ENVIRONMENTAL IMPACT OF PREDOMINANT BUILDING MATERIALS OF MOSQUES IN MOSUL, IRAQ FROM 1100s TO 1800s AD

By

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LIST OF ABBREVIATIONS

CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CML	Centre of Environmental Science of Leiden University
EE	Embodied Energy
EPA	Environmental Protection Agency
GaBi	Ganzheitliche Bilanzierung (Life Cycle Engineering)
GHG	Greenhouse Gas
HAPs	Hazardous Air Pollutants
IAQ	Indoor Air Quality
ISO	International Organization for Standardization
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
OE	Operating Energy
OSHA	Occupational Safety and Health Administration’s
PBTs	Persistent Bio accumulative and Toxic
PEC	Primary Energy Consumption

RI	Relative Index
SACs	Sustainable Assessment Criteria
TRACI	Tool for the Reduction and Assessment of Chemical and other environmental Impacts
UAE	United Arab Emirates
UN	United Nations
US	United State
VOCs	Volatile Organic Compounds

LIST OF SYMBOLS

CFCs Chlorofluorocarbons

CO_2 Carbone Dioxide

$HCFC_s$ Hydrochlorofluorocarbons

NO_x Nitrogen Oxide

pH Scale measures how acidic or basic a substance is. It ranges from 0 to 14. A pH of 7 is neutral.

PTFE Polytetrafluoroethylene

PVC Polyvinylchloride

QUAL Dominant qualitative methodology

qual qualitative methodology

QUAN Dominant qualitative methodology

quan quantitative methodology

LIST OF PUBLICATIONS

Five supporting publications that are related to this thesis are already published by the refereed journals or refereed conferences either at international or national level by the candidate with collaboration with the supervisor. Listed here are:

Published Papers in Refereed Journals

1. Yahya, H. A., and Abdul Samad, M. H., (2015), Environmental Impacts of Building Materials for Minarets of Historical Mosques, Advances in Environmental Biology, Vol. 9 (4), pp. 1-4.

2. Yahya, H. A., and Abdul Samad, M. H., (2014), The Role of Building Materials in Architectural Design, Applied Mechanics and Materials, Vol. 679, pp. 6-13.

3. Yahya, H. A., and Abdul Samad, M. H. (2012), Impact of Materials on Conservation of the Built Environment: Case Study of Historic Mosques in Mosul Old Cit. Iranica Journal of Energy & Environment, Vol. 3 (Special Issue on Environmental Technology), pp. 24-31.

Published Papers in Symposium/ International Conferences/Proceedings

1. Yahya, H. A., and Abdul Samad, M. H. (2014). The Role of Environmental Impact in Building Material's Selection. Cihan University, First International Scientific Conference. 20th-21st April 2014, Erbil, Iraq.

2. Yahya, H. A., and Abdul Samad, M. H. (2012). Impact of Materials on Sustainability of Historic Mosques in Old Mosul City. 3rd International Conference on Environmental Research and Technology (ICERT 2012). 30th May-1st June 2012, Penang, Malaysia.

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IMPAK PERSEKITARAN BAHAN-BAHAN UTAMA MASJID DARIPADA 1100 HINGGA 1800 AD DI MOSUL IRAQ

ABSTRAK

Impak persekitaran adalah salah satu faktor utama dalam pemilihan bahan bagi rekabentuk senibina lestari. Walau bagaimana pun, terlalu sedikit kajian yang telah menilai impak persekitaran bagi bahan bangunan. Maka, terdapat satu keperluan supaya lebih banyak kajian yang menggalakkan pendekatan yang sistemetik bagi menilai bahan bangunan dari aspek tersebut. Kajian ini mengaplikasi Analysis Impak Kitaran Hayat bagi menilai impak persekitaran bahan bangunan. Kajian ini menggunakan kaedah campuran kualitatif dan kuantitatif dan bermula dengan kajian deskriptif terhadap 12 bangunan masjid yang telah dibina antara tahun 1100_s and 1800_s bagi mengenalpasti data mentah bahan binaan dan rekabentuk masjid-masjid tersebut. Analisis kuantitatif melalui aplikasi 'GaBi Educational' telah digunapakai bagi menganalisis data untuk menilai impak persekitaran bahan bangunan pada masjid-masjid tersebut sekiranya dibina dan digunakan pada konteks masa kini. Kajian terperinci deskriptif telah mengenalpasti empat bahan utama, iaitu: batu kapur, marmar tempatan, batu 'daub' dan bata tanah liat. Masjid-masjid bersejarah di Mosul menggunakan batu di dalam setiap hampir kesemua elemen senibina, manakala bata tanah liat hanya digunakan pada elemen senibina seperti kubah dan minaret. Penemuan kajian menunjukkan perbezaan yang ketara impak persekitaran bagi empat bahan binaan yang digunakan dalam masjid tersebut. Bata tanah liat mempunyai impak yang lebih tinggi berbanding bahan lain iaitu batu 'daub', manakala marmar tempatan mempunyai impak yang lebih besar berbanding batu kapur. Sifat-sifat bahan bangunan memberi kesan ketara terhadap elemen

senibina dan gaya (style) masjid di Mosul. Akhirnya, kajian ini mencadangkan penggunaan semula bahan binaan yang terdapat di rantau tempatan Mosul dan perlu mengurangkan risiko dan impak persekitaran dengan memperbaiki teknologi pengeluaran.

ENVIRONMENTAL IMPACT OF PREDOMINANT BUILDING MATERIALS OF MOSQUES IN MOSUL, IRAQ FROM 1100s TO 1800s AD

ABSTRACT

Environmental impact is the key factor in materials selection in sustainable architectural design. However, a few researches assess the environmental impact of building materials. Thus there is a necessity for more studies suggest a systematic approach to assess the building materials in terms of environmental impact. This study applied Life cycle Impact Assessment to evaluate the environmental impacts of buildings materials. The study uses mixed qualitative and quantitative methods. This study's descriptive survey represents raw data obtained from 12 mosques built within 1100_s and 1800_s. Quantitative analysis via GaBi Educational application was then used to analyse the data in order to assess the environmental impact of the building materials. From detailed descriptive survey four predominant materials were identified include: limestone, local marble, daub stone and clay brick. The historical mosques of Mosul used stones in almost all of their architectural elements, despite the use of clay brick in some architectural elements like domes and minarets. The study findings showed significant differences in the environmental impact of the four building materials that were used in various architectural elements. Clay brick had a higher environmental impact as compared to other building materials such as daub stone, whereas local marble had a higher impact as compared to the limestone. The properties of building materials had obvious effect on the architectural elements and the style of the mosques in Mosul. Finally, the study recommended reusing traditional building materials that are available in local region of Mosul and can reduce environmental risks by enhancing the production technology.

