ASSESSING CEMENT BLOCKS IN THE CONTEXT OF SUSTAINABLE CONSTRUCTION

Disna Suraji Weerasekera

(108529T)

Degree of Master of Science in Project Management

Department of Building Economics

University of Moratuwa

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Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science in Project Management

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DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or institute of higher learning, and to the best of my knowledge and belief, it does not contain any material previously published or written by another person, except where acknowledgement is made in the next.

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(108529T)

The above candidate has carried out research for the Masters dissertation under my supervision.

Signature of the Supervisor: ……………………. Date: ……….................

Mr. Ravihansa Chandrathilaka,

Senior lecturer,

University of Moratuwa.

DEDICATION

I dedicate this dissertation to my dearest Parents, Husband and Little Daughter……

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ABSTRACT

The task of assessing cement blocks represents an important strategy in the sustainable design and construction of a building. A principal challenge is the identification of assessment criteria based on the concepts and principles of sustainability, and the process of prioritizing and aggregating relevant criteria into an assessment framework .Therefore, the purpose of this study is to fill these gaps by describing the development stages of key assessment criteria used within an assessment tool under development for sustainable CB in the building industry.

After conducting a thorough and systematic literature review, a total of 24 sustainability assessment criteria based on the triple bottom line and the needs of building stakeholders were identified. A survey of engineers and architects was conducted to capture their perceptions on the importance of the criteria. Survey questionnaires were randomly mailed and handed over to 231 engineers and 110 architects. Ninety eight (98) effective responses were received, after removing the invalid ones. The response rate was 28.7 per cent. Factor analysis was utilized to group the criteria into assessment factors for modelling sustainability of CB.

Ranking analysis revealed that all criteria were highlighted at “high” or “high-medium” levels in selecting cement block building material. A total of 12 criteria was highlighted at the “high” importance level, with aesthetics, embodied energy and initial acquisition cost to make the top three criteria of importance. After the literature review, questionnaire survey and expertise opinion, the top criterion is the embodied energy. The second high criterion is the aesthetics and the third top criterion is the initial acquisition cost of CB. Factor analysis shows that these SACs can be aggregated into six factors, namely; “ environmental impacts”, “resource efficiency”, “waste minimization”, “life cycle cost”, “social benefit”, and “performance capability”. Since these criteria were derived from the survey through expert opinion, consideration of these six criteria in sustainable block making processes and products will ensure sustainability of building projects.

According to the six criteria in the cement block material selection, the environmental issues are not strongly considered, despite the need of reducing the environmental impact of building activities. Hence the result is an example of evidence pointing to the trend that environmental aspects are no longer the least important factors for cement block material selection in building projects.

The current study contributes to the building industry and sustainability research in at least two aspects. First, it widens the understanding of the degree of importance of sustainable CB making processes and products. It also provides building stakeholders a new way to select CB, thereby facilitating the sustainability of building projects.

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List of Abbreviations

ASTM - American Society for Testing and Materials

BEE - Building Environmental Efficiency

BREAM - Building Research Establishment Environmental Assessment -- Method

CB - Cement Blocks

CASBEE - Comprehensive Assessment System for Building Environment Efficiency

CEB - Compressed Earth Blocks

GB - Green Building

LCCA - Life Cycle Costing Analysis

LEED - Leadership in Energy and Environment Design

RI - Relative Indices

SAC - Sustainability Assessment Criteria

SEDA - Scottish Ecological Design Association

UK - United Kingdom

VOC - Volatile Organic Compounds

WCED - World Commission on Environment and Development

CHAPTER 1

INTRODUCTION TO THE RESEARCH

CHAPTER 1 - INTRODUCTION TO THE RESEARCH

1.1 Background

Most building growth is taking place in developing countries (WBCSD, 2007). In many of these countries, cement blocks are the most widely used building material. This means there are both economic and environmental incentives to see that cement is used in the most effective way to make best use of resources. (Isaksson & Taylor, 2009, Isaksson & al., 2010a, 2010b).Cement blocks are now almost a universally available building material. They can be manufactured in a variety of thicknesses and can be either solid, hollow or cellular to suit the wall diameter and load needed. The demand for these blocks in the construction sector is significant at present. The use of cement blocks for masonry construction has developed rapidly due to the various advantages which they possess over traditional building materials such as bricks and stones. Production of a great diversity of blocks with varying sizes and tolerances, and varying properties can be harmful in the long term. Use of cement blocks in high strength applications also necessitates the need for careful quality control and regular testing of blocks. Block work, hollows are generally left unfilled; in applications where the loads are high, the hollow may be filled with concrete. Such columns or walls could also be reinforced. Hence this type of block can be used for multi-storey buildings.

Cement block technology offers a speedier cost effective, environmentally sound alternative to conventional walling materials. Prof. S. R. de S. Chandrakeerthi is the first researcher in Sri Lanka who did a lot of work on cement block productivity in the year 1993.He did more studies about block sizes and Compressive Strength. In the study of Prof. S. R. de S. Chandrakeerthi, the size of the blocks was selected as 300 mm length and 200 mm in height. Thickness can be either 100mm or 125 mm. The size specified in SLS 855 : Part 1 : 1989 have lengths of 390 mm , 440 mm and 590 mm. It is based on the principle of densification of a lean cement mortar to make a regular shaped, uniform high performance masonry unit. The cement block is a good fire resistant material for wall construction. The type of course employs an important role in evaluating the fire resistance rating of the wall. Sound reduction within a building is particularly important for a building meant for educational purposes. Sound absorption plays a key role in such applications. The surface characteristics of the building unit affects the way in which the sound waves impinging upon it are reflected, absorbed and transmitted. A coarse surface absorbs more sound than a smooth dense surface. Results have indicated that exposed cement block walls absorb sound about six times more than plastered walls. An internal noise reduction can be obtained by careful control of aggregate size, distribution mix proportions, amount of water and the degree of compaction. The construction of a block wall is a little faster. The following factors such as size, joints, modifications (corner blocks, laying of electrical installations) ability to leave openings for doors and windows, and the ability to fix doors and windows to such openings need careful attention of the builder Life-cycle of the cement block is in the figure-1.1) (Construction material text book , The Open University of Sri Lanka, level -3: Block 1, Block 2).

Suitability of chip concrete blocks for single storey houses was introduced by Dr. M. T. R. Jayasinghe from one of his researches. In his study, he has done an evaluation of the cost-effective mix proportions that could be in HMCC blocks. Establishment of the applicability of the strength values given in BS 5628: part I: 1992, for the structural design of HMCC blocks.

Most building growth is taking place in developing countries (WBCSD, 2007). In many of these countries, such as Tanzania, concrete blocks are the most widely used building material. This means that there are both economic and environmental incentives to see that cement is used in the most effective way to make best use of resources. There is a substantial improvement potential in reduced costs, improved customer value and reduced environmental impact in the building material supply network in Dar-es-Salaam, Tanzania (Isaksson & Taylor, 2009, Isaksson & al., 2010a, 2010b). But even though reasonably simple solutions with good payback for capturing the potential exist, change seems to be slow.(Dar-es-Salaam)

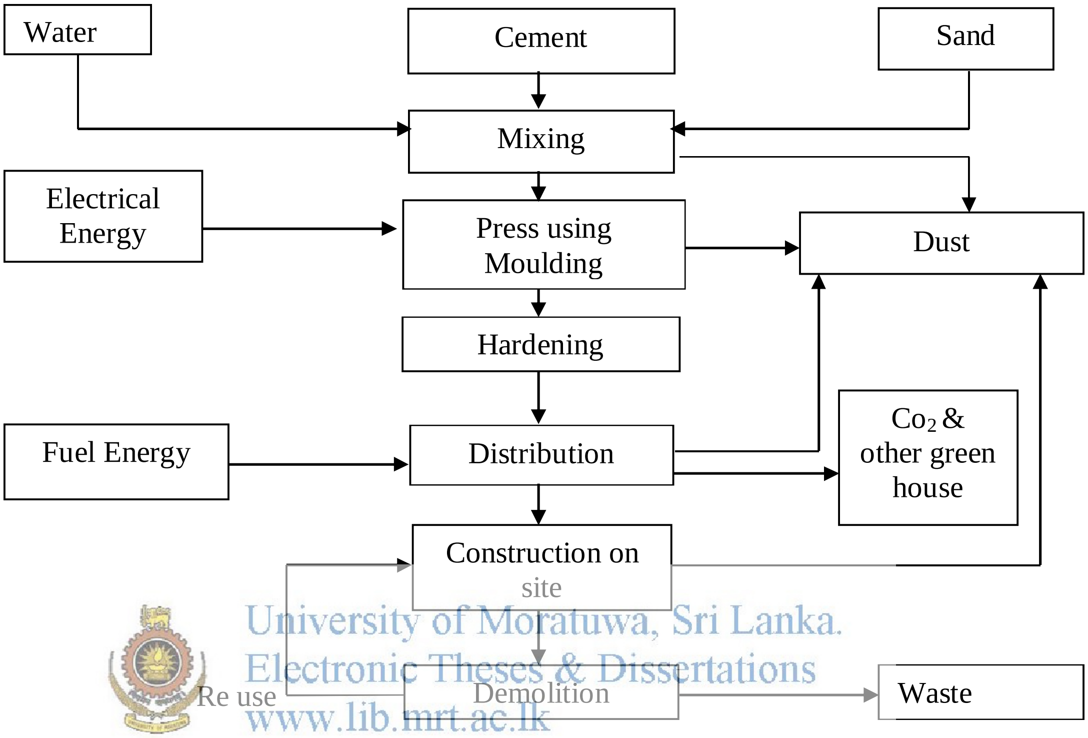

Figure 1.1: Life-cycle of cement blocks

The current market preference of 6 inch solid blocks makes it impossible to make best use of the cement. The theoretical strength potential of cement cannot be achieved since the cement content becomes too low, which leads to a high water: cement ratio and loss of strength. The current method itself has multiple areas of improvement, which are technically simple. Strong habits seem to be the main reason for lack of change. Manpower in the block making plants often consists of day labourers with a low level of education, who are paid per block produced. This results in clear priority on quantity and not on quality. Most stakeholders in the system would gain if the cost of poor quality could be reduced. In the current situation both uses are often poor and the environment (CO_2-emissions) is losing, without anybody gaining. The main cause for the development being slow is that the potential has not been visualised and that there is no clear owner for the entire performance system. Local authorities could be seen to have part of the responsibility. It could also be discussed that if TPCC, being part of the major global player Heidelberg Cement, should not become more engaged as part of their Corporate Social Responsibility. This could possibly be carried out in a “Private Public Partnership” meaning, financial collaboration between the public and the private sector, which is a common way of doing things in East Africa and Tanzania (Idman et al. 2012).

Apart from the economic benefits, the carbon footprint of the blocks could be halved resulting in yearly reduced emissions of some 100, 000 tonnes of CO_2. Changing the main product from solid blocks to hollow blocks would also reduce the consumption of sand used for blocks to about 3 million tonnes per year at the current level of production of 300 million blocks. The density variations in tested blocks, explain some 60% of the variance of the MPa Blocks indicator. The reason for density variations is believed to relate to the use of varying equipment and the use of varying times for compaction, in combination with lack of knowledge of the importance of density. (Idman et al. 2012).

There are cultural aspects affecting the use of solid and/or hollow blocks. Traditionally, solid blocks are used for private houses and one or two-storey buildings. Levels of formal training and education being low, and lack of trust in block makers’ knowledge leads to an unwillingness to risk eventual shortcomings in quality performance of the blocks. People in general do not trust the quality of the available blocks and, therefore, base their acquisitions on limited personal knowledge. This results in preference for the traditional product instead of the uncertainty of new innovations. Because building needs are important, building activity would probably increase if block prices were reduced. (Idman et al. 2012).

With respect to such a significant influence of the cement block industry, the sustainable building approach has a high potential to make a valuable contribution to sustainable development. Use of sustainable construction materials is an important decision in building projects (Nasssar etall, 2003). It is an area of the design process, taking place largely in the detail design phase where important decisions are made with regard to building assembly (Gething, 2011).

1.2 Research problem statement

There has been an intensive process of urbanization which brought about the need for rapid, sustainable construction of buildings during the end of the last century. Therefore, development of sustainable building construction is a high priority for a developing country such as Sri Lanka. Building construction using cement blocks is one of the predominant construction materials used in most of the developing countries due to economic adaptability, and this has emerged as a cost effective construction material suitable for certain local conditions. This research will cover; how it is possible to develop cement blocks as a sustainable building material in manufacturing and assembly, and how one can investigate the requirements of building stake holders' on cement blocks as a sustainable walling material.

1.3 The Aims and Objectives

1.3.1 Aims

a. To study more sustainable building material making processes and products.

b. To assess the requirements of building stake holders' on cement blocks selection as a sustainable walling material.

1.3.2 Objectives

a. To identify the building materials' sustainability criteria.

b. To review Sustainability Assessment Criteria (SAC) for building materials

c. To develop SAC for cement block selection as a sustainable walling material.

d. To assess cement blocks in the context of sustainable construction.

