Rethinking low-cost green building material selection process in the design of low-impact green housing developments

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RETHINKING LOW-COST GREEN BUILDING MATERIAL SELECTION PROCESS IN THE DESIGN OF LOW-IMPACT GREEN HOUSING DEVELOPMENTS

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A thesis submitted in partial fulfillment of the requirements of the University of Westminster for the degree of Doctor of Philosophy

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DECLARATION

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ABSTRACT

Since 1950, the world population has increased by more than double. The sprawling demographic shift due to continuous migration from rural to urban areas in developing countries imposes socio-economic and environmental pressures to the urban areas. Apparently, the high demand for housing and the unsustainable construction practices underlying its production in recent times constitute issues that merit the attention of low-impact green housing developments. The feasibility of such developments also lies in the effective use of low-cost green building materials and components (LCGBMCs), primarily because of their potential to conserve energy use, reduce life-cycle cost, lessen ecological footprints, and revive lost cultural traditions.

Until recently however, only very few of these products have been widely established in mainstream, on account that most designers are constrained by their vaguely informed knowledge as to their sustainability impacts during the early stages of the design decision-making process, when most of the important decisions relating to sustainability are made. With the scale of complexity on how to incorporate sustainability principles in the early stages of the material selection decision-making process, and quest to stimulate the motivation for their use in a wider industry context, a clear gap is identified.

Drawing on the concept of sustainability, this research aims to narrow the underlying gap by exploring and evaluating the significance of an integrated modular-oriented mode of assessment that is able to assist designers in developing an improved capability to make early-informed choices, when formulating decisions to select LCGBMCs at the early conceptual stages of the design process. With results derived from the relevant literature, industry-wide surveys, and through empirical evidence gathered from interviews with a cross-section of house build stakeholders in Nigeria, key sustainability principle indicators impacting the selection of building materials are identified, analysed, grouped and ranked according to the relative importance that each decision factor holds, using a suite of statistical analytical methods.

The information gathered from the analysis with inputs elicited from experienced professionals are used to develop a Multi-Criteria Material Selection Decision Support System (MSDSS), and later refined with feedbacks obtained from selected builder and developer companies. The above integration is enhanced using Macro-in-Excel Database Management System (DBMS), while the Analytical Hierarchy Process (AHP) model is adopted as the ideal assessment methodology, given its ability to transform objective and subjective variables into weighted scores. Expert surveys are then used to demonstrate the usefulness of the suggested decision support system. The applicability and validity of this model are further illustrated using an ongoing housing project in Nigeria. By comparing the outputs from the model to monitored data from the case study, it would emerge that LCGBMCs, when properly assessed with consideration of the key sustainability principle indicators (influential factors) at the early stages of the design decision-making process, could reduce the potential life-cycle carbon embodied energy of a typical residential housing project by nearly 40% and yield energy savings of roughly 30-50% per year, when compared to their conventional carbon-embodied equivalents.

This study concludes that by addressing integration of sustainability principles into the material selection decision making processes at the early stages of the design, better support will be provided to key decision makers with the expectation of improved understanding and better informed choices, hence stimulate the motivation for more use of LCGBMCs in a wider industry context. The limitations of the study are highlighted and future research directions to better exploit the model capabilities are proposed.

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Thank you all! No words can say enough.

DEDICATION

This research is dedicated to God Supreme- the One whose inevitable divine grace knows no bound.

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
ARCON	Architects Registration Council of Nigeria
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
ATHENA	Advanced Technologies for Interoperability of Heterogeneous Enterprise Networks and Their Applications
BEPAC	Building Environmental Performance Assessment Criteria
BEES	Building for Environmental and Economic Sustainability
BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CEPAS	Comprehensive Environmental Performance Assessment Scheme for Buildings
CIB	International Council for Building
DCLG	Department for Communities and Local Government
EATT	Environmental Assessment Trade-Off Tool
EPM	Environmental Preference Method
ERG	Environmental Resource Guide
FHA	Federal Housing Authority
FMBN	Federal Mortgage Bank of Nigeria
GDP	Gross Domestic Product
IEA	International Energy Agency
KMO	Kaiser-Meyer-Olkin
LCA	Life Cycle Analysis
LCCA	Life Cycle Cost Analysis
LEED	Leadership in Energy and Environmental Design
MCDM	Multiple Criteria Decision Making
NBS	National Bureau of Statistics
NIA	Nigerian Institute of Architects
NIB	Nigerian Institute of Builders
NIESV	Nigeria Institute of Estate Surveyors and Valuers
NIQS	Nigeria Institute of Quantity Surveyors
NITP	Nigerian Institute of Town Planners