CHAPTER 1: INTRODUCTION

1.1 Introduction

According to the study by Wackernage and Rees (1996), environmental footprint all around the world for materials resources consumption shows that humans consume more resources than the earth can replace. The study, concludes that human being consuming more than the earth's carrying capacity by 20% (Wackernagel & Rees, 1996). As illustrated in Figure 1.1 the countries have been stretched to indicate their effective consumption based upon 2005 Global Footprint Network (Fuad-Luke, 2013). The colours gradient from green to red refers to ecological deficit measured with global hectares per capital however, blue represents insufficient data.

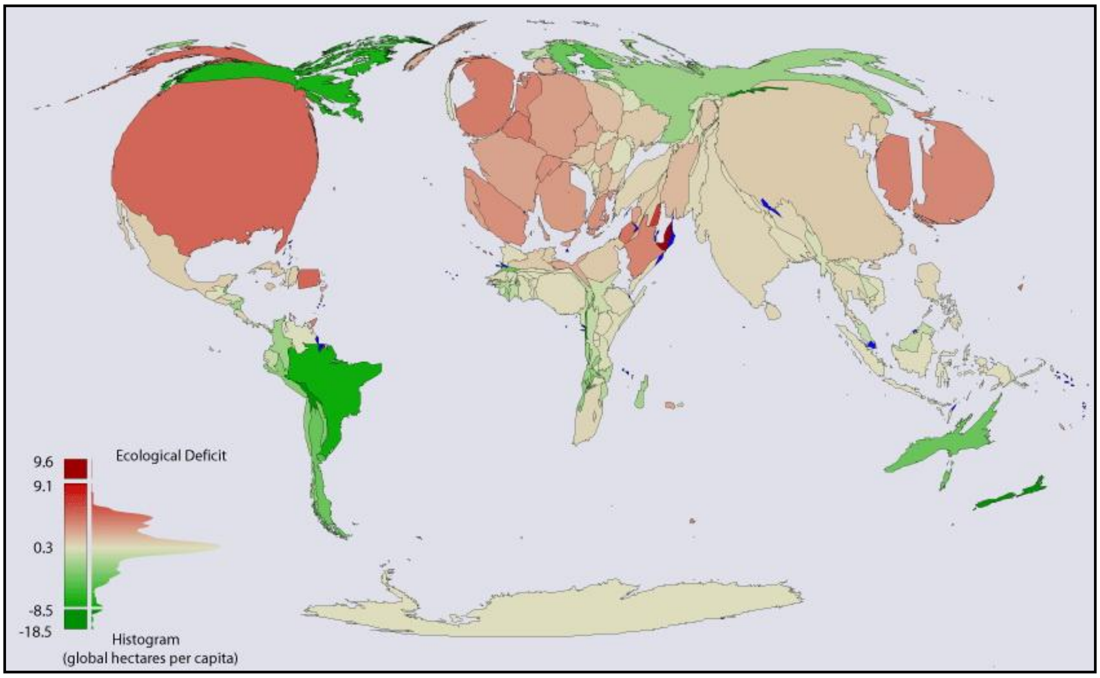

Figure 1.1 The World consumption cartogram in 2005. *Source: (Fuad-Luke, 2013)*

Americans use four times materials resources of the world average consumption of the most of any country worldwide. If every country consumes as many resources as Western countries do, three more Earths are needed to sustain the human survival (Calkins, 2009). According to World Watch, one-tenth of the global economy is customized to constructing, operating, and equipping buildings (Shi, 2009). Such a demand would account for roughly 40% of the material flow of the world economy for buildings (D. Thomas, 2002). Annually above three billion metric tons of natural components are required to manufacture building materials around the world (Calkins, 2009). The building industry is the second largest consumer of raw materials after the food industry (Halliday, 2008). Apart from economic factors, buildings also have strong environmental impact on the earth planet.

Figure 1.2 illustrates the general problem highlighted in this research that needs to be managed sensitively to reduce global environmental risks. Currently, there are at least four vital challenges, that required to be addressed and they are; pollution, resource utilization, over-consumption, and overpopulation (Ljungberg, 2007). Buildings and related industry are responsible for a large part of the environmental load; 42% of all energy consumption, 40% of all atmospheric emissions, 30% of all raw materials used, 25% of water usage, 25% of solid waste, and 20% of liquid waste (Szokolay, 2008). Both solid waste and liquid waste contribute to pollution. Besides raw materials and water usage contribute to materials resources utilization, energy consumption contributes to over consumption. Overpopulation can further be viewed, in a long term perspective, as existing when a population cannot be maintained given the rapid depletion of non-renewable resources or given the degradation of the capacity of the environment to give support to the population (Ehrlich & Ehrlich, 1990). In order to reduce global environmental risks, it must control the environmental impacts of building and associated. This corresponds to the aims of sustainable architecture which are to reduce the impact on the overall environment as possible without polluting both indoor and outdoor environments, as well as to generate sufficient, comfortable and secure buildings (Al-Tassan & Bahobail, 2006).

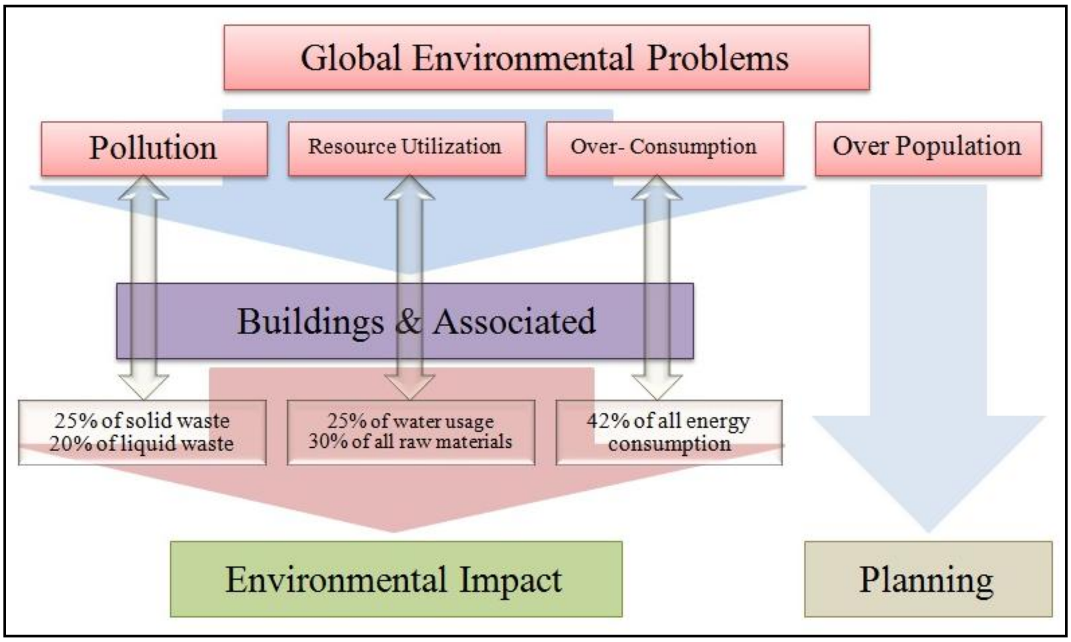

Figure 1.2 General problem.