1.4 Research methodology

This study investigates two groups of engineers and architects involved in cement block material selection. The research was conducted using the literature on sustainability research, expert's opinion, questionnaire survey and a statistical analysis of the survey data. Figure 1.2 illustrates the research framework and methodology. Chapter 3 consists of research approach, research techniques, data collection techniques, research process, initial impetus, questionnaire development, data collection and sample and method of data analysis.

1.5 Scope and limitations

1.5.1 Scope

The scope of research was investigations regarding the research problem using literature on sustainability research, expert's opinion, questionnaire survey and a statistical analysis of the survey data.

1.5.2 Limitations

The sampling method does not include other stakeholders, who in a way influence CB selection as a walling material, such as the client and manufactures of CB.The sample size may need to be extended to include more stakeholders involved in CB selection, in order to minimize sampling error.

1.6 Main findings

The result revealed that all criteria were considered important. The three top criteria considered for CB are "Embodied energy ", "Aesthetics " and "Initial acquisition cost ”. Factor analysis shows that these SACs can be aggregated into six factors, namely; “environmental impacts”, “resource efficiency”, “waste minimization”, “life cycle cost”, “social benefit”, and “performance capability”. Since these criteria were derived from the survey through expert opinion, consideration of these six criteria in sustainable block making processes and products will ensure sustainability of building projects.The sustainability requirements envisaged in a building are to a greater or lesser extent interrelated. The challenge for new sustainable studies is to bring together these different sustainability requirements in innovative ways. These sustainability requirements will be applicable throughout the different stages of the building’s life cycle, from its design, during its useful life, up until management of the building waste in the demolition stage.

All criteria related to CB were rated with “high” and “high-medium” importance levels. In the assessing of CB in the context of environmental, social-economic and technical sustainability in sustainable construction, it can be recommended that cement block material is the sustainable building material.

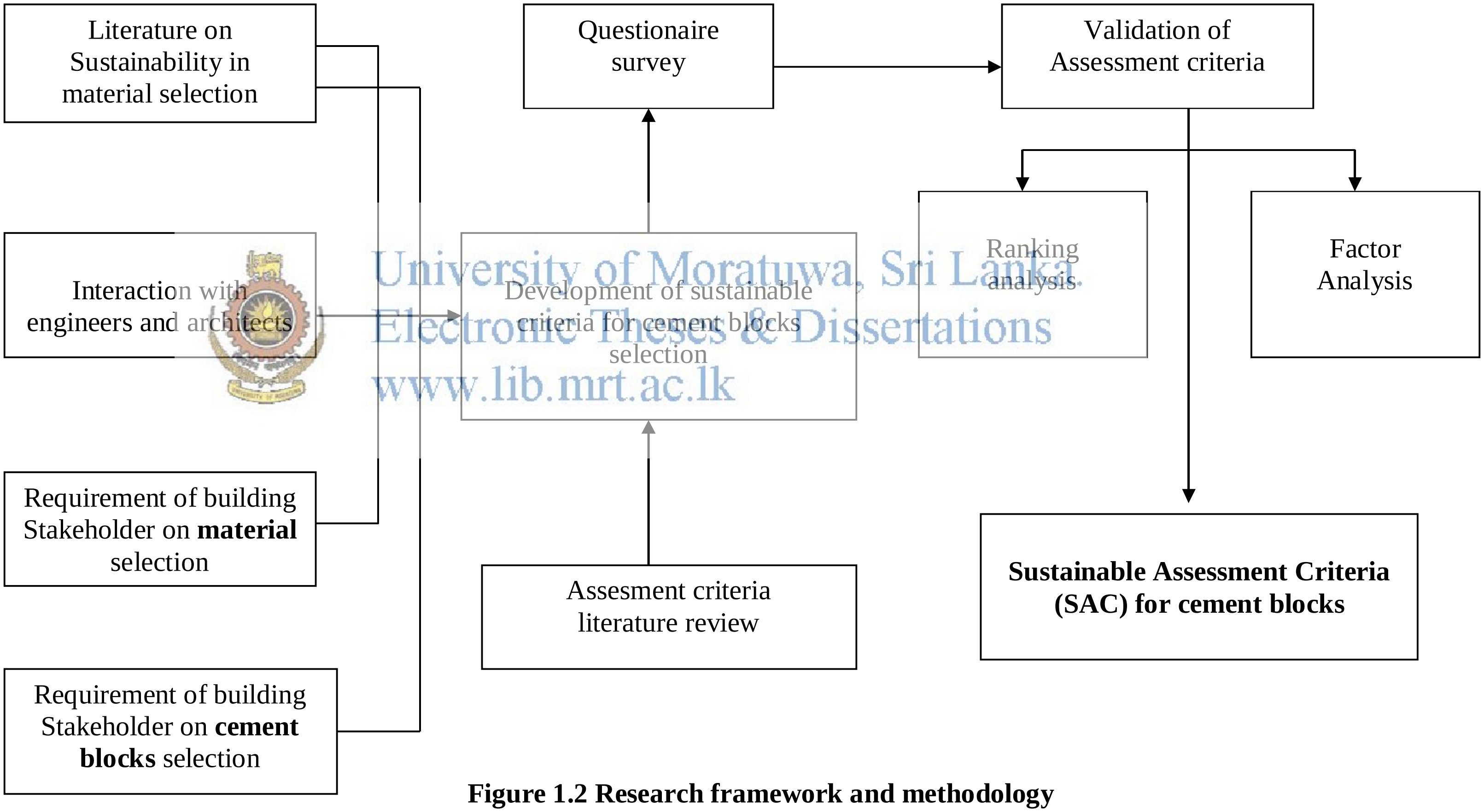

Figure 1.2 Research framework and methodology

1.7 Chapter breakdown

Chapter 1 : Introduction to research

Chapter 1 of this report introduces research background and identifies research problems with aims and objectives, methodology, scope and limitations, and chapter breakdown.

Chapter 2: Literature review

Chapter 2 discusses the theoretical status and research issues through a comprehensive literature review and synthesis, in order to understand and establish the significance of the research problem and develop hypotheses to address the research problem, mainly to provide a focus for data collection.

Chapter 3: Research Methodology

Chapter 3 presents the research approach and research process used in this research study.

Chapter 4: Data analysis and discussion

Chapter 4 presents and discusses the research findings from the study.

Chapter 5 : Conclusion and recommendations

Chapter 5 draws conclusions of the research with respect to the research issues to be addressed and explains recommendations of the research, and limitations and opportunities available for further research under this area of study.

1.8 Summary

This chapter has introduced the broader research area of this study and identified research problems with aims and objectives, methodology, scope and limitations of this study. Finally, the main findings were summarized and the chapter breakdown of the report is explained. The next chapter explores the theoretical status and research issues through comprehensive literature review and synthesis.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

The building construction industry is a vital component of any economy in the world, that has a major impact on the environment. Each step of the construction process, from gathering raw materials, manufacturing, distribution, and installation, to ultimate reuse or disposal, is examined for its huge factor of human impact on the environment, both directly (through material and energy consumption and the consequent pollution and waste) and indirectly (through the pressures on often inefficient infrastructure). Careful selection of environmentally sustainable building materials is the easiest way for engineers and architects to begin incorporating sustainable design principles in building projects (Godfaurd, 2005). Building construction practitioners have begun to pay attention to controlling and correcting the environmental damage due to their activities. With respect to such significant influence on the building industry, the sustainable building approach has a high potential to make a valuable contribution to sustainable development.

In the construction process, there are owners, managers, designers, firms etc. Specially engineers and architects' decisions lead to the pace of actions towards sustainable applications. (Braganca , 2007; Abidin,2010). Use of materials as a sustainable construction material is an important decision in building projects. The selection of the building material is regarded as a multi – criteria decision problem (Nasssar , 2003), largely based on trusting experience rather than using a numerical approach due to lack of formal and availability of measurement criteria (Chen, 2010). It is an area of the design process, taking place largely in the detail design phase where important decisions are made with regard to building assembly (Gething, 2011). A number of conceptual project plans exist that aim to guide designers through a project; the most widely known of which is the Royal Institute of British Architects (RIBA) "plan of work" which, implicitly divides the design process into five main stages: preparation, design, pre-construction, construction, and use. Although it is recognized that in practice, there may be some overlap, it is at the detail design stage that building material assessment and selection should take place (Gething, 2011).

This chapter reviews the literature on the concept of Sustainability, Sustainability assessment tools commonly used in construction industry, review of criteria related studies under the topic of Development of Sustainable Assessment Criteria (SAC) effective in building materials selection, Criteria developed, Sustainability Assessment Criteria (SAC) effective in cement block selection, and Comparative analysis of the cement blocks with other walling materials through literature review. This chapter consists of the Sustainability Assessment Criteria (SAC).

2.2 Sustainability

Sustainability, as a concept, comes into consideration with the establishment of the World Commission on Environment and Development (WCED) by the United Nations (commonly known as the Bruntland Commission) in 1983. The sustainability as a policy concept has its origin in "Our Common Future", the report of the WCED (1987) as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. That document was concerned with the tension between the aspirations mainlined towards a better life on the one hand, and the limitations imposed by nature on the other. In the course of time, the concept has been re-interpreted as encompassing three dimensions, namely social, economical and environmental. Many definitions regarding sustainability recognized common characteristics which are development needs that occur within the limits of the earth; development should be equitable both between individuals within a given generation and across generations over time; and, development needs to take account of the relationships between the economy, the environment and the (society). (Rics, 2004). Many alternative definitions of sustainability have been proposed and diverse interpretations of the concept made (Popeetal, 2004). Sustainable construction optimizes the use of resources while minimizing any inconvenient impact on the environment (Andrews , 2006). The study by Mateus and Braganca (2011) shows that the various issues of sustainability are interrelated, and the interaction of a building with its surroundings has important ramifications.

According to Pesqueux (2001), there are two aspects to sustainable development in actual fact - a development feature (social and economic) and a strictly environmental feature.

2.2.1 Green building concept

A sustainable building or “Green building” is an outcome of a design which focuses on increasing the efficiency of resource use - energy, water, and material, while reducing building impacts on human health and the environment during the building’s life cycle, through better siting design, construction, operation, maintenance and removal. Sustainable building practices target to minimize the environmental impact of buildings. Buildings account for a large amount of land, are heavy on energy and water consumption, and air and atmosphere modification. Therefore “ sustainable building brings together a vast array of practices and techniques to reduce and ultimately eliminate the impacts of buildings on the environment and human health.” (International Engineering & Trading Co. 2007)

The green building concept has gained recognition as an approach to create environmentally efficient buildings by using an integrated approach of design so that highly significant negative impacts of buildings on the environment can be reduced (Ali and Wsairat, 2009).

Green buildings, which by an integrated and holistic approach to location, siting, design, specification and use of energy and resources, seek to minimize their environmental impact (Shiers 2000). According to Zhou and Lowe (2003), the promotion of sustainable construction has been restricted due to the perception that it will result in higher risk and increasing construction costs. Therefore, sustainable construction faces some economic challenges. Typically, buildings were designed to meet building code requirements, whereas green building design, challenges designers to go beyond the code to improve overall building performance, and minimize life-cycle environmental impact and cost (Gowri 2004).

Mateus and Braganca (2011) stated that optimization of the site, potential preservation of regional and cultural identity; minimization of energy consumption, protection and conservation of water resources, use of environmentally friendly materials and products, healthy and convenient indoor climate optimized operational construction. Some developers’ only concern is about green certification and a higher sale price. They do not really care about energy saving and environmental protection. Therefore, economic analysis provides a direct image for green building.

2.2.2 Social Sustainability

Under social sustainability, the quality of human life and human living environment which includes social benefits are highlighted. (Zhou and Lowe, 2003) Social benefits mean culture, education, improved occupant comfort and health, reduced absenteeism and turnover rate, and reduced liabilities and inter-generational equity (On Andrews 2006, Pitt, 2009)

2.2.3 Environmental sustainability

Environmental sustainability is the notion that sustainable construction needs to protect the natural environment rather than pollute; it encourages the use of removable resources and reduces the use of water energy materials and in early stage of a project (Zhou and Lowe2003).

Andrews et al 2006 refer to environmental benefits such as improved air and water quality, reduced energy and water consumption, and reduced waste disposal. Sustainable development requires not just that sustainable energy resources be more used, but that the resources are used efficiently (Rotenetal, 2008). Moreover Rotenetal, 2008, clarifies that increased efficiency reduces environmental impacts, and resource requirements to create or maintain systems to harvest energy, but society seeking sustainable development utilizes only energy resources which cause no environmental impact. Devitofrancesco (2010) illustrates this in another way. The environmental sustainability based approach to construction is focused on the definition and awareness management of a healthy built up environment, making an effective and ecological use of resources. Forsystn (2011) says, a specific aspect of environmental sustainability is energy and resource sustainability.

2.2.4 Economical sustainability

Zhou and Lowe, (2003) defines economical sustainability as the use of full cost accounting methods and real cost pricing, to set prices and tariffs for goods and services, and achieves more efficient use of resources. Economic benefits include reduced operating costs, reduced maintenance costs, and greater revenue (Andrews et al., 2006). Moreover Zhou and Lowe (2003) conclude that some concepts in the economic terms, which create a profitable market for sustainable construction such as value for money, maximum output with minimum input, integration of short term return and long term benefits leads to stakeholder partnership between the demand and supply sides of the industry, and business pattern changes from a linear process to a cyclic process.