NSE	Nigerian Society of Engineers,
OECD	Organisation for Economic Cooperation and Development
SBAT	Sustainable Building Assessment Tool
TOPSIS	Technique of ranking Preferences by Similarity to the Ideal Solution
UKGBC	United Kingdom Green Building Council
UNDESPD	United Nations, Department of Economic and Social Affairs, Population Division
UNDP	United Nations Development Plan
UNEP	United Nations Environment Programme
UNHR	United Nations Habitat Research
USDOE	United States Department of Energy
USGBC	United States Green Building Council
W	*Kendall's coefficient of concordance*
WCED	World Commission on Environment and Development
SPeAR	Security Protocol Engineering and Analysis Resource
SCIAN	Society of Construction Industry Arbitrators of Nigeria

Chapter I

General introduction and background

CHAPTER 1: GENERAL INTRODUCTION

1.1 Introduction

The number of housing completions in sub-Saharan Africa has been on a downward trend since the 1950s (World Bank, 2012). However, the number of households has been forecast to increase by 300 million over the next 25 years, equivalent to around 12,000,000 each year (Giddings, 2007). Recent statistics even show that on top of the previous estimate there will be additional 100,000 new households each year (National Bureau of Statistics, 2013). The under-supply of housing underlines the need to build more homes to meet the increasing housing demand (Nubi and Omirin, 2010). This, combined with the urgent need to address current environmental crises have driven the house build industry to review its current approach to housing development, and to seek alternative approaches to delivering high quality affordable low-impact green housing projects in a more sustainable manner, by using low-cost green building materials and components due to their lower embodied energy requirements and potential to boost sustainability credibility.

Today however, the use of LCGBMCs is not widespread and limited to some applications in mainstream architecture (Oruwari et al., 2002; Kibert, 2008; Oyekanmi and Abisuga, 2014). The decision of selecting such products for housing projects is for the most part ignored due to the apparent lack of knowledge and long acquaintance with their conventional higher carbon-embodied equivalents (Seyfang, 2009a). A direct effect of this is that design professionals have to rely on their past experience and individual knowledge for decision-making at the early stages of the design, as they lack understanding of the complex nuances associated with their sustainability impacts. In the absence of rationalised informed data, many decision-makers tend to make choices based solely on intuition, which often lead to decision-making failures during planning and design stages of housing projects.

Advances in Information Technology and specific attention to DSS research in housing construction is rising- having been shaped largely by the pursuit for sustainable built environments. Yet, existing body of knowledge shows little evidence to justify the assumption that there are tools of demonstrable reliability that most specifically deal with the assessment of LCGBMCs for LIGHDs. In this event, decision-making failures during planning and design stage(s) hinder their use in terms of their industrial capacity utilisation.

There is thus, a need to improve the decision-making process and understanding of the sustainability impacts of each material in hopes of mitigating potential risks of decision-making failures during the crucial stages of the design. This research contributes to knowledge by introducing an integrated modular-oriented approach that can integrate the relevant data, structure the decision-making process, improve the quality of the information on which the decision is based, hence exemplify the nature of the problems better. This is in order to assist designers in developing an improved capability to understand the sustainability impacts of individual materials so as to make early-informed choices, when formulating decisions to select LCGBMCs at the early conceptual stages of the design.

This chapter articulates the research problem in section 1.2. It examines current issues associated with material selection and management, and discusses the challenges and potential benefits of current technology in the material selection decision-making process in sections 1.2.1 and 1.2.2, respectively. It summarises the important findings and issues emerging from the preliminary research activities in section 1.3, formulates the key research question in section 1.4, and presents the aim and objectives of the study in section 1.5. The proposed research methodology is discussed briefly in sections 1.6. Section 1.7 presents the core definitions relevant to this study; section 1.8 discusses the rationale for the study; section 1.9 defines the scope of the study while section 1.10 highlights the significance of the study. A summary of the project work plan and structure is set out in section 1.11.

1.2 Statement of Research Problem

Housing in Nigeria, just as in many developing countries, has been described as the most unsolvable problem- making itself most conspicuous in slums, where the vast majority of urban poor live (Jiboye, 2009). Nigeria's housing deficit of an estimated 17 million units is well documented (Nubi, 2008; FMLHUD-2012). This equates to an investment need of nearly $600 billion when based on an average house price of a modest N5 million (approximately $27,500) (Global Construction, 2009). Nigeria can boast as Africa's largest housing construction market as well as being the economy's second fastest growing sector– second only to telecoms (National Bureau of Statistics, 2013). The booming housing industry, however, serves the upper end of the market well, while there is very little investment at the bottom end where the need for housing is greatest (Oluwakiyesi, 2011). A report by the United Nations Statistics (2013) estimates that 68% of Nigerians are below the international poverty line of $1.25 per day, and records that the vast majority is excluded from the formal housing market altogether (UN, 2012).