Sustainable architecture considers every feature of the building which could affect the environment as well as to humans. It looks at material employment as well as embodied energy, solar access, natural-passive heating and cooling, ventilation, water and energy use, so as to minimize their requirement for fossil fuels or non-renewable resources. Furthermore, sustainable architecture helps to reduce total consumption of materials and energy demands for constructing buildings. An environmental impact is defined as any change to the environment, whether adverse or beneficial, resulting from facility's activities, products, or services (Olsthoorn, Tyteca, Wehrmeyer, & Wagner, 2001).

The concept of environment in Islamic perception means more than a simple enumeration of its components of the ecological system; it transcends this to establish a link between these components and human. Thus, built environment in Islamic World is a reflection of Muslims view of the environment as a living entity (Shahin & Al-Zubaidi, 2008). From the Islamic perspective, the human's relation to the environment is closely related to Muslims' faith (Omer, 2002). This view is materialized in different levels whether in the city planning or architectural design that was shaped by the beliefs and actions of the inhabitants who adhered to the Islam as a way of life with social ideas. Islam calls for the main principles of sustainability for centuries by rational resource utilization, materials conservation and reduce pollution. This rule is known as no extravagance (Shahin & Al-Zubaidi, 2008).

"O Children of Adam! Take your adornment (by wearing your clean clothes), while praying [and going round (the *Tawaf* of) the *Ka'bah,*] and eat and drink but waste not by extravagance, certainly He (Allah) likes not *Al-Musrifun* (those who waste by extravagance)*"*

(*Al-A'raf* 31)

In this research, mosques, as a building type, have been selected to be examined, due to their significance in Islamic society. Mosque acquires its importance from being the main spiritual centre for Muslims. Mosques are multi-function buildings; besides facilitating the praying activity, they also provide educational and social activities (Mounis, 1981).

As shown in Figure 1.3 majority of mosques are smaller buildings with simple architecture, and rarely high altitude. The biggest examples of the historical mosques are Al-Kutubiah in Morocco, Ibn Tolon in Cairo, Al-Milwiya in Samarra, Al-Sulaimaniah in Istanbul and Qutub in Delhi are smaller than any of the Cathedral such as Canterbury in London, Notre Dame in Paris, Saint Peter in Rome, Dom in Cologne or Saint Marco in Venice. The size and weight of the stone which built Notre Dame is equal to which built four or five big mosques.

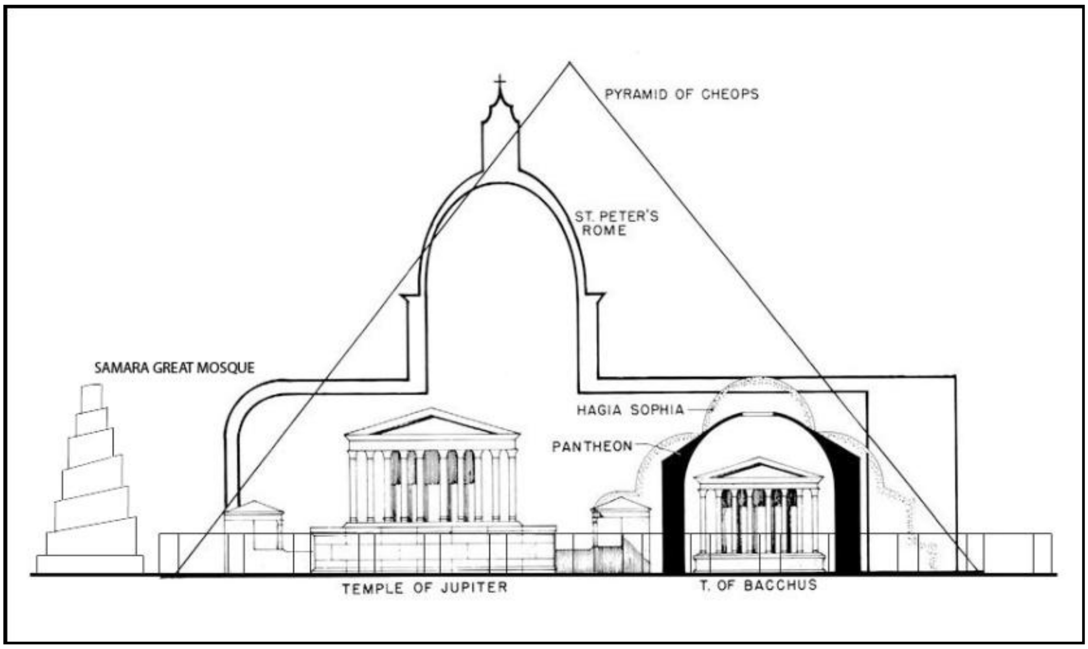

Figure 1.3 The visual size comparison for some of the largest sacred sites in the world. *Source: (Destinations, 2005)*.

For more comparison, Table 1.1 compares the volumes, areas, and heights of largest religious buildings in the world according to their capacity. Beside that most of the mosques areas are open space without roofs (courtyard) (Mounis, 1981).

Table 1.1 Largest Religious Buildings in the World. *Source: (Destinations, 2005) updated by researcher*

Category	Building	Location	Volume m^3	Area m^2	Height m	Capacity Per.
Largest Buddhist temple	Borobudur Temple	Central Java, Indonesia	60,000	15,129	34.5	
The largest church	Our Lady of Peace Basilica	Yamoussoukro, Côte D'Ivoire		30,000	158	18,000
The tallest church	Ulm Münster	Ulm, Germany	190,000	8,260	161.5	20,000
Largest cathedral	Cathedral of Saint John the Divine	New York City, USA		11,200	70.7	5,000
Largest Orthodox cathedral	Cathedral Church of Christ the Savior	Moscow, Russia		6,800	103.5	10,000
Largest Orthodox cathedral	Cathedral of Saint Sava	Belgrade, Serbia	170,000	8,162	82	10,800
Largest mud building	Great Mosque of Djenne	Djenne, Mali		5,625	16	3,000
Largest mosque	The Holy Mosque	Mecca, Saudi Arabia		750,000		1 Million1
The largest pyramid	Great Pyramid of Cholula	Puebla, Mexico	4.45 Million	202,500	66	
The Largest Ziggurat	Ziggurat of Ur	Tell El-Muqayyar, Iraq		2,787	30	

1.2 Problem statement

In spite of the reasonable evolution of mosque design and its function over centuries, many of contemporary mosques do not fit to the sustainable environmental demands. These are clearly indicated as follows:

i. In many Islamic countries new mosques were built with extraneous concepts which, caused affectation in construction and operational systems. Social and political factors participate in the transformation from simplicity to complexity and from economy to extravagant.

ii. The clear decline in the use of local materials and traditional construction techniques and adopting some new materials and new techniques which do not fit to the environment.

iii. Deactivating the principles of sustainable architecture in contemporary mosques construction and operation. For example Shekh Zaid Grand Mosque in UAE covers an area of 22,000 m^2 ; 33,000 tons of steel, 120,000 m^3 of concrete, 7000 foundation piles, 30,000 tons of enhanced materials, 120,000 m^2 of white marble from Italy, Macedonia and China, 35 tons of wool and 12 tons of cotton for 37 tons of carpet, 12 tons of steel, copper and 40 million piece of crystals for the chandlers (Affairs, 2012).