Popescu, (2012) also performed a study to show that if investment in energy performance really translate into economic value, it would be helpful in improving energy audit methodologies. An energy audit is a detailed report on the energy characteristics, and on the recommended measures to increase energy efficiency, including economic analysis of profitability, monitoring the impact of energy policies, developing appraisal methodologies that take energy efficiency into consideration (Popescu, 2012).

Sustainability Equations

- **Environment + Social – Economic = No money to pay for progress**
- **Social + Economic – Environment = No natural resources for growth**
- **Environment + Economic – Social = no workers, consumers**

Figure 2.1 : Sustainability equations (Source : Bonifert, 2012)

2.3 Sustainability assessment tools commonly used in the construction industry

2.3.1 BREEAM

The first real attempt to “establish a comprehensive means of simultaneously assessing a broad range of sustainability considerations in building materials” was the Building Research Establishment Environmental Assessment Method (BREEAM) (Crawley and Aho, 1990). BREEAM known as the first commercially available and most widely used assessment method was established in 1990 in the UK.

A BREEAM assessment uses recognized measures of performance, which are set against an established benchmark, to evaluate a building’s specification, design, construction and use. The measures used represent a broad range of categories and criteria, from energy to ecology. They include aspects related to energy and water use, the internal environment, pollution, transport, materials, waste, ecology and management process (BREEAM, 2012).

A certified BREEAM assessment is delivered by a licensed organization, using assessors trained under an accredited competent person or scheme, at various stages in a building’s life cycle. This provides clients, developers, designers and others with: Market origination for low environmental impact buildings, inspiration to find innovative solutions that minimize the environmental impact: A benchmark that is higher than regulation: A system to help reduce running cost, improve working and organizational environmental objectives (BREEAM,2012).(Figure2.2)

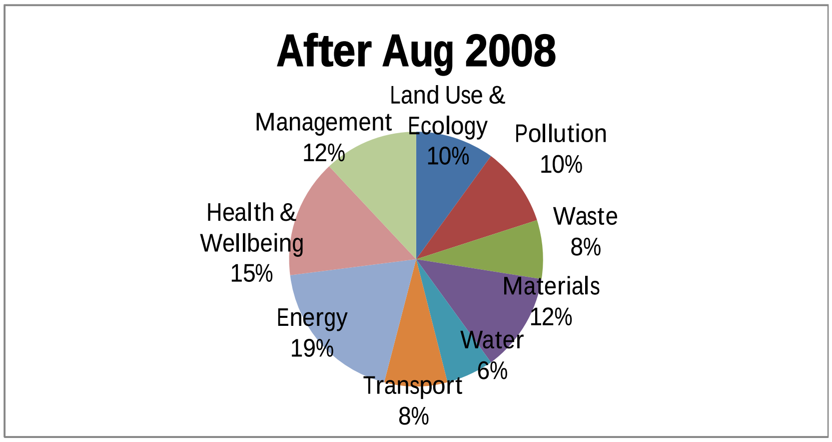

Figure 2.2 BREEAM weighting

Source : Sturge (2009)

2.3.2 CASBEE

The Comprehensive Assessment System for Building Environment Efficiency (CASBEE) was introduced in Japan as a voluntary building assessment system in 2001, by the Japan Sustainable Building Consortium (JSBC, 2011). Detailed statistical values of the predicted consumption of energy, water, land use, materials and environmental emissions, as well as the measurable aspects of indoor environmental conditions, are required in this building assessment system. CASBEE evaluates the building's environmental quality against the amount of resources the building consumes from nature. As mentioned by Potbhare et al. (2009), CASBEE can be categorized into two basic divisions named as Building Environmental Quality (Q) and Building Environmental Loading (L). Building Environmental Efficiency (The BEE portion) is the major indicator of overall performance (Kay, n.d.).

$$BEE = \frac{\text{Building Environmental Quality and Performance (Q)}}{\text{Building Environmental Loadings (L)}}$$

In CASBEE, the points allocated are based on the building's environmental performance in each of the sub-categories. These points are multiplied by the weighting coefficients to obtain the final score, which was shown on a graph as well as on the radar chart (JSBC, 2011).

2.3.3 LEED

LEED is a voluntary rating program whose goal is to evaluate environmental performance from the whole building's life cycle, providing a definitive standard for what constitutes a green building (Potbhare, et al. 2009).

Like many of the available rating systems, the LEED rating system is based on credits and points. Through each credit, the system evaluates the performance of the candidate building and awards points if the requirements reached in a variety of areas such as sustainable sites, indoor environmental quality, material and resources. According to the LEED rating system, the selection of environmentally responsible materials considers material accessibility, by encouraging the use of materials extracted, processed, and manufactured regionally, and, at the same time, promoting the development of regional economics. The LEED system also encourages the use of high re-cycled content, rapid renewable cycle, and low-emitting contaminating materials, which aim to reduce their impact on the environment and indoor air quality of the building. As a result, the design of a GB requires a comprehensive process for material selection that considers not only the previously described standards, but also design and budget requirements that are key factors for the success of the building (Lacouture, 2009).

LEED awarded one credit for more than 55% of the exterior structure or more than 50% of the interior non-stuctural elements, with two credit points awarded for demolished building materials (from the retired building) being diverted from the disposal to being reused for an assessed building or being recycled. The researcher identified that no credit is allocated for cost of the material and cost saving from the material (Lee al, 2011).

However Jingwei et al. (2011) found out that LEED 2009 has not done the special economics analysis.

2.3.4 GB TOOL

GB Tool is the method used to assess the potential energy and environmental performance of the case-study projects in the Green Building Challenge process (Larsson and Cole, 2002).

The Green Building Challenge is a collaboration of more than 20 countries committed to developing a global standard for environmental assessment. The first draft of the assessment framework was completed in 1998 and a spreadsheet tool (GB Tool) was developed for participating countries to adapt the framework by incorporating the regional energy and environmental priorities (Gowri, 2004).

GB Tool provides a standard basis of components for the wide range of buildings compared in the Green Building Challenge. It requires a comprehensive set of information not only on the building assessed, but also for a benchmark building for use in comparing how well the green building performs compared to the norm. GB Tool requires the group using it to establish benchmark values and weights for the various impacts (Harputlugil and Hensen, 2006).

Assessment of green performance is made on (7) general performance issues: which are - Resource Consumption, Loading, Indoor Environmental Quality, Quality of Service, Economics, Pre- Operations Management, and commuting Transportation (Cole and Larsson,2002).

Moreover Harputlugil and Hensen (2006) mention that the basic difference of GB Tool among others is to provide different assessments for every sub-phase of the design process.

2.3.5 DGNB

The DGNB certificate is a tool developed from practice for the straightforward assessment and planning of sustainable buildings. These aspects define with broad consensus covering six fields: ecology, economics, socio-cultural and functional aspects, technology, processes, and site (DGMB,2011). One of its strengths is that it covers all essential aspects of sustainable building.

Each field contains special criteria that can be designed and weighted differently depending on the scheme; each field is also viewed over the building’s entire life cycle. If the building fulfills the criteria, it recives the DGNB certificate in gold, silver, or bronze depending on the total performance index. Building owners and investors can then clearly document the high quality of their real estate (DGNB, 2011).

DGNB system is the only one that pays as much attention to the economic side of sustainable building, such as assessing life cycle cost as to environmental criteria (DGNB, 2011).

Many of these evaluation methods have been criticized for over – emphasizing the environmental aspects (Wong and Li, 2008), BREEAM, LEEDS and other existing methods for assessing buildings whose remit is largely restricted to other existing methods for assessing buildings, largely based on utility for assessing social and economic factors - which are all significant parameters directly related to sustainability – as opposed to environmental sustainability; since they are predominantly focused on environment, which is just one of the four principles underpinning sustainable building. In recognition of these challenges, a new standard BS 8905 was launched in 2011, targeting product manufacturers to help them initiate and advance their supply – chain sustainability factors. This new standard falls short of aligning material selection practices with broad level sustainability goals at the building design stage, a stage where material assessment and selection usually takes place.

Therefore, there is a need for a systematic and holistic, sustainable material selection process of identifying and prioritizing relevant Sustainable Assessment Criteria (SAC) to assist design team members in the selection of building materials to be used in building projects. These criteria enable the incorporation of sustainability principles in building material selection and design making process. As a result, the likelihood of sustainable building is enhanced, thereby increasing the efficiency of the building industry.

Zhou et al. (2009)	Sirisalee et al. (2004)	Mangoon (1999)	Ashby and Johnson (2002)	Esin (1980)	Ashby (1992)
Mechanical Properties	Mechanical Properties	Physical factors	General attributes	Production requirement	General properties
Economic Properties	Cost	Mechanical factors	Technical attributes	Economic factors	Mechanical Properties
Environmental Properties		Life of material factors	Eco-attributes	Maintenance factors	Thermal properties
		Cost and availability	Aesthetic attributes		Wear
		Codes, statutory and others			Corrosion

Table 2.1- Summary of different sources defining the effective material aspects for the materials selection process

2.4 Development of Sustainable Assessment Criteria (SAC) effective in building materials selection

2.4.1 Review of criteria related studies

The assessment of the sustainable performances of building materials is a complex issue which requires the use of a set of comprehensive criteria. These criteria, are intended to foster more sustainable building design, construction and operations, by assigning additional credits or scores to materials that meet some requirements like, for instance, a minimum recycled content, or which are recyclable, local materials are made from renewable resources, without considering the material specific production processes and their environmental impacts.

In different architectural design-based sources, the criteria that affect the materials selection are grouped under various subtitles, which can be followed in Table 2.1. In most of these sources, the design process is defined as converting both technical and non-technical criteria, but in reality, they mostly concentrate on the technical side, thereby dominating the architectural-based source. Zhou et al. (2009) states that, when a designer selects a material, he must consider fulfilling the three basic properties: mechanical properties, economic properties and environmental properties. According to him the economic property is the most important aspect in material selection. Purchase cost, process cost, transportation cost and recycle/disposal cost are the four factors considered under economic property. The material must also be able to stand the test of time. Zhou et al. (2009) put those properties of materials under ‘Mechanical properties”. Finally, they state that in a world with limited resources and serious environmental pollution, it is obvious that a more sustainable lifestyle will be more important. So the “environmental property” of material is especially important.

In a similar study, Sirisalee et al, (2004) identified the “mechanical properties of materials: and the “cost” as the two basic requirements in materials selection. The authors explain that, the acknowledgement on the basis of the mechanical properties of materials encourages designers to explore new use areas for new materials; because the mechanical properties of materials define their usage and environment. Strength and rigidity, quality and durability were listed as the most important mechanical properties. They add that, mechanical properties are especially important because they are indicators of strength, productivity and durability. Knowledge of the criteria is valuable in determining which material to use in a specific application.

In another source, Esin (1980) groups the factors considered in materials selection under three categories: functional requirements, economic requirements and maintenance requirements. Esin explains that, functional requirements are of vital importance for a correct material comparison: measurements of the alternatives are determined by their technical and functional requirements (e.g. Strength and stiffness). As a consequence, weaker alternatives that require more material, and alternatives with a shorter life span that need to be maintained or replaced more often (both leading to higher annual costs). The author believes that the greatest limitation to any material is the final cost of the product manufactured from it. Finally, Esin states that, the designer must also consider the maintenance requirements; whether replacement or repair, as envisaged will depend upon the size of the part, the extent of possible damage and the acceptable level of replacement or repair costs.

Mangonon (1999) recommended five factors having an influence on materials selection: physical factors, mechanical factors, life of material factors, cost and availability and (5) codes - statutory and others. Named differently, life of material factors herein relates to the point in time where a material can no longer effectively perform their intended function in the environment to which they are exposed. He listed properties in this group as comprising: corrosion, wear resistance, creep and fatigue. As it is seen, he combined “cost” and “availability” criteria, and pointed out that, in a market-driven economy, these two factors are inseparable, for the last category codes, statutory and other factors. Mangonon states that, codes are set for technical requirements that are imposed on the material or the component. These are usually set by the customer, or are based on those of technical organizations such as the American Society for Testing and Materials (ASTN). Statutory factors relate to government regulations about materials and processes used for the disposal of the material. These deal with health, safety and environmental requirements.

Ashby and Johnson (2002), besides the general, technical and eco-attributes, add the aesthetic attributes of materials (which are the sensorial properties of materials, such as warmth, softness, etc.) into their material properties list for designers. In addition to the aesthetic attributes of materials, they define the material’s two overlapping roles as: providing technical functionality and creating product personality. Accordingly, they redefine their list of requirements, adding some intangible issues: technical, economic, sustainability (related to environmental issues), aesthetic, perceptions and intentions. Other sources that dealt with material selection can be found in Wong and Li (2008), Ashby (1992), Abeysundra et al, (2007), Emmanuel (2004) and Jahan et at, (2010).

Findings from the above studies suggest that criteria of decision making for material selection have been well documented. It is evident that the sources put more emphasis on the technical properties of materials, ignoring and less emphasis on environmental and intangible factors necessary in material selection. The project team also found that in a follow-up survey, many of the criteria listed were not recorded in any meaningful way and are outside the remit of the architectural profession. The assessment of building materials must be held up against functional, socio-economic and environmental performance. Integration of all these factors (i.e. environmental, economic and social) provides an overall picture of a material and thus, helps in selecting suitable materials for buildings through a multi-criteria decision-making approach. In this context, assessment of environmental burdens associated with different building materials used for building is necessary in order for decision makers to select sustainable materials.

