percent.

Additionally, rising up the amount of glass mixture in the concrete, i.e. increasing the cement replacement up to 60 percent would significantly enhance the resistivity to water penetration as well as chloride ions. Moreover, achieving a replacement of 60 percent of cement into the glass in concrete has minimized the amount of electrical resistance into 95% and water penetration into 80%.

The compressive strength value was tested and found that 60 percent replacement has provided 85 percent of original compressive strength in case conventional cement is utilized. Glass provided all these remarkable characteristics as well as strong durability as of the microstructure of its particles. Table (3-1) illustrates the mechanical characteristics of glass and its components.

Table 3-1 Chemical composition of glass powder. Source: Du and Tan, (2014)

No.	Material		Glass Powder (%)
1	SiO_2		72.08
2	Al_2O_3		2.19
3	Fe_2O_3		0.22
4	CaO		10.45
5	MgO		0.72
6	Na_2O		13.71
7	K_2O		0.16
8	TiO_2		0.1
9	Cr_2O_3		0.01

It can be noted from table (3-1) that the largest component of glass (in percentage) is silicon dioxide (SiO_2), which is responsible for higher electrical resistivity, higher resistance to water, and compressive strength strengthening. Additionally, figure (3-2) illustrates the microstructure of glass particles in an SEM image.

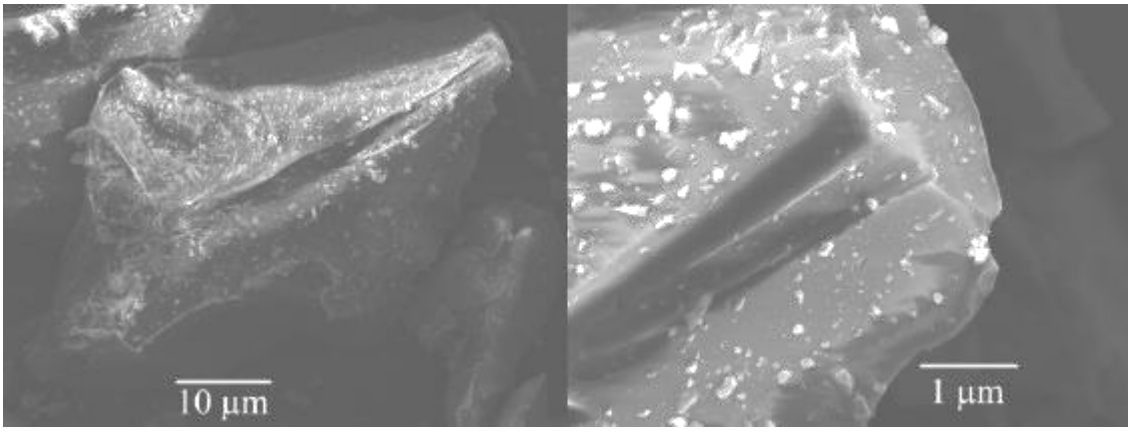


Fig. 3-2 Scanning electron microscope (SEM) image of glass microstructure. Source: Du and Tan, (2014).

From this image, figure (3-3) illustrates the distribution of particles inside the glass. An additional curve was plotted and indicates the ordinary Portland cement (OPC).

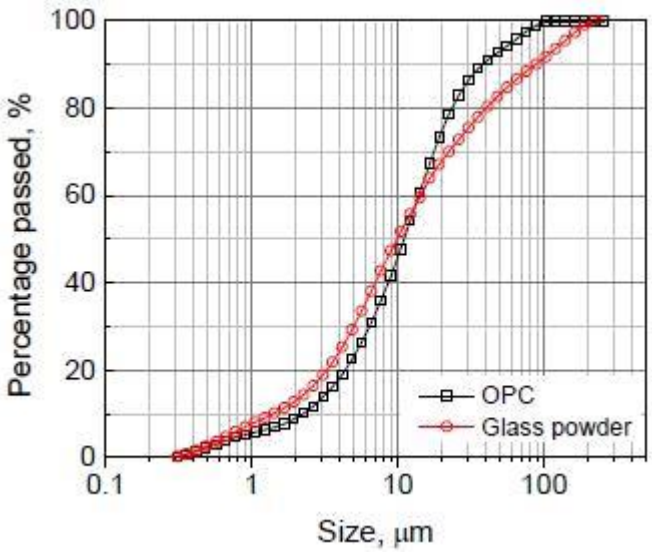


Fig. 3-3 Particles distribution according to their size inside the glass and OPC. Source: Du and Tan, (2014).

From figure (3-3), it can be noted that the largest particles inside the glass correspond to 100 micrometers, and these contribute to a large amount inside the glass.

In Jordan, large quantity of glass is dumped into Jordanian landfills. For this purpose, it is an essence to utilize this glass in concrete and mortar before being thrown in the landfills. Saidan and Abu Drias, (2016) mentioned that in 2014, 4% of total waste in Jordan was from the glass. To recycle the waste glass, it must follow a particular process presented in the following:

1- Collecting glass from landfills or from C&DW sites.
2- Washing the glass to remove contaminants and pollutants.
3- Classifying glass by its color, size and types.
4- Crushing glass.
5- Melting the crushed particles.
6- Forming new glass.

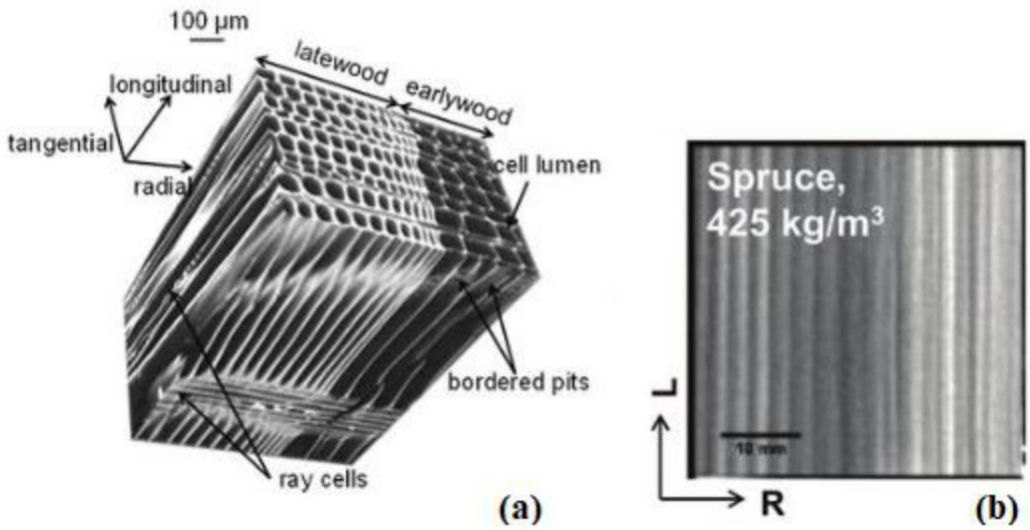
On the other hand, utilizing glass in Jordan for construction must follow the following steps:

a- Gathering glass from C&DW sites.
b- Crushing the glass after removing the contaminants and pollutants.
c- Mixing the glass aggregate into mortar and make a proper replacement of cement.

From the previous discussion, it can be shown that utilizing glass in Jordan is highly effective and does not consume much budget to achieve.

3.2.2 Wood and Sawdust

Sawdust and wood are utilized as insulation for house's exterior walls and ceilings with a replacement percentage of (95%). After conducting a survey related to materials from C&DW, it was found that sawdust and wood can be appropriate and resistant to mold for house's exterior walls and ceilings in case certain modifications and adjustments are performed. Figure (3-4)



illustrates a SEM image of spruce wood.

Fig. 3-4 Physical features of wood fibers for spruce. Source: Gilani et al., (2013).

In Jordan, especially in industry zones -Sweileh and Wadi Al-Seer, there are massive amounts of sawdust, and wood fractions which can be effectively utilized as a construction material for house's ceilings and walls.

In order to make wood resistant to mold, Didecyl dimethyl ammonium chloride (DDAC) can be mixed and integrated with wood. Kampf, (2018) reported that DDAC is a highly efficient antiseptic material which can be exploited to protect the wood and sawdust from mold and harmful microorganisms. To recycle wood fraction and sawdust, they must follow certain steps. Figure (3-

5) illustrates the steps of the recycling process of sawdust and modifications added in order to be capable to serve a facility as insulation for exterior walls.

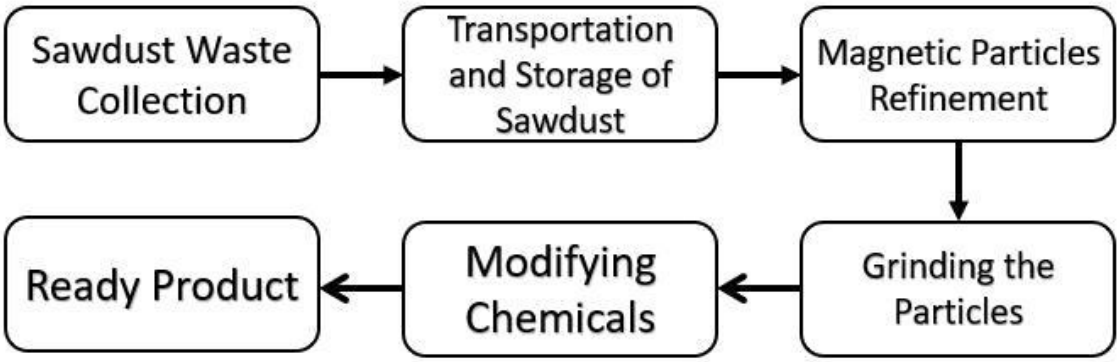


Fig. 3-5 Recycling process of the sawdust for new effective product in construction.