The 'image' of the mosque across the Muslim world was manipulated for political, cultural, or ethnic purposes than just serving its basic message of Islam. In some cases, the architecture of the mosque was enlarged to a 'monumental' scale for political purposes, whereas in other cases the mosque was erected for ideological conflicts. Thus, some argue that the role of the mosque has been deliberately derailed in terms of architecture and conceptual. A number of questions arise to scrutinize ideas to do with the social-functional, cultural, economic, political, planning and urban planning contexts of the architecture of the mosque across Muslim states in the past and present.

Consequently, the conceptual problem addressed in this study arose under the blurring of the mosque design principles. These principles limited to the direct jurisprudential (Fiqh) instructions while neglecting the main Islamic principle which organizes the relation between the environment and human in accordance sustainable architecture. Part of this general problem which this study investigates in the next chapters is to fulfil the gap of knowledge that illustrated in Figure 1.4.

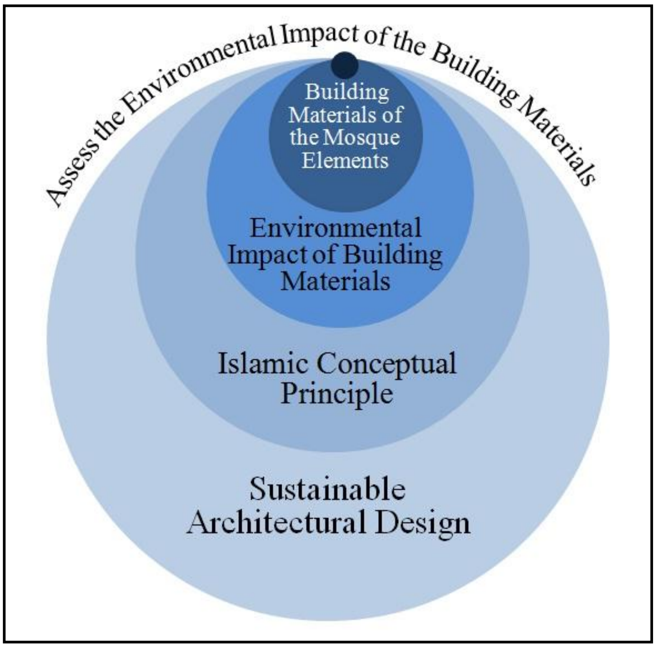

Figure 1.4 The domain of the study.

1.3 The significance of the study

This research studies the impacts of building materials for their entire life cycle, which are used in historic mosques in Mosul. These data would provide guidance to designers, decision makers and institutions involved in building industry. The importance of the study stems from the fact that presenting and propagating design experiences that demonstrate successful and innovative utilization of sustainable architecture's principles.

The study emphasizes to serve and improve mosque architecture without jeopardizing heritage identity and encourage advocating the concept of sustainability in architecture. The study offers an assessment model to guide the architect to assess building materials for architectural elements within the principles of sustainable architecture in order to select ecological material in their designed projects. The proposed approach in this study helps interested communities to assess the existing mosque buildings with compatible sustainable principles (see Figure 1.5).

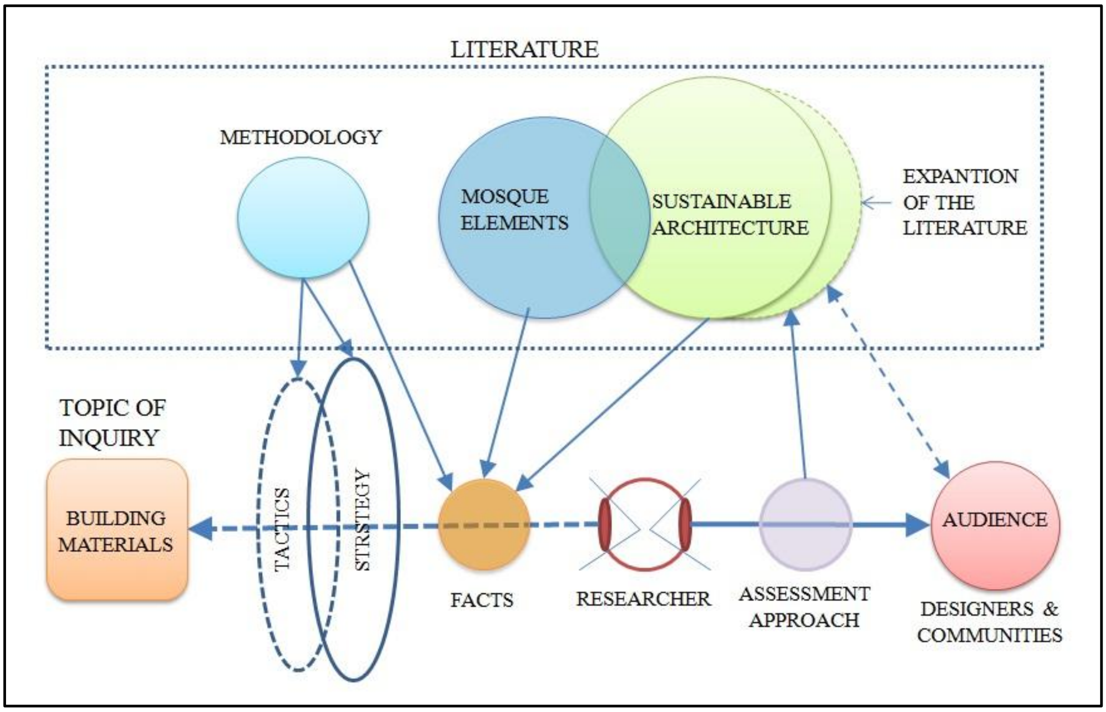

Figure 1.5 Research significant to the body of knowledge.