In order to facilitate such comparisons, it is vital to establish a list of holistic criteria based on the sustainable triple bottom line and requirements of different project stakeholders, which may better capture the potential performance of building materials and facilitate the sustainable development of a built environment.

2.4.2 Criteria developed

In trying to develop a set of criteria, Foxon et al. (2002) proposed the consideration of two key factors.

1) What use will be made of this set of criteria?
2) To what extent can any set of criteria encompass the range of issues to be considered under the heading of “sustainability”?

Some of these issues have been considered in approaches developed by other researchers (Singh et al., 2007; Wong and Li, 2008; Buchholz et al., 2009; Chen et al., 2010). The following set of guidelines has been developed to aid the choice of criteria to assess the options under consideration:

Comprehensiveness:

The criteria chosen should cover the four categories of economic, environmental, social and technical, in order to ensure that account is taken of progress towards sustainability objectives. It interprets sustainable development as meeting social, economic and environmental objectives at the same time. The criteria chosen need to have the ability to demonstrate movement towards or away from sustainability, according to these objectives.

Applicability:

The criteria chosen should be applicable across the range of options under consideration. This is needed to ensure the comparability of the options.

Transparency:

The criteria should be chosen in a transparent way, so as to help stakeholders to identify which criteria are being considered, to understand the criteria used and to propose any other criteria for consideration.

Practicability:

The set of criteria chosen must form a practicable set for the purposes of the decision to be assessed, the tools to be used, and the time and resources available for analysis and assessment.

2.4.3 Sustainability Assessment Criteria (SAC) effective in cement block selection

It is obvious that the choice of sustainability criteria for cement block material will influence the outcome of the decision being made, as well as the method of comparison or aggregation chosen. Comprehensiveness, applicability, transparency and practicability factors provide the guidance in the choice of criteria. Combined with several researches in related areas, sustainable concerns and requirement of project stakeholders, such as clients, a list of assessment criteria (Table 2.2) was developed. These criteria are identified under three categories;

- Environmental;
- Technical; and
- Socio-economic.

These categories aim to encapsulate the economic, environmental and social principles of sustainability, together with technical criteria, which relate primarily to the ability of buildings and its component systems to sustain and enhance the performance of the functions for which it is designed. For any decision process, the selected criteria must be broadly applicable to all of the options if comparative evaluation is to be achieved. A summary of selection criteria is listed in Table II. Overall, a total of 24 SACs was selected for cement blocks assessment, with seven SACs in socio-economic criteria, six SACs in the technical category and 11 SACs in environmental criteria, respectively. These can be used as the basis to assess the walling material option to know if it is moving towards or away from sustainability. It is important to note that sustainability criteria as identified in this research may be confined to the time of the research, as people's perception of sustainability awareness and conditions may change. The criteria will thus require regular updates, which is not unexpected.

2.4.4 Sustainability Assessment Criteria

Sustainability Assessment Criteria for cement blocks comprehensive literature review.(Table 2.2)

2.4.4.1 Environmental criteria

- E1: Potential for recycling and reuse of cement blocks (Asokan et al ,2009,Osmani et al.,2008;Thormark,2006)
- E2: Availability of environmentally sound disposal options of cement blocks (Beder,2006)
- E3: Impact of cement blocks on air quality (Spiegel and Meadows, 2010; Bahareh et al, 2011; Medineckien et al,2010)
- E4; Ozone depletion potential of cement blocks (Spiegel and Meadows,Anderson et all.,2009;Scheuer et al.,2003)
- E5: Environmental impact during cement blocks harvest (Kim and Rigdon,1998)
- E6: Zero or low toxicity of cement blocks (Spiegel and Meadows,2010;Kim and Rigdon,1998)
- E7: Environmental statutory compliance for cement blocks (Kien and Ofori,2002;Bunz et. al. ,2006)
- E8: Minimise Pollution of cement blocks – e.g. air, land (Spiegel and Meadows,2010;Bahareh et al, 2011)

2.4.4.2 Social – economic criteria

- S1: Disposal cost of cement blocks (Kibert,2008;Chen et al.2010:Emmitt and Yeomans, 2008)
- S2: Health and safety factors of cement blocks (Kien and Ofori,2002;Spiegel and Meadows,2010; Anderson et al.,2009)
- S3: Maintenance cost of cement blocks (Halliday, 2008;Wong and Li,2008)

- S4: Aesthetics in cement blocks (Ashby and Johnson,2002)
- S5: Use of local material for cement blocks (Kim and Rigdon,1998;Bunz et. al.,2006)
- S6: Initial acquisition cost of cement blocks (Emmitt and Yeomans,2008;Kim and Rigdon,1998)
- S7: Labour availability for cement block production (Calkins,2009)

Table 2.2- Sustainability Criteria for cement blocks selection

Environmental Criteria	Social – Economic Criteria	Technical Criteria
E1: Potential for recycling and reuse of cement blocks (Asokan et al , 2009, Osmani et al.,2008;Thormark, 2006)	**S1: Disposal cost of cement blocks** (Kibert,2008;Chen et al.2010;Emmitt and Yeomans, 2008)	**T1: Maintainability of cement blocks** (Spiegel and Meadows,2010;Nelms et al., 2007)
E2: Availability of environmentally sound disposal options of cement blocks (Beder,2006)	**S2: Health and safety factors of cement blocks** (Kien and Ofori,2002;Spiegel and Meadows,2010; Anderson et al.,2009)	**T2: Ease of construction using cement blocks** (Buildability) (Calkins,2009;Kibert,2008)
E3: Impact of cement blocks on air quality (Spiegel and Meadows, 2010; Bahareh *et al*, 2011; Medineckien et al,2010)	**S3: Maintenance cost of cement blocks** (Halliday, 2008;Wong and Li,2008)	**T3: Resistance to decay of cement blocks** (Pearce et al.,1995; Joseph and Tretsiakova-McNally,2010)
E4; Ozone depletion potential of cement blocks (Spiegel and Meadows,Anderson *et all*.,2009;Scheuer *et al*.,2003)	**S4: Aesthetics in cement blocks** (Ashby and Johnson,2002)	**T4: Fire resistance of cement blocks** (Spiegel and Meadows, 2010 ; Nelms et al., 2007; Pearce et al.,1995)
E5: Environmental impact during cement blocks harvest (Kim and Rigdon,1998)	**S5: Use of local material for cement blocks** (Kim and Rigdon,1998;Bunz et. al.,2006)	**T5: Life expectancy of cement blocks** (e.g.strength, durability,etc.)(Wong and Li, 2008;Nelms et al.,2007;Kim and Rigdon,1998)

Environmental Criteria	**Social – Economic Criteria**	**Technical Criteria**
E6: Zero or low toxicity of cement blocks (Spiegel and Meadows,2010;Kim and Rigdon,1998)	**S6: Initial acquisition cost of cement blocks** (Emmitt and Yeomans,2008;Kim and Rigdon,1998)	**T6: Energy saving and thermal insulation of cement blocks** (Goggins et al., 2010;Anderson et al.;2009)
E7: Environmental statutory compliance for cement blocks (Kien and Ofori,2002;Bunz *et. al.*,2006)	**S7: Labour availability for cement block production** (Calkins,2009)	
E8: Minimise Pollution of cement blocks – e.g. air, land (Spiegel and Meadows,2010;Bahareh *et al*, 2011)		
E9: Amount of likely wastage in use of cement blocks (Kien and Ofori, 2002)		
E10: Method of raw material extraction of cement blocks (Kien and Rigdon,1998;Kien and Ofori,2002)		
E11: Embodied energy within cement blocks (Goggins *et al.*, 2010: Monahan and Powell,2010;Bank *et al.*,2011)		

2.4.4.3 Technical criteria

- T1: Maintainability of cement blocks (Spiegel and Meadows,2010;Nelms et al., 2007)
- T2: Ease of construction using cement blocks (Buildability) (Calkins,2009;Kibert,2008)
- T3: Resistance to decay of cement blocks (Pearce et al.,1995; Joseph and Tretsiakova- McNally,2010)
- T4: Fire resistance of cement blocks (Spiegel and Meadows, 2010 ; Nelms et al., 2007; Pearce et al.,1995)
- T5: Life expectancy of cement blocks (e.g.strength, durability,etc.) (Wong and Li, 2008;Nelms et al.,2007;Kim and Rigdon,1998)
- T6: Energy saving and thermal insulation of cement blocks (Goggins et al., 2010;Anderson et al.;2009)

2.5 A comparative analysis of cement blocks with other walling materials through literature review.

There are cultural aspects affecting the use of solid and/or hollow blocks. Traditionally, solid blocks are used for private houses and one- or two-storey buildings. Levels of formal training and education are low and lack of trust in block makers' knowledge leads to an unwillingness to risk eventual shortcomings in quality performance of the blocks. People in general do not trust the quality of the available blocks and, therefore, base their acquisitions on limited personal knowledge. This results in preference for the traditional product instead of the uncertainty of new innovations. Because building needs are important, building activity would probably increase if block prices were reduced, and hence it satisfies the social-economic criteria and technical criteria. (Isaksson & Taylor, 2009, Isaksson & al., 2010a, 2010b).

In many countries, such as Tanzania, concrete blocks are the most widely used walling material. This means that there is both economic and environmental incentive to see that cement is used in the most effective way to make best use of resources. Earlier research indicates that there is a substantial improvement potential in reduced costs, improved customer value and reduced environmental impact in the building material supply network in Dar-es-Salaam, Tanzania The customer base consists mainly of house builders, professional contractors, and other customers building larger projects, who are familiar with the advantages of hollow blocks. The site manager estimates that of his total sales, 80% are hollow blocks. However, he also declares that his customers are mainly of European and Chinese origin. First time customers tend to ask for solid blocks, but the site manager claims that after selling the advantages of hollow blocks (insulation, price, safety) they often buy the hollow blocks. He further states that hollow blocks are more profitable in comparison to solid ones. It can be satisfactory due to the environmental sustainable criteria and the social-economic sustainable criteria and technically sustainable criteria. (Isaksson & Taylor, 2009, Isaksson & al., 2010a, 2010b).

Fly ash–lime–phosphogypsum (FaL-G) hollow blocks are one of the best substitutes for conventional burnt clay hollow bricks or concrete hollow blocks in the construction industry. The compressive strength, water absorption and weight of FaL-G hollow blocks give more benefits to the stakeholders. FaL-G hollow blocks have sufficient strength for their use in general building construction It has satisfied the technical and the social-economic criteria. not the environmental criteria.(Building and Environment Volume 38, Issue 2, February 2003, Pages 291–295).

In Makurdi, the capital of Benue State of Nigeria and its surrounding towns, the most common walling materials are the conventional sandcrete blocks and fired clay bricks. The cost of sandcrete blocks, coupled with the low strength properties of commercially available blocks, necessitated the search for an alternative that was fired clay bricks. Firing of bricks requires great quantities of firewood and energy loss in the form of heat is about 40-50%. In addition to the environmental problem, clay bricks can only be produced in locations where suitable clay soil deposits exist.

Cost comparison of available walling materials in Makurdi metropolis showed that the use of bricks made from 45% sand and 5% cement resulted in a saving of 30 - 47% when compared with the use of sandcrete blocks, while the use of fired clay bricks resulted in a savings of 19% per square meter of wall. The study, therefore, recommends the use of laterite bricks in Makurdi and other locations because it is more economical and environmentally friendly than fired clay bricks. (Isaac Olufemi AGBEDE and MANASSEH JOEL Department of Civil Engineering, University of Agriculture, Makurdi Benue State, Nigeria)

The economic considerations showed that the price of straw-cement blocks competes well with the price of traditional bricks in the Egyptian marketplace. The thermal testing demonstrated that the blocks could be used as both building units and thermal insulation units at the same time. Regarding the structural testing, the material has a low compressive strength, but this could be resolved by applying reinforcement material during the construction. Therefore, our study showed that straw-cement blocks as building materials have two main advantages: one as a thermal insulation material for energy conservation, and second as cheap recyclable building material compared to traditional bricks or blocks. Overall, the study found that the new straw-cement blocks represent a good low-cost sustainable building material for low-cost housing projects in Egypt. Straw-cement blocks as building materials have low performance in comparison to CB material.(A. Mansour(Civil & Architectural Department, National Research Centre, El Tahrir St., Cairo, Egypt.), J. Srebric and 2. B.J. Burley (Department of Architectural Engineering, Pennsylvania State University, PA, USA.(2007))

A considerable amount of energy is spent in the manufacturing processes and transportation of various building materials. Conservation of energy becomes important in the context of limiting of greenhouse gas emission into the atmosphere and reducing costs of materials. Total embodied energy of load bearing masonry buildings can be reduced by 50% when energy efficient/alternative building materials are used.(B.V Venkatarama Reddy, K.S Jagadish:2002)

Fibre reinforced mud bricks, provide the expected technical performance for the thermal isolation and mechanical properties, according to ASTM and Turkish standards. The fibre reinforced mud bricks fulfil the compressive strength and heat conductivity requirements of the ASTM and Turkish standards. Mud bricks with plastic fibers showed a higher compressive strength than those with straw, polystyrene and without any fibers. Basaltic pumice as an ingredient was found to decrease the thermal conductivity coefficient of fibre reinforced mud bricks. The fibre reinforced mud brick house has been found to be superior to the concrete brick house, for keeping indoor temperatures stationary during the summer and winter. (Hanifi Binicia, Orhan Aksoganb, Mehmet Nuri Bodurc, Erhan Akcad , Selim Kapurd : 2005)

Apart from the economic benefits, the carbon footprint of the blocks could be halved resulting in yearly reduced emissions of some 100,000 tonnes of CO_2. Changing the main product from solid blocks to hollow blocks would also reduce the consumption of sand used for blocks with about 3 million tonnes per year at the current level of production of 300 million blocks. (Isaksson & Taylor, 2009; Isaksson & al., 2010a, 2010b).