As figure (3-5) indicates, sawdust is collected, then it is transferred to the operating factories and stored. Thereafter, they are subjected to magnetics that collects iron and other metals from sawdust particles. Then, particles of sawdust are transferred into the grinding process where they are crushed and ground into tiny particles. Finally, specific chemicals are added to these particles in order to increase their capability for insulation and water résistance.

Cetiner and Shea, (2018) stated that wood waste is highly functional to recycle and utilize again as a construction material for houses and other facilities as more than 90% of building and structural materials in the global market are toxic, nonorganic and have a negative impact on the environment.

Huang et al., (2018) stated that worldwide the largest type of materials that enter the environmental flow per Annum is the construction materials. Additionally, Huang et al., (2018) stated that roughly 50% of all materials extracted from the planet is converted into construction materials.

On the other hand, wood waste from carpentry shops serves a green material for construction as of its cost-effectiveness as well as environmentally friendly properties. Pedreño-Rojas et al.,

(2017) found that utilizing 20% of wood sawdust in the manufacturing process of thermal-resistant construction material is actually effective and contributes to enhancing the material mechanical and acoustic characteristics.

3.2.3 Plastic Wastes

In this work, recycled plastic wastes are used as plastic lumber for house's floor. Valinejadshoubi et al., (2013) stated that domestic-urban plastic water bottles can be used as a sustainable building material instead of conventional construction material. Plastic lumbers are made out of 100% plastics. They are made by combining several types of plastics together at approximately 400 ºC and then shaped into desired forms. Valinejadshoubi et al., (2013) stated too, that recycling water plastic bottles are more flexible and highly feasible to perform, besides being beneficial to the environment, due to the fact that there is a huge number of plastic bottles thrown worldwide per annum. Figure (3-6) shows an illustration of the number of plastic bottles found in Aqaba gulf.

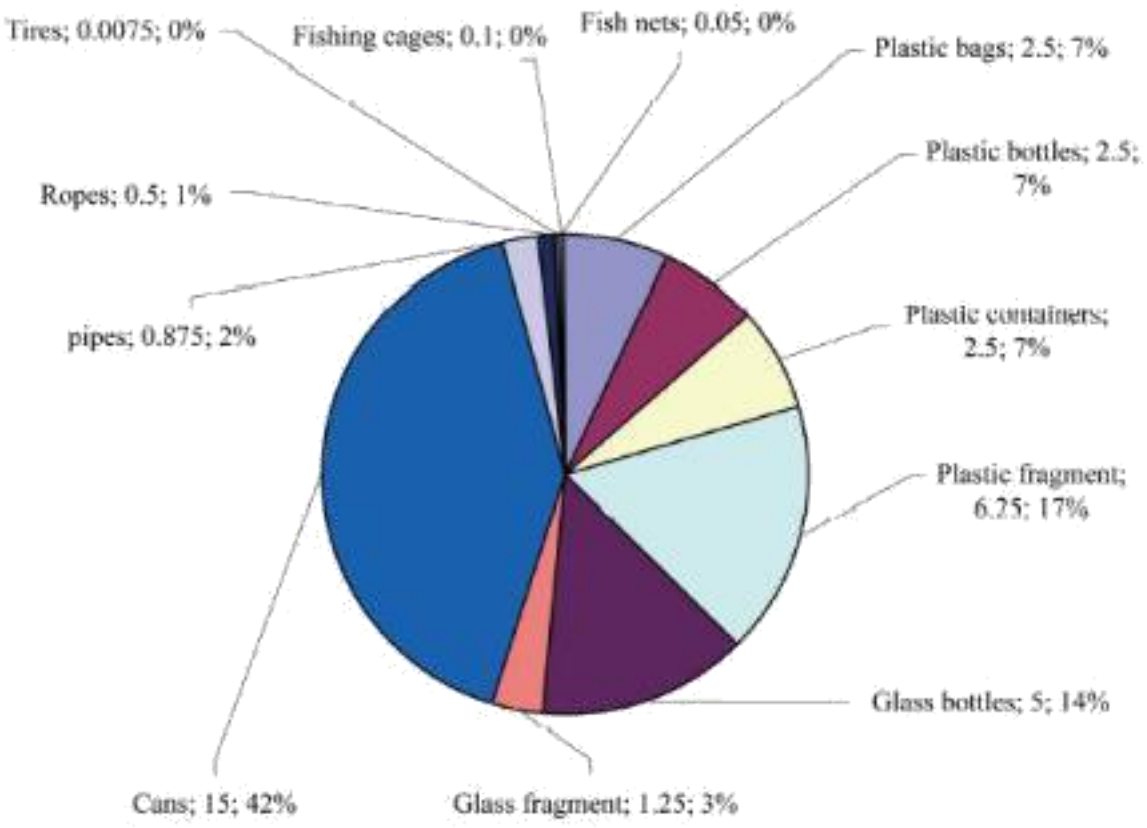


Fig. 3-6 Waste amount collected from Ghandoor, Aqaba. Source: Abu Hilal, (2008).

From figure (3-6), 7% of the whole waste collected from Ghandoors' site in Aqaba gulf was from water plastic bottles. As Valinejadshoubi et al., (2013) mentioned, the amount of water plastic bottles is very cheap as well as available to all classes of societies.

For this reason, they can be distributed into the environment very fast and thus corresponds to a higher carbon footprint than other types of waste. In Jordan, the bottled water is safer than tap water, hence, many Jordanian citizens rely on these products. Recycling plastics in Jordan to manufacture plastic lumbers would be very effective for Jordan. The reasons go back to the following:

(A) Firstly, plastics do not degrade making them much hazardous to the environment.

(B) Secondly, plastics are the most waste product that occupies a much wide area of landfills.

(C) Thirdly, the consumption of plastics in Jordan is still increasing linearly per annum, as shown in figure (3-7).

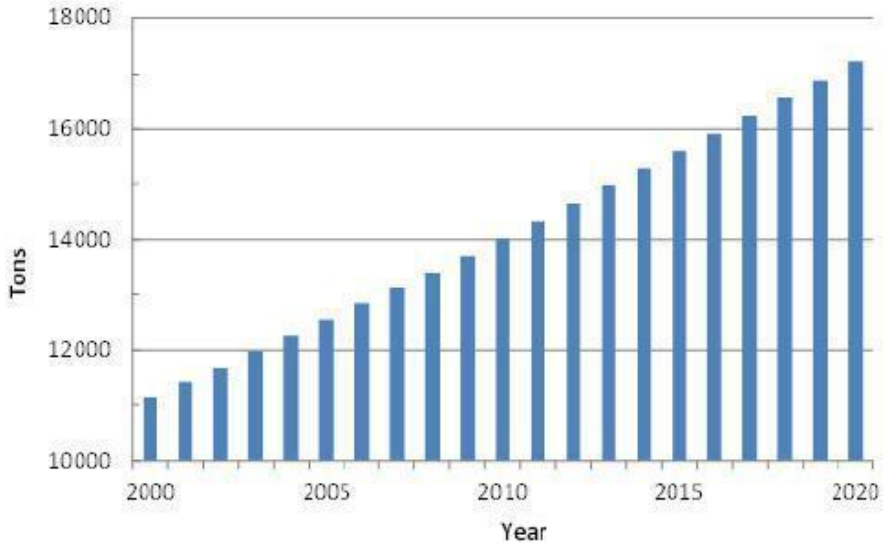


Fig. 3-7 The amount of plastic waste generated, particularly in Jordan. Source: Saidan et al., (2017).

(D) Fourthly, there were no definitive policies concerning how to recover, reuse, or reduce the amount of plastic wastes in Jordan.

(E) Fifthly, recycling plastic in Jordan can cut down carbon emissions and pollution that may be generated as a result of burning them.

Consuming plastic bags in Jordan is still increasing to a great extent due to their cheap price, lightweight, strength, and wide range of sizes that allow them to be exploited for different purposes.

For this reason, informing Jordanian individuals with recycling knowledge and increasing the awareness of local citizens regarding recycling plastic waste became an essence in order to be managed and thus minimize the waste generated annually. Figure (3-8) represents the steps used to make the plastic panels.

Fig. 3-8 Configuration of water plastic bottles recycle process, source: Goodship, (2007)

As can be noted from figure (3-8), the steps of recycling plastic water bottles are much flexible and effortless which do not consist of multiple complicated tasks or complex procedures to execute.

Another research conducted by Zhang et al., (2018), showed that plastics can be utilized as a filler material in concrete, mortar, and bricks. They executed a review which explains that plastic waste including plastic bottles or PET, plastic straws, PVC pipes, PVC materials, and tools and other types of plastics were used successfully in the construction material.

The weight replacement of plastics into concrete, bricks and mortar ranges between 0.1 and 15% of the weight. Few studies investigated utilizing plastics with 50%, 80% of replacements in concrete and mortar. The results showed that utilizing a higher amount of plastics would rise up the strength of the concrete and bricks. In this work, the replacement of floor tiles with recycled plastic lumber is 100%.