1.4 The scope of the study

Ashby and Johnson (2009) in Figure 1.6 suggest five input factors in the design process; the market, technology, investment climate, the environment and industrial design. The central circle represents the design process. A good designer is always alert to developments in technology, deriving from underlying scientific research. New technology is exploited in ways that are compatible with the investment climate of the company, itself conditioned by the economic conditions within countries in which the product will be made and used. Concern to minimize the ecological burden created by engineered products heightens the awareness of design for the environment and in the longer term, design for sustainability. Consumers want much more than a product that functions well and at an affordable price; they also want satisfaction and delight, making inputs from industrial design and aesthetics a high priority.

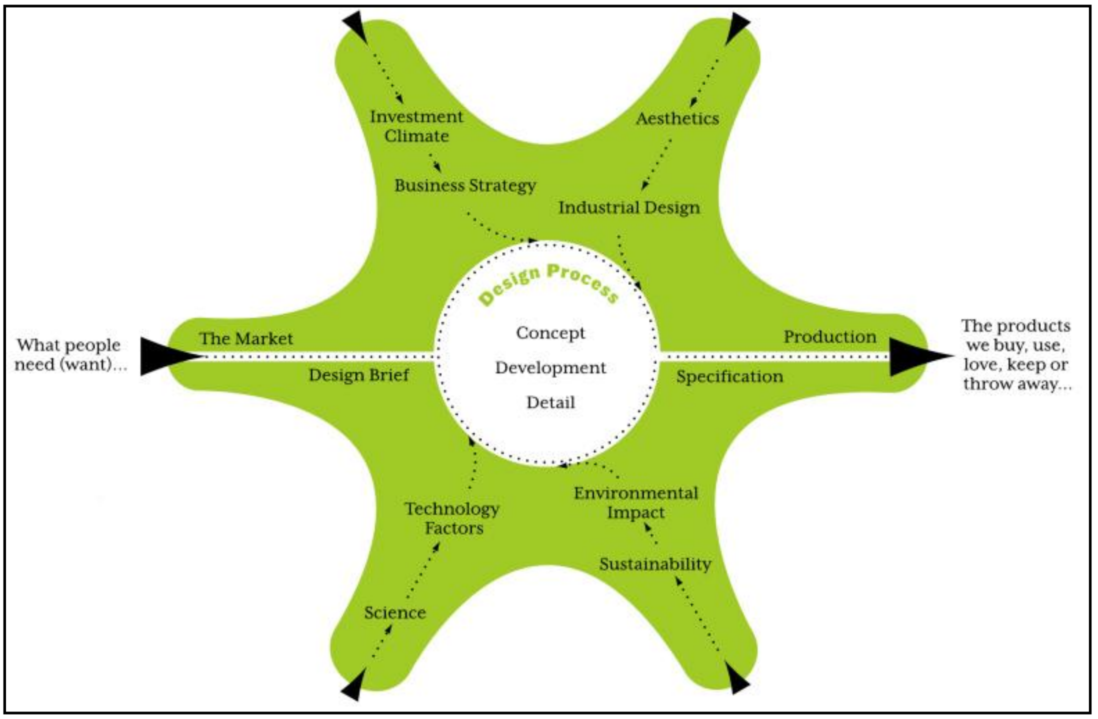

Figure 1.6 Inputs to design process. *Source:(M. Ashby & Johnson, 2009).*

This research will be conducted in a variety of sub-disciplines, including design and technology, history of architecture and mainly environmental impact studies that Ashby and Johnson mentioned as an input factor in the design process.

The current environmental practices such as environmental selection of building materials, eco-labelling, and green building assessment, in the construction industry, depend mainly on the results of Life Cycle Impact Assessment (LCIA) for building materials. The research focuses on the application of LCIA for building materials which has been internationally standardized from International Organization for Standardization (ISO) 14040. The LCIA methodology has been widely adopted by the building sector and recognized as a valuable tool in support of sustainable building (Traverso, Rizzo, & Finkbeiner, 2010).

According to ISO 14040 (2006), LCIA is defined as "a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle" (NSAI, 2006). The literature indicates that there is a strong need to adopt LCIA in selecting building materials through the design process to fulfil sustainable architecture.

1.5 Research questions

According to the former research on building materials assessment and various literatures which will be discussed further in the next chapter, the following questions will be the research questions:

i. What are the predominant building materials used in architectural elements in historic mosques in Mosul city?

ii. What are the features of building materials that characterize the architectural elements of historic mosques?

iii. What is the assessment criteria of the environmental impact of building materials?

iv. What are the environmental impacts of predominant building materials when using them in the present context?

v. What are the possibilities of re-using the predominant building materials to the present and future?

1.6 Research objectives

The main aim of this research is to assess the environmental impact of predominant building materials used in historical mosques in Mosul. To achieve this aim, four objectives are defined as follows:

i. To identify the predominant building materials and characterizations of the architectural elements of historic mosques in Mosul City.

ii. To determine the assessment approach of building materials in terms of their environmental impact.

iii. To test the environmental impacts of predominant building materials in the present context.

iv. To propose the possibilities of re-using the materials to the present and future.

1.7 Research methodology

Architectural researches employ different methods depending on the topic of the study. Research methods range from experimental to descriptive depending on the nature of the research problem under investigation. According to Joroff and Morse, the research problem for conceptual framework of architectural research, is either objective or subjective (1983), as shown in Figure 1.7. These methods have different strategies include; interpretive historical, qualitative, correlation, experimental and quasi-experimental, simulation and modelling, logical argumentation and case study, and combined strategies (Groat & Wang, 2002).

Both quantitative data and qualitative data need to be collected. The base issue for a mixed methods design is the combination of the both kinds of data offers a much better knowledge of a research problem compared to either quantitative or qualitative data independently. Mixed methods models are processes for gathering, analyzing, and combining both quantitative and qualitative data in one study or in a multiphase series of studies (J. Creswell, 2012). Within this method, it includes to decide the emphasis that can be given to each type of data (priority), which type of data that will collected first (concurrent or sequential), how to "mix" the data (integrating or connecting), and whether theory will be used to guide the study.

