ACHIEVING BUILDING SUSTAINABLILITY THROUGH INDIGENOUS BUILDING MATERIALS

FINAL YEAR PROJECT UG 2013

By

201306887 Muhammad Awais Ali Chishti

201304604 Syed Danial Mehdi Zaidi

201305516 Waqas Ali Kiyani

201304606 Hamza Mubashir

NUST Institute of Civil Engineering
School of Civil and Environmental Engineering
National University of Sciences and Technology, Islamabad, Pakistan

2016

CERTIFICATION

This is to certify that the

Final Year Project Titled

ACHIEVING BUILDING SUSTAINABLILITY THROUGH INDIGENOUS BUILDING MATERIALS

Submitted by

201306887 Muhammad Awais Ali Chishti

201304604 Syed Danial Mehdi Zaidi

201305516 Waqas Ali Kiyani

201304606 Hamza Mubashir

Has been accepted towards fulfillment

of the requirements

For Bachelors in Civil Engineering

Fahim Ullah

Lecturer

NUST Institute of Civil Engineering

School of Civil and Environmental Engineering

National University of Sciences and Technology, Islamabad, Pakistan.

ABSTRACT

Due to increase in environmental issues, construction industry is continuously in search of materials that do not pose hazard to the environment. The aim of this study is to choose the best locally available material to produce lightweight concrete which has required strength, lower cost, density, electrical conductivity and thermal conductivity than the normal concrete. Low density means less dead load, hence reduced size of foundations and pillars which reduces cost and concrete production. Low thermal conductivity leads to energy efficient housing. For this purpose, three samples will be taken. First sample will be made using bloated Shale from NUST, Islamabad as replacement for aggregate in concrete, second using bloated Shale from Karachi and third using bloated Slate from Peshawar as replacement of aggregate. Concrete samples will be tested for strength, electrical conductivity and thermal conductivity. Moreover, their cost and density will be calculated and a comparison will be done to choose the best material.

DECLARATION

It is hereby solemnly and sincerely declared that the work referred to this thesis project has not been used by any other university or institute of learning as part of another qualification or degree. The research carried out and dissertation prepared was consistent with normal supervisory practice and all the external sources of information used have been acknowledged.

DEDICATION

We dedicate this project to our parents and our teachers without whom we would never have been able to achieve anything.

ACKNOWLEDGMENT

First of all, we thank Allah Almighty for giving us strength to undertake this project. We are also grateful to our parents who believed in us and provided constant support. We also take this opportunity to acknowledge and thank our advisor, Lecturer Fahim Ullah for not only his precious time and guidance but also his consistent faith in us.

We are also thankful to our Head of Department (CE&M), Dr. Jamal Thaheem for his support and motivation throughout our project.

We would also like to mention the Head of Department (Structures), Prof. Dr. Syed Ali Rizwan for assisting us in matters related to Structural Engineering and the students of MS Structures for working with us in this project.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background:

The future of our planet is a matter of great concern. Environmental issues and how man / human communities affect ecosystem concerns have been part of human society from the beginning. Sustainable development has become a recognized goal for human society since the deterioration of environmental conditions in many parts of the world (Bossel, 1999). Therefore humanity is forced to pay more attention to the environment. This is becoming more and more important as modern industrial society requires even more burdens on nature (Wall & Gong, 2001). Thus it is found that the concept of sustainable development has an important role in business.

1.2 Problem Statement :

The intense climate change in the last decade has leads to increased problems for society and environment. Due to increase in environmental issues, construction industry is continuously in searching for materials which reduce both the energy and Carbon emission in buildings.

Energy consumption from the buildings is heavily effecting the environment, as 90% of the impact is causing by the energy consume by the building (Faludi et al., 2012).

According to U.S. Green Building Council *"About 40% of the world's energy is consumed by the buildings and this value is way more than that of energy consumption by transportation. In the next 25 years, the amount of* CO_2 *emission is going to be increase from building sector as compared to any other sector, with an average increase in 1.8% per year from commercial sector in USA".*

Reducing this building energy consumption will prove significant in reducing environmental impact. Structures must be designed in such a way that they have a least environmental impact over their lifetime, while fulfilling the normal level of comfort and durability for inhabitants. Sustainable development of buildings reduces the use of energy, land, water, raw materials and many resources. It also decreases the greenhouse gases emission, thus reducing the impact of pollution in environment and thus safeguarding people's health. By increasing the efficiency of buildings with the help of sustainable construction will result into energy efficient building thus causing money saving, longer life span of buildings and least maintenance and operation cost.

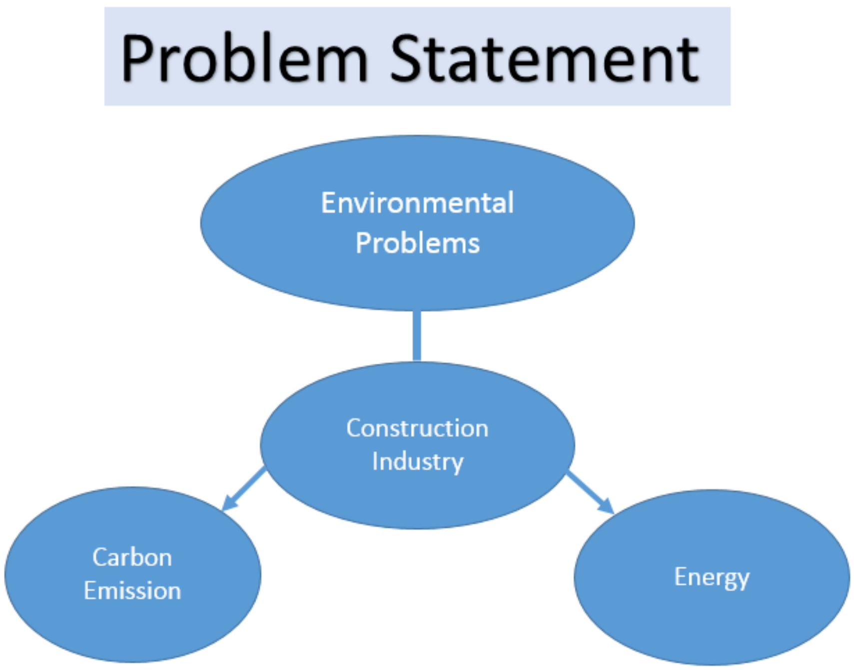

Figure 1. Problem Statement

1.3 Objective:

- To achieve a balance between environmental and economical sustainability in construction industry of Pakistan.
- To identify the most sustainable locally available construction material to be used as an alternative to aggregates in traditional concrete.

1.4 Why Lightweight Concrete ?

The most influential material in construction is concrete and many natural resources are utilized for its production (Robati et al., 2016). It has three major components that are cement, water and aggregate. The most carbon intensive components in manufacturing concrete are cement and aggregates. Physical properties of concrete like grade, moisture absorption, thermal conductivity etc. are directly related with the aggregate characteristics which is used in concrete (Gravitt, 2013).It provide excellent thermal insulation due to its low value of heat flux as compared to normal weight concrete. (Zhang and Poon, 2015).

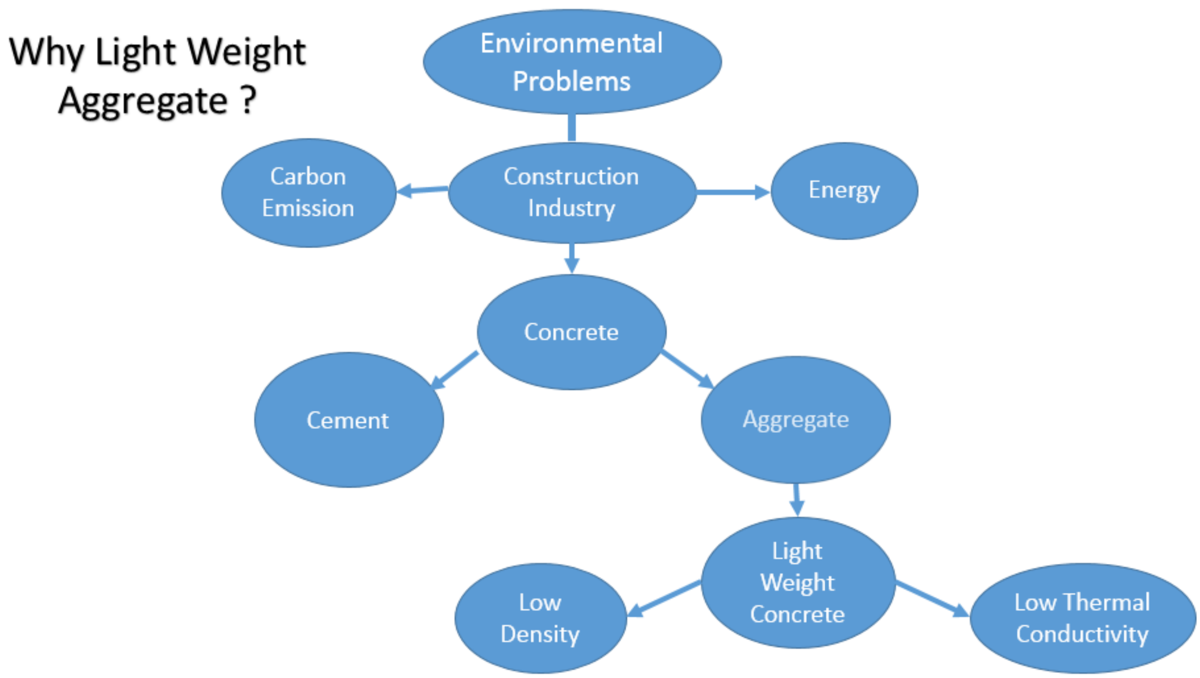

Figure 2. Why Light Weight Aggregates ?

So in this study for sustainable construction, lightweight concrete is used, which has excellent thermal insulation property and low density and adequate dry density ranging from 300kg/m3 to 1840kg/m3. (Desai , 2014).