3.2.4 Concrete and Demolition Waste Aggregate

In this work, concrete and demolition waste aggregate are exploited for house's concrete and cement slab with a replacement percentage of (20%). Ganiron, (2015) investigated utilizing concrete aggregate and debris generated from C&W stages into manufacturing new concrete that utilizes these components with the aim of minimizing the environmental impact of these wastes. In Jordan, aggregate sources can be found near a variety of buildings and facilities.

Collecting these debris would be highly effective not only for the environment, but also for the economic feasibility in Jordan. In his work, Ganiron, (2015) explained in an experiment that these C&DW can be crushed into fine concrete aggregate and utilized again in the mortar mixture which will be highly economical compared to the use of conventional mortar. Figure (3-9) illustrates the steps of recycling and processing of concrete debris and aggregate into the final mortar.

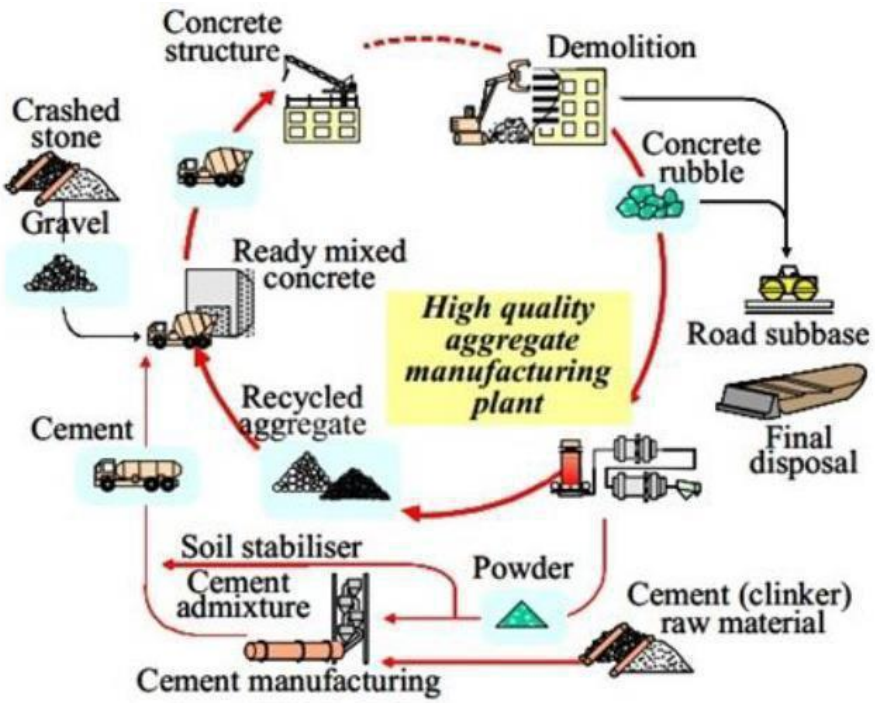


Fig. 3-9 Concrete waste and mortar aggregate recycling process layout. Source: Ganiron, (2015).

This process can be utilized in Jordan too, as the same sources of the new resulting product, i.e. recycled concrete can be obtained through the waste concrete as well as aggregates from the construction sites debris in Jordan. In addition, figure (3-10) illustrates the process of recycling for concrete aggregates.

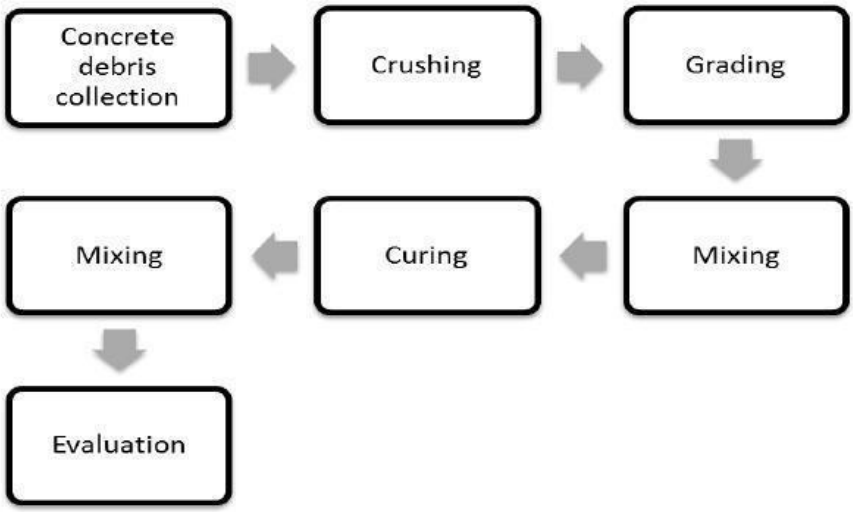


Fig. 3-10 Recycling procedure of waste concrete aggregate into new concrete.

As figure (3-10) illustrates, the concreate aggregate follows seven steps in order to accomplish the target of recycling waste concrete from aggregate and producing new concrete that is highly viable in terms of cost for the construction project as well as minimizing debris in the environment.

3.2.5 Rubber

Waste rubber is utilized as a replacement of brick for house's interior walls. There is a huge potential in Jordan of utilizing waste rubber made out from tires to be a component in construction materials. Anuma, (2015) investigated the utilization of waste rubber as a replacement material of cement inside bricks, tiles, and concrete. He stated that replacing sand with rubber will make no remarkable change to the mechanical properties of bricks, tiles, and concrete.

He stated too, in his investigation, that in case 15 percent of sand is replaced into rubber, this would save 97.5 million kilograms of sand, which may be used for construction. At the same, this also will reduce 97.5 million kilograms of waste rubber, which may cause an issue to the environment. Additionally, table (3-2) presents the outputs of the investigation he executed.

Table 3-2 Investigation results correlated to the utilization of rubber in concrete. Source: Anuma, (2015)

Item	Compressive Strength (MPa)	Water Absorption (%)
Conventional Block	28.4	4.2
Rubberized Block	25.2	4.9

It can be inferred that rubberized block has a relatively the same value of compressive strength compared to conventional block. Additionally, it was found that the water absorption percentage of the rubberized block is approximately the same to the value of the conventional block, for this purpose, it is recommended to utilize waste rubber in construction material.

3.2.6 Waste Steel and Other Metals

In this work, waste steel and other metals are used for a replacement of house's conventional steel. In Jordan, there is much waste of metals that is generated from C&D processes. As Saidan and Abu Drias, (2016) indicated in their report, the amount (in percentage) of metals disposed, in Jordan, was 4% in 2014. Utilizing those metal wastes in the concrete and mortar, as Qureshim, (2015) indicated can be economically feasible. In their work, Qureshim, (2015) conducted an experiment to strengthen the mortar and concrete via metal waste. Table (3-3) illustrates some of these results.

Table 3-3 Reinforcement of steel data analysis.

ASTM (A615) – Reinforcement steel bars	Minimum Yield Strength (MPa)	Minimum Tensile Strength (MPa)
Grade 40	275	420
Grade 60	415	620
Grade 72	500	690

From table (3-3), it can be inferred that reinforcement steel bars with the grade classification of 72 has the maximum potential of minimum yield as well as minimum tensile strengths. Figure (3-11) presents these tests.

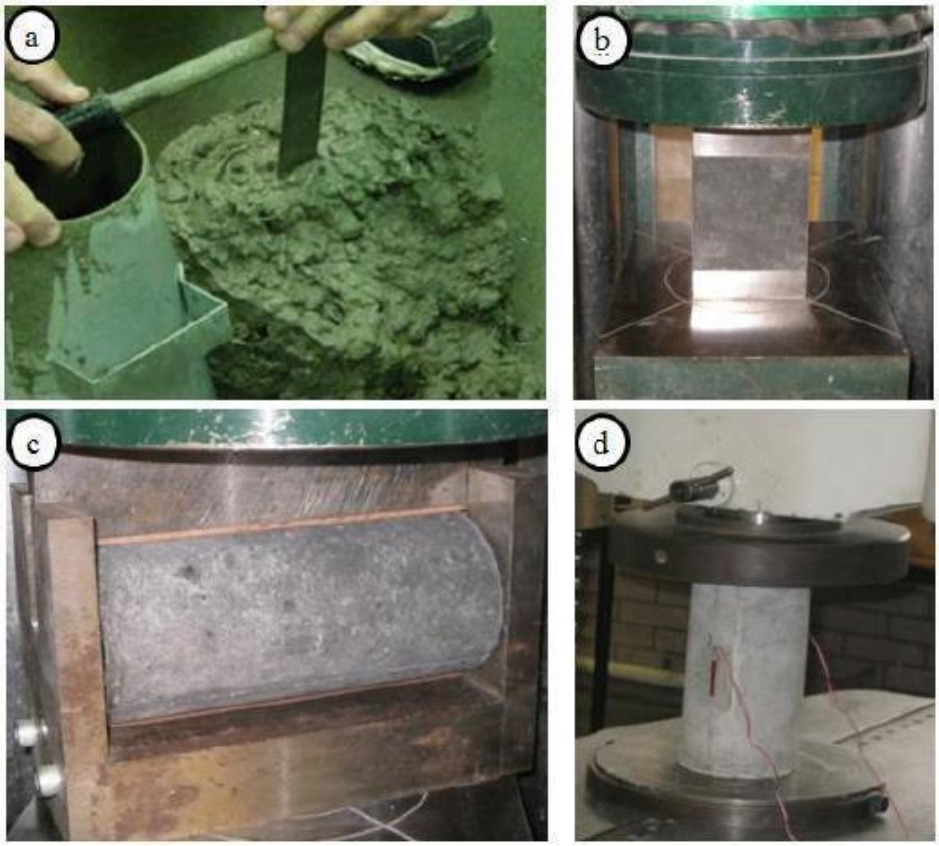


Fig. 3-11 Configuration of: (a) Slump, (b) compressive strength testing setup, (c) tensile strength testing setup, and (d) modulus of elasticity testing setup. Source: Qureshim, (2015).