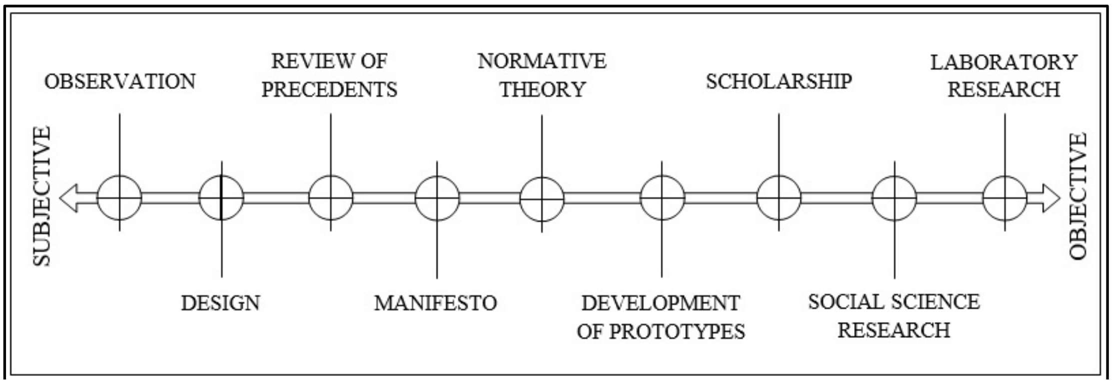

Figure 1.7 Maceal Joroff and Stanley Morse's conceptual framework for architectural research. *Source: (Groat & Wang, 2002).*

The methodology adapted to fulfil these research objectives is combined strategy which can be categorized as fully mixed sequential dominant status design (F4 QUAL → quan) as shown in Figure 1.8. This characterization is according to Leech and Onwuegbuzie conducted in 2009. They defined three criteria distinguish mixed methods design: level of mixing (integrating or connecting), time orientation (concurrent or sequential), and emphasis on approaches (priority). Crossing these three criteria led to eight mixed methods designs. Most mixed methods studies can be represented by one of these eight designs which establish the national system for mixed method design (Leech & Onwuegbuzie, 2009). Where, capital letters denote priority, the (+) sign represents a concurrent relationship and the (→) sign represent a sequential relationship.

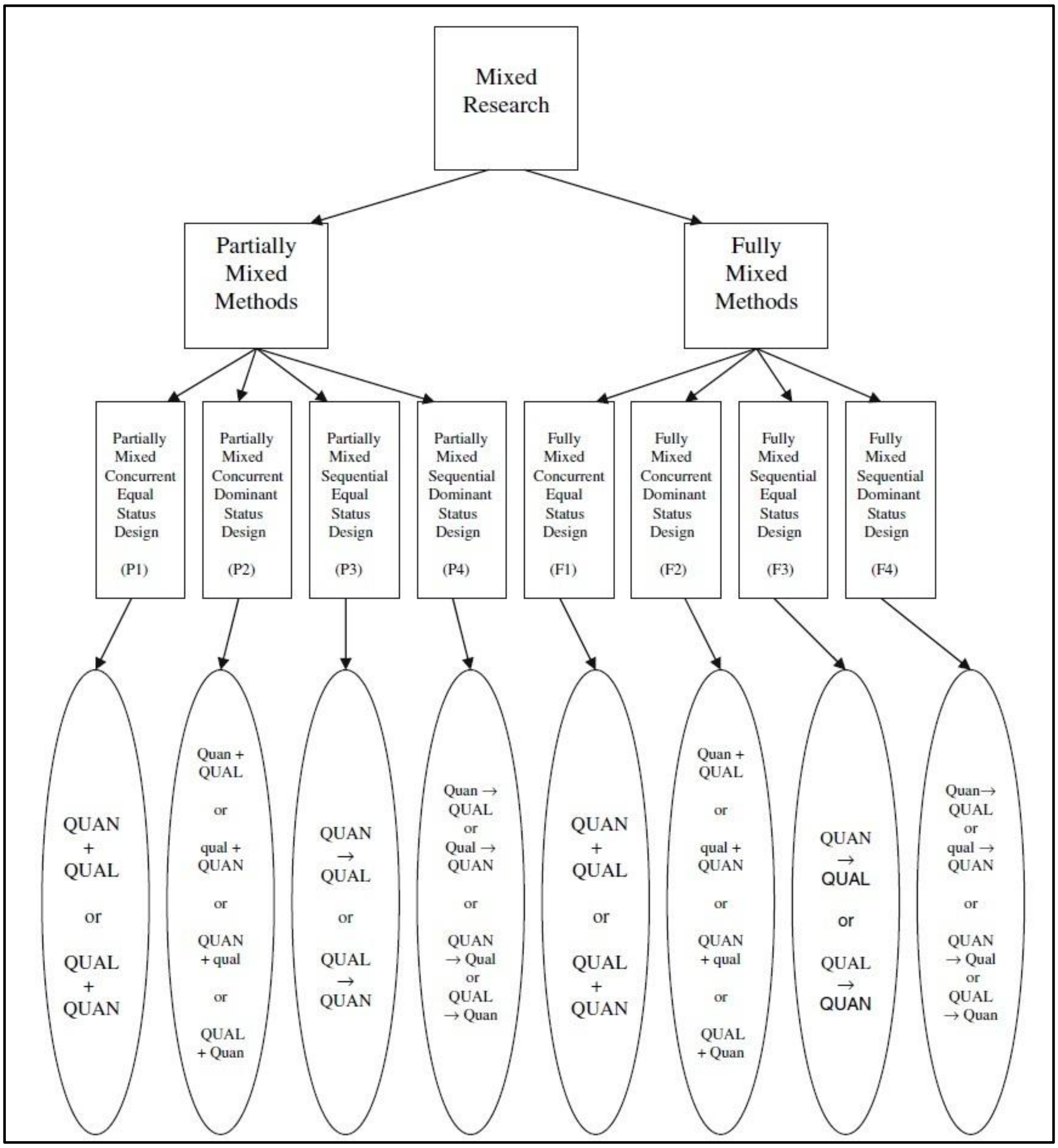

Figure 1.8 National system for mixed method designs. *Source: (Leech & Onwuegbuzie, 2009).*

To address the research objectives, purposes and questions the effective design method is (F4 QUAL → quan). The data collection will be conducted in two stages, with the first stage involving qualitative data collection. Two methods will be applied to collect qualitative data; inventory field survey and site investigation (observation). In the second stage quantitative data will be collected as primary and secondary data to convert these data into GaBi software to predict the environmental impact.

Qualitative data will be collected for twelve historic mosques in Mosul city. The purpose is to identify the predominant building materials used in historic mosques and explore the architectural characterizations of the traditional elements of historic mosques in Mosul city. Photos, historical resources, and drawings (plans and sections) will be present to support the qualitative data collection in this stage. The results of the data that collected in this stage will be analyse and present in form of tables in Chapter Five.

The second stage will start with the converting the qualitative and quantitative data with aid of GaBi Educational software to build the (processes plans) for the life cycle of predominant building materials used in historical mosques that concluded from the descriptive survey in first stage. The processes plan is the manner the system in which the investigation is described in the software and will be explained in Chapter Three in more details. Secondly, to validate the approach feasibility, the procedure will be implemented by testing out the process plan to predict the environmental impact of building materials. Site investigation method will be used to collect quantitative data of building materials quantities. The results of quantitative data will be analysing by computer simulation with the aid of GaBi application and present in form of charts in Chapter Five.