1.3 History :

It is evident that ancient civilization of Indus valley and Roman empire built their towns with the help of light weight aggregate for example Colosseum, Pantheon, Harappa and many more. Many materials like Pumice and Palm shell oil are used to make light weight concrete. Most of material used are derived from nature like from volcano. These materials can be used as fine as well as coarse aggregate both. (Chandra and Berntsson, 2002).

Most of the natural light weight aggregate do not provide significant strength in concrete, which is desirable in construction. This problem led to use such material, that would result into high strength concrete to fulfil the modern construction demand.

1.5 Choice of Aggregate:

The choice of aggregates is very much related to a local supply chain. So in this study we choose the best locally available aggregate to produce lightweight concrete which has required strength, minimum cost, low density, electrical conductivity and thermal conductivity. For this purpose, three samples would be taken. First sample was made using bloated Shale from NUST Islamabad as replacement for aggregate in concrete, second using bloated Shale from Karachi and third using bloated Slate from Peshawar as replacement of aggregate.

As the most important property, is its lightweight, which will result into decrease in dead load, thus enabling the use of lightweight foundations, reducing cost in handling and transportation and enhancing the time of construction. Decrease in dimensions of structural members and good thermal and acoustic insulation can be achieved from its low density.

Increased cost of Lightweight aggregate can be covered based on its ease in handling, less energy requirement in demolishing, less waste requirement and high durability due to the strong bond of aggregate and matrix.

CHAPTER 2

LITERATURE REVIEW

2.1 General:

Sustainable development is a type of cost-effective and efficient growth, which must fulfil the welfare objectives of society, and it must fulfil the needs and wants of the society in present without compromising and effecting the future generation's needs in short, medium and long terms. The sustainable development of society highlights the three major sectors of human existence, which are ecological, economy and social (Duran et al, 2015). The basic purpose of sustainable development is to achieve a balance between three sectors.

Sustainable construction is a way constructing building to achieve the basic principle of sustainable development by considering the environmental, cultural and socio-economic affairs. However, buildings, environment and infrastructure are related with each other. (Majdalani, 2006).

The Economic prosperity is dependent on the provision of facilities and infrastructure in order to achieve a balance in economic development. This is leading towards the excessive natural resources usage, causing a major impact on the environment, both locally and globally.

Construction has been held accountable for causing environmental problems due to the excessive consumption of natural resources for the manufacture of building materials (Ding, 2008).Thus construction industry along with the materials industry thus contributing towards the unsustainable development. The rapid pace of construction is leading towards more carbon dioxide emission and high energy consumption. Energy consumption by the buildings is one of the main factors for increased environmental problems.

In construction industry, concrete is the mostly used material for the building construction. It is the material with the highest influence on the environment, since it has two major carbon intensive components, which are cement and aggregate and it is the material, which consume excessive natural resources for its manufacturing. Due to increase in environmental issues, construction industry is continuously in search of materials, which can reduce both the energy consumption and carbon dioxide emission in buildings (Majdalani, 2006).

The grade of cement is usually same throughout the world, so the focus of this study is entirely on aggregate, since it is easily available locally and has various types. The objective of this study is to identify and use that material which is environmental friendly and cost effective, so light weight aggregate is selected as a material of our research.

2.2 Light weight aggregate concrete :

Manufacture of lightweight structural aggregate concrete (LWSAC) involves using of variety of lightweight aggregate. LWSAC fulfils to the standard, defined in (ASTM C 330, 2014) “it should have a least compressive strength of 17MPa nearly equal to 2500 psi at 28 days and it should have a dry density value ranging between 1120–1920 kg/m^3”. Those aggregates whose particle density is not greater than 2000kg/m3 or loose bulk density is not greater than 1200kg/m3 are termed as light weight aggregates (LWA) (EN13055-1, 2002).

Light weight aggregates can exist naturally or can be made artificially using industrial processes (ACI, 2003). Most of the time artificial lightweight aggregates are preferred. The properties of the lightweight concrete like strength, thermal and acoustic insulation depend on the type of aggregate used for its production, so consideration of aggregate properties is very important for the manufacture of light weight concrete.

Most of the countries now a days are manufacturing light weight expanded aggregates called LECA (light expandable clay aggregates), using some clay which can expand called bloated clay. This clay is heated in a horizontal rotary kiln at about 1200 degree Celsius, using wet process. In this process paste of water and clay is made which is then fed into the kiln where it is broken into smaller granules, resulting into the formation of porous structure (Chandra and Berntsson, 2002). High porosity is the main property of light weight aggregate, which results into low specific gravity..

Strength of the light weight aggregate particles depends on source and type of aggregate. The strength of the concrete is not dependent on the strength of the coarse aggregate since there is no exact relationship between aggregate strength and concrete strength. Generally, the compressive strength of concrete is related to the content of cement at a given particular slump instead of water to cement ratio (w/c). In some cases, compressive strength can be increased by using good quality natural sand in place of fine light weight aggregate.

The normal weight aggregate zone is stronger in conventional concrete as compared to the interfacial transition zone (ITZ) and cement matrix. Contrary to that, introduction of LWA in concrete mixture significantly affects the mechanical and elastic properties of light weight aggregate concrete, since they are the weakest constituents (Cui et al., 2012). Literature tells that the strength of the concrete is determined by its weakest component. Stress transfer takes place through aggregate and mortar, when aggregate is the rigid constituent. If the aggregate is weak, then transfer of stresses occurs through the cement matrix, resulting into the cracks propagation throughout the light weight aggregate particles. This suggest that the light weight aggregate itself is weaker than ITZ (Bogas and Gomes, 2013). That’s why the density and the volume of constituent light weight aggregate is very important to get results comparable with normal weight concrete (Ke et al, 2009). Light weight concrete is subjected to more creep and shrinkage as compared to the equivalent normal concrete cylinder. Such factors should be considered during the design of structure.

The significance of using LECA in concrete mix is better bond formation between mix constituents. As (Lo and Cui, 2004) showed that the “Wall Effect” which is related to the particle packing does not exist on the surface of expanded clay aggregates in lightweight concrete by SEM (Scanning Electron Microscopy) and BSEI (Back Scattered Electron Imaging), resulting in a better bond and much thinner interfacial zone than the normal concrete.

Expandable light weight aggregates have better thermal resistivity and insulation as compared to the normal concrete because of lower co-efficient of thermal expansion, lower thermal conductivity and fire stability since they are made by heating at very high temperatures of 2000-degree F. The lower thermal conductivity causes the exposed members to achieve a steady state temperature at a higher time, thus decreasing the internal temperature changes. This time difference lag moderate nightly cooling effect and solar buildup in buildings. Such property of thermal resistivity can be useful in tall buildings where exposed lightweight columns have no large volume and stresses variations due to lower coefficient of thermal expansion (Norazila, 2010).

2.3 Application :

The application of light weight concrete results in the reduction of dead load of concrete structure, which gives degree of freedom to the designer to decrease the size of column, footing and other load bearing elements. Lightweight Concrete is ideal for roof deck repairs, stair pan fill, elevated floor slabs or overlays on existing floor decks. It can also be used for appliance platforms, curbs, down spout gutters, balconies, floors, fish ponds, walls, setting posts, castings etc. Lightweight Concrete also offers slower temperature transfer rates than standard weight concrete, resulting in improved insulation factors (Norazila, 2010).

The major characteristic offered by the light weight concrete is that it's excellent insulation properties. It is widely used as loose-fill insulation in masonry construction where it enhances fire ratings, reduces noise transmission, does not rot and termite resistant. (Norazila, 2010).

2.4 Autoclaved lightweight aggregate properties:

The effect of curing on physical and mechanical properties of concrete is studied. The ultimate strength of the concrete greatly affected by the high temperature and there is an increase in early strength of the concrete if curing is done at moderate high temperature. The proper curing of concrete depend on key factors, which are curing temperature and moist curing duration. The early strength gain of LWC also depend and effected by the composition of concrete, compaction factor, properties of material and concrete replacement.

The type of lightweight concrete depends on mortar matrix composition and type of aggregate used. Various type of lightweight aggregate such as natural aggregates which are obtained from volcanic sources including diatomite, pumice and artificial aggregate which are made by some artificial process including expanded shale ,slate are used to make concrete having specific set of properties such as strength, density, thermal conductivity etc. The major property of lightweight aggregate is its higher porosity, which causes its low specific gravity.

Following conclusions were obtained:

- The materials that are more porous have higher values of Specific porosity and Water absorption.
- Autoclaving has no effect on the unit weight of LWC.
- Autoclaving has no effect on thermal conductivity of lightweight concrete.
- By autoclaving, there is an increase of about 75% in the strength of light weight concrete in 37 hours which is higher than the samples which were cured for 28 days in water. (Topcu and Uygunoglu, 2007)

Following set of properties has been specified in this study:

1. **Strength:** The concrete should have the minimum compressive strength of 2500psi at 28 days, so that it can be used as a structural concrete (ASTM C330, 2014).

2. **Density:** Low density of the light weight aggregate concrete will result into the reduction of dead load, which proves to be cost effective in terms of less initial construction cost, since it leads toward the smaller footing sizes, smaller supporting members like beams, girders and reduces inertial seismic forces.(ACI 213R-03).

3. **Cost:** Cost is the major concern in order to achieve economic sustainability. Light weight aggregate has low transportation cost, due to its ease of handling. The decrease in truck load will directly results into less number of trucks required, hence causing transportation savings (ACI 213R-03).

4. **Thermal Conductivity:** Low thermal conductivity of light weight concrete will leads towards the environmental sustainability, since there will be no excessive energy consumptions. This will results into the thermal efficiency (Norazila, 2010).

5. **Electrical Conductivity:** The electrical conductivity has a direct impact on steel corrosion and results into the concrete deterioration. Electrical conductivity is the reciprocal of thermal resistivity. More the resistivity, lesser will be conductivity and hence more durable the concrete will be (Hornbostel et al, 2013).