Furthermore, utilizing steel bars and other metal waste in Jordan generated from C&D phases can remarkably minimizes effort, time and cost, as they can directly be utilized in concrete and mortar in the purpose of strengthening the facility's construction. For this reason, this work will focus too on utilizing waste steel bars and other metals for reinforcement of concrete and mortar in building a house.

3.2.7 Cardboards

In this work, cardboard is used as a decoration of house's exterior bricks with a replacement of (29%). Cardboard is utilized as a construction material for the exterior bricks. Ahmad et al., (2018) utilized cardboards as a replacement of construction aggregate. This eco-friendly construction material contributes with a major structural cost reduction. Ahmad et al., (2018) prepared several

rates of brick mixing. They utilized cement, sand, and cardboard with the following mixing proportions: 1:1.5:1, 1:2:1, and 1:4:2. They utilized trial-and-error approach to find the best ratio of brick mixture with cardboard. They tested compressive strength for the three specimens during 7, 14, and 28 days.

Their results were similar to Ritzawaty, (2008) work, as they both found that eco-bricks with a higher volume of cardboard would fail in the compressive strength, while bricks with the proportion mixture of 1:1.5:1 in Ahmad et al., (2018)'s work, or 5% in Ritzawaty, (2008)'s work, are the most appropriate as an alternative to conventional brick, plus they were lighter than conventional bricks.

Cardboard has much simple procedures during folding, compressing, and heat treatment to prepare for the final product (i.e. eco-brick). Figure (3-13) illustrates the structure of cardboard including the composition shape and SEM image of inside structure.

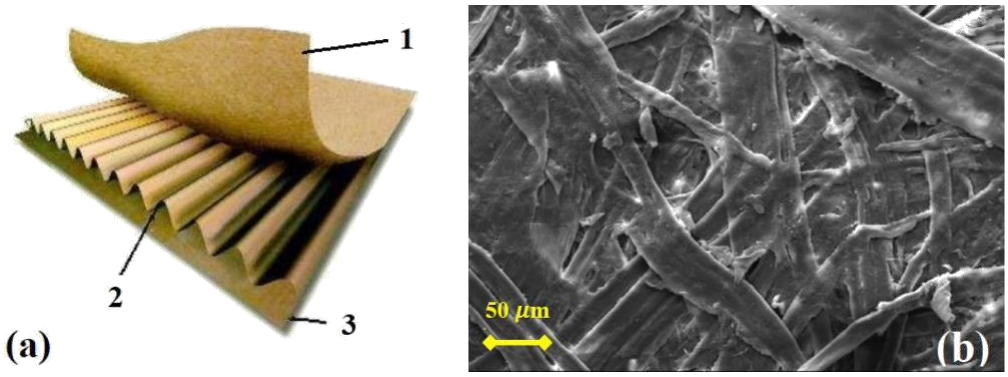


Fig. 3-12 Layout of: (a) Cardboard Structure; Source: (da Silva, 2020), (b) Cardboard Microstructure. Source: Candiani, (2011).

As shown in figure (3-12), (a), the layers (1) and (3) are two softcover walls that govern the inside zigzag core. On the right side of figure (3-12), the microstructure of corrugated cardboard is magnified 250 times presenting the pores and grooves of the cardboard. From cardboard microstructure, it can be seen that the structure is much similar to the fibers taken from the trees, which makes it feasible to recycle into sustainable eco-brick.

Chapter Four: FEASIBILITY ANALYSIS OF WASTE MATERIALS

4.1 Introduction

This chapter illustrates fiscal data regards to waste materials from C&D phases in Jordan, which are utilized for building the house.

4.2 Waste-Materials Feasibility Analysis

In this work, seven waste materials from C&D phases in Jordan are investigated in terms of their economic feasibility. Those are: (1) waste glass, (2) waste wood and sawdust, (3) waste plastic, (4) concrete and demolition waste aggregate, (5) waste rubber, (6) waste steel and other metals, and (7) cardboards. Their price will be compared to conventional construction materials to check their cost effectiveness.

4.2.1 Waste-Glass

As discussed in chapter three, waste glass is utilized as aggregate replacement to house's concrete walls. Waste glass does not consume any valuable cost except for the salaries of the workers that are needed to collect the glass. Other procedures can be executed on site as a part of construction project. The only required costs needed to recycle the glass are the salaries to collect it, though, in case it is not crushed, it will need transportation and modification then it will be ready to be mixed in concrete and mortar for construction activities for house. Table (4-1) illustrates costs of recycling glass in case it is used as a replacement of conventional concrete. By contacting construction contracting and consulting companies it was found that collecting and gathering glass would cost 10 JD per worker per day produce 2 cubic meters per day. 5 workers are needed to

collect and crush 10 m^3 of glass per day at a cost of 50 JD per m^3 per day. Transportation and delivery for waste glass would also cost 20 JD per 10m^3 or less than 10 m^3 by a truck.

Table 4-1 Cost and quantity analysis of waste glass in concrete.

Item	**Replacement Percentage**	**Quantity Desired**	**Total Cost (JD)**
Waste glass	60%	5.4 m^3	27
Conventional Concrete	35%	3.15 m^3	189
Other Materials	5%	0.45	40
Transportation	---	5.4 m^3	20
Total Cost	---	---	276

The price database was obtained via contacting engineering contracting and consulting companies. It was found that one-meter cube of conventional concrete costs 60 JD, which corresponds to 189 JD, in case 3.15-meter cube of conventional concrete is used for construction. Additionally, contacting engineering contracting and consulting companies were asked about the cost of recycling, but recycling companies in Jordan provided more database regards the price of waste glass and how much does it cost for the transportation process. Table (4-2) illustrates the cost and quantity analysis conducted in case conventional concrete are used for house's exterior walls.

Table 4-2 Cost and quantity analysis conventional concrete.

Item	Cost per unit	Quantity Desired	Total Cost (JD)
Exterior Wall Concrete	60 JD per 1 m^3	9 m^3	540

4.2.2 Wood and Sawdust

Wood and sawdust utilized in this work as insulation for house's exterior walls and ceilings. After contacting several carpentry shops in Jordan; specifically, in Wadi Al-Seer and Sweileh industry zones, rich fiscal and technical data regarding sawdust sales and weight were obtained and illustrated in table (4-3).

Table 4-3 Financial details regarding the cost of sawdust.

Sawdust Quantity	**Cost (JD)**
1 ton pure (i.e. free of pollutants, nails and tailings)	**140 – 160**

Commercially, sawdust is sold out as bags with several sizes, either in large-scale for large industries and businesses, i.e. in tons, or in small scale, for small industries and businesses. The amount of sawdust that was utilized in the house was calculated by finding the surface area of all rooms' walls in the house (which was 160 m^2) then multiplying it by the thickness of sawdust that

must be exploited as insulation, i.e. 5 cm (0.05 m), leading to 8.00 m^3. Total chemicals that are utilized for building house including chemical substances and liquids that are added to sawdust are estimated to be 50 kg. Table (4-4) illustrates the sawdust cost analysis with combining other modification materials for insulation.

Table 4-4 Sawdust cost analysis.

Item	Cost per unit	Quantity desired	Total Cost (JD)
Sawdust quantity	150 JD	1 ton	150
Other materials	2 JD	50 kg of chemicals	100
Total	---	---	250

In case conventional materials, such as foam, are utilized instead of sawdust for insulation, the cost will differ as shown in table (4-5).

Table 4-5 Cost analysis of conventional insulation materials.

Item	Cost per unit	Quantity desired	Total Cost (JD)
Insulation of external walls	2.52 JD	160 m^2	403 JD

Khalda construction and insulation shops were contacted via phone in order to know exactly the amount of insulation required per 1-meter square and how much would it cost incase conventional insulation materials are utilized. Purchasing and selling sawdust in Jordan is very popular as sawdust is widely used for different purposes such as poultry farms, a fold of horses, sheep, and other livestock, and cars' workshops in case of oil replacement and cleaning. Natural Swedish and beech woods are the main sources of sawdust in most of the carpentry shops in Jordan. Additionally, in terms of location, sawdust is obtained mainly from the industrial zones located in Sweileh and Bayader Wadi Al-Seer. Before selling sawdust to customers, sawdust is modified and purified from any type of pollutants that may affect the quality of sawdust. Predominantly, when sawdust is obtained from carpentry shops, from the locations mentioned above, it needs to be purified from screws, fasteners and other sharp metals that carpenters left during their work.

4.2.3 Recycled Plastic Lumber

As discussed in section 3.2.3, waste plastics are used to manufacture recycled plastic lumber which is used for 100% of house's floor. In order to recycle plastics into recycled plastic lumber (RPL), variety of mixed waste plastics are collected, then thermally treated to be effectively used. Firstly, those mixed waste plastics are formulated into single blocks. Secondly, those collected plastics are cleaned.

Thirdly, they are treated at very high temperature and subjected to high pressure via compression process. Fourthly, they are extruded and molded to flat shape such as larger tiles to shape plastic lumbers.