1.8 Research limitation

In almost every part of the Islamic world, there are a large number of traditional mosques which were built at various times in history. However, it is impossible to give examples from all in this study. The disadvantage of requiring extensive data collection as well as the time required for this process is long. The testing of an instrument adds considerably to the length time of this design required to be implemented. Therefore, this study is only focused to cover the mosques located in the old city of Mosul in Iraq. Old Mosul, where many traditional mosques are located, is chosen as the area of research. In further studies, it is possible to compare them with mosques samples from other regions of the Islamic world.

1.9 Thesis organization

The structure of the thesis is shown in Figure 1.9. Chapter Two reviews the researches related to materials selection to investigate the evaluation criteria for materials' selection. The gap of knowledge is demonstrated in order to address the research problem. It is also an overview of materials' role in architectural design. The aim is to identify formal functionality, aesthetic attribute, and identify the significant of building materials in design process. The third part explain the relation between building materials and environmental risks to explore the environmental impact of building materials and the sustainable building product on human health, ecological degradation and energy consumption. The study suggests life cycle approach as a method to assess the environmental impact of building materials according to ISO 14040 and ISO 14044 standards. Definitions of the main terms which characterize life cycle methodology will be presented.

Chapter Three reviews the methods adopted to conduct the descriptive field survey and reveal the flow of research methodology which explains the research design. Identify how to select sample for the study was discussed, and the process of inventory of the historic mosques will be described. The detailed descriptions of descriptive survey were presented. The framework of life cycle methodology according to ISO 14044 and ISO 14040 standards will be described. The third section puts forward a method of assessing the environmental impact using GaBi Educational application. Converting all information and data that collected to GaBi project will be present and discuss step by step explanation to simulation process, at the end of the chapter.

Chapter Four are introduces history of the building materials in Islamic architecture and presents evolution of building materials in mosques. The second section of this chapter will review the samples of the study. Chapter Five presents the implementation and results of life cycle impact assessment of building materials for historical mosques in two stages. The first stage shows the results of the survey of the predominant building materials used in historical mosques. While in second stage the life cycle impact assessment of building materials by applying GaBi software is discussed. Interpretation of the results include two primary steps; identification of significant issues and evaluation. In Chapter Six the results are checked and evaluated to test its consistency with the goal and scope defined in data documentation form. Interpretation of the results include two primary steps; identification of significant issues and evaluation. Finally, Chapter Seven discusses the findings and the limitations of proposed methodology of life cycle impact assessment. Additionally, the contribution of the research and recommendation for future work are identified.

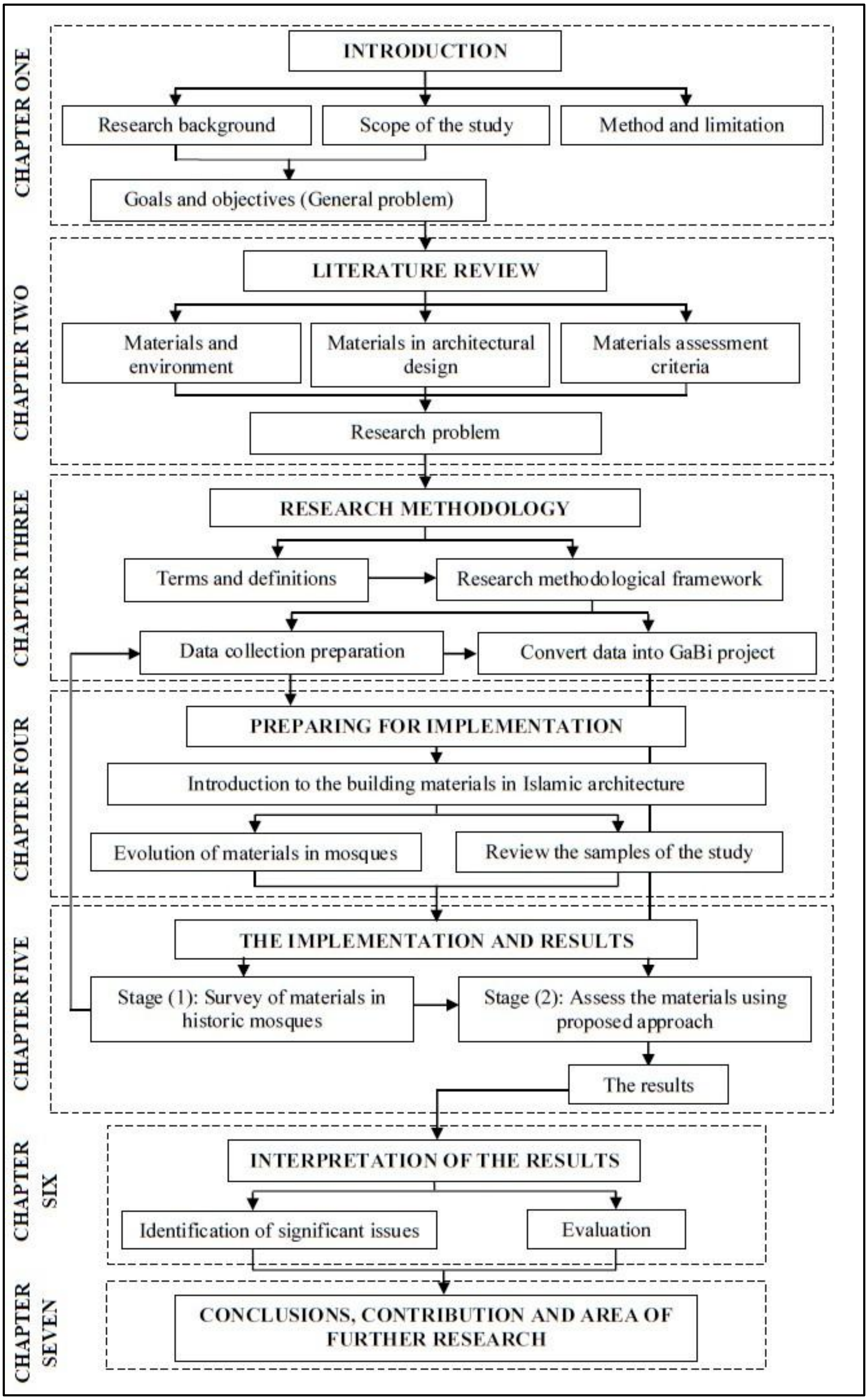

Figure 1.9 Thesis Structure.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Chapter One has defined and outlined the research area and scope of the research which is to assess of building material selection of mosque elements which is an important part of the concept of sustainable architecture. This chapter reviews earlier researches conducted by others in this field of study and also focus on the theoretical framework as well as the assessment approaches adopted for selecting building materials in sustainable architecture.