2.7 Methods for Testing Thermal Conductivity:

2.7.1 Guarded Hot Plates System, ASTM C177:

The test is suitable for those low density materials which have low thermal conductivity value.

- Measurable range of thermal conductivity value: 0.01 to 2 $Wm^{-1}K^{-1}$

- Mean sample temperature range requirement: 98K (-175°C) to 477K (204°C)
- Requirement of sample size: a pair of 6 inch square specimens with up to 2 inch thick
- Test accuracy %: ± 3% to ± 5%
- Test reproducibility %: ± 2%

2.7.2 Heat Flow Meter System, ASTM C518:

The test is suitable for materials, which have thermal conductivity from medium to low.

- Range of thermal conductivity: 0.1 to 2 $Wm^{-1}K^{-1}$
- Range of mean temperature of sample: 193K (-180°C) to 473K (200°C)
- Size of sample: customized size
- % Accuracy of test: ± 5% to ± 8% depending on sample and conductivity
- % Test reproducibility: ± 2%

2.7.3 HOT Wire Technique, C1113:

This test is based on ASTM C1113 which is used to measure the thermal conductivity of thermally dielectric insulation materials whose k< 5 $Wm^{-1}K^{-1}T$. This test is performed at room temperature and can vary to 773K (500°C) in any medium such as air, inert gas or vacuum.

2.7.4 Liquid Thermal Conductivity:

Modified ASTM E1225 technique is used to measure the thermal conductivity of liquids having high viscosity such as slurry, oil and paste. A hot wire method can also be used.

Test can be performed to get measurements at a temperature ranging from 273K (0°C) to 363K (90°C).

CHAPTER 3

METHODOLOGY

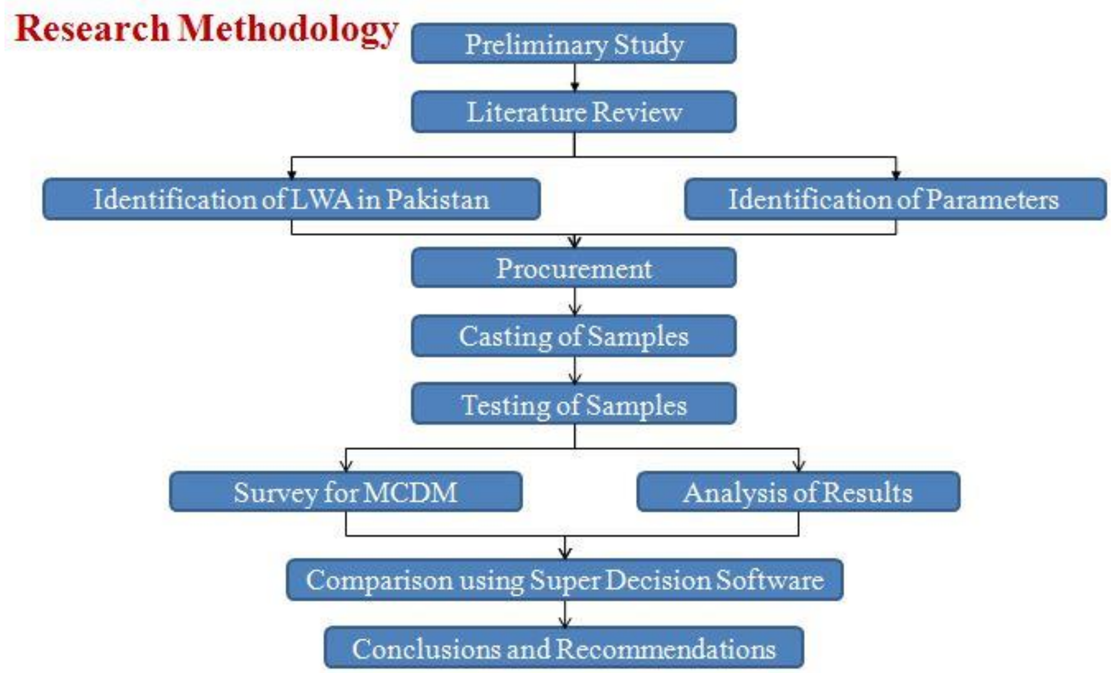

Figure 3. Methodology

3.1 Parameters Identification :

Initially a preliminary study of research papers and content on the Internet was studied to identify the problem statement and the scope of work. One of the main reasons of environmental problems is energy consumed by the construction industry. Therefore, a detailed literature review was carried out to identify different solutions. One of the main challenges in sustainable design of buildings is to improve the energy efficiency of the building during its lifetime along with reducing the environmental impact of the design (Robati et al, 2016). It is therefore important to explore environmentally and economically sound design and development techniques to ensure that buildings and infrastructure are sustainable, healthy and affordable (Majdalani et al, 2006).

Concrete is the most widely used construction material in the building industry and consumes the second highest amount of natural resources (ISO15673). In order to make concrete more environmentally sustainable, it should be energy efficient. Thermal conductivity is the most influencing factor in energy efficiency of concrete. Thermal conductivity of concrete is dependent on the type of aggregates used in the concrete mixture. Some published construction properties databases associate thermal conductivity to concrete density, for example ACI122R and CIBSE. Therefore, it is possible to make concrete more energy efficient by replacing conventional aggregates with low density lightweight aggregates.

The value of thermal conductivity of concrete is decreased by $0.13Wm^{-1}K^{-1}$ with the introduction of lightweight aggregate in concrete and proven by the research work (Sengul et al., 2011). Properties other than Thermal Conductivity were also studied. The following properties of LWAC were identified:

1. High Compressive Strength
2. Low Density
3. Low Modulus of Elasticity
4. Low Thermal Conductivity
5. Low Bond Strength
6. Higher Durability
7. Low Water Absorption
8. No Alkali Aggregate Reaction
9. Abrasion Resistance
10. Low Electrical Conductivity
11. High Sound Insulation
12. High Fire Resistance

(ACI-213, Madhavi & Annamalai, 2016, Lesovik et al., 2014, ACI-216.1)

3.2 Materials:

After the identification of properties, availability of Lightweight aggregate was located. Artificial Lightweight aggregates were chosen for further research.

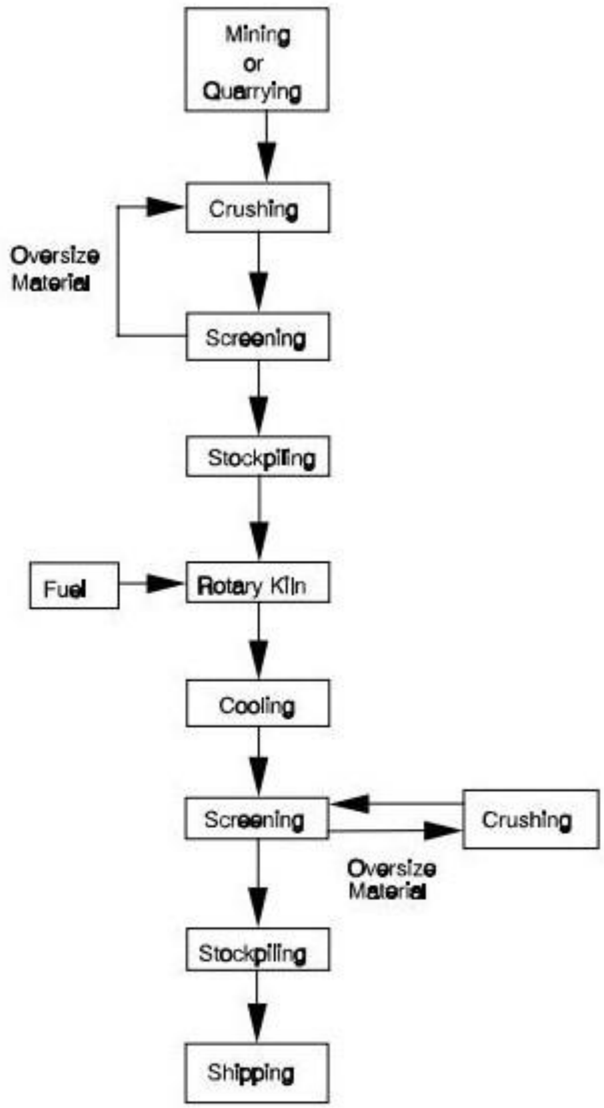

Figure 4, Process flow diagram for lightweight aggregate manufacturing.

1. Shale Clay from NUST, H12, Islamabad
2. Shale Aggregate from PCSIR Lab, Karachi

3. Slate Aggregate from PCSIR Lab, Peshawar

Shale in clay form was extracted from NUST Gate 10 and was taken to PCSIR Laboratories Peshawar. In carrying out our process the clay was prepared by reducing it to a finely divided state, mixing it with the bloating agent, if necessary, and with suitable amounts of water to impart sufficient plasticity, and shaping it into individual particles as by extrusion and division into desired lengths. Exact pre-shaping of the particles is, however, unnecessary and it is sufficient to break up the clay into particle sizes correspondingly smaller than the desired bloated size. The size of the particles will therefore vary considerably but generally it is preferred that they have a size distribution such that when bloated will yield lightweight aggregate conforming to the prevailing specifications in the industry. In the preparation of shale’s it is necessary only to roughly size the shale. Those shale’s, which do not naturally bloat, must be reduced to a fine powder and mixed with a bloating agent before shaping. Slate may be prepared similarly to a non-bloating shale by reducing it to a fine powder, mixing it with a bloating agent and shaping (US 2654136 A).

Shale was expanded by heating in a rotary kiln. This process is called bloating. In this process the first crushing and storing of shale is done. Then it is introduced into the back end of rotary kiln from storage silo at constant rate. The length of the kiln is about 175 feet and diameter of kiln is 11 feet. The initial temperature in the kiln is about 800°F. If there is any moisture present in the shale, it is evaporated and it keep on moving forward in rotary kiln and continuous heat is provided. For about 45 minutes, the shale is retained in the kiln. When the shale reaches the front end of the kiln, which is called burning zone, the temperature increases. In this zone, the temperature is maintained at 2000- 2100 °F. At this stage gases are formed which become entrapped, causing expansion due to formation of air voids. Then shale is transferred to grate cooler to cool the expanded shale. From cooler, the shale is transferred into storage stockpile for storing purpose.