Common rock types which are used for wall constructions are sand stone, lime stone, quartzite and slate, which are internally very durable building materials. Fired brick and cement concrete blocks are rather new building materials in the area . These walling units are laid in cement- sand mortar, and are used in load bearing as well as infills in weak RC frame construction. In general, wall thickness is 230 mm in the case of brick units and 200 mm in the case of concrete blocks. Brick masonry is not only used for small dwellings, but also for schools, shops, dispensaries and other community buildings. Concrete blocks are made from cement, sand (fine stone powder, when sand is not available in high reaches) and coarse aggregate in various dimensions. Typical dimension being approximately 300 mm X 225mmX 150 mm. Many factors have contributed to growing usage of concrete blocks such as unavailability of new quarries, time consuming and labour intensive activity of laying stone and slate masonry uneconomical due to the large quantity of cement -

sand mortar required per unit volume of masonry, transportation of clay bricks from the plains, and in general, poor performance of stone.(lna sonryIla Gu pta, R. Shankar and Amita Sinvha l Dep a rtmen t of Architecture an d Pla nni ng II-Departmen t of Earthquake Engin eeri ng Indian Institute of Technology Roorkcc Roorkee, Uttarancha l State 247 667 India).Major usage in the world for construction is clay bricks; many researchers are presently looking for newer options because they need low cost materials, which are also environmentally friendly. The process of manufacturing clay bricks also requires high energy to burn due to the emission of CO_2 gas from this process. Stabilized compressed earth blocks (CEB) include; uniformed building component sizes, use of locally available materials and reduction of transportation. Uniformly, sized building components can result in less waste, faster construction and the possibility of using other pre-made components or modular manufactured building elements. The use of natural, locally-available materials make good housing available to more people, and keeps money in the local economy rather than spending it on imported materials, fuel and replacement parts. The earth used is generally subsoil, leaving topsoil for agriculture. Building with local materials can provide employment for local people, and is definitely considered more sustainable in times of civil economic difficulties. People can often continue to build better shelters for themselves, regardless of the political situation of the country. The reduction of transportation time, cost and attendant pollution can also make CEB more environmentally friendly than other materials.(Sadek Deboucha and Roslan Hashim, Department of Civil Engineering, Faculty of Engineering, University of Malaya, Lembah Pantai, 50603 Kuala Lumpur, Malaysia. Accepted 18 March, 2010).

2.6 Summary

This chapter described the concept of sustainability, which integrates environmental, socio-economic and technical objectives striving to develop Sustainable Assessment Criteria (SAC) for cement block selection as a sustainable walling material, with the sustainability assessment tools commonly used in the construction industry to objectively evaluate building material rating systems. This is mainly to provide a focus for data collection. The next chapter describes research methodology of this study.

CHAPTER 3

RESEARCH METHODOLOGY

CHAPTER 3 - RESEARCH METHODOLOGY

3.1 Introduction

Chapter two discussed the theoretical status and key research issues through a comprehensive literature review. This chapter aims to set out the methodological framework, which is used to accomplish the aims and objectives of this research study. It describes the research methodology used in completing this research philosophy, research approach, research techniques used for data collection and research process, as well as, data analysis.

3.2 Research methodology

Research methodology refers to the principles and procedures of logical thinking processes, which apply to a scientific investigation (Fellow and Liu, 2003). The outcome of a research depends heavily on its research design. Therefore, it is of paramount importance to develop the most appropriate research design for a particular research study. Thus, the sub-section below describes in detail the research methodology of this research study.

3.2.1 Research approach

Sekaran (2003), stated that research approaches helped to organize research activities, including the collection of data, in ways that are more likely to achieve research aims. According to Yin (1994), five different types of research approaches can be adapted to a research, namely; experiment, survey, archival analysis, case study and history.

By using a qualitative approach, the researcher will study the whole population as individuals or groups and will identify beliefs, understandings, opinions and views of people and analyze them to find solutions (Fellow and Lui, 2003). Qualitative methods are essentially descriptive and inferential in character, and focus primarily on the kind of evidence (what people tell you, what they do) that will enable to understand the meaning of what is going on. They are studies that include the context in which the studied phenomenon is embedded. Their great strength is that they can illuminate issues and turn up possible explanations: essentially a search for meaning (Giham, 2005; Wigren, (2007), consists of focusing on understanding the naturalistic setting, or the everyday life of a certain phenomenon, by the investigator.

The research approach of this study is the questionnaire survey in the quantitative method including the collection of data to achieve the research aim.

3.2.2 Research techniques

Once the research approach is selected, suitable research techniques will also have to be identified to operationalize the research. Research techniques can be discussed under two broad categories – as data collection techniques and data analysis techniques. These comprise data collection and data analysis methods. The data analysis techniques will act as the media to interpret the data collected and achieve a conclusion. Statistical analysis, content analysis, pattern-matching are the commonly used techniques in data analysis. It is very important to identify the appropriate techniques to be used in a research as a part of the research design. Thus, the data collection and analysis techniques employed in this research have described below.

3.2.3 Data collection techniques

A variety of data collection techniques can be used in research, such as interviews, questionnaires, document surveys, observations, participation (Tan,2002).

Particular study will proceed on achieving a conceptual finding. Therefore, the data collection process of this particular research consisted of both literature survey and questionnaire survey.

3.3 Research process

The research process of this study, which was based on survey research method comprised the following stages: initial impetus, literature review, problem statement, development of hypotheses and operationalisation, questionnaire design, data collection, data analysis, and, write-up. The succeeding sections follow this sequence in explaining the whole research process of this study.

3.3.1 Initial impetus

The initial impetus to conduct this research was mainly driven through opportunity given by the Department of Building Economics for the fulfilment of dissertation study for post-graduate candidates for the award of a Master of Science degree. During the topic searching stage, an interesting research paper written by Peter O. Akadiri and Paul O. Olomolaiye on the topic of 'Development of sustainable assessment criteria for building materials selection' paved the way to do this research. Development of sustainable assessment criteria for cement blocks is the way to use of cement blocks as a sustainable building material. Then the study moved to a literature review to find a reachable problem and a specific focus for this study.

3.4 Questionnaire development

Development of sustainable assessment criteria can be found out for building material selection (Peter O. Akadiri and Paul O. Olomolaiye, 2012 United Kingdom) in the literature review. There was no comprehensive list of assessment criteria that covers the principles of sustainability to be developed specially for sustainable cement block selection in building projects. To compile a meaningful and a holistic criteria, several researches in related areas were conducted. Combined with sustainability concerns and requirements of building stakeholders, a list of initial criteria was developed. Based on the derived criteria, an industry questionnaire survey was designed to investigate the perspective of engineers and architects on the importance of the criteria for material selection. In order to evaluate the clarity and comprehensive nature of the questionnaire, as well as the feasibility of the survey as a whole, a pilot survey was conducted. The pilot study was also used to test the suitability of proposed sustainability criteria and respondents were invited to add new criteria if necessary. As a result of the analysis of the pilot survey, the questionnaire was taken through a process of revision to make it more suitable for the main questionnaire survey.

3.5 Data collection and sample

The questionnaire, first sought the background information of respondents and their organizations. Thereafter, respondents were asked to rate the level of importance of the derived criteria based on a scale of 1-5, where 1 is "least important", 2 "fairly important" , 3 "important", 4 "very important" and 5 "extremely important" . A little description of each criterion was given in the questionnaire to a better understanding of the criteria. At the same time, respondents were encouraged to provide supplementary criteria that they consider (necessary) to influence cement blocks material selection but were not listed in the provided questionnaire. A total of 441 questionnaires were mailed out to participants for completion. To achieve a high- response rate, the survey was sent out over three rounds by mail and accompanied by a covering letter and a statement of the objective of the study, to guide the respondents on the potential contribution they could make to good practice. Survey questionnaires were randomly mailed and handed over to 110 architects and 231 engineers. Responses were received accordingly, including a number of incomplete responses. Ninety eight (98) effective responses were received after removing the invalid ones. The response rate was 28.7 per cent.

It is appreciated that there are deficiencies with the survey procedure. In this instance, the survey of the study was based on data collected from a random sampling of engineers and architects to form a composite sample. This sampling method does not include other stakeholders, who, in a way, influence cement block material selection, such as the client. The sample size may need to be extended to include more stakeholders involved in cement block material selection in order to minimize sampling error. However, the importance of the study remains, for the limitations do not detract from them, but provide scope for further research.

3.6 Method of data analysis

Data obtained conformed to either the nominal or ordinal scale for this research. To ensure that the rating scale of the response was rating scale (1-5) for measuring the criteria yields the same result over time, a reliability analysis using the internal consistency method was first examined. In order to identify the relative importance of Sustainable Assessment Criteria (SAC) based on the survey data, a ranking analysis was formed. It must be noted that most of the responses were ratings measured on the Likert scale. Such data cannot be treated using parametric statistical methods, unless precarious, and perhaps, unrealistic assumptions are made about the underlying distributions (Siegel and Castellan, 1988). It was, therefore, found appropriate to analyse it using non-parametric statistics involving descriptive statistics analysis, relative index analysis and factor analysis.

Relative index analysis was selected in this study to rank the criteria according to their relative importance. The following formula is used to determine the relative index (Olomolaiye et al., 1987; Chinyio et al., 1998; Chan and Kumaraswamy, 1997; Adetunji, 2005; Braimah and Ndekugri, 2009):

$$RI = \sum w / A \times N$$

Where "w' is the weighting as assigned by each respondent on a scale of one to five, with one implying the least and five the highest. "A" is the highest weight (i.e. 5 in our case) and "N" is the total number of the sample. Based on the ranking (R) of relative indices (RI), the weighted average of the two groups will be determined. The ranking index is labeled differently depending upon the context, e.g. "importance index", "awareness index", "frequency index", etc. Following the work of Chen et al, (2010), five important levels are transformed form RI values: High (H) ($0.8 \leq RI \leq 1$), High-Medium (H-M) ($0.6 \leq RI < 0.8$), Medium (M) ($0.4 \leq RI < 0.6$), Medium-Low (M-L) ($0.2 \leq RI < 0.4$) and Low (L) ($0 \leq RI < 0.2$).

High(H) ($0.8 \leq RI \leq 1$)
High – Medium(H-M) ($0.6 \leq RI < 0.8$)
Medium (M) ($0.4 \leq RI < 0.6$)
Medium -Low (M-L) ($0.2 \leq RI < 0.4$)
Low (L) ($0 \leq RI < 0.2$)

Figure 3.1 Five important levels transformed from RI values

Knowing that the derived SACs are likely interrelated through an underlying structure of primary factors, obtaining a concise list of SACs likely interrelated through an underlying structure analysis was also utilized. Factor analysis is a multivariate statistical technique for examining the underlying structure or the structure of interrelationships (or correlations) among a large number of variables (Hire et al., 1998). This analysis yields a set of factors or underlying dimensions which, when interpreted and understood, describe the data in a parsimonious but a more meaningful number of concepts than the original selection criteria. There was a considerable risk of the analysis of the responses yielding diverse results. Thus, in establishing the list of criteria, it was also independent.

In all these, the statistical package for the social sciences (SPSS) and Microsoft Excel for Windows application software package were employed for data analysis. Before the factor analysis, a validity test for factors was conducted according to the method by Kaiser (1974). By the Kaiser method, a value called eigenvalue under 1 is perceived as being inadequate and therefore unacceptable for factor analysis. Based on Kaiser's eigenvalue rule, factor analysis is performed and the retained factor requires the eigenvalue to be larger than one (1/. After the primary factor analysis, Varimax rotation method was used to look for a linear combination of the original factors, such that the variance of the loadings is maximized).

3.7 Summary

This chapter has presented the research approach and research process used in this research study. The next chapter analyses and discusses the findings from the study in detail.

CHAPTER 4

DATA ANALYSIS AND DISCUSSION

CHAPTER 04 - DATA ANALYSIS AND DISCUSSION

4.1 Introduction

Chapter 3 discussed the research methodology used in this research study. The aim of this chapter is to present and analyse the research findings. First, this chapter presents the sample characteristics and criteria of importance in rating . Second, it explores Factor Analysis to show the structure of interrelationships among the criteria. Third, it attempts to six latent factors to present the underlying structure of the criteria used for selecting material for a building project.Finally, this chapter presents the overall discussion of results by comparing the findings with the literature review.