The advantage of plastic lumber is that it is long lasting. After making several phone calls to recycling plant factories and other recycling authorities in Jordan, it was found that one ton of plastic costs 180 Jordanian dinars to 250 Jordanian dinars for recycling. After comparing the prices of mixed plastic wood on different websites, it was found to cost roughly 0.2 JD per kilogram. The floor measures approximately 180 m^2. Total construction weight with RPL in this area will be 2,850 kg. Table (4-6) illustrates the cost and quantity and cost analysis of plastic lumber.

Table 4-6 Cost and quantity of plastic lumber.

Item	Cost per unit	Quantity desired	Total Cost (JD)
Plastic Lumber	3 JD per 1 m^2	190 m^2	570 JD

Additionally, table (4-7) shows the cost of using parquet as insulation for the house's floor.

Table 4-7 Cost and quantity Analysis of Parquet.

Item	Cost per unit	Quantity desired	Total Cost (JD)
Parquet for the floor	4.5 JD per 1 m^2	190 m^2	855 JD

The prices for the parquet were obtained from contacting several parquet shops as well as construction shops in Khalda and Abdoun. Figure (4-1) shows the plastic lumber that is manufactured from waste plastics. This is an innovative product which can be used effectively for insulation.

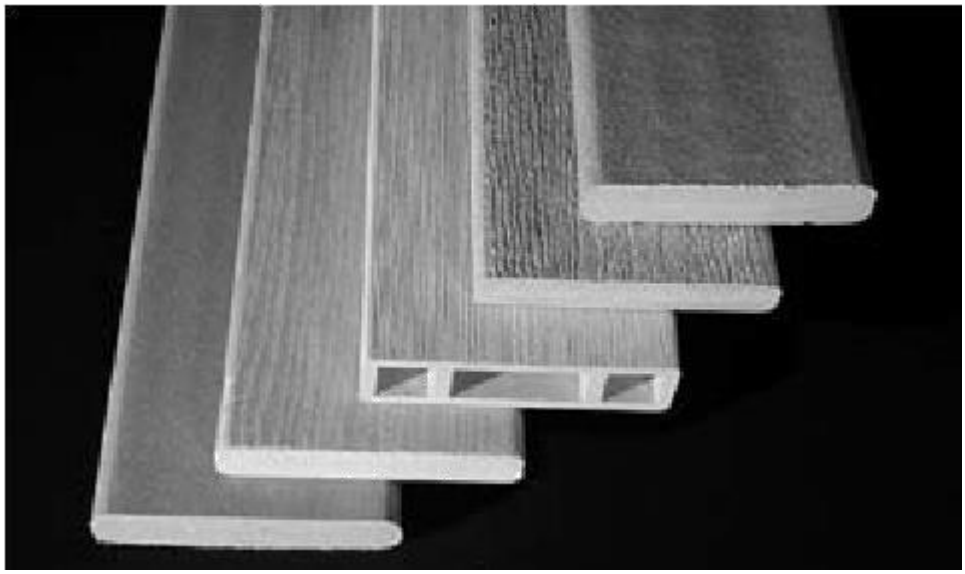


Fig. 4-1 Plastic Lumber made out of waste plastics. Source: Caulfield, (2012).

4.2.4 Concrete and Demolition Waste Aggregate

Concrete and demolition waste aggregate are used for concrete. Recycling and collecting debris of waste concrete aggregate will consume slight share of budget as it depends only transportation by manpower and vehicles. Table (4-8) presents the cost of using waste aggregate as a partial replacement in the slab concrete.

Table 4-8 Cost analysis related to waste aggregate utilization in the slab.

Item	**Cost per unit**	**Quantity desired**	**Total Cost (JD)**
Slab concrete with Aggregate	45.5 JD	60 m^3	2730 JD

The slab concrete price that utilizes aggregate was checked via contacting contracting and consulting companies. At the same time, table (4-9) presents the cost of building slab via conventional concrete.

Table 4-9 Cost analysis of conventional concrete slab.

Item	**Cost per unit**	**Quantity desired**	**Total Cost (JD)**
Slab concert	65 JD	60 m^3	3900 JD

It can be inferred from two previous tables, that the utilization of aggregate in the concrete slab would save 1,170 JD.

4.2.5 Rubber

Waste rubber in this thesis is utilized for supporting cement mortar and bricks. Figure (4-2) illustrates the waste tires that are utilized as a source of rubber.

Fig. 4-2 Waste rubber source. Source: Mohajerani et al., (2020)

Nor et al., (2010) investigated utilization of waste rubber made out from waste tires to make paving blocks. Their aim was to provide a methodology by which the waste tires can be effectively managed. The major characteristics of conventional bricks is that they have high compressive strength capability, though, lower value of toughness. For this reason, in order to raise the value of toughness, adding waste rubber from waste tires would be feasible, but it would lower the value of compressive strength as rubber is highly flexible. They tested this idea via adding several replacement mixing percentages of waste rubber into the blocks. 4,300 paving blocks were made of waste rubber commercially.

At the same time, 348 blocks were tested for compression and scraping criteria. They found that rubber should be added to blocks by a percentage which must not exceed 20% in order to achieve valid utilization to commercial and construction scale. Waste rubber added was found effective in absorbing the dynamic loads and minimize the number of cracks in the road. Table (4-10) illustrates the cost analysis AS well as quantity for waste rubber.

Table 4-10 Cost analysis of utilizing waste rubber for making bricks.

Item	Cost per unit	Quantity desired	Total Cost (JD)
Rubber brick for exterior wall	6.2 JD per m^2	180 m^2	1116
Internal walls	6.2 JD per m^2	50 m^2	310
Cost of Labor	1.25 JD per m^2	230 m^2	287
Total cost	---	---	1713

Consequently, table (4-11) illustrates cost of house's exterior wall construction via traditional brick. Here, the cost of brick is calculated as 6.75 JD per square meter. The quantity needed to build the house with these traditional bricks would be 230 m^2.

Table 4-11 Cost analysis of utilizing conventional bricks for exterior buildings.

Item	**Cost per unit**	**Quantity desired**	**Total Cost (JD)**
Brick for exterior wall	6.75 JD per m^2	180 m^2	1215
Internal walls	6.75 JD per m^2	50m^2	337
Cost of Labor	1.25JD per m^2	230 m^2	287
Total cost	---	---	1840

Those prices were obtained from contracting and consulting companies and from agencies which work with rubber recycling. From table (4-11), it can be concluded that the cost of building the exterior walls via conventional bricks would be more than building via waste rubber. Utilizing rubber in brick would save 127 JD. Additionally, rubber will provide more insulation capability than conventional brick which would reduce the heat loss during heating and cooling seasons.

4.2.6 Waste Steel and Other Metals

As mentioned in section 3.2.6, waste steel is utilized for a replacement of house's conventional steel. Applying recycling of waste steel in Jordan has large potential. In Jordan, waste steel can be collected

first. The major sources of waste steel in Jordan are demolition phases of construction industry. After collection of waste steel, it goes to modification process in which it is cut into several pieces, then melted and thermally treated, and then formulated into required shapes. The cost of all these processes would be lower than using conventional steel for building house as reinforcement. The cost analysis of waste steel and quantity are illustrated in table (4-12).

Table 4-12 Cost analysis of waste steel utilization in the house.

Item	**Cost per unit**	**Quantity desired**	**Total Cost (JD)**
Waste Steel	450JD per ton	22 ton	9900 JD

In addition, Table (4-13) describes cost of reinforcement in case conventional steel was utilized for the same purpose.

Table 4-13 Price of conventional steel in case it is utilized in house.

Item	**Cost per unit**	**Quantity desired**	**Total Cost (JD)**
Conventional Steel Reinforcement	510 JD	22 ton	11220 JD

It can be inferred from the table above that utilizing waste steel after applying modification process and recycling would be more economic feasible than using conventional steel. Regardless to the fact that using waste steel required recycling and modification process, yet this will remain economic feasible than using conventional steel for building.

4.2.7 Cardboards

Cardboard is utilized here as a cladding material to the conventional exterior brick (or as a decoration of house's exterior bricks). Before calculating the cost of utilizing cardboards' waste as a structural material, i.e. eco-brick, table (4-14) presents the cost of utilizing cardboard in case partial replacement was achieved in the brick to build exterior walls.

Table 4-14 Price of cardboard utilized in the house.

Item	Cost per unit	Quantity desired	Total Cost (JD)
Cardboard Replacement	6 JD per m^2	160 m^2	960

The price of cardboard was obtained via contacting recycling companies in Jordan that work with the treatment of waste cardboard. The cost of building exterior walls is presented in case conventional bricks are utilized for the same goal in table (4-15).

Table 4-15 Price of conventional bricks utilized in the house.

Item	Cost per unit	Quantity desired	Total Cost (JD)
Conventional exterior bricks	12.25 JD	160 m^2	1960

It can be inferred that the cost of building the exterior walls would be 960 JD, which is cheaper than using conventional bricks. Using conventional bricks will cost 1,960 JD, which means that utilizing cardboard as a partial replacement of cement in bricks would save 1,000 JD. Table (4-16) presents the percentage that were applied similar to the work of Cripps, (2004).

Table 4-16 Results of cardboard's and other materials' proportion mixture. Source: Cripps, (2004)

Material	By Volume (%)	By Weight (%)
Concrete	46	85
Timber	7	2
Cardboard	29	3
Other Substances	18	10

The data of table (4-16) were simulated from a similar work of Esmieo et al., (2018) who investigated the economic feasibility of carboard recycling.