Figure 5. Rotatory Kiln

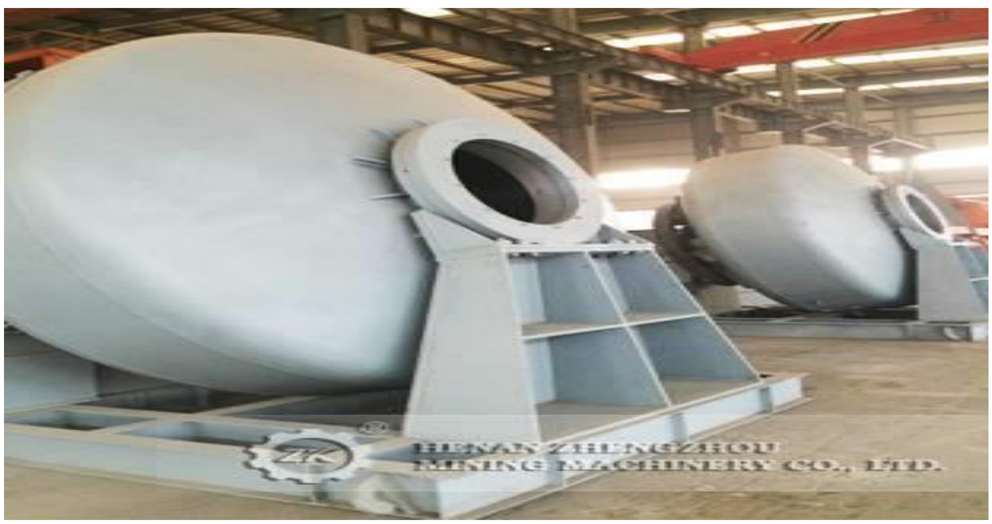

Figure 6. Rotatory Kiln Cylinder

One of the industrial waste produced by the timber industry is Sawdust. If it is not disposed properly, it causes problem to both health and environment. (Elinwa and Mahmood, 2002)

The block strength is affected by the tannin presence in sawdust, which act as a retarder, confirmed by the research work. The percentage replacement of sand should be less than

10% in order to achieve better result by the use of sawdust for block (Adebakin et al. , 2012.)

In this study Ultra Fluid 235 water reducing admixture is used.

3.3 Experimental Procedures

3.3.1 Bulk Density of Aggregates

This test used to find out the bulk density of aggregate, which can be useful for the selection of proportions for concrete mix, and to find out the mass over volume (M/V) relationship for conversions in purposes of purchase agreements.

Apparatus: Balance, Tamping Rod, Measure, Shovel, Calibration Equipment

Procedure: Fill the aggregate 1/3rd and perform levelling of surface. Perform the tamping on the surface of aggregate layer with the help of the tamping rod with 25 strokes evenly over the entire surface. Now again fill up to 2/3rd and again perform tamping. Finally, fill the aggregate up to such extent that it overflow and again rod the aggregate layer. Perform levelling with the help of straight edge or any other instrument such that to fill the large voids of aggregate in the final layer. Tamping should not be done forcibly and it should not penetrate into the aggregate layer.

Determine the mass of the container with aggregate and the mass of the container itself, measure the value, and record the values to the nearest 0/1lb. (0.05kg). (ASTM C 29/C 29M-97 2003)

The bulk density is calculated by following formula:

$D = (a - b)/c$

in which:

D = Aggregate bulk density in kg/m3

a = Aggregate mass along with container mass in kg

b = Measure mass in kg

V = Container volume in m3

Table 1. Bulk Density

LWA	**Bulk Density**
Slate Peshawar	930 kg/m3
Shale Peshawar	986 kg/m3
Shale Karachi	1080 kg/m3
Conventional Aggregate	1459 kg/m3

3.3.2 Absorption Capacity of Aggregates

First aggregate is cleaned and submerged in a clean for around 24 hours. After 24 hours, the submerged sample is removed and it is dried from the surface in order to calculate its surface dry mass whereas its volume is calculated by how much water is displaced during its submergence, which is water displacement method. After this the sample is put into the oven for drying purpose and after some time it is removed from the oven and its mass is calculated. Masses calculated are used to determine density, specific gravity and absorption by using formulas.

Absorption values are used to check out the variation in the aggregate mass, because of absorbed water in the pore spaces as compared to the dry condition. For laboratory standard, the dry aggregate is submerged in water for a specific time. Aggregate, which are present below the water table, have moisture content greater than the absorption value, which is obtained by this test, if proper drying is not done. Free moisture percentage of the aggregate, which has been in contact with water, is find out by determining the total moisture content by Test Method C 566 and then deducting absorption from it. (ASTM C-128)

Table 2. Absorption Capacity

LWA	Absorption Capacity
Slate Peshawar	5%
Shale Peshawar	7%
Slate Karachi	7%
Conventional Aggregate	3%

3.3.3 Compressive Strength Test :

A total number of 15 samples were casted for compressive strength test.

Table 3. Casting ratios of Compressive strength test samples

LWA	Mix Ratio	w/c Ratio	Plasticizer
Slate	1:1.5:3	0.5	1.5%
Shale Peshawar	1:1.5:3	0.5	1.65%
Shale Karachi	1:1.5:3	0.5	1.6%
Shale Karachi with 10% Sawdust	1:1.5:3	0.5	1.6%
NWC	1:1.5:3	0.5	-

Table 4. ACI mix proportions

Mix Proportion*	Slump, mm	Air-dry Density, kg/m^3	Compressive Strength, MPa	
			7 days	28 days
1:1.5:0.5–1.0/0.6	200–0	1890–1725	10.0–2.5	15.0–5.5
1:2.0:0.5–1.0/0.6	230–5	1930–1780	8.0–2.0	11.5–5.0
1:2.5:0.3–0.75/0.6	260–10	1985–1895	9.5–5.5	15.5–8.0
1:1.25–2.5:0.6/0.6	115–60	1905–1935	7.0–8.0	11.0–11.5
1:2.0:0.6/0.40–0.85	0–260	2050–1840	16.5–0	20.5–0

* Mix proportion—cement:sand:palm oil shells/water-to-cement ratio.

Table 3.3—Relationships between *w/c* and compressive strength of concrete*

Compressive strength at 28 days, psi (MPa)	Approximate water-cement ratio, by weight	
	Nonair-entrained concrete	Air-entrained concrete
6000 (41.4)	0.41	—
5000 (34.5)	0.48	0.40
4000 (27.6)	0.57	0.48
3000 (20.7)	0.68	0.59
2000 (13.8)	0.82	0.74

*Values are estimated average strengths for concrete containing not more than 2% air for non-air-entrained concrete and 6% total air content for air-entrained concrete. For a constant *w/c* or *w/cm*, the strength of concrete is reduced as the air content is increased. Twenty-eight-day strength values may be conservative and may change when various cementitious materials are used. The rate at which the 28-day strength is developed may also change.

Strength is based on 6 x 12 in. (150 x 300 mm) cylinders moist cured for 28 days in accordance with the sections on "Initial Curing" and "Curing of Cylinders for Checking the Adequacy of Laboratory Mixture Proportions for Strength or as the Basis for Acceptance or for Quality Control" of ASTM C 31 of *Making and Curing Concrete Specimens in the Field*. These are cylinders moist cured at 73.4 ± 3 °F (23 ± 2 °C) before testing.

The relationship in this table assumes a nominal maximum aggregate size of about 3/4 to 1 in. (19 to 25 mm) For a given source of aggregate, strength produced at a given *w/c* or *w/cm* will increase as nominal maximum size of aggregate decreases. See Section 2.3.

Figure 7. Relationship between w/c and compressive strength of concrete

Three Cylindrical samples (6x12) for each lightweight aggregate were casted and tested at 28 days for compressive strength. In this method, cylinders are subjected under axial compressive load for some time until the sample fails. The maximum load, which is attained by sample before its failure, is divided by the sample cross section area to get compressive strength of sample. (ASTM C 39)

Apparatus: Compression Testing Machine

Location: Structures Lab, NICE, NUST, Islamabad

3.3.4 Density

Density of concrete samples were calculated at 28 days. Mass of the concrete cylinders were measured using Weighing machine while volume was calculated by using the dimensions of 6x12 standard cylinders. Mass is divided by volume to calculate density.

3.3.5 Cost

Cost for 1 cubic foot of each sample of concrete was calculated.

3.3.6 Thermal Conductivity Test

1 sample (4x4x4 in cube) for each type of concrete was casted. The sample was further cut down to a size of 2x2x1 in as it was the requirement of the apparatus. The samples were sent to NED University Karachi for testing of Thermal Conductivity. The thermal conductivity test is done by using Guarded Heat Flow Meter.

In this test the minimum requirement of sample thickness is 25mm. However this test is useful for those materials which have thermal resistance, ranging from 10 to 400 × 10^{-4} m^2KW^{-1} and gives thermal conductivity between 0.1 to 30 $Wm^{-1}K^{-1}$ over 150 to 600 K temperature range.