4.2 Data analysis

4.2.1 Sample characteristics

Basic factual data were collected relating to the respondent's personality as a professional engineer/architect, and his/her organization. This data is presented in this section. Respondents were mainly from engineering/architectural organizations. Experience of respondents was highly impressive as 60.5 per cent have over 20 years experience working in the building industry, 12.2 per cent have industry experience ranging between 11 and 20 years, while 24.3 per cent have at least ten years or less. Virtually all the respondents have reasonable experience in sustainable building design and construction. As for the size of organization, 85.8 per cent work in small-to-medium size organizations, with a small proportion (12.2 per cent) working in large organizations with over 250 staff. Summary of respondent characteristics is shown in Table 4.1.

Table 4.1 Summary of respondents characteristics

Variable	Number	%
Work experience (years)		
<5	7	7.7
6 -10	16	17.6
11-20	14	15.4
>20	54	59.4
Size of organization (by staff)		
< 10	44	48.4
11 -50	17	18.7
51-249	18	19.8
250-500	5	5.5
>500	7	7.7
Age of organization (years)		
<5	12	13.2
6-10	7	7.7
11-20	20	22.0
21-30	23	25.3
31-40	10	11.0
>40	19	20.9
Type of organization		
Engineering/Architecture/design/construction	87	95.7
Education	3	3.3
Government agency	1	1.1
Area of building project specialization		
Commercial	5	5.5
Residential	56	61.6
Institutional	29	31.9
Industrial	1	1.1
Organization's annual turnover (Rs.)		
> 5 m	58	63.8
6 – 25 m	18	19.8
26 – 100 m	12	13.2
> 100 m	3	3.3

Form the above it can be concluded that respondents played an important role in their organizations, with good educational background and are very experienced. These characteristics make their view on the relevance of SAC obtained through the survey important and their ratings dependable.

4.2.2 Criteria importance rating

To ensure that the rating scale (1-5) for measuring the criteria yields the same result over time, a reliability analysis using the internal consistency method was first examined. Cronbach's α was calculated to test the internal consistency reliability of the generated scale. The α reliability coefficient normally ranges between 0 to 1. The closer α is to 1 the greater the internal consistency reliability of the criteria in the scale. Cronbach's α values for economic criteria, social criteria, environmental criteria and all criteria are 0.831, 0.837, 0.922 and 0.926, respectively. All α values are > 0.7, indicating that all reliability coefficients are acceptable and the internal consistency of the criteria included in the scale is excellent.

In order to identify the relative importance of SACs based on the survey data, ranking analysis was performed. Relative index analysis was used to rank the criteria according to their relative importance. Table 4.2 shows the ranking results for each criteria category (e.g. Environmental) by using the relative index analysis in Equation (1). Based on these ranking results, 12 criteria were highlighted to have "high" importance levels in evaluating cement block material with an RI value between 0.798 and 0.888.

"Aesthetics(S4)" was ranked as the first priority in the socio-economic category with an R1 value of 0.888, and it was also the highest among all criteria and was highlighted at "high" importance level. This was closely followed by "maintainability" which has been a concern among architects and designers. Akadiri (2011) observed that there is a perception of ambiguity surrounding the long-term maintenance of sustainable material. This is not entirely a surprise given that

Table 4.2 Rank for sustainable criteria for building material selection

Valid percentage of score									
Sustainable Performance Criteria	**1**	**2**	**3**	**4**	**5**	**Relative index**	**Ranking by category**	**Overall ranking**	**Importance level**
Environmental criteria									
E7: environmental statutory compliance	4.4	1.1	13.2	29.7	51.6	0.836	1	7	H
E8: minimize pollution of CB	1.1	1.1	18.0	46.1	33.7	0.829	2	10	H
E6: zero/low toxicity	3.3	2.2	22.2	38.9	33.3	0.783	3	13	M-H
E4: ozone depletion potential	3.3	8.8	19.8	39.6	28.6	0.763	4	15	M-H
E1: re-cyclable/re-usable material	1.1	7.7	29.7	38.5	23.1	0.739	5	17	M-H
E9: amount of likely wastage in use	3.3	7.7	29.7	39.6	19.8	0.719	6	18	M-H
E11: embodied energy in material	1.1	9.9	28.6	47.3	13.2	0.882	7	02	M-H
E2: environmental sound disposal options	1.1	10.1	36.0	34.8	18.0	0.707	8	20	M-H
E3: impact on air quality	4.4	8.8	35.2	39.6	12.1	0.682	9	21	M-H
E5: impact during harvest	4.4	15.4	31.9	37.4	11.0	0.660	10	22	M-H
E10:methods of extraction of raw materials	5.5	19.8	45.1	20.9	8.8	0.605	11	24	M-H

Technical criteria									
T1: maintainability	0.0	0.0	3.3	47.3	49.5	0.713	1	19	H
T6: energy saving and thermal insulation	0.0	0.0	3.2	50.4	46.2	0.800	2	11	H
T5: life expectancy (e.g durability)	0.0	0.0	4.4	50.5	45.1	0.871	3	4	H
T4: fire resistance	0.0	0.0	13.2	44.0	42.9	0.849	4	5	H
T3: ease of construction/buildability	0.0	0.0	9.9	53.8	36.3	0.853	5	6	H
T3: resistance to decay	1.1	1.1	28.6	48.4	20.9	0.843	6	14	M-H
Socio-economic criteria									
S4: aesthetics	0.0	0.0	10.1	30.3	59.6	0.888	1	1	H
S3: maintenance cost	0.0	0.0	12.1	56.0	31.9	0.829	2	8	H
S2: health and safety	1.1	3.4	15.9	40.9	38.6	0.815	3	9	H
S6: Initial acquisition cost of CB	0.0	5.5	14.3	49.5	30.8	0.876	4	3	H
S1: disposal cost	1.1	0.0	22.0	47.3	29.7	0.798	5	12	H
S5: use of local materials	3.3	5.5	23.1	48.4	19.8	0.742	6	16	M-H
S7: labour availability	5.5	16.5	39.6	29.7	8.8	0.629	7	23	M-H

Table 4.2 Rank for sustainable criteria for building material selection

maintenance free buildings are increasingly sought by clients, anxious to minimize the running costs associated with buildings. “First cost” have been, and will continue to be, a major concerns for building designers, as well as important traditional performance measures: ease of construction, the extent of the facility of construction, basically, has close relationships with time, cost and quality performance.

4.2.3 Expertise opinion of the SAC

At the survey, Aesthetics (S4) (Ashby and Johnson,2002) was ranked as the first priority in the socio-economic category with R1 value of 0.887, and it was also the highest among all criteria and was highlighted at “high” importance level. Embodied energy (E11) (Goggins, 2010: Monahan and Powell,2010;Bank, 2011) within cement blocks was ranked as the second priority in the socio-economic category with an R1 value of 0.882, But according to the Professor Mrs. Jayasinghe embodied energy (E11) within cement blocks (Goggins, 2010: Monahan and Powell,2010; Bank ,2011) was the highest criteria in the Sri Lankan context when considering the sustainability of CB. (The embodied energy involved in the acquisition, processing, manufacturing, and transportation of CB during the construction phase, the operational energy of the building and the demolition energy in the destruction, removal, and recycling of CB.) According to the expertise??? (experts’) opinion, all criteria were considered important, with “Embodied energy”, “Aesthetics ” and “Initial acquisition cost ” (Emmitt and Yeomans,2008;Kim and Rigdon,1998) the three top criteria considered for CB.

4.3 Factor analysis

Factor analysis was employed to analyse the structure of interrelationships among the criteria. Although the most significant criteria were identified using ranking analysis, some of them are likely to be interrelated with each other through an underlying structure of primary factors. Factor analysis was used to obtain a concise list of SACs. It is conducted through a two-stage process: factor extraction and factor rotation. Before the factor analysis, a validity test for factors is conducted according to the method by Kaiser (1974). By the Kaiser method, a value called eigenvalue under 1 is perceived as being inadequate and therefore unacceptable for factor analysis.

For the socio- economic criteria, the analysis results showed that the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.606, > 0.5, suggesting that the sample was acceptable for factor analysis. The Bartlett test of sphericity was 90.100 and the associated significance level was 0.000, indicating that the population correlation matrix was not an identity matrix. Both of the tests showed that the obtained data in socio-economic category supported the use of factor analysis and these could be grouped into a smaller set of underlying factors. Using principal component analysis, the factor analysis extracted two latent factors with eigenvalues > 1.0 for the seven socio-economic criteria, explaining 53.7 per cent of the variance. The rotated factor-loading matrix based on the varimax rotation for the two latent factors is shown in Table 4.3.

The component matrix identifies the relationship between the observed variables and the latent factors. The relationships are referred to as factor loadings. The higher the absolute value of the loading, the more the latent factor contributes to the observed variable. Small factor loadings with absolute values < 0.5 were suppressed to help simplify Table 4.3. For further interpretation, the two latent factors under the socio-economic category are given names as: Factor1: life-cycle cost and Factor 2: social benefit.

Similar factor analyses were performed to identify the underlying structures for technical and environmental categories. For environmental category, both the KMO measure of sampling adequacy test (0.801) and Bartlett's sphericity (P – 0.000) were significant, which indicated that factor analysis was also appropriate. Three factors under environmental category were extracted from the factor analysis, namely, Factor 3: environmental impact; Factor 4: resource efficient; and Factor 5: waste minimization. Along with rotating factor-loading matrix, the percentage of variance attributable to each factor and the cumulative variance values are shown in Table 4.4. From the table, it can be seen that the three factors accounted for 71.3 per cent of the total variance of the eleven environmental criteria.

In the technical category, the results for the factor analysis showed that the KMO measure was 0.804 and the Bartlett's test (p – 0.000) was also significant, which indicated that the factor analysis was also appropriate in identifying the underlying structure of the technical category. The results of the analysis are presented in Table 4.5 Just one factor named Factor 6: performance capability was extracted, explaining 50.3 per cent of the total variance of the six technical criteria.

Overall, a total of six latent factors was extracted to present the underlying structure of the criteria used for selecting material for a building project. Three factors were under environmental category, two factors belong to socio-economic category, and one factor for the technical dimension. Descriptions of the six latent factors are presented in the next section.

4.3.1 Factor1: Life-cycle cost

The first assessment factor "life-cycle cost" includes criteria such as initial cost (purchase cost), maintenance cost and disposal cost. Cement block buildings represent a large and long-lasting investment in financial terms as well as in other resources (Oberg, 2005). Improvements of cost effectiveness of such buildings is consequently of common interest to all stakeholders. With increasing pressure to provide environmentally responsible building, stakeholders are putting significant foci on the early identification of the financial viability of building projects. Goh and Yang (2009) observe that traditionally, there has been an imbalance between sustainable measures and project budget. They observe that historically, decisions concerning the design and construction of building projects have been based largely on the first-cost mentality approach. On the other hand, environmental experts and technology innovators often push for the ultimate sustainable building without much of a concern for cost. This situation is being quickly changed as the industry is under pressure to continue to return a profit, while better adapting to current and emerging global issues of sustainability (Goh and Yang., 2009).

The concept of sustainability as applied to the construction of cement block buildings is intended to promote the utmost efficiency and reduce financial costs (San-Jose and Cuadrado, 2010). In order to ensure that these objectives are achieved, the concept of Life-cycle Costing Analysis (LCCA) will play significant roles in the economics of a building project. LCCA makes it possible for decision makers to evaluate competing material options and identify the most sustainable growth path for the common building project (Goh and Yang, 2009). A cost analysis study by Abraham and Dickinson (1998) shows that the cost of maintaining a cement block building can be quite significant and may often exceed the initial costs. Thus, decisions based solely on initial cost may not turn out to be the best selection in the long term and this method can be effectively utilized to realize the benefits of long-term cost implications of sustainable development in a building project. Accordingly, consideration should not only be given to the economic requirement in the project design phase, but also throughout the entire life cycle of the building.

4.3.2 Factor2: Performance capability.

Factor 2 is labelled “performance capability” and is associated with fire resistance, resistance to decay, energy saving and thermal insulation, life expectancy of the material (durability), ease of construction and maintainability. One of the aspects of building design is to find trade-offs that satisfy a multitude of performance objectives. The performance concept provides a rational framework for building design and construction that are flexible and amenable to accommodating innovations and change (Becker, 1999; Wang, 2009). When applied systematically

Table 4.3: Factor loadings for Socio-economic criteria after Varimax rotation

Observed socio-economic variable	**Latent socio-economic factors**	
	Lif cycle cost	**Social benefit**
S3: Maintenance cost of cement blocks	0.747	
S6: First cost	0.684	
S1: Disposal cost of cement blocks	0.566	
S4: Aesthetics in cement blocks		0.82
S5: Use of local materials for cement blocks		0.749
S2: Health and safety factors of cement blocks		0.569
S7: Labour availability for cement blocks		0.546
Eigenvalues	1.546	2.195
Percentage of variance	22.224	31.495
Cumulative of variance(%)	22.224	53.726

Table 4.4 : Factor loadings for environmental criteria

Observed Environmental Variable	Latent environmental factors		
	Environmental impact	**Resource efficiency**	**Waste minimization**
E7:Environmental statutory compliance	0.872		
E6: Zero/low toxicity of cement blocks	0.814		
E4: Ozone depletion potential	0.709		
E8: Minimize pollution of cement blocks	0.576		
E3: Impact of cement blocks on air quality	0.547		
E10: Methods of extraction of raw materials		0.883	
E9: Amount of likely wastage in use		0.763	
E11:Embodied energy within cement		0.578	
E5:Environmental impact during harvest		0.536	
E2:Availability of env. sound disposal options			0.902
E1: Potential for re-cycling and re-use			0.861
Eigenvalues	5.495	1.206	1.106
Percentage of variance	22.224	11.047	10.139
Cumulative of variance (%)	50.038	61.095	71.244

throughout the building process, the performance concept is supposed to enable the design and execution of buildings that are highly suitable for the functions and activities of their occupants, provide thermally, acoustically and visually comfortable and healthy internal conditions while conserving energy and the environment. According to Wong and Li (2008), a building that fails to recognize the significance of performance criteria and systems interface, may lead to system incompatibility, malfunctioning and risk of obsolescence. If the building system malfunctions, it affects the business operations of occupants. The maintenance cost and the cost associated with a potential plunge in revenue arising from loss of tenants have an adverse effect on the financial viability of the building (Wong and Li, 2008; Clements-Croome, 2001). The failure to match occupants' and clients' expectations may eventually lead to disenchantment and a serious decline in interest and confidence in a building. Based on these problems, the analysis of performance requirements of building material options during the design stage is considered important.