Section 2.2 reviews the earlier researches and their major findings which investigates the evaluation criteria for materials' selection. The research problem is presented in Section 2.3 which indicates that there is a stated need to adopt life cycle impact assessment LCIA in selecting building materials through the design process to fulfil sustainable architecture. This problem is defined the gap in knowledge to be filled with this research.

Section 2.4 reviews the role of building materials in architectural design. The aim is to identify formal, aesthetic, structural, and internal and external environment effects of materials. Section 2.5 explores the environmental impact of building materials on human health, ecological degradation and energy consumption. Finally, Section 2.6 builds the conceptual framework and Section 2.7 proposes life cycle approach for evaluating the environmental impacts of building materials.

2.2 Research on materials assessment criteria

This section is to explore researches of the materials assessment criteria, which mostly takes place in materials based sources. The aim of this exploration is to underline the limitations of these sources for material assessment model for sustainable architecture. Materials assessment criteria grouped under different subtitles in the related studies. Most of these studies concentrate on the technical side of the materials properties as follows:

2.2.1 Scientific American Editors (1967)

The mechanical properties of materials and the cost are identified as the two basic requirements in materials selection (Editors, 1967). The authors explain that, the acknowledgment on the basics of the mechanical properties of materials provides the development of material science and encourages designers to explore new use areas for new materials; because mechanical properties of materials define their usage and environment. Strength and rigidity, quality and durability of the surface are listed as the most important mechanical properties.

2.2.2 Patton (1968)

Patton (1968) states that, when a designer selects a material, the designer must consider fulfilling the three basic requirements: service requirements, fabrication requirements and economic requirements. According to him, the service requirements are supreme. The material must stand up to service demands, which commonly include dimensional stability, corrosion resistance, adequate strength, hardness, toughness and heat resistance. The material must also be possible to shape and join to other materials. Patton puts those properties of materials under 'fabrication requirements'. Finally, Patton states that, the objective of a designer is to minimize overall cost of the product and manufacturing. For example, a more expensive free-machining metal may be substituted for a standard metal, since the saving in machining cost may overweigh the increased cost of the more expensive metal.

2.2.3 Esin (1981)

Esin (1981) groups the factors under three categories: functional requirements, economic requirements and maintenance requirements. Esin believes that the main limitation to any material is the final cost. So Esin considered the functional requirements are vital importance, which determined by their functional and technical requirements (e.g. strength and stiffness). Consequently, weaker alternative demand more material, material with a short life span need to be maintained or replaced more often, which both causing a higher cost. The maintenance requirements take the consideration of whether replacement or repair is expected will depend on the size of the part, the extent of possible damage and the acceptable level of replacement or repair cost.

2.2.4 Ashby (1992), (2002), and (2010)

Ashby (1992) puts the emphasis on; general properties, mechanical properties, thermal properties, wear and corrosion/oxidation properties of materials. Ashby and Johnson (2002) add the aesthetic attributes of materials beside the general, technical and Eco attributes of the material properties. Besides, they define the list of requirements adding technical, economic, sustainability (related to environmental issues), aesthetic, perceptions, and intentions. In the more recent edition of his book, Ashby (2010) defines the basic design limiting properties of materials as: general properties of materials (density and price), mechanical properties, thermal properties, electrical properties, optical properties, eco-properties, and environmental resistance properties of materials.

2.2.5 Lindbeck and Wygant (1995)

According to Lindbeck and Wygant (1995), requirements related to the physical properties (material's melting point, density, moisture content, porosity, and surface texture); chemical properties (resistance to corrosion and dissolution); thermal properties (heat conductivity, heat resistance); electrical properties (materials' conductivity and resistance to electrical charges); acoustical properties (materials' reactions to sound), and optical properties (materials reactions to light), must be fulfilled through appropriate materials selection. Lindbeck and Wygant add that, mechanical properties are especially important because they are indicators of strength, predictability, and durability. Knowledge of such forces and the ways in which materials react to them are valuable in determining which material to use in a specific application.

2.2.6 Budinski (1999)

Budinski (1999) divides the factors to be considered in materials selection into four major categories: chemical properties, physical properties, mechanical properties and dimensional properties. As being different from other sources, Budinski uses 'dimensional properties' as an individual title. Dimensional category is not listed in property handbooks, and it is not even a legitimate category by most standards. However, Budinski emphasizes that, the available size, shape, finish, and tolerances on materials are often the most important selection factors. Another unique term used by Budinski is 'business issues'. Budinski also stresses the significance of 'availability'.

2.2.7 Froeschle (1999)

Froeschle developed a method for the Environmental Assessment & Specification of Green Building Materials as published in 1999. Froeschle recommended sixteen environmental criteria to be used in green building product assessment and evaluation (Froeschle, 1999) as follows:

1. Low toxicity; reduce toxicity or nontoxic and avoid carcinogenic compounds and ingredients.
2. Minimal emissions; minimal chemical emissions, emit low or no volatile organic compounds (VOC_s), and avoid the use of chlorofluorocarbons (CFC_s).
3. Low VOC assembly; minimal VOC producing compounds or no VOC in mechanical attachment methods and minimal hazard.
4. Recycled content; identifiable recycled content in the material including post-industrial content with a preference for post-consumer content.
5. Resource efficient; reducing energy consumption, minimizing waste, and reducing greenhouse gases.
6. Recyclable; materials that are recyclable at the end of their useful life.
7. Reusable; component that can be reused or salvaged.
8. Sustainable; renewable natural materials harvested from sustainably managed sources and preferably that have an independent certification.
9. Durable; material that are longer lasting or comparable to conventional product with long life expectation.
10. Moisture; materials that resist moisture or inhibit the growth of biological contaminants in buildings.
11. Energy efficient; materials that help reduce energy consumption in building and facilities.

12. Water conserving; products that help reduce water consumption in building and conserve water in landscape areas.
13. Improves Indoor Air Quality (IAQ); systems and equipment that promote healthy IAQ by identifying indoor air pollutants or enhancing the air quality.
14. Healthfully maintained; materials that require only simple, nontoxic or low VOC methods of cleaning.
15. Local product; building materials found locally or regionally saving energy and resources in transportation to the project site.
16. Affordable; materials life cycle cost comparable to conventional materials or as a whole, are within a project defined percentage of the overall budget.

Froeschle proposed that the environmental assessment of building materials can be divided into three phases: research, evaluation and selection. The procedure is useful when comparing similar types of products, a rating system can be established by given higher points to materials that meet the environmental criteria (Froeschle, 1999), as shown in Table 2.1.

Froeschles' assessment model encounters the following difficulties:

1. The research part of the process is the most time consuming aspect.
2. Evaluation can be equally difficult and dependent on product information that provided by manufacturers that is often incomplete as it relates to environmental issues.
3. Since there is currently no standard format for providing environmental product information, interpreting and comparing product information can also be difficult.
4. The model restricted on comparing similar types of building materials.