In this test a sample and a heat flux sensor, which is a transducer (HFT), is placed between two plates, having controlled different temperature, which causes heat flow. To ensure the proper contact resistance between sample and surface of the plate, test application is subjected to some load through some pneumatic mean. To minimize the heat losses, a guard is used around the plates, which is maintained at the mean temperature of plates. The difference in temperature between the surfaces is measured with the help of the sensors, which are placed in plates along with the heat flux transducer electrical output. This electrical output voltage is directly proportional to the heat flow through the specimen. Before taking any measurement, calibration of the instrument is done with the help of the sample of known value of thermal resistance to obtain the proportionality. (ASTM E1530 – 11)

Figure 8. Guarded heat flow meter for thermal conductivity

3.3.7 Electrical Conductivity

1 sample (4x4x4 in cube) for each type of concrete was casted. The sample was further cut down to a size of 2x2x1 in as it was the requirement of the apparatus. The samples were sent to NED University Karachi for testing of Electrical Conductivity using Two Electrode Soil Box Method. (ASTM G187 – 12a)

Figure 9. Measurement of Resistivity Using the Two-Electrode Method

In this method, a sample is placed between two opposite faces of a box. A voltage is applied between two opposite faces of box, which act as electrode. Current start flowing between the electrodes, causing a voltage drop, which is measured. This voltage drop is proportional to the voltage by Ohms law. Resistivity is measured with the help of the formula:

r = (*a**R*)/*D*

where:

a = area of cross section in cm^2

R = sample resistance in ohms

D= distance between electrodes in cm

3.3.8 Multi Criteria Decision Making (Analytical Hierarchy Process)

There were 5 parameters on the basis of which the concrete samples had to be analyzed.

1 Strength
2 Density
3 Cost
4 Thermal Conductivity
5 Electrical Conductivity

As there were more than one conflicting parameters, Multi criteria decision-making method was used. A sub-branch of MCDM, the AHP reduces multidimensional problem into one-dimensional. Hence, AHP was applied on the conflicting parameters.

The Analytic Hierarchy Process (AHP) defines a complex problem by making a hierarchy of elements and gives the best judgment based on pair wise comparison between alternatives and decision-making factors. However, the decision-making factors require some scale to explain the preference of one factor over another. However, the final judgment can be inconsistent and how much consistency can be improved by improving the judgment can also be done by AHP.

To solve a problem to get a decision in an organized way, following steps are done:

1 State the objective of the problem.
2 Make a hierarchy of three level, which is called clusters. The first level contains the basic goal of problem that what is the ultimate goal of the problem that is desirable to achieve. The second cluster is a collection of decisions, which contain the parameters based on which evaluation is required. The last clusters contains the alternatives, which are subjected for comparison.
3 Create a link between levels to make pairwise comparisons matrix. In pairwise matrix, each element of first cluster is compared with the elements of the following cluster.

4 Give weightage to each element of the cluster and define that how much one element is prior to another element in the cluster itself and in the comparison between different clusters. (Thomas L. Saaty, 2008)

Super Decision software was used to apply MCDM. A model was created in the software to choose the best alternative i.e. concrete from among 5 different types of concrete samples on the basis of 5 parameters.

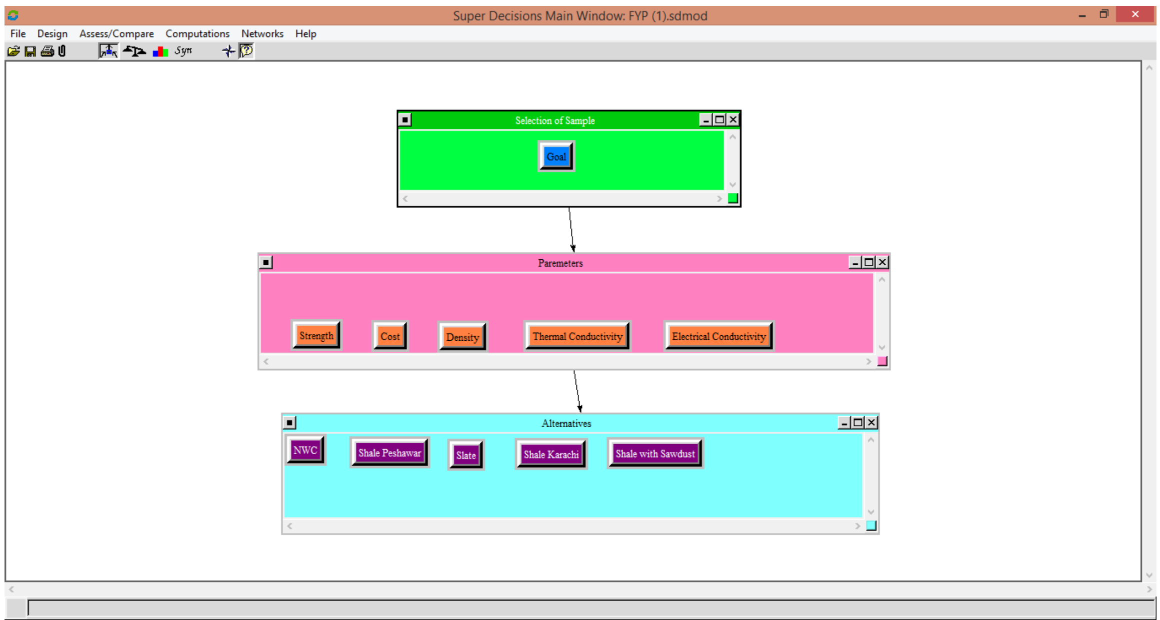

Figure 10. Model made in Super Decision Software

3.3.8.1 MCDM Survey

It was a requirement of the software to enter test results as well as survey results. Therefore, a survey was conducted to find out the relative weightages of different parameters according to the experts.

Survey

Just fill 10 empty boxes in yellow colour.

		2nd Alternatives				
		Strength	Density	Cost	Thermal Conductivity	Electrical Conductivity
1st Alternatives	Strength	1				
	Density		1			
	Cost			1		
	Thermal Conductivity				1	
	Electrical Conductivity					1

Compared to the second alternative, the first alternative is	Ranking
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1

Figure 11. Questionnaire for survey

The people on whom the survey was conducted had the following distribution:

1 55% End Users

2 35% Engineers

3 10% Architects

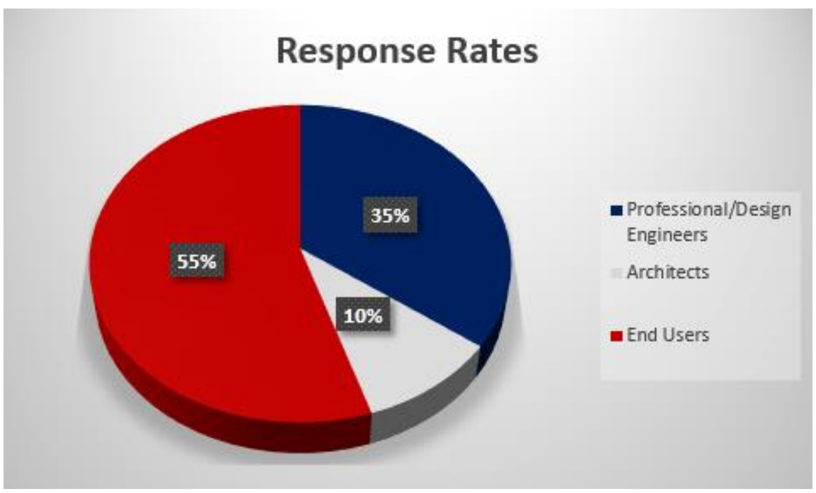

Figure 12. Survey response rate

CHAPTER 4

ANALYSIS AND RESULTS

4.1 MCDM

MCDM evaluates multiple conflicting parameters in decision making. One by one putting test results and survey results in MCDM. The Super Decision software integrated the survey results and test results and gave us overall ranking with respect to all the parameters.

4.1.1 Test Results

The software compares the alternatives on the basis of pairwise comparison of each parameter according to the test results. Hence the test results were incorporated in the software for pairwise comparison.

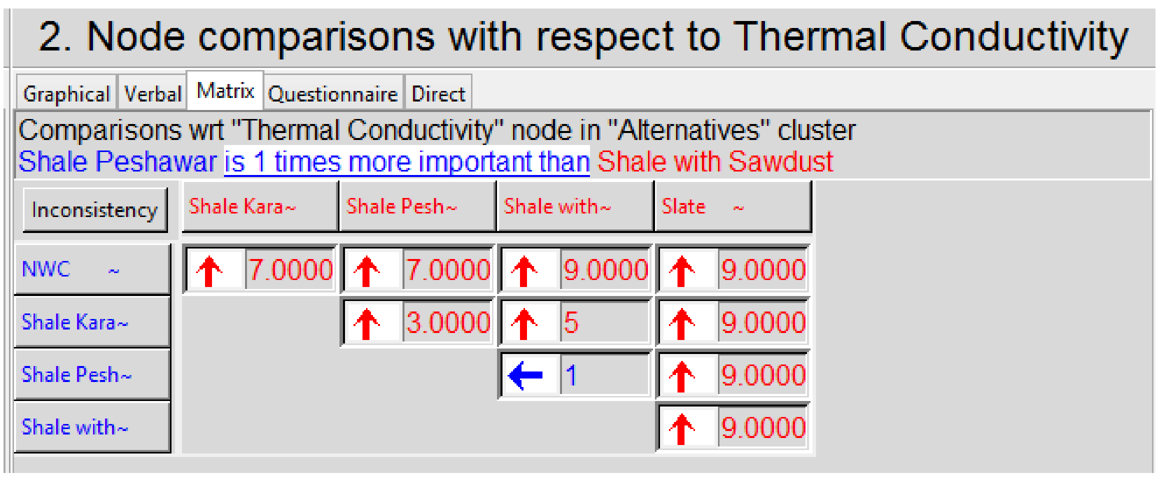

Figure 13. Pairwise comparison

4.1.1.1 Compressive Strength Test

Test results for compressive strength are shown below in table. Strength test results shows that normal weight concrete has the highest strength and shale Karachi with 10% sawdust has the lowest strength. On the basis of pairwise comparison putting their relative scores in the software and result extracted from the software shows that NWC is best alternative with respect to compressive strength.