All these qualities are expected to be realized during the service life of the building without excessively increasing its life-cycle cost. It seems, therefore, that it should be the long-term task of the architects and designers to provide the reliable means and tools for reaching this target by considering performance criteria in building design and cement block material selection.

4.3.3 Factor 3: Resource efficiency.

Variable loading on latent Factor 3 focus on "resource efficiency" such as method of raw material extraction, environmental impact during harvest, amount of likely wastage in the use of material and embodied energy. "Resource efficiency" is the process of doing more with less, using fewer resources for less scarce resources to accomplish the same goals (Wilson, 1998). The concept has become a major issue in debates about sustainable development. Halliday (2008) observes that certain resources are becoming extremely rare and the use of remaining stocks should be treated cautiously. The author called for the substitution of rare material with renewable-materials.

Table 4.5: Factor loadings for Socio-economic criteria after Varimax rotation

Observed technical variable	Latent technical factors
	Performance capability
T4: Fire resistance of cement blocks	0.789
T3:Resistance to decay of cement blocks	0.73
T6: Energy saving and thermal insulation of Cement blocks	0.714
T5: Life expectancy of cement blocks (e.g durability)	0.702
T2: Ease of construction	0.702
T1: Maintainability of cement blocks	0.648
Eigenvalues	3.006
Percentage of variance	50.264

Bold statements about the need for radical improvements in the use of cement block materials and energy resources have achieved recognition in policy circles. The argument is that productivity improvement is necessary to minimize impacts on the capacity of natural systems to assimilate waste cement block material and energy (Halliday, 2008). According to Graham (2003), the building industry is a major consumer of natural resources, and therefore, many of the initiatives pursued in order to create ecology sustaining buildings are focusing on increasing the efficiency of resource use. He stated that the ways in which these efficiencies are sought are varied. He cited examples ranging from the principles of solar passive design which aim to reduce the consumption of non-renewable resources, the consumption of energy production, life-cycle design and design for construction. Methods for minimizing material wastage during the design and construction process and providing opportunities for re-cycling and re-use of building material also contribute to improving resource consumption efficiency. Calls to be resource efficient h have come from concern for the increasing depletion of non-renewable natural resources.

4.3.4 Factor 4: Environmental impact.

The fourth factor is related to “environmental impacts” such as environmental statutory compliance, toxicity, ozone depletion potential, pollution and air quality. Since building materials have considerable impacts on the environment, it has become necessary to pay more attention to environmental issues in their selection and use. Environmental criteria are essential to guide design decisions and choices in this regard, and should complement overall environmental goals. Based on the environmental criteria established for a cement block material selection, the sustainability of a building can be accomplished.

Environmental impact of cement block materials must also be accommodated within a broad spectrum of other design issues and constraints. No environmental approach to building design can be successful, which addresses any issue or principle exclusively and in isolation of other considerations. While improved building performance can occur more easily and readily in some areas than in others, it is the integration of all issues into comprehensive design strategies that will constitute the basis of successful environmental principles. A building and its impact on, and integration with, the external environment must be viewed as a total system, and design must focus on the successful integration of criteria and strategies rather than instituting the assemblage of a series of discrete techniques for conserving or optimizing resource use (Cole, 2005).

4.3.5 Factor 5: Waste minimization.

“Waste minimization” criteria in this cluster include availability of an environmentally sound disposal option and potential for re-cycling and re-use. Waste in the building industry is important not only from the perspective of efficiency, but concern has also been growing in recent years about the adverse effect of the waste of building materials on the environment. Cement block materials waste is difficult to re-cycle due to high levels of contamination and a large degree of heterogeneity, and often there is insufficient space for its disposal in large cities. In Scotland, the Scottish Ecological Design Association (SEDA) stated that the landfill situation is now critical, with local authorities having to resort to transporting waste further and further afield or else burning it and releasing pollution into the air (Morgan and Stevenson, 2005).

It is, therefore, important for the designer to align all parties to the design intent of waste minimization, in order to optimize the benefits. Osmani et al. (2008) listed the benefits of waste minimization for designers to include design finesse relating to a more informed relationship between designers and suppliers, which, in turn, greens the supply chain and minimizes local impacts and compliance costs. Improving the waste efficiency can generate economic benefits. In addition to potential economic benefit, implementing waste reduction, avoidance and management strategies can generate cost savings, and can result in resource conservation, pollution and emissions prevention, reduced costs for waste disposal and less time spent on dealing (with) waste (Hylands, 2004; Osmani et al., 2008).

Consideration of waste efficiency of cement block material not only reduces environmental impacts, but also raises awareness and generates behavior change across industry groups. This may include improving an individual’s understanding of the waste implications of design decisions, not only related to their professional activities, but also to material selection. For building owners, waste avoidance, reduction and management at the operational phase have long-term implications in terms of building maintenance and service life. Similarly, disposal of waste is a problem in the absence of any environmentally sound means.

4.3.6 Factor 6: Social benefit

The sixth factor concerns aesthetics, use of local materials, labour availability and health and safety. “Social benefit” is much more difficult to quantify. The multi-faceted dimensions of the sustainability concept are evident in the definition of sustainable development given by the "International Council for Local Environmental Initiatives" in 1994. "Development that delivers basic social, economic and environmental services to all without threatening the viability of the natural, built and social systems upon which these services depend." Thus, the social aspect may be included as a further component in achieving sustainability in a building project.

Use of local material is a criteria, which due to increasing awareness of its ramifications is often thought to be synonymous with employment generation (Behm, 2005). Building aesthetics as stated by San-Jose and Cuadrado (2010) is a further value to bear in mind, with a view to conserving the architectural asset that blends in with the built environment of the local area or promotes a company image. They went on to say that the aesthetic aspect should be an implicit part of the construction and should not be sacrificed for greater productive capacity. A company will often promote the construction of its buildings with a corporate image, which identifies it and gives it greater prestige and by doing so, it is emphasizing the aesthetical requirement as a sustainable aspect.

A further factor to consider is health and safety, which is of great importance to the final cost of the building. Health and safety are defined as the degree to which the general conditions promote the completion of a project without major accidents or injuries (Bubshait and Almohawis, 1994). Research and practice (Behm, 2005; Frijters and Swuste, 2008; Ikpe, 2009) have demonstrated the benefit of health and safety consideration in building design to include reduced insurance premiums of constructors for injuries and accidents, which translate into lower costs to the project. Therefore, design professionals (i.e architects and designers) are in a position to help improve building safety, by addressing safety during material selection, thus improving the safety of the constructor (Behm, 2005).

4.4 Discussion

Among the top 12 criteria (Table 4.6), it is observed that only two criteria from the environmental category, out of 11 listed, were rated “high” among the selection criteria. The environmental issues are not strongly considered despite the need of reducing environmental impact of building activities.

In the SAC, a total of 12 criteria, consisting of nine environmental criteria, one technical criteria and two socio-economic criteria, were recorded to have “high-medium” importance levels. Although these 12 criteria (Table 4.7) were in the same importance level category, the socio-economic criteria (average R1 = 0.685) were considered to be less important compared to the technical criteria (average R1 = 0.764) and environmental criteria (average R1 = 0.706). It should be noted that environmental criteria account for 39.2 per cent in this importance level. The result is an example of evidence pointing to the trend that environmental aspects are no longer the least important factors for material selection in a building project. Some criteria in the three categories were ranked relatively higher in the “high-medium” level. For example, “zero/low toxicity (E6)” was rated as third in the environmental sub-category, and ranked as first in the 12 criteria with an R1 value of 0.783. Material toxicity issues are of paramount importance to all project participants. Volatile organic compounds (VOCs) and other hazardous chemicals are contained in cement block materials. Cement blocks with high levels of VOC’s pose a health risk to the occupant and construction workers alike. Using low-VOC CB can significantly reduce the emission of VOCs and has been acknowledged by the industry as a crucial component to any successful project. It has also been hailed as an important step in sustainable building.

An interesting observation is that none of the criteria fall under the medium and other lower importance level. This clearly shows how important the sustainability

Table 4.6 Rank of Sustainable Criteria for building material selection – importance level “High” (Top twelve criteria)

Sustainable Performance Criteria Importance level - “High”	Relative index
1. S4: Aesthetics in CB	0.89
2. E11:Embodied energy in CB	0.882
3. S6: Initial acquisition cost of CB	0.876
4. T5: Life expectancy of CB (e.g durability)	0.871
5. T4: Fire resistance of CB	0.849
6. T3:Ease of construction using CB	0.843
7. E7:Environmental statutory compliance for CB	0.836
8. S3: Maintenance cost of CB	0.829
9. S2: Health and safety factors of CB	0.815
10. E8: Minimize pollution of CB	0.810
11. T6: Energy saving and thermal insulation of CB	0.800
12. S1: Disposal cost of CB	0.798

Table 4.7 Rank of Sustainable Criteria for building material selection – importance level “High- Medium”

Sustainable Performance Criteria Importance level - “High - Medium”	Relative index
13. E6: Zero/low toxicity CB	0.783
14. T2: Resistance to decay	0.764
15. E4: Ozone depletion potential of CB	0.76
16. S5: Use of local materials of CB	0.742
17. E1: Recyclable/reusable material	0.739
18. E9:Amount of likely wastage in use of CB	0.719
19. T1: Maintainability of CB	0.713
20. E2: Environmental sound disposal options of CB	0.707
21. E3: Impact on air quality CB	0.682
22. E5: Impact during harvest of CB	0.660
23. S7: Labour availability of CB	0.629
24. E10: Methods of extraction of raw materials	0.605

criteria are to building designers in evaluating building materials. All criteria were rated with “high” or “high-medium” importance levels.

The sustainability requirements envisaged in a building are to a greater or lesser extent inter-related. The challenge for new sustainable studies is to bring together these different sustainability requirements in innovative ways. These sustainability requirements will be applicable throughout the different stages of the building life cycle, from its design, during its useful life, up until management of the building waste in the demolition stage.

The Table 4.8 presents how one can get the comparative analysis of CB with other walling material. It should be surveyed using SAC for selected walling material among engineers, architects and stakeholders. Then it can get the comparative analysis of the CB and can find what is the position of the CB related to other walling materials.

4.5 Summary

This chapter presented and analysed the research findings of the empirical study. The next chapter provides conclusions and recommendations. Further, Chapter 5 presents the guides to further research studies.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 5 - CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Chapter 4 presented and analysed the findings of the research within the context of the (literature / data) set out in Chapter 2. The aim of this chapter is to provide conclusions and recommendations.

5.2 Conclusion

This study describes the development of a set of assessment criteria, assisting engineers and architects, in the selection of sustainable cement block materials for building projects. The first objective of this study is to identify the building materials' sustainability. It was identified through the sustainable triple bottom line and sustainability assessment tools in the literature survey.

The second objective of this study is to review Sustainable Assessment Criteria (SAC) for building materials. Table 2.1 of the summary of different sources defines effective material aspects of the materials selection process. In different architectural design-based sources, the criteria that affect the materials selection are grouped under various subtitles. In most of these sources, the design process is defined as converting both technical and non technical criteria, but in reality, they mostly concentrate on the technical side, thereby dominating the architectural-based source.When a designer selects a material, he (he/she) must consider fulfilling the three basic properties: mechanical properties, economic properties and environmental properties.

The third objective of this study is to develop SAC for cement block selection as a sustainable walling material. A total of 24 criteria were identified based on the sustainable triple bottom line and requirements of building stakeholders. They include criteria which may capture the sustainability of cement block materials better, as opposed to the traditional measures of cost, time and quality. All the criteria were derived from a thorough literature review and discussion with selected experts in the use of sustainable cement block materials for building projects. To obtain the perceived importance of the criteria, a questionnaire was distributed to a sample of engineers and architects experienced in designing environmental friendly buildings.

Six latent factors present the underlying structure of the Sustainable Assessment criteria(SAC) for selecting cement block material for building project..