Chapter Five: RESULTS, SURVEY AND DISCUSSIONS

5.1 Introduction

This chapter shows the results of this work related to economic feasibility of utilizing waste materials generated from C&D phases for house, and the results of the questionnaire conducted in order to know the opinions of general managers and engineers concerning this work, followed by discussions of these findings.

5.2 Results concerning Seven Waste Materials

In this work, a cost analysis was conducted to find the economic feasibility of utilizing waste materials as a replacement of conventional construction materials. Seven materials were used to build a house. Those seven materials are: (a) waste glass, used for partials replacement in exterior wall, (b) waste wood for insulation element in the exterior walls of the house, (c) waste plastic that can be converted and recycled into plastic lumber as an alternative to parquet, (d) construction and demolition waste aggregate that used as an alternative to traditional cement in the slab, (e) waste rubber which was used in interior and part of exterior walls of the house, (f) waste steel bars as an alternative to traditional steel in the house, and (g) cardboard that was used as exterior brick cladding. Table (5-1) presents a summary of House's construction cost analysis via waste construction materials.

Table 5-1 Summary of house's construction process via waste materials.

#	Item	Use	Cost per Unit	Quantity desired	Total Cost (JD)
1	Waste-Glass	replacement in concrete for exterior wall	33.6 JD per m^3	9 m^3	276
2	Wood and Sawdust	Walls' insulation	1.56 JD per 1 m^2	160 m^2	250
3	Waste Plastic	Plastic Lumber	3 JD per 1 m^2	190 m^2	570
4	Concrete Waste Aggregate	Slab concrete with aggregate	45.5 JD per 1 m^3	60 m^3	2730
5	Waste Rubber	interior brick	7.44 JD per 1 m^2	230 m^2	1713
6	Waste Steel	Replacement for steel	450 JD per 1 ton	22 ton	9900
7	Waste Cardboard	Replacement of exterior brick	6 JD per m^2	160 m^2	960
--	Total	---	---	---	16,399

To find whether utilizing those seven waste materials in construction was appropriate in terms of economic feasibility, a cost analysis was conducted for utilizing conventional construction materials in case they are used to build the same house, which is presented in table (5-2), noting

that the same values of volume and area were utilized for both tables to make the comparison more effective.

Table 5-2 Summary of house's construction process via conventional materials.

No.	Item	Use	Cost Per Unit	Quantity Desired	Total
1	Concrete	Exterior Wall	60 JD per 1 m^3	9 m^3	540
2	Insulation Material	Walls insulation	2.52 JD per m^2	160 m^2	403
3	Tiles	Covering the floor	4.5 JD per 1 m^2	190 m^2	855
4	Concrete	Slab concrete	65 JD	60 m^3	
5	Bricks	Internal Walls	8 JD per m^2	230 m^2	1840
6	Steel	Reinforcement for the slab	510 per ton	22 ton	11,220 JD
7	Bricks	Exterior wall	12.25 JD per 1 m^2	160 m^2	1,960
Total	---	---	---	---	20,718

From the tables (5-1) and (5-2), it can be inferred that utilizing those seven smart materials that are abundant in Jordan would successfully prove its economic feasibility, and at the same time, maintain the same mechanical and physical characteristics of those waste materials. The total cost of building a house using conventional materials would be 20,718 JD, whereas building the same house from waste materials in construction would cost 16,399 JD, achieving total saving of 4,319 JD.

5.3 Questionnaire

In this work, a questionnaire was conducted in order to know and predict the degree of C&DWM implementation by contracting and consulting companies, and whether if they apply the principles of recycle, reuse, recover and reduce the amount of waste generated from the construction industry in Jordan.

5.3.1 Questionnaire Structure

Table (5-3) presents the survey questions which was formulated using seven questions. Each question focuses in an area that is related to this work. Five-points scale (Likert-scale) of rating are corresponding to the degree of satisfaction and agreement as shown below:

- **1: Strongly disagree.**
- **2: Disagree.**
- **3: May be.**
- **4: Agree**
- **5: Strongly agree.**

Table 5-3 C&DWM Thesis Questionnaire.

#	Question	1	2	3	4	5
1	Do you think that the idea of this project is successful and is applicable to all projects in Jordan?					
2	To what extent do you agree that utilizing the seven materials in this work is cost effective?					
3	Do you think that recycling waste materials from C&DW can be done directly, without adding particular modifications and adjustments such these in the model of this work?					

4	To what degree do you believe that utilizing the seven materials used in this work was successful and valid using the percentage of mixing and replacement to conventional construction materials?					
5	To what degree do you apply C&DWM strategy in your company and projects?					
6	Do you think that these seven materials are abundant and available in Jordan to be used in wide scale?					
7	Do you agree to apply this concept to utility and large-scale projects in Jordan?					

5.3.2 Survey Sample

The society of the questionnaire is separated into three main groups. Group #1 is related to the high level of project management and civil engineering in Jordan, and includes seniors, general managers, and chefs who have an engineering experience not less than 20 years. It also covers the engineering society with these who has at least Master certificate and PhD in engineering.

Group #2 is related to large share of engineering staff, including site engineers, supervisors, junior engineers, experienced engineers in project management, and different area of engineering with an experience which does not exceed 20 years. The final group, i.e. group #3 will include those who are workers with large experience, and supervisors of workers and engineering trainers who have an engineering experience which not exceed 3 years.

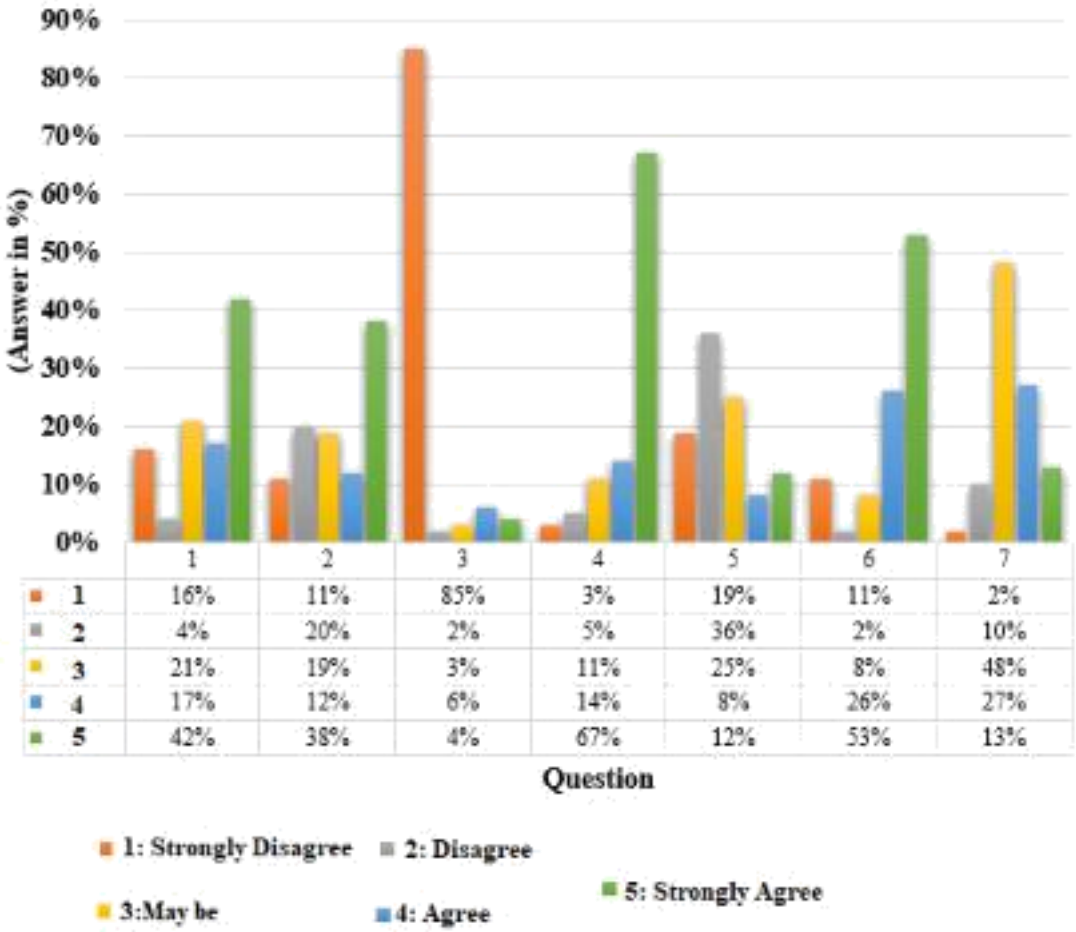
The survey society will comprise first- and second-class contracting companies, as well engineering consulting companies which execute small and large projects inside and outside Jordan, but their headquarters are in Jordan.

5.3.3 Survey Procedure

In order to execute the survey, several meetings will be executed via MEET/ ZOOM software tools, due to the COVID-19 quarantine which limits the visiting and face to face discussion concerning the topics of this thesis. For this reason, and in order to cut down time, effort and cost of visiting and meeting, phone calls , besides online meetings, will be conducted, and survey questions will be discussed and illustrated through the phone call.

5.4 Results concerning the Thesis Questionnaire

Through the short meetings and cell phones that were executed with several engineering consulting companies in Dabouq, seventh circle. Fourth circle, Abdoun, Tila'a Al-Ali, Khalda, Wadi Saqra, it was found that there are divergent opinions as well different points of view concerning the C&DWM criteria in Jordan. Figure (6-1) presents the results of the survey conducted to know the opinions of all survey's society in this work.