Table 5. Compressive strength test results

Concrete Samples	Strength (Psi)
Slate	2873
Shale Peshawar	2805
Shale Karachi	2740
Shale Karachi with 10% Sawdust	2613
NWC	3683

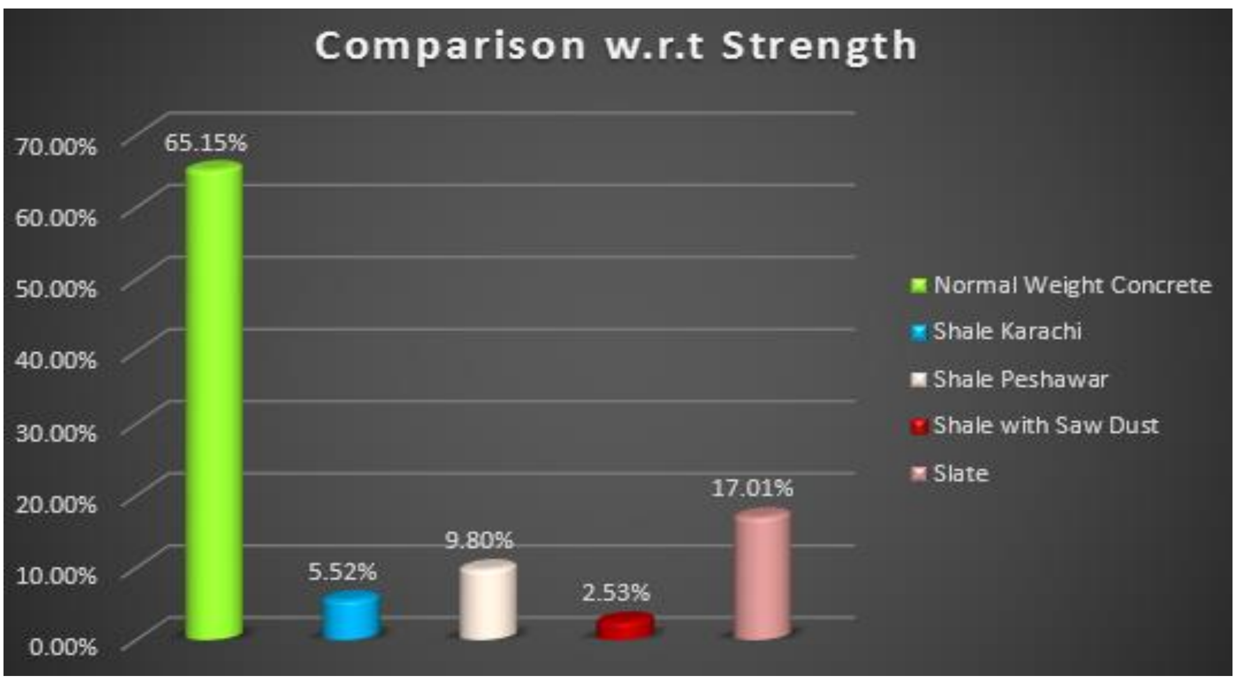

Figure 14. Comparison of samples on the basis of strength

4.1.1.2 Density Calculation

Calculated densities are shown in the table below, Density calculation shows that normal weight concrete has the highest density and shale Karachi with 10% sawdust has the lowest density. The lesser the density the lesser will be the dead load by the building hence results in reduction in column, beam and foundation sizes. Based on pairwise comparison putting their relative scores in the software and result extracted shows that Shale Karachi with 10% sawdust is best alternative with respect to density.

Table 6. Density Calculation

Concrete Samples	**Density (lbs/ft3)**
Slate	122.9
Shale Peshawar	116.3
Shale Karachi	112.9
Shale Karachi with 10% Sawdust	106.2
NWC	145

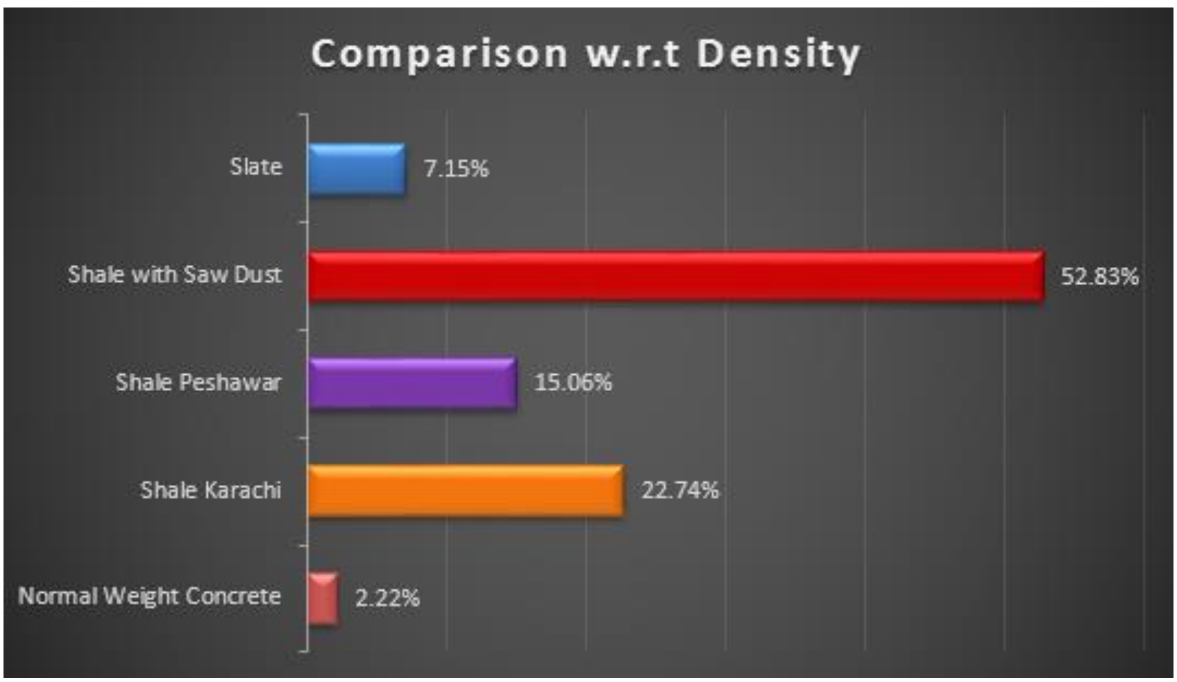

Figure 15. Comparison of samples on the basis of density

4.1.1.3 Cost Calculation

Calculated costs are shown in the table below, cost calculation shows that normal weight concrete has the lowest cost and shale Karachi with 10% sawdust has the lowest highest cost. On the basis of pairwise comparison putting their relative scores in the software and result extracted shows that NWC is the most cost effective alternative.

Table 7. Cost Calculation

Concrete Samples	Cost (PKR)
Slate	1797
Shale Peshawar	1797
Shale Karachi	1797
Shale Karachi with 10% Sawdust	1798
NWC	192

Figure 16. Comparison of samples on the basis of cost

4.1.1.4 Thermal Conductivity

Results for thermal conductivity are shown below in the table. Thermal Conductivity test results shows that normal weight concrete has the highest Thermal Conductivity and Slate has the lowest Thermal Conductivity. The lesser the Thermal Conductivity the lesser will be the heat passed through the building hence results in reduction in energy consumed by the building. On the basis of pairwise comparison putting their relative scores in the software and graph extracted shows that Slate is best alternative with respect to Thermal Conductivity.

Table 8. Thermal Conductivity test results

Concrete Samples	**Thermal Conductivity (W/ K.m)**
Slate	0.16
Shale Peshawar	1.807
Shale Karachi	1.855
Shale Karachi with 10% Sawdust	1.792
NWC	2.003

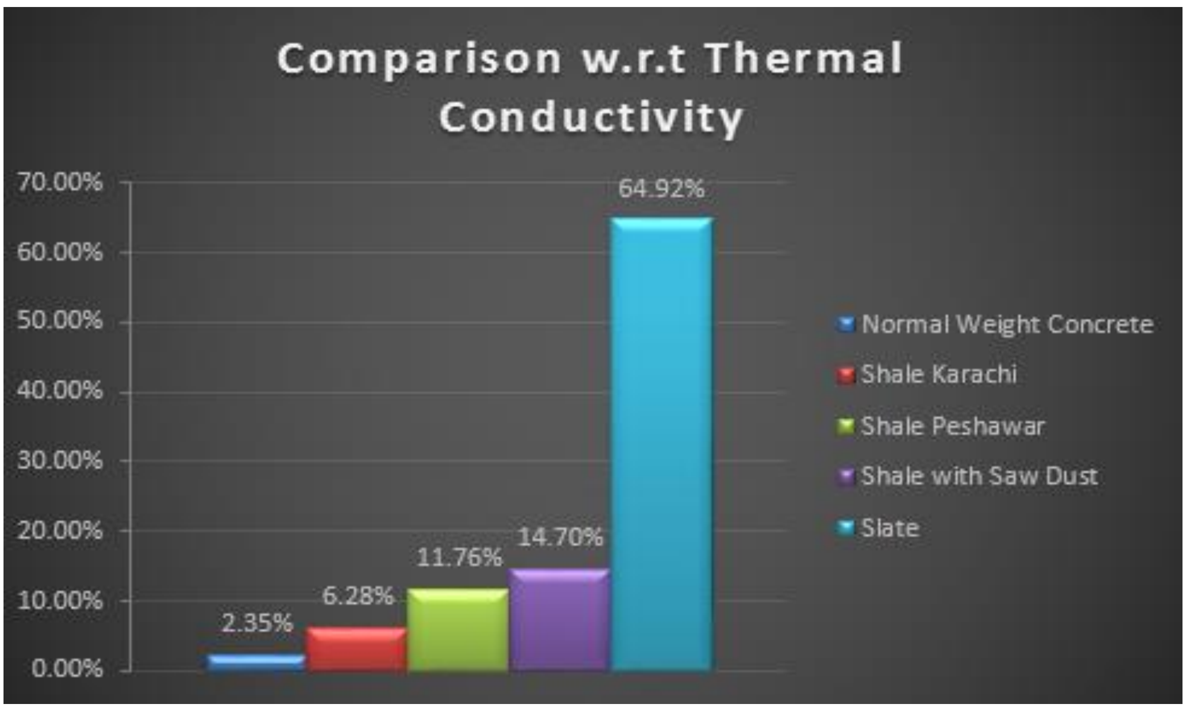

Figure 17. Comparison of samples on the basis of Thermal Conductivity

4.1.1.5 Electrical Conductivity

Electrical Conductivity test results are shown in the table below, Electrical Conductivity test results shows that normal weight concrete has the highest Electrical Conductivity and Shale Karachi with 10% sawdust has the lowest Electrical Conductivity. On the basis of pairwise comparison putting their relative scores in the software and results obtained shows that Shale Karachi with 10% sawdust is best alternative with respect to Electrical Conductivity.