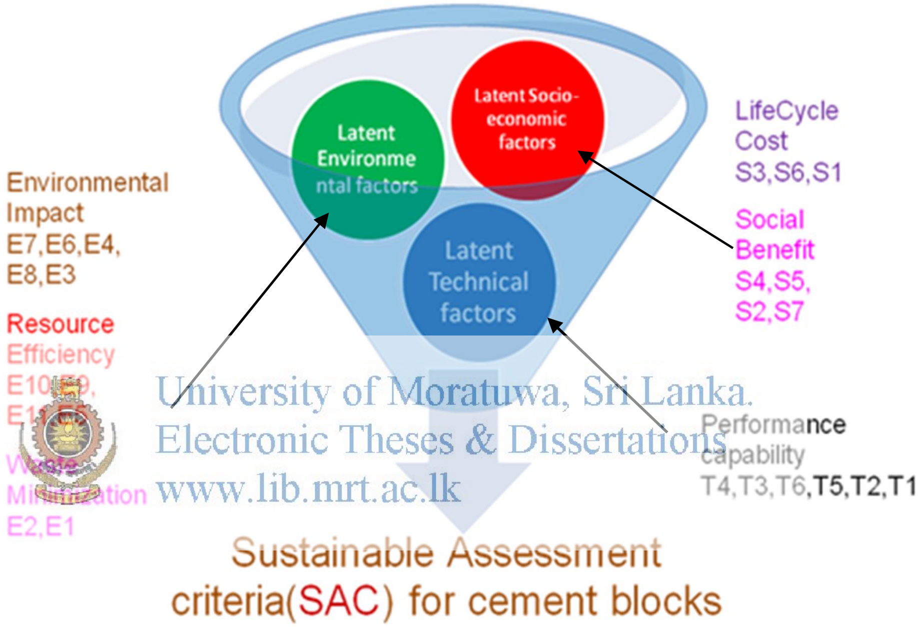

Figure 5.1- Model for Sustainable Assessment Criteria (SAC) for cement blocks

The fourth objective of this study is to assess cement blocks in the context of sustainable construction. Ranking analysis revealed that all criteria were highlighted at “high” or “high-medium” levels in selecting cement block building material. A total of 12 criteria was highlighted at the “high” importance level, with aesthetics, embodied energy and initial acquisition cost the top three criteria of importance. After the literature review, questionnaire survey and expertise opinion The first top criterion is the embodied energy. The second top criterion is the aesthetics and the third top criterion is the initial acquisition cost of CB. Factor analysis of the data generated a total of six latent factors from the criteria. Two of these factors are under the socio-economic category: life-cycle cost and social-benefit; three under environmental category, environmental impact resource efficiency, waste minimization, and one under the technical category: performance capability.

Since these factors are derived from the survey through expert opinion, they symbolize the sustainable criteria that promote socio-economic, technical and environmental consideration in cement block assessment and selection. According to six criteria in cement block material selection, the environmental issues are not strongly considered despite the need of reducing environmental impact of building activities. Hence, the result is an example of evidence pointing to the trend that environmental aspects are no longer the least important factors for cement block material selection in a building project. Model in the figure 4.1 shows that consideration of these six criteria in cement block material selection will ensure sustainable development in building design and construction.

5.3 Recommendations for further research

- All criteria related to CB were rated with “high” and “high-medium” importance levels. According to the RI values any observed variables (Sustainable performance criteria) were not ranked in the important levels of the medium (M) ($0.4 \leq RI < 0.6$), medium-low (M-L) ($0.2 \leq RI < 0.4$) and low (L) ($0 \leq RI < 0.2$). In assessing cement blocks in the context of environmental, socio-economic and technical sustainability in sustainable construction, it can be recommended that cement block material is the sustainable building material.

- The sustainability requirements envisaged in a building are to a greater or lesser extent interrelated. The challenge for new sustainable studies is to bring together these different sustainability requirements in innovative ways. These sustainability requirements (SACs) will be applicable throughout the different stages of the building life cycle, from its design, during its useful life, up until management of the building waste in the demolition stage.

- The final goal of an exercise such as the present study is to develop a decision support model, enabling building industry professionals to make rational decisions about the environmental consequences of their choices. The present study is only a tentative beginning in this direction. The next stage will utilize the available criteria in developing a decision support model for sustainable cement block building material selection. The model will be validated by demonstrating it to the selection of cement block material for a proposed building project.

- The same study can be extended by conducting it with larger sample that represents more large contracting organisations among engineers, architects and stakeholders in Sri Lanka. It will be interesting to discover whether the new study repeats the results discovered through this research study and strengthens the ab8ility to generalize the results of this research.

- This developed SAC can apply to any walling material (examples : Clay bricks, Compressed earth blocks, Cabok) to find the importance level of sustainability throughout the different stages of the building life cycle in any project to take comparative analysis of the materials (See table 4.8)

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APPENDIX A : QUESTIONNAIRE

Dear Sir / Madam,

I am a post graduate candidate of Department of Building Economics, University of Moratuwa , conducting a research under the supervision of Mr. Ravihansa Chandrathilaka, University of Moratuwa as a partial fulfillment of the requirement for the Degree of Master of Science in Project Management.

The research title:

Assessing Cement Blocks in the Context of Sustainable Construction.

Aim of the research:

To investigate requirement of building stake holders on cement blocks selection as a sustainable building material and to develop a model for sustainable cement blocks selection.

I here by gurantee the responses of the questionnaires will be used only for the aforementioned purpose and will not be exposed to any third party. The research publication will not contain any personal details of the respondents. You are requested to sincerely respond to all the questions in the questionnaire.

Thank you.

Yours truly,

D. Suraji Weerasekera

Instructions

1 . Purpose of this survey is to collect information on the selection at cement blocks for sustainable developments as a sustainable building material to identification of assesment criteria based on the concepts and principles of sustainability, and the process of prioritizing and aggregating relevant criteria into an assessment framework.

2 . This questionnaire should be filled with persons from the staff related to the field of construction in the organization[Building Designers (Engineers & Architects)].

3 . This questionnaire survey consists of Part A, Part B and Part C and you are requested to fill all three parts.

4 . **The collected information will remain confidential.**

Company background information

Name of the organization: ☐

Work experience (years):

< 5 ☐

6 - 10 ☐

11 - 10 ☐

> 20 ☐

Size of the organization (by staff):

< 10	☐
11- 50	☐
51 - 249	☐
250 - 500	☐
> 500	☐

Age of organization (years):

< 5	☐
6 - 10	☐
11 - 20	☐
21 - 30	☐
31 - 40	☐
> 40	☐

Type of organization :

Architecture/design ☐

Education ☐

Government agency ☐

Area of building project specialism:

Commercial ☐

Residential ☐

Institutional ☐

Industrial ☐

Organizational annual turn over:

> 5m ☐

6 - 25m ☐

26 - 100m ☐

> 100m ☐

Part B : Information about respondent

Name of the respondent (optional):

Designation/Title:

Years in the field of construction

Years in the company

Sex Male ☐

Female ☐

Part C :- **Questionnaire Survey**

This Sustainable Criteria for cement blocks selection is developed specifically for sustainable cement blocks selection in building projects.Combined with sustainable concerns and requirements of building stakeholders, a list of criteria was developed. Please rate the level of importance of the derived criteria based on a scale of 1 - 5, where 1 is "least important", 2 "fairly important" , 3 "important ", 4 "very important" and 5 "extreamly important & add new criteria if necessary.

1.0 Environmental criteria

1. **Potential for recycling and reuse of cement blocks** [Cement blocks capacity as a resource in the creation of new product.]
   1. least important ☐
   2. fairly important ☐
   3. important ☐
   4. very important ☐
   5. extremely important ☐
2. **Availability of environmentally sound disposal options of cement blocks** [There is no insufficient space for its disposal in cities. The land filling is critical with local arthorities]

   1. least important ☐
   2. fairly important ☐
   3. important ☐
   4. very important ☐
   5. extremely important ☐
3. **Impact of cement blocks on air quality** [Cement blocks can remove odors and chemicals when natural or artificial ventilaton is inadequate.]
   1. least important ☐
   2. fairly important ☐
   3. important ☐
   4. very important ☐
   5. extremely important ☐

4. **Ozone depletion potential of cement blocks** [Green House Gas (GHG) emissions originate from each stage of material's life cycle.]

   1. least important ☐
   2. fairly important ☐
   3. important ☐
   4. very important ☐
   5. extremely important ☐

5. **Environmental impact during cement blocks harvest** [Productivity improvement is necessary to reduce impacts on the environment to minimize waste material and energy.]

   1. least important ☐
   2. fairly important ☐
   3. important ☐
   4. very important ☐
   5. extremely important ☐

6. **Zero or low toxicity of cement blocks** [Cement blocks emit fumes for only a short time period during and after installation.]

   1. least important ☐
   2. fairly important ☐
   3. important ☐
   4. very important ☐
   5. extremely important ☐

7. **Environmental statutory compliance for cement blocks** [The government regulations about the sustainable cement block selection.]

   1. least important ☐
   2. fairly important ☐
   3. important ☐
   4. very important ☐
   5. extremely important ☐

8. **Minimise Pollution of cement blocks – e.g. air, land** [Pollution, caused by the process taking place during the production of cement blocks material.]

1. least important ☐
2. fairly important ☐
3. important ☐
4. very important ☐
5. extremely important ☐

9. **Amount of likely wastage in use of cement blocks** [Waste in the building industry is important not only from the perspective of efficiency, but also concern has been growing in recent years about the adverse affect of the waste of building material on the environment .]

1. least important ☐
2. fairly important ☐
3. important ☐
4. very important ☐
5. extremely important ☐

10. **Method of raw material extraction of cement blocks** [The impact of extraction of sand and quarry rock dust for block making.]

1. least important ☐
2. fairly important ☐
3. important ☐
4. very important ☐
5. extremely important ☐

11. **Embodied energy within cement blocks** [The amount of energy required to produce a material and supply to the point of use.]

1. least important ☐
2. fairly important ☐
3. important ☐
4. very important ☐
5. extremely important ☐

2.0 Social - economic criteria

12. **Disposal cost of cement blocks** [The demolition of buildings and disposal of the resulting waste has a high environmental cost.]

1. least important ☐
2. fairly important ☐
3. important ☐
4. very important ☐
5. extremely important ☐

13. **Health and safety factors of cement blocks** [Building products contain compounds, which adversly affect the health and safety of occupants of a building.]

1. least important ☐
2. fairly important ☐
3. important ☐
4. very important ☐
5. extremely important ☐

14. **Maintenance cost of cement blocks' buildings** [Maintenance consumes a significant portion of a building's life time and maintenance can easily exceed the original construction cost of the building.]

    1. least important ☐
    2. fairly important ☐
    3. important ☐
    4. very important ☐
    5. extremely important ☐

15. **Aesthetics in cement blocks' building** [Aesthetic quality of a building]

    1. least important ☐
    2. fairly important ☐
    3. important ☐
    4. very important ☐
    5. extremely important ☐

16. **Use of local material for cement blocks** [The use of building material sourced locally can help lessen the environmental burdens. This would considerably cut transportation cost and provide support of the local economics.]

    1. least important ☐
    2. fairly important ☐
    3. important ☐
    4. very important ☐
    5. extremely important ☐

17. **Initial acquisition cost of cement blocks** [All stake holders interest for cost effectiveness of building materials.]

    1. least important ☐
    2. fairly important ☐
    3. important ☐
    4. very important ☐
    5. extremely important ☐

18. **Labour availability for cement block production** [Less labour involving is caused to reducing costs, increasing productivity and allowing to build faster. Day labours with a low level of education results in clear priority on quantify and not on quality]
    1. least important ☐
    2. fairly important ☐
    3. important ☐
    4. very important ☐
    5. extremely important ☐

19. **Maintainability of cement blocks' building** [The maintennance cost has an adverse effect on the financial viability of the building]
    1. least important ☐
    2. fairly important ☐
    3. important ☐
    4. very important ☐
    5. extremely important ☐

20. **Ease of construction using cement blocks** [In general the construction of a block wall is little faster.]
    1. least important ☐
    2. fairly important ☐
    3. important ☐
    4. very important ☐
    5. extremely important ☐

21. **Resistence to decay of cement blocks**[Materials should be resistant to decay.]
    1. least important ☐
    2. fairly important ☐
    3. important ☐
    4. very important ☐
    5. extremely important ☐

22. **Fire resistence of cement blocks**[The type of course aggregate used in block making plays an important role in evaluating the fire resistence rating of the wall.]

1. least important ☐
2. fairly important ☐
3. important ☐
4. very important ☐
5. extremely important ☐

23. **Life expectancy of cement blocks** [Service life of the building is increased it's life-cycle cost.]

1. least important ☐
2. fairly important ☐
3. important ☐
4. very important ☐
5. extremely important ☐

24. **Energy saving and thermal insulation of cement blocks** [Buildings should be suitable for the functions and activities of their occupants.Buildings should be provide thermally, acoustically and visually comfortable and healthy internal conditions while conserving energy and the environment.]

1. least important ☐
2. fairly important ☐
3. important ☐
4. very important ☐
5. extremely important ☐

I would like to thank you for the information given and time you have dedicated to this reserch. If you are intrested to know the outcome of this research, it would be my pleasure to share it with you.