Although social housing has been supported through direct government interventions in the form of huge investments and increased funding, the housing crisis for the vulnerable poor is still one of rising challenges in Nigeria. Evidence (Oluwakiyesi, 2011) holds true that Nigeria's underdeveloped housing and uncompetitive manufacturing sector leaves the door open to imported materials, as 50% of construction materials, which make up some 60% of the cost of construction and roughly 25% of CO_2 emissions, are imported (Jiboye 2009). The recent spate of global warming resulting from the use of highly carbon-intensive imported building materials and their insidious effects on both the economy, and the environment make the need for low-cost green building materials pronounced, due to their inherently lower cost/energy/carbon intensity in production, and relatively low through-life maintenance attributes and requirements (Seyfang, 2010).

Unfortunately, the influence of their value and benefits on volume house build to date has been minimal, as there appears to be a lack of knowledge and understanding amongst designers of their sustainability impacts and best practices in mainstream. This situation is worsened by the fact that information on the different materials available is normally limited or lacking at the conceptual design stage. This is significant given that designers-although experienced, are constrained by their vaguely informed knowledge of best practices, and lack of better informed data on the available materials, and so feel difficult to provide direct and well-informed judgments, even though there are currently a wide range of low-cost green building material alternatives, being supplied by some manufacturers and suppliers in Nigeria.

Moreover, the large number of criteria and material options are simply overwhelming for decision-makers to make informed-selections. It is thus very unlikely for any single decision maker to meaningfully combine all of these bits of information and make informed decisions. Designers are now concerned with how to incorporate sustainability principles into the design-decision-making process to avoid wrong early decisions. Under such circumstances, more scientifically integrated modular-oriented methods have to be used to facilitate handling complex decision-making process.

Hence, finding an alternative means with which to view the management of the early stages of the material selection decision making process, may provide a greater understanding and appreciation of the scope and scale of complexity in formulating decisions when selecting LCGBMCs, and may therefore assist designers in developing an improved capability to make early-informed decisions, hence identify an “early warning” for the decision-making success or failure of the potential housing project.

1.2.1 Material Selection and Management Issues

The choice of materials has been identified as an important design variable that can significantly affect the overall life-cycle energy cost in housing projects, and influence the building's life cycle impact on the environment (Nassar et al, 2003). The consequences of a decision according to Gluch and Baumann (2004) are often observable long after decisions are made at the onset of the design. Thus, making informed decisions at the early stages of the design offer a greater chance of reducing life-cycle cost, and enhancing the eventual technical, socio-cultural, environmental and economic success of a product, than when considered at the construction or occupancy stage (Ding, 2008).

Hence, it is important that designers are better enabled to incorporate sustainability principles and understand which material decisions most significantly determine a building's life cycle impact at the earliest stage of the design, when the design problem is typically not well defined, and the potential to reduce environmental impacts is greatest. As such, conventional material assessment methodology employs life cycle cost analysis (LCCA) technique to aid this process (Van Pelt 1994).

Although the benefits of LCCA have been reiterated in various studies, there are growing concerns that this approach often undermines environmental and socio-cultural issues, leading to overuse and depletion of environmental assets and neglect of societal needs (Ding 2008). Literature on LCCA and environmental protection have indicated that using a single objective in the evaluation process is insufficient when taking environmental and socio-cultural issues into account (Ding, 2008). Consequently, multi-criteria analysis, which uses a weighted score approach to evaluate economic environmental and social issues has gained significant attention in operational research (Hobbs and Meier, 2000; Ding, 2008).

With the growing interest to reduce the overall environmental, and socio-economic impact of a building using the multi-criteria approach, information systems are increasingly recognised as a key-supporting tool in the material-selection decision-making process (Trusty, 2003). While there is evidence of the usefulness of Information and Communications Technology (ICT) in the assessment of conventional building materials, questions and doubts of their appropriateness in the assessment of LCGBMCs for LIGHDs, remain. Little attention is paid to material assessment systems that embrace significant sustainability criteria where LCGBMCs are assessed using an appropriate assessment method that best suits their nature (Kibert, 2008; Seyfang 2010). Therefore, there is a need for a multi-criteria approach that incorporates the principal determinants of sustainable development principles into the decision-making process when selecting LCGBMCs.

1.2.2 Technology in Material Selection and Management

As the house build industry now faces the prospect of increasing energy efficiency in buildings and improving occupants health, material selection decision-making has become more complex. Support provided to decision makers by traditional approach has evolved from simple predefined reports to complex and intelligent-based analysis and judgments (Ding, 2008). This is because modern support systems have been expanded and upgraded through integration of new technologies, and processes into decision support paradigm to aid better-informed decision-making.

New data management technologies have been widely employed in various developed economies to handle data and information integration from multiple sources, in order to provide material knowledge to users. While many integration frameworks have been effective in improving the performance of multi-unit residential developments in many developed countries (Ellis, 2009), there is little in the current literature to demonstrate such efforts in developing countries (Malanca, 2010).

This is so because of the recognition that decision support systems established in industrialised nations are not always desirable, and most often unsuccessful in developing regions due to their geographical and cultural differences (Norton, 1999).