Table 9. Electrical Conductivity test results

Concrete Samples	Electrical Conductivity (micro S/m)
Slate	0.156
Shale Peshawar	0.159
Shale Karachi	0.142
Shale Karachi with 10% Sawdust	0.122
NWC	0.184

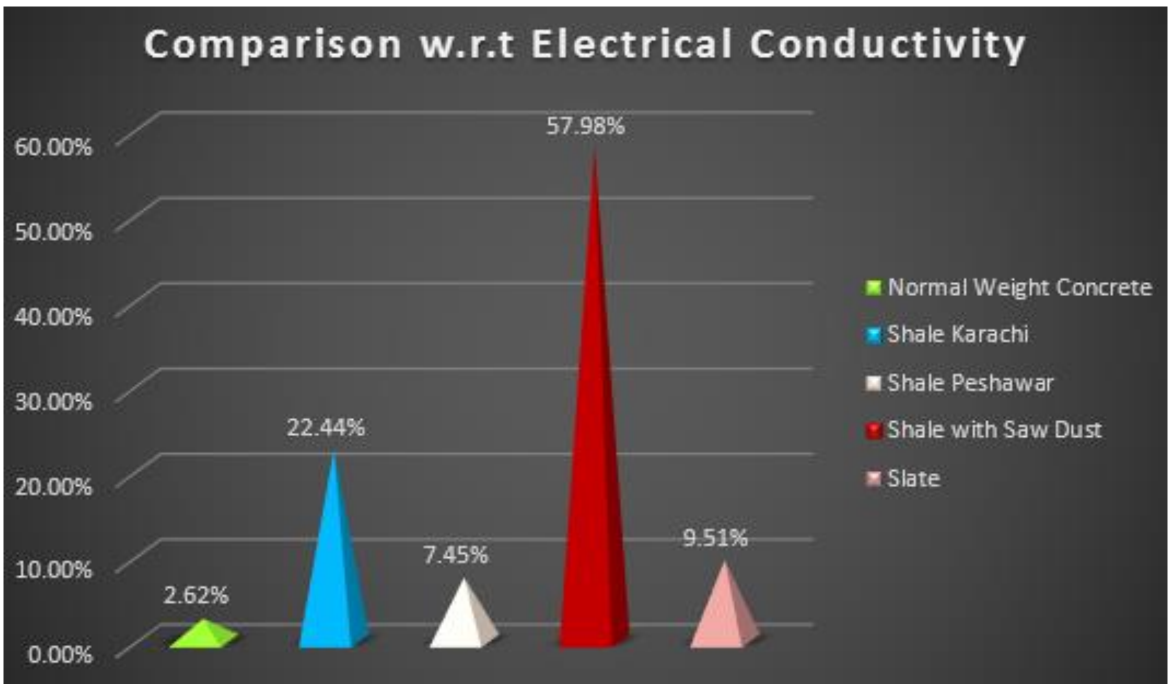

Figure 18. Comparison of samples on the basis of Electrical Conductivity

4.1.1.6 Overall Test Results

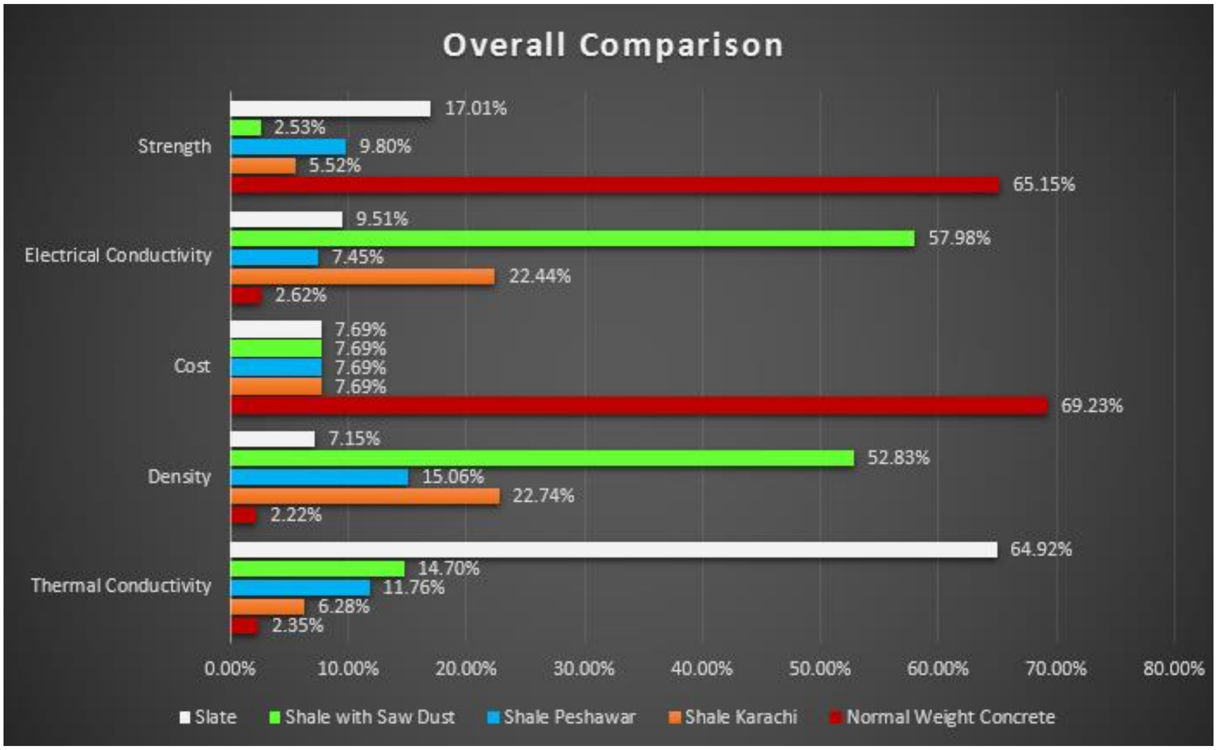

Figure 19. Overall test results

4.1.2 Survey Results

After conducting the survey we came to know that professional engineers were most concerned about strength whereas end users were more concerned about cost and thermal conductivity. The results of the survey were incorporated into the software for further analysis and comparison. Results shows that cost is the most preferred factor and thermal conductivity is 2nd most preferred factor. Electrical conductivity is least preferred by the people.

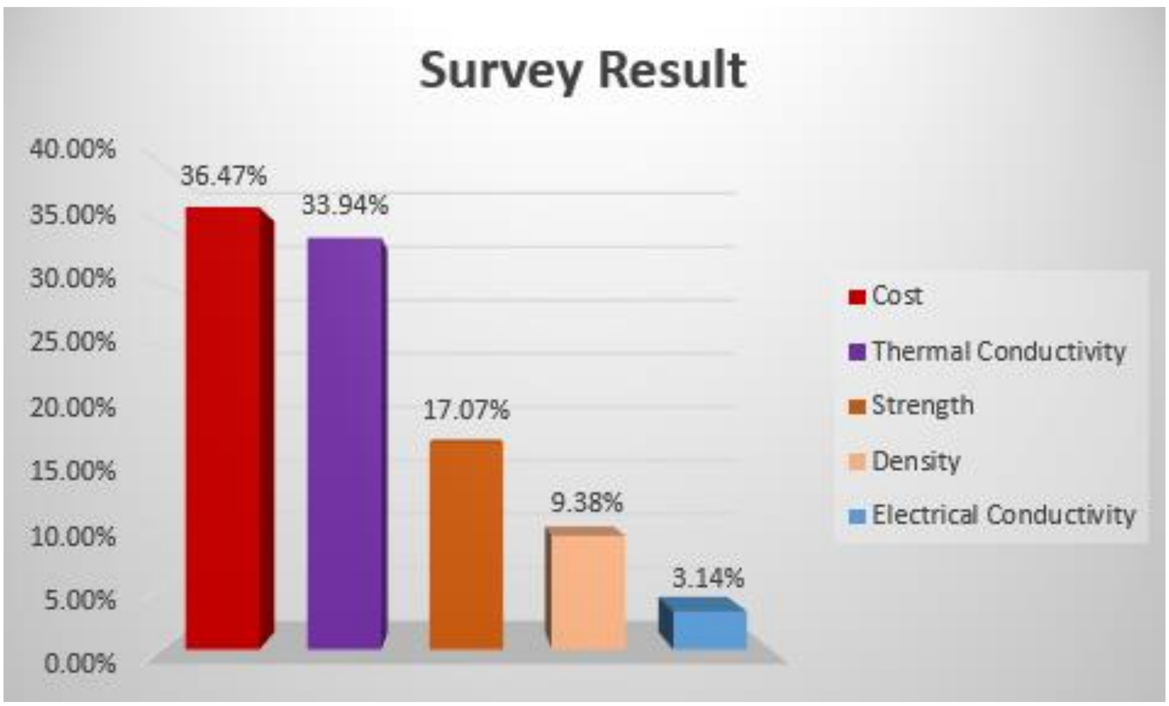

Figure 20. Survey results

4.1.3 Final Ranking By MCDM

Table shows that NWC still ranks at number 1. Now questions arises why NWC still ranks at number 1 , it is because of NWC has the least cost and cost is the most preferred factored by the people.