	1	2	3	4	5	6	7
1	16%	11%	85%	3%	19%	11%	2%
2	4%	20%	2%	5%	36%	2%	10%
3	21%	19%	3%	11%	25%	8%	48%
4	17%	12%	6%	14%	8%	26%	27%
5	42%	38%	4%	67%	12%	53%	13%

Fig. 5-1 C&DWM thesis survey findings.

For instance, in question number one, that states: “Do you think that the idea of this project is successful and is applicable to all projects in Jordan?”, roughly 40% of general managers, different engineers and seniors surveyed reported that there is much of waste generation from construction industry in Jordan and most of them agreed that it must be a C&DWM strategy for all companies to make recycling for this type of waste.

For question number two which states: “To what extent do you agree that utilizing the seven materials in this work is cost effective?”, most engineers and general managers surveyed agreed that recycling those seven materials is highly effective. They said that those seven materials are abundant, cheap and easy to collect and recycle. They urged to collect those materials and invest

them before they go to the landfills in Jordan and waste much of time, cost and effort for recycling. Some of them were restricted as they have no rich experience in the price of those seven waste materials.

In question number three which states: “Do you think that recycling waste materials from C&DW can be done directly, without adding particular modifications and adjustments such these in the model of this work?”, large portion of the questionnaire’s society surveyed explained that modifications and on the structure and features of those seven materials used in this work must be added as this model did, in order to maintain the mechanical; and physical properties of construction material which are similar in their function to the conventional structural material.

In question number four, which states: “To what degree do you believe that utilizing the seven materials used in this work was successful and valid using the percentage of mixing and replacement to conventional construction materials?”, many engineers thought that using the mixing and replacement percentage for the seven materials compared to conventional construction materials was relatively acceptable. Few stated that the percentage of replacement for some types of materials such as cardboard and rubber may be exceeded 20%, yet particular modification must be added to make them valid for the use in construction.

In question number five that states: “To what degree do you apply C&DWM strategy in your company and projects?”, variety of general managers and senior engineers agreed that they to some degree apply several principles of C&DWM. They said that there are no obligatory regulations which urge them to apply C&DWM criteria in their projects. For this reason, they often apply it and, in some circumstances, but not constantly.

In question number six, which states: “Do you think that these seven materials are abundant and available in Jordan to be used in wide scale?”, most of the society members surveyed said that: “Yes, rubber, cardboard, steel, glass, plastics, aggregate and sawdust are widely disposed from

Jordanian construction industry, and in case a C&DWM criteria is available they must be recycled and recovered, in a way not to waste their beneficial value in other areas".

Finally, many general managers, engineers and seniors reacted positively with question seven, which states: "Do you agree to apply this concept to utility and large-scale projects in Jordan?". They stated that large- and utility- scale projects in Jordan demand large amount of construction materials, and as construction materials are becoming expensive and increasing in their price, many strategies such the model used in this work must be performed in a way to save cost.

From the previous discussion, it can be concluded that engineers, project managers, and workers have validated the statement of alternative hypothesis, (1), which states that waste materials generated from C&D phases in Jordan, are more economically feasible than conventional construction materials, and their mechanical and physical properties are sufficient to be utilized in construction industry in Jordan, especially to build a house through this work. While survey community did not validate or respond positively through questionnaire's questions statements to hypothesis null **( ).**

5.5 Discussions

The results presented in the previous chapter shows that it is economically feasible to utilize the seven waste materials, i.e. waste glass for concrete in exterior walls, waste wood and sawdust for insulation, waste plastics for plastic lumber as a floor covering, waste C&D aggregate for concrete slab, waste rubber for bricks, waste steel as a replacement of conventional steel, cardboard for exterior walls of the house. However, there are some considerations that was taken into account to assure that those materials would be effective in construction. For instance, those waste materials must be feasible in terms of cost. Additionally, they must meet the mechanical, physical, and

chemical characteristics and buildings standards and criteria of those original or traditional materials used in construction. Many researches, as discussed in the literature, investigated the utilization of waste materials in construction as a partial replacement of conventional building materials components such as cement, clay and sand with a specific mixing percentage, considering that no change in the mechanical, chemical, and physical characteristics would occur. They found, as this work found, that several waste materials were successful to be exploited in construction without any change in material properties compared to conventional material. Though, there must be some constraints to utilize these waste materials in construction. For instance, the replacement ratio must not exceed a particular value in some waste materials. Additionally, some modifications and adjustments must be added and achieved to assure that those waste materials are proper to effectively utilize in construction.

Chapter Six: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter illustrates the conclusions of this thesis, as well offer recommendations for future work that can be made by scientists and researchers to improve the work of C&DW management.

6.2 Conclusions

It can be inferred from these two previous tables (i.e. table (6-1) and table (6-2)), that utilizing waste materials for construction the house in this work provided successfully an option which is economic feasible. The following points concluded the results obtained:

1- Utilizing waste glass as a partial replacement with a percentage of (60%) in the concrete was more economic feasible than utilizing concrete alone. In terms of cost, waste glass costed 276 JD to be utilized in building the house, while utilizing conventional concrete alone costed 540 JD. This means that glass utilization saved 264 JD.

2- Exploiting conventional insulation materials would cost 403 JD for insulating house's walls. At the same time, in case waste wood and sawdust with a percentage of (95%) were utilized for insulation purposes with modified chemicals that improve their physical and chemical characteristics would cost 280 JD, which means that waste wood and sawdust waste materials would save 123 JD.

3- Using conventional tiles to cover house's floor with would cost 855 JD for covering 190 square meters. While using plastic lumber with a percentage of (100%) for covering house's floor would cost 570 JD. This means that utilizing plastic lumber for covering house' floor achieved 285 JD of savings.

4- Exploiting conventional concrete components such as cement and sand for building the slab would cost 3,900 JD. On the other hand, in case waste aggregate in construction with a percentage of (20%) is utilized, it would cost 2,730 JD. This means that making construction waste aggregate part of the construction materials saved 1,170 JD.

5- Employing conventional brick for building exterior walls costed 1,840 JD, while utilizing rubber in these bricks by making a partial replacement with a percentage of (20%) costed 1,713 JD achieving a saving of 127 JD.

6- Harnessing waste steel with a percentage of (100%) after it was recycled and processed for building the house costed 9,900 JD. Whereas in case conventional steel was used for building and concrete reinforcement would cost 11,220 JD. This means utilizing waste steel saved 1,320 JD.

7- In case conventional bricks were utilized for building exterior walls it would cost 1,960 JD. On the other hand, if cardboard is utilized in brick as a partial replacement of brick's components with a percentage of (29%), it will cost an overall of 960 JD for building the house, which means it can achieve savings of 1,000 JD.

8- Moreover, for all seven waste materials that were utilized, the selection of the replacement percentage was chosen considering that mechanical and physical characteristics of conventional materials will not be changed.

9- It was found that alternative hypothesis, $_1$, was valid and correct, as waste materials generated from Jordanian C&D phases, and utilized for constructing the house in this work, were cost competitive and mechanical properties were valid and sufficient for construction compared to conventional construction materials. For these reasons, this work stays far from validating null hypothesis, $_0$, which has opposite assumptions to alternative hypothesis.

6.3 Recommendations

This work recommends for researches who are interested to work in cardboard waste management to:

1- Add more modifications on waste materials to enhance their mechanical, physical and chemical properties of the new brick made out of waste.

2- Consider utilizing waste aluminum which is obtained from demolition waste in Jordan for recycling or as a construction material for minimizing the cost of conventional aluminum.

3- Make a law that make regulations for recycling waste materials which is resulted from construction industry sector in Jordan.

4- Intensifying the number of investigations and researches regards to recycling and recovering C&DW from Jordanian construction industry in order to promote the awareness of this waste management strategy and minimize the negative impact on the environment.

5- Imposing taxes/ levies against the C&DW to significantly minimize the impact against Jordanian environment.

6.4 Future Work

The author of this work proposes the following as future works: 1- to continue analyze the rest of house's components such as finishing and landscape to utilize waste materials to design and construct these house components via waste materials.

2- To further conduct analysis of this house by minimizing the amount of chemicals added to modify waste materials.

3- To implement the contribution of this work into large scale projects.

6.5 Limitations

COVID-19 has made some constraints on performing the activities of this work, as many construction activities and shops were shut down. Additionally, COVID-19 quarantine has prohibited authors from visiting the sites to make measurements and performing the activities of this work, as many construction activities and shops were shut down.