Giorgetti and Lovell (2010) for example contrast the credibility of existing decision support systems with what they describe as “overly comprehensive’, noting that additional documentation to existing guidelines in developed economies could increase the perceived burden on housing in LDCs, since some of the materials commonly used in the developed regions may not be affordable, available or even suitable in developing countries. They noted that many existing support systems designed by countries with more developed economies such as the UK-where the scale of social issues and lack of access to resources are simply not as critical as observed in the LDCs, do not, by design, address designated priorities relevant to developing nations.

Although the roles and benefits of Technology Transfer (TT) have been demonstrated in most literature (Ofori, 2006), such benefits remains relatively under-explored and are yet to be realised in LDCs. Reciprocating such potentials in developing regions will require universal evenness in economic, social, geographical and cultural character, which is very unlikely to occur.

Therefore, the technology to be adopted in this study must thus, correspond to local conditions, economy, culture, existing pattern of knowledge, rules, regulations, consensual expectations, assumptions, or thinking shared by the actors of that region, and work in conjunction with the materials and architecture of the region. Hence, for a technology to be successfully diffused, such system must have to be designed to fit the prevailing circumstances and the current technological regime of that region.

1.2.3 Summary

In summary, this brief review has developed a theme that has identified the need for sustainable low-impact green housing to meet and cater to the inevitably changing needs of the growing number of households, and highlighted the significance of low-cost green building materials in achieving this objective. It has also noted the lack of knowledge and experience amongst building professionals and designers, and their reticence in the informed selection of LCGBMCs. It has been noted that a variety of researchers have identified the role of information technology in aiding decision making in this respect with the proviso that they are designed or tailored for the specific markets in which they are to be used. The above background study and the preceding reviewed literature therefore, underscored the need for improving understanding of relevant data associated with LCGBMCs, hence acknowledged the potential of a support system to positively influence the attitudes of stakeholders involved in the production of the built environment in Nigeria, in order to stimulate the motivation for more use of LCGBMCs in a wider industry context.

Recognising the limitations of the reviewed literature in terms of examining current research thinking in respect of material selection support systems for LCGBMCs, a preliminary research study was carried out with targeted building professionals from various regions of both the developed and developing countries (see **Appendix C** for results). The following section summarises important findings and issues emerging from the preliminary research activities.

1.3 Findings From Preliminary Research Study: Need for Further Study

To build upon knowledge gained from the literature review, it was decided that a preliminary study would be required as opposed to purely relying on the research of others, since this research aims to produce new perspectives on current issues associated with the informed selection of LCGBMCs on which previous empirical studies seemed rather limited. The following are highlights of the findings and conclusions from the preliminary study.

- From an overview of the preliminary study, it was found that certain assessment parameters of existing tools in the developed countries do not complement product categories in developing countries, due to the differences in their environmental, socio-cultural and economic needs.

- Another finding was that within similar levels of economic performance, countries exhibit significant variation(s) in their levels of economic, social, environmental sustainability;

- Monitoring and evaluation mechanisms that focus on material selection were found to be inconsistent in their methodologies since they assume values and priorities of the developer, thus make little or no impact when applied to a different scenario;

- Most building professionals still consider cost and environmental factors as conventional project priorities when selecting building materials;

- There were clear indications that the resulting and consequent lack of requisite knowledge by designers about the implications of each product choice was the prime source of the decision making failures associated with the mainstream use of LCGBMCs rather than poor housing policy implementation reform schemes, as have been hypothesised by previously reviewed studies.

- There was no demonstrable and compelling evidence of technical research on available resources that could better enable the integration of sustainability principles at the early stage(s) of the design decision-making process, when formulating decisions to select LCGBMCs for LIGHDs.

As may be interpreted from the above findings and the reviewed literature, it can be deduced that quite a number of design and building professionals still do not have a clear idea of the issues, requirements, constraints and opportunities specific to the use of LCGBMCs. The analysis of the preliminary study thus reaffirms the identification of the knowledge gap in the reviewed literature, which brings this study to the key research question.

1.4 Key Research Question

The identification of the research need and knowledge gap in the introductory and background sections of the study, therefore necessitates the qualitative and quantitative elements to answer the key research question:

— How can designers be better enabled to incorporate sustainability principles into the material selection decision-making process with the expectation of improving their understanding of the impacts of LCGBMCs -when formulating decisions during the early design stages of LIGHDs, so as to aid better-informed material choice decisions in hopes of stimulating the motivation for their use in a wider industry context?

1.5 Research Aim and Objectives

To answer the key research question posed in section 1.4, this research aims to explore and evaluate the significance of an integrated modular-oriented mode of assessment that is able to assist designers in developing an improved capability to make early-informed choices, when formulating decisions to select LCGBMCs at the early conceptual stages of the design process.

To achieve this aim, the following research objectives are to:

I. Elicit current views and background information on themes related to the economic, environmental and social impacts of housing construction activities in the Global and Nigerian contexts, with emphasis on the role of material selection decision-making in sustainable housing;

II. Compare and contrast various technologies currently used at national and international levels for modelling decision-making in the selection of building materials and components; to highlight their strengths and weaknesses;

III. Identify the key sustainability principle indicators (influential factors) that affect the selection of building materials;

IV. Establish and specify the impact weight of each key influential factor;

V. Develop a Multi-Criteria Decision Support System for aggregating the weighted factors needed for the assessment of LCGBMCs

VI. Test and validate the developed system.

The next section briefly sets out the methodology adopted to carry out this research.

1.6 Research Methodology in Brief

The research adopted multi-dimensional design strategy that involves a variety of quantitative and qualitative approaches, which include fieldwork approach (pilot study, survey), questionnaire, interviews – semi-structured, and critical approach. Data collection and analysis was divided into four phases.

The first phase was based on interaction between archival ethnographic approach and preliminary interviews. A literature search using a range of information collection tools such as books and peer-reviewed journals from libraries and internet-based sources helped to examine the relative impacts of decision-making on housing, as well as current and previous research in the area of material evaluation and assessment. It also explored background issues relating to low-impact green housing developments in both developed and developing regions.

Following the identification of the key issues disclosed in the literature, a preliminary research study conducted with leading researchers who influence the selection of building materials in the field of housing helped to explore the topic further, and observe how well their views relate to the themes identified in the literature review. To determine the initial set of sustainability principle indicators that would inform the selection of LCGBMCs for LIGHDs, an analysis was carried out on factors that impact on material choices. Further review examined material assessment systems that are considered by far the most comprehensive and methodological tools developed. The review focused on the strength and weaknesses, and the elements of success of implementation of these tools, which helped the study to identify practical ways of enhancing the proposed system.

In the second phase, a primary research was conducted with targeted building professionals who influence the selection of construction materials from throughout the construction value chain in Nigeria, to gather information that had not been previously collected or found in the literature base. This required the use of both questionnaire surveys for obtaining large samples, and interviews for obtaining as much useful qualitative data to elaborate on less detailed responses received on the questionnaires. The research assumed the semi-structured approach in the questionnaires and interviews–to identify the categories, indicators, parameters and the main features that should be included in the proposed assessment system. The target group involved a variety of stakeholders such as architects, designers, builders, civil engineers, contractors, decision makers, and members of various housing associations. A subsequent study observed the available expert systems most commonly used in building firms in the UK. This involved interviewing experts, with years of experience in the industry, who had implemented such systems, by directly observing how they were constructed and how effective they were during operation. The information generated in the literature and preliminary studies informed the conversational guide and interview process.

For the third phase, data analysis was carried out using a suite of nonparametric techniques given that the data drew on the interests of respondents with conflicting views, which suggested the likelihood of a skewed sample distribution. The Descriptive statistics was used at the preliminary stages to provide useful insights, with more detailed analysis done using Relative index analysis, Kendall coefficient of Concordance, Chi-square tests, Factor analysis, and other statistical tests of significance. The Statistical Package for the Social Sciences (SPSS v20) was employed to aid analysis. This phase helped to define weighs for each of the key sustainability principle indicator (influential factors).

In the fourth phase, a suitable database management system was used to assemble the key components needed to develop the proposed integrated modular-oriented material selection system. Given that the database consisted of a cluster of complex information, macro-in-excel VBA was identified as the ideal spreadsheet application due to its speed, accuracy, and ability to manage large and complex data. A subsequent part of this phase was inputting relevant data to test the internal links and know what needed to be measured within the system. Expert survey was conducted using feedback questionnaires to obtain respondents' judgments about the system functionality based on the Analytic Hierarchy Process (AHP). The final part of this phase validated the effectiveness and robustness of the system using an on-going case study building project in Nigeria to review the potential savings of the new materials proposed by the model. Chapter 4 details the research methods, design and their methodological consequences.

1.7 Definitions

For the purposes of this study, definitions may be found in **Appendix A**. However two key definitions are included here, and are defined as follows:

Low-cost green building materials and components (LCGBMCs)- which consist mainly of locally-sourced and recycled building materials, may be defined as materials, which by virtue of their location, availability, sense of place, recyclability, lower cost and reduced carbon-embodied energy, meet the environmental, socio-cultural, technical, sensorial and economic requirements across their life cycle when compared to competing products that serve the same purpose.

Low-Impact Green Housing Development (LIGHD) would be defined as "any development-which through its effective and harmonious use of LCGBMCs, yields a low negative carbon-embodied life-cycle energy impact that either enhances or does not significantly diminish the economic, socio-cultural and environmental quality of the user or region it intends to serve".

1.8 Rationale and Motivation for the Research

The housing construction industry is facing increasing pressure to deliver adequate and affordable low-energy/low-impact green housing projects. Designers, especially architects, have been identified as central to the delivery of low-energy/low-impact green housing projects since their decisions at the conceptual stage of the design have significant impacts on the overall performance of the building, as well as play crucial role in achieving the low impact green targets for homes in Nigeria (Abisuga and Oyekanmi, 2014).

As an architect with special interest in sustainable low-energy/low-impact green architecture, and having worked on numerous housing projects, there arise the need for alternative building materials and systems to address the housing backlogs within the sub-urban and urban dwellings resulting from high costs and scarcity of imported building materials. However, architects have not adopted existing systems widely; because they do not fit in with the way architects make design decision(s) at various stages of the design process when selecting low-cost green building materials. The struggle to find information with which to assess LCGBMCs, whilst working on a series of low-impact green housing projects peaked the curiosity that motivated the search for an alternative approach that provides information base available to undertake effective material evaluation and selection at the critical stages of the design process, since current policies, and decision tools, although so many, seem not to be sufficient towards this realisation.

Hence, adequate decision-support tools to support designers to achieve low impact housing was seen as critical in achieving more environmentally efficient buildings. Consequently, it was deemed important for architects to have appropriate tools that are in tune with design decisions at the various stages of the design process, and developed in a format that can be easily understood and interpreted by non-specialist designers when selecting LCGBMCs, hence arose the need for further research to address this problem.

1.9 Scope of the Research

The research carried out in this study is significant to design and building stakeholders, and the findings from the study are centered on evaluating the selection of LCGBMCs for low-impact green housing projects. The research results may only be valid for the characteristics and culture of design and building professionals in Nigeria. The scope of the study is further discussed in chapter 7.

1.10 Significance of the Study

This study will be a significant endeavor in promoting best practice guide in low-cost green building material assessment, and will attempt to stimulate motivation of its use in a wider industry context. The establishments of such precedents would spark and facilitate a considerable shift in awareness as to the potential role of low-cost green building materials and components in achieving sustainably built environments and in effect might be a declaration by government that alternative approaches to their selection process in housing may be actively explored or even encouraged. This would improve the generalisability of the tool as previous models have been developed on a more limited scale. It will also serve as a future reference for researchers on the subject of material support and management systems, and in turn act as a primary locus for further innovations and technological progress in housing.

The results of the study will also be beneficial in enriching knowledge on the sustainability impacts of each material, and in enabling the refinement of the tool to suit user requirements in a broader domain. By understanding the impacts of each product and consequences of their decisions, decision-makers will be assured of more competitive and sustainable choice of materials.

1.11 Structure of the Thesis

The research structure is presented in **Figure 1.1**. The contents of each chapter are summarised as follows:

1.11.1 Chapter 1: General Introduction

This chapter provides the background information for the study and nature of the problem investigated. It identifies the research gap, which the present study focuses on. The research problem, aim, objectives, research method and significance of the study are also highlighted.

1.11.2 Chapter 2: The Housing Construction Industry

This chapter describes the nature of the housing construction industry, and examines the relative impacts of housing activities on the environment. It emphasises on the need for sustainable housing, and highlights the benefits of low-impact green housing in sustainable construction. The priorities of low-cost green building materials are discussed, and the importance of incorporating sustainability principles into the material selection decision-making process is also established. It investigates the core factors used in developing the multi criteria decision model for material selection. The argument established provides a platform for further investigating the literature concerning material selection support systems.

1.11.3 Chapter 3: Technology in Material Selection and Management

Chapter 3 presents the theoretical review of existing decision support frameworks currently used at both national and international levels for managing, and monitoring data associated with building materials. The argument provided establishes the need for a more robust framework to assess the decision-making process when selecting LCGBMCs. A multi-criteria approach for material evaluation is reviewed and contrasted to the conventional market-based approach.

1.11.4 Chapter 4: Research Methodology

Following the review of literature in chapters 2 and 3, this chapter provides an elaborate discussion on the research methodology adopted for undertaking this research. It establishes the epistemology framework on which the research was conducted. Arguments are presented justifying the choice of a conciliatory approach and the specific methods applied to collect and analyse data. The data collection and analytical processes are also detailed in this chapter.

1.11.5 Chapter 5: Development and Testing of the MSDSS Model

Chapter 5 is devoted exclusively to the design, development, and testing of the multi-factor based material selection decision support system. It specifies the factors needed to be incorporated in the model and aggregates the factors into a composite index for material selection. The MSDSS model is the final output in this chapter.

1.11.6 Chapter 6: Validation of the MSDSS Model

Chapter 6 presents the results of the semi- structured interviews carried out to refine and validate the MSDSS model using a case study of a proposed building project in Nigeria. This chapter explores and elaborates on the implications and inferences drawn from the exercise.

1.11.7 Chapter 7: Summary, Conclusions and Recommendations

Chapter 7 is the concluding chapter of the thesis, which presents the key research findings. It summarises the overall research process adopted and presents the conclusions derived from the overall research findings, recommendations and suggestions for further research. Limitations of the research and the possibilities of further research are made at the end of this chapter.

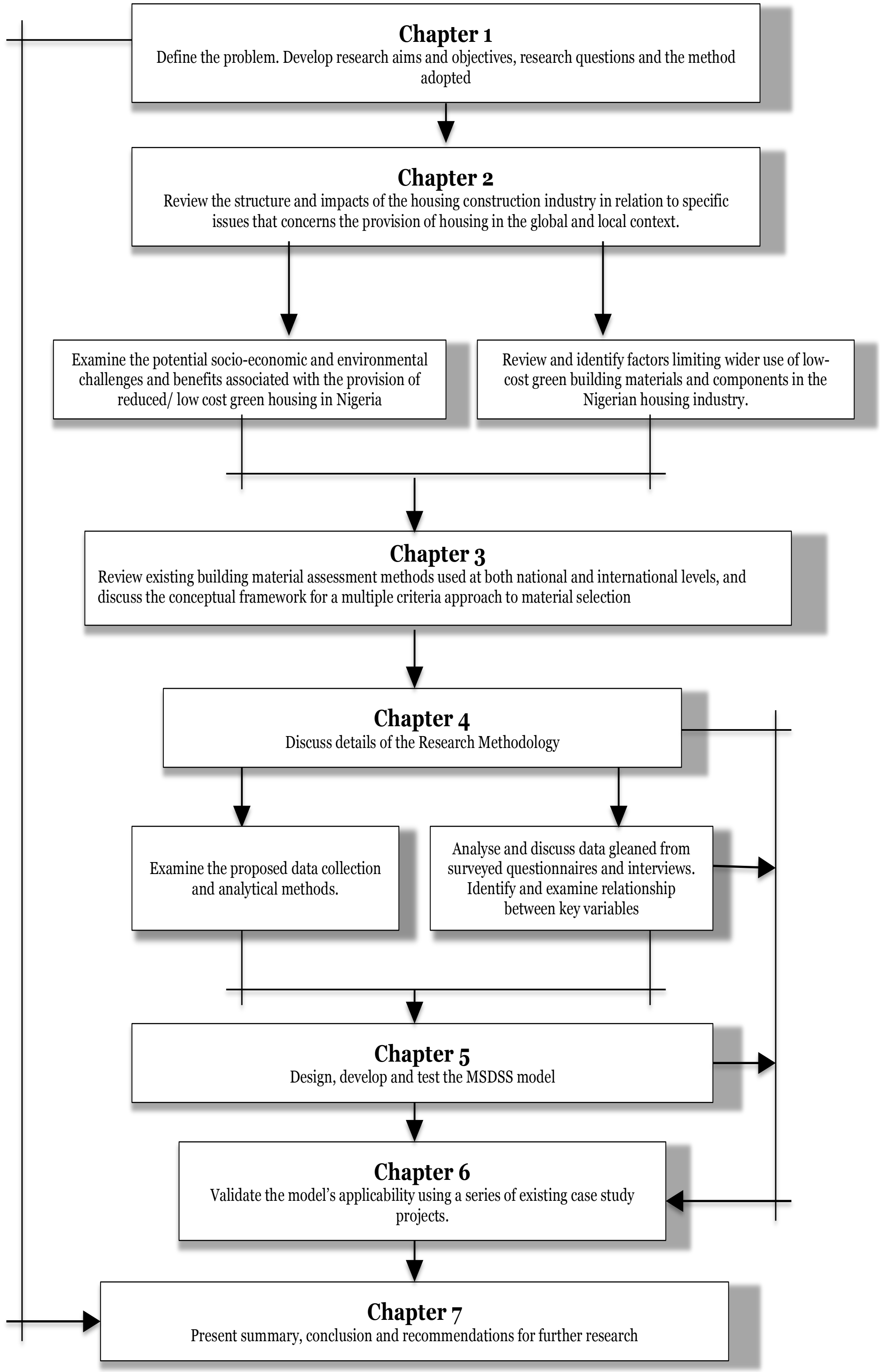


Figure 1.1. Research Structure

Chapter II:

Exploring the role of the housing construction industry, current trends and challenges with focus on low-impact green housing development as a model for sustainable architecture and design

CHAPTER 2: THE HOUSING CONSTRUCTION INDUSTRY

2.1 Introduction

Chapter 1 defined the requisites and rationales that surround the background and theoretical framework of this study, by appraising existing research efforts through published and unpublished academic work, and documentary studies of relevant reports to fulfill the first part of objective 1.

The first part of this chapter serves to demonstrate the role and characteristics of the Housing Construction Industry (HCI) from the global perspective. It exemplifies the resultant effects of decision-making as it pertains to housing construction activities in section 2.3, seeks to identify the most appropriate decision-making approach to housing development in section 2.4, and throws more light in section 2.4.1 on the principles and impacts of the sustainable development (SD) concept in the built environment. The priorities of, as well as barriers to low-impact green housing- as a model of sustainable housing in both developed and developing countries, are further discussed in sections 2.4.2 and 2.5 based on a critical review of extant literature.

The second part of this chapter provides in section 2.6, a quantified illustration of the current structure of the Nigerian housing construction industry. It reviews the socio-economic, health and environmental impacts of the housing construction industry, in relation to population growth and urbanisation. The need for sustainable practices in housing construction is emphasised. Section 2.6.7 further examines low impact green housing developments (LIGHDs) as one way of approaching the ideals of sustainable housing development in Nigeria. Section 2.6.8 seeks to discover how LIGHDs could be incorporated as useful models in future housing developments, through optimal use of low-cost green building materials and components (LCGBMCs).

Section 2.6.9 looks at the modern realities of housing problems, draws specific attention to current decision-making approaches to material selection in the Nigerian housing industry, and identifies drivers and barriers to the implementation of LCGBMCs. Section 2.7 examines the importance of sustainable building material selection approach and attempts to identify the key influential factors that determine sustainable material selection. Section 2.8 concludes the chapter. Chapter 2 fulfills Objective 1 of this research and also provides a basis for achieving the remaining objectives of the study.

2.2 The Role of the Housing Construction Industry: The Global Market Trend Analysis and Statistics

The Housing Construction Industry (HCI) has been identified as one of the main engines responsible for driving wealth creation, stimulating employment, and engineering socio-economic growth in any economy (Du Plessis, 2002). Various writers and international bodies (Adetunji et al; 2003; Ofori, 2006; Du Plessis, 2007; Ogunbiyi, 2014) many of whom have focused on developed (DCs) and less developed countries (LDCs), have addressed extensively, the characteristics, activities and the role of the housing construction industry in socio-economic development from their respective points of view(s). The HCI according to Druker and White (1996) comprises new housing construction work, general construction and demolition work, the construction and repair of buildings, the installation of fixtures and fittings, and building completion work. In a broad context, it is concerned with the planning, regulation, design, material selection, manufacture, construction, repair and maintenance- extension and conversions renovations and refurbishment of buildings (Burtonshaw-Gunn, 2009). Murdoch and Hughes (2008) stated that there is no clear definition as to what the HCI entails, as the issues that pertain to housing construction are broad. As a result of this, there are now many descriptions of the roles and characteristics of the housing construction sector, drawn from different specialist disciplines.

While there are many interpretations given to housing construction in the literature, it will be considered in the context of this study as encompassing the broader process of human settlement creation, everything related to the business of housing, and a comprehensive project cycle (Du Plessis, 2007). Ofori (2004) notes that the HCI contributes to economic development by satisfying some of the basic objectives of housing development including output generation, employment creation and income generation and redistribution (Ofori, 2004). A Global Insight Report (2012) revealed that the global housing construction market is worth over US$ 5.7 trillion per annum according to estimates for the year 2012, enjoying a compounded growth rate of 48% since 1998 where the world housing construction output was estimated at over US$ 3.2 trillion. The analysis in table 2.1 shows the Compound Annual Growth Rate (CAGR) percentage value of the housing construction industry of various DCs and LDCs.

Table 2.1. Annual average growth rates of some nations

Top 10 Market Size Country				Top 10 Annual Growth Country			
Country	Market (100mil.USD)	GDP	Housing CAGR GDP (%)	Country	Market (100mil.USD	GDP	Housing CAGR GDP (%)
U.S.A	8815	2.4	20.5	Vietnam	115	6.0	38.5
Japan	7698	-0.1	26.2	Romania	82	1.8	26.2
China	4182	7.4	42.6	UAE	4016	3.6	59.0
UK	2634	2.6	19.8	Venezuela	262	-4.0	49.3
France	1783	0.2	19.4	Panama	18	6.2	22.1
Germany	1692	1.6	30.7	Columbia	132	4.6	38.2
Spain	1553	1.4	23.1	India	1130	7.4	30.1
Italy	1417	-0.4	23.4	Peru	80	2.4	36.8
South Korea	1247	3.3	38.2	Ukraine	56	-6.8	25.4
Canada	1185	2.9	18.5	Russia	414	0.6	36.3
South Africa	300	1.5	29.5	Nigeria	700	6.3	20.7

Source: Adapted from Global Insight (2015) and Word Bank National Accounts Data (2015)

Giang & Pheng (2011) revealed that an expansion of the HCI could stimulate the expansion of supply industries such as the Building Materials Industry (BMI). The impact of such an expansion on the BMI, they add, could be significantly large as much of the building materials (BMs) could be provided by unskilled labor-intensive domestic recourses. They note that the value added by HCI through BMs account for a considerable proportion (roughly 50% to 80% of its total value) of the global GDP.