Table 10. Final Ranking by MCDM

Alternatives	**Score**	**Rank**
Normal Weight Concrete	0.1837	1
Slate	0.1436	2
Shale with 10% saw dust	0.0750	3
Shale Peshawar	0.0506	4
Shale Karachi	0.0436	5

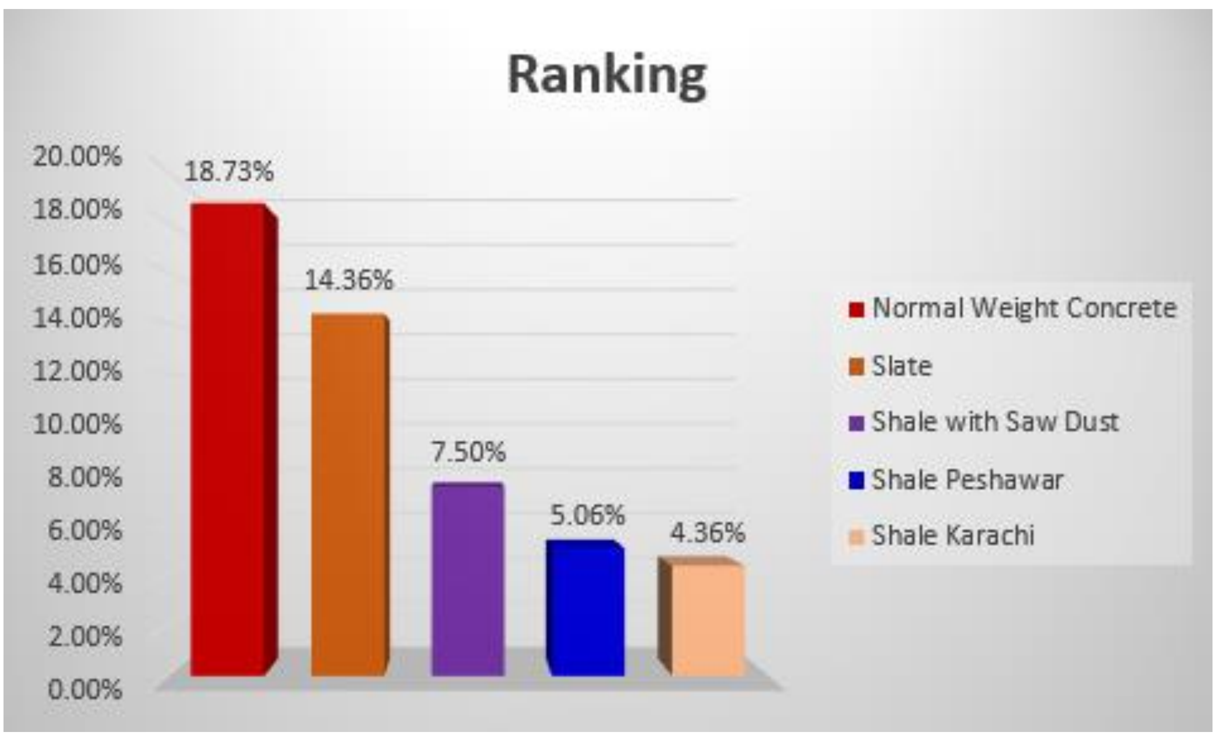

Figure 21. Ranking

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

- The most influential factor is cost even today that pushes the construction industry towards conventional concrete.
- In Pakistan there is lack of awareness about energy efficiency hence more steps are required on policy making level.
- Although the initial cost of LWAC is high, it can be partially compensated by :
  - ✓ Reduction in steel area.
  - ✓ Reduction in structural member areas.
  - ✓ Reduction in foundation areas.
  - ✓ Lower transportation, handling and labor cost.
  - ✓ No additional Thermal Resistance Treatment required.
- The thermal efficiency of the building increases hence results in lower energy consumption by the building.

5.2 Recommendations

Lightweight Aggregate Concrete should be used because:

- ➢ Initial cost can further be reduced by mass production of Lightweight Aggregate.
- ➢ Decreased dead load allows construction on ground with a low load-bearing Capacity.
- ➢ Lower Electrical Conductivity hence less corrosion of concrete samples. Strength can be increased by addition of various admixtures.
- ➢ Provides sound insulation Higher fire resistance.

5.3 Future Recommendations

- Cost reduction of aggregate due to mass production.
- Carry out further investigation on the effect of lower thermal conductivity on building energy envelop.
- Determining the reduction in size of footing due to reduction in dead load.
- Life cycle cost assessment.

REFERENCES

Bossel, H. (1999). Indicators for sustainable development: theory, method, applications.

Wall, G., & Gong, M., (2001). On exergy and sustainable development—Part 1: Conditions and concepts. An International Journal 3, 128-145.

Chandra, S., & Berntsson, L. (2002). *Lightweight aggregate concrete*. Elsevier.

Robati, M., McCarthy, T. J., & Kokogiannakis, G. (2016). Incorporating environmental evaluation and thermal properties of concrete mix designs. Construction and Building Materials, 128, 422-435.

D. Gravitt, Eco-efficient construction and building materials, Constr. Manage.

Duran, D. C., Gogan, L. M., Artene, A., & Duran, V. (2015). The Components of Sustainable Development-A Possible Approach. Procedia Economics and Finance, 26, 806-811.

Econ. 31 (11) (2013) 1164–1165.

Majdalani, Z., Ajam, M., & Mezher, T. (2006). Sustainability in the construction industry: a Lebanese case study. Construction innovation, 6(1), 33-46.

Desai, D. (2014). Development of Light Weight Concrete. *Civil Engineering Portal*.

Ding, G. K. (2008). Sustainable construction—The role of environmental assessment tools. Journal of environmental management, 86(3), 451-464.

Merikallio, T., Mannonen, R., & Penttala, V. (1996). Drying of lightweight concrete produced from crushed expanded clay aggregates. *Cement and concrete research*, *26*(9), 1423-1433.

ASTM C330/330M, Standard specification for lightweight aggregates for structural concrete, ASTM International, West Conshohocken, PA, US, 2014.

EN13055-1, 2002. Lightweight Aggregates — Part1: Lightweight Aggregates for Concrete, Mortar and Grout. European Committee for Standardization CEN.

ACI Committee 213R, Guide for structural lightweight-aggregate concrete, American Concrete Institute, Farmington Hills, MI, 2003.

Cui, H. Z., Lo, T. Y., Memon, S. A., &Xu, W. (2012). Effect of lightweight aggregates on the mechanical properties and brittleness of lightweight aggregate concrete. Construction and Building materials, 35, 149-158.

Bogas, J. A., & Gomes, A. (2013). Compressive behavior and failure modes of structural lightweight aggregate concrete–Characterization and strength prediction. Materials & Design, 46, 832-841.

Ke, Y., Beaucour, A. L., Ortola, S., Dumontet, H., & Cabrillac, R. (2009). Influence of volume fraction and characteristics of lightweight aggregates on the mechanical properties of concrete. Construction and Building Materials, 23(8), 2821-2828.

Lo, T. Y., & Cui, H. Z. (2004). Effect of porous lightweight aggregate on strength of concrete. Materials Letters, 58(6), 916-919.

Norazila, K. (2010). An investigation on effect of quarry dust as sand replacement on compressive and flexural strength of foam concrete (Doctoral dissertation, Universiti Malaysia Pahang).

Topçu, İ. B., &Uygunoğlu, T. (2007). Properties of autoclaved lightweight aggregate concrete. *Building and Environment*, *42*(12), 4108-4116.

Dilli, M. E., Atahan, H. N., &Şengül, C. (2015). A comparison of strength and elastic properties between conventional and lightweight structural concretes designed with expanded clay aggregates. *Construction and Building Materials*, *101*, 260-267.

Hubertová, M., &Hela, R. (2013). Durability of lightweight expanded clay aggregate concrete. *Procedia Engineering*, *65*, 2-6.

Hornbostel, K., Larsen, C. K., & Geiker, M. R. (2013). Relationship between concrete resistivity and corrosion rate–A literature review. Cement and Concrete Composites, 39, 60-72.

Mehdi Robati , Timothy J. McCarthy , Georgios Kokogiannakis, Incorporating environmental evaluation and thermal properties of concrete mix designs - Construction and Building Materials 128 (2016) 422–435

ISO15673, Guidelines for the Simplified Design of Structural Reinforced Concrete for Buildings, The International Organization for Standardization, Switzerland, 2005

ACI122R, Guide to Thermal Properties of Concrete and Masonry Systems, American Concrete Institute, 2014.

CIBSE, Environmental Design: Cibse Guide A, London, 2006.

Sengul, O., Azizi, S., Karaosmanoglu, F., Tasdemir, M.A., 2011. Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete. Energy Build. 2e3, 671e676.

Method of making lightweight aggregate US 2654136 A

ASTM C 29/C 29M-97 2003 Standard Test Method for Bulk Density

ASTM C 566 Test Method for Total Evaporable Moisture Content of Aggregate by Drying

ASTM C 128 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate

ASTM C 39/ 39M – 17 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM E1530 – 11 Standard Test Method for Evaluating the Resistance to Thermal Transmission of Materials by the Guarded Heat Flow Meter Technique

ASTM G187 - 12a. Standard Test Method for Measurement of Soil Resistivity

Thomas L. Saaty, Decision making with the analytic hierarchy process, Int. J. Services Sciences, Vol. 1, No. 1, 2008

Elinwa, A. U., & Mahmood, Y. A. (2002). Ash from timber waste as cement replacement material. *Cement and Concrete Composites*, *24*(2), 219-222.

Adebakin, I. H., Adeyemi, A. A., Adu, J. T., Ajayi, F. A., Lawal, A. A., & Ogunrinola, O. B. (2012). Uses of sawdust as admixture in production of lowcost and lightweight hollow sandscrete blocks. *American Journal of Scientific and Industrial Research*, *3*(6), 458-463.