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البناء المستدام للنفايات الصلبة

إعداد

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ملخص

قبل ثلاثة عقود، تبنت العديد من الشركات العالمية فكرة المباني المستدامة باستخدام إدارة النفايات لإنشاء مرافقها وبعض فروعها في مناطق مختلفة في العالم. هنا في المملكة الأردنية الهاشمية، تتنافس العديد من المنظمات والشركات بما في ذلك القطاعين الخاص والعام والمؤسسات الوطنية والحكومية الدولية لبناء مثل هذه المباني التي من شأنها تحقيق استدامة من النفايات. في هذا العمل، تم بناء منزل من خلال مخلفات مواد البناء، مع مراعاة الجدوى الاقتصادية للمبنى الجديد إلى جانب الحفاظ على نفس الخصائص الفيزيائية والميكانيكية للمواد الإنشائية التقليدية. بعد إجراء هذا العمل، وجد أن هناك سبع مواد نفايات رئيسية يمكن استخدامها على نطاق تجاري لتحقيق الجدوى الاقتصادية دون التأثير على الميزات الميكانيكية والفيزيائية لمواد البناء الجديدة مقارنة بالمواد الإنشائية التقليدية. كانت مواد النفايات السبعة هذه:)أ(نفايات الزجاج، المستخدمة لاستبدال جزئي في الجدار الخارجي،)ب(نفايات الخشب لعنصر العزل في الجدران الخارجية للمنزل،)ج(نفايات البلاستيك التي يمكن تحويلها وإعادة تدويرها إلى خشب بلاستيكي كبديل للباركيه، نفايات البناء والهدم التي تستخدم كبديل للإسمنت التقليدي في البلاط،(نفايات المطاط التي تم استخدامها في الجدران الداخلية وجزء من المنزل الخارجي،)و(نفايات الحديد الصلب كبديل للصلب التقليدي في المنزل و)ز(الكرتون ككسوة خارجية من الطوب. كما وجد أن استخدام هذه المواد لم يغير بشكل ملحوظ الخصائص الميكانيكية والفيزيائية للمواد التقليدية. تم التأكد أن الفرضية البديلة ، H_1 ، هي صحيحة ومحققة في حين أن فرضية الصفرية

لم تكن صحيحة، حيث أن تكلفة المنزل المبني باستخدام مواد النفايات من مراحل البناء والهدم في الأردن كانت أقل من مواد البناء التقليدية. بالإضافة إلى ذلك ، كانت الخصائص الميكانيكية والفيزيائية لمواد النفايات مماثلة لتلك المتعلقة بمواد البناء التقليدية. تم إجراء مسح لدعم فرضية هذا العمل. غطت الدراسة والمسح المديرين والمهندسين من شركات المقاولات والاستشارات ، ووجدت أن معظم المجتمع الذين شملهم الاستطلاع وافقوا على أن استخدام مواد النفايات في البناء في ظل ظروف معينة سيكون أكثر فعالية من حيث التكلفة من مواد البناء التقليدية. يوصي هذا العمل بإجراء مزيد من التحليل على المواد التي استخدمت في البحث من أجل تحسين جودتها وخصائصها وبالتالي استخدامها في نطاف واسع في البناء.

الكلمات المفتاحية: إدارة مخلفات البناء، زجاج، قضيب الصلب، المطاط، الكرتون، نشارة الخشب، نفايات بلاستيكية، الأردن.

Appendix A

Author	year	recycled material	replacement material	component or stage	full reference
M. Contreras ,, S.R. Teixeira, M.C. Lucas, L.C.N. Lima , D.S.L. Cardoso , G.A.C. da Silva ,G.C. Gregório , A.E. de Souza, A. dos Santos	2016	Construction and demolition waste	bricks	This work reuses this waste as substitute of natural aggregate to produce bricks. Lime and cement were used as binding agents and were pressed using a uniaxial hydraulic press.	Contreras, M., Teixeira, S. R., Lucas, M. C., Lima, L. C. N., Cardoso, D. S. L., Da Silva, G. A. C., ... & Dos Santos, A. (2016). Recycling of construction and demolition waste for producing new construction material (Brazil case-study). Construction and Building Materials, 123, 594-600.
Ali Toghroli*1, Mahdi Shariati**1,2,3, Fathollah Sajedi4,			gravel or	it should be crushed and screened	Toghroli, A., Shariati, M., Sajedi, F., Ibrahim, Z., Koting, S., Mohamad, E. T., & Khorami,

Zainah Ibrahim1, Suhana Koting1, Edy Tonnizam Mohamad5 and Majid Khorami6	2018	*Glass*	sand.	to provide the most proper design gradation	M. (2018). A review on pavement porous concrete using recycled waste materials. *Smart Struct. Syst*, *22*(4), 433-440.

Madeh Izat Hamakareem (Article)	2017	*Brick*	filling materials	bricks are recycled by crushing	https://theconstructor.org/concrete/construction-waste-recycling/1088/
Dr. Yash P. Gupta	2011	Plastic-Waste	Perforated Polymer Concrete	The aggregate was heated to a temperature of around 1200 C. The shredded plastic-waste was added over hot aggregate while carrying on constant stirring to give a uniform coating of plastic waste over aggregate. The plastic waste got softened and got coated over the aggregate. The hot plastic waste form of block and compacted	https://www.nbmcw.com/tech-articles/others-article/25787-infrastructure-construction-with-recycled-materials.html

Kaushal Kishor Sahoo, Mohanish Gupta, Ravi Sahu, Kshitij Mudgal and Y. Shiva Shankar	2019	Plastic-Waste	plastic coarse aggregate (PCA) and plastic fine aggregate (PFA)	Marshall stability test was assessing the load resistance, flow value, air voids, and voids filled with bitumen, for the specimen prepared with varying binder content (4, 5, and 6%) and the fine PFA (100%) in preparation of specimen.	Sahoo, K. K., Gupta, M., Sahu, (2019). Experimental Investigation for the Feasible Applications of Processed Recyclable Plastic Waste in Construction Sector. in Advances in Waste Management (pp. 155-169).
Kaushal Kishor Sahoo, Mohanish Gupta, Ravi Sahu, Kshitij Mudgal and Y. Shiva Shankar	2019	Plastic-Waste	Blocks	Blocks were prepared with 1:2:3 propor- tions of cement, stone dust, and coarse aggregate, respectively. In the present study, stone dust has been replaced with PFA (100%); water to cement ratio was main- tained as 0.5 for preparing the blocks. Coarse aggregates used in the study were in the size range passing through BIS sieve 10 mm and retained on 4.75 mm	Sahoo, K. K., Gupta, M., Sahu, R., Mudgal, K., & Shankar, Y. S. (2019). Experimental Investigation for the Feasible Applications of Processed Recyclable Plastic Waste in Construction Sector. In Advances in Waste Management (pp. 155-169). Springer, Singapore.

Loryuenyong V1, Panyachai T, Kaewsimork K, Siritai C.	2009	Waste glass	bricks	The waste glass can be mixed with clay in different proportions to prepare high quality bricks. Clay bricks with suitable physical and mechanical properties can be obtained at a proper firing temperature by using waste glass with a content in the range of 15 to 30% by weight of clay	Loryuenyong, V., Panyachai, T., Kaewsimork, K., & Siritai, C. (2009). Effects of recycled glass substitution on the physical and mechanical properties of clay bricks. Waste Management, 29(10), 2717-2721.
Bose, P. Bansal	2019	waste plastics	bricks	The results of the study reveal a clear possibility of adding all kinds of waste thermoplastics in bricks with a limited compromise on mechanical properties. These bricks possess favorable properties of construction materials as they are lightweight, porous and are of high thermal resistance. The process of making porous bricks as espoused in this paper is nondestructive involving no combustion or incineration.	Mondal, M. K., Bose, B. P., & Bansal, P. (2019). Recycling waste thermoplastic for energy efficient construction materials: An experimental investigation. Journal of environmental management, 240, 119-125.

I.F. Sáez del Bosque Heede b , N. De Belie b , M.I. Sánchez de Rojas c , C. Medina	2020	recycled construction and demolition waste aggregate	concrete	This article explores carbonation performance in concrete with 25% or 50% mixed recycled construction and demolition waste aggregate, alone or in conjunction with cement containing 25% fired clay construction and demolition waste.	del Bosque, I. S., Van den Heede, P., De Belie, N., de Rojas, M. S., & Medina, C. (2020). Carbonation of concrete with construction and demolition waste based recycled aggregates and cement with recycled content. Construction and Building Materials, 234, 117336.
D. Rajput [a], S.S. Bhagade [a], S.P. Raut [b], R.V. Ralegaonkar [b], Sachin A.	2012	Paper Mills waste and cotton waste	Crete Bricks	. Waste Crete Bricks with varying content of cotton waste (1–5 wt.%), Recycle Paper Mills waste (89–85 wt.%) and fixed content of Portland cement (10 wt.%) have been prepared and tested as per IS 3495 (Part 1–3): 1992 standards.	Rajput, D., Bhagade, S. S., Raut, S. P., Ralegaonkar, R. V., & Mandavgane, S. A. (2012). Reuse of cotton and recycle paper mill waste as building material. Construction and Building Materials, 34, 470-475.
Snehal Anilkumar Kumbhar a, Anilkumar Gupta b , Dadaso Balaku Desai	2013	Construction and demolition	recycled fine aggregate recycled coarse	Heating and rubbing method Eccentric-shaft rotor method	Kumbhar, S., Gupta, A., & Desai, D. (2013). Recycling and reuse of construction and demolition waste for sustainable development. OIDA

C		waste	aggregate		International Journal of Sustainable Development, 6(7), 83-92.
Sung Bae Kim a, Na Hyun Yi a, Hyun Young Kim a, Jang-Ho Jay Kim a,*, Young-Chul Song b	2010	waste plastics	high strength concrete	method to recycle wasted PET bottles is presented, in which short fibers made from recycled PET are used within structural concrete. To verify the performance capacity of recycled PET fiber reinforced concrete, it was compared with that of polypropylene (PP) fiber	Kim, S. B., Yi, N. H., Kim, H. Y., Kim, J. H. J., & Song, Y. C. (2010). Material and structural performance evaluation of recycled PET fiber reinforced concrete. *Cement and concrete composites*, *32*(3), 232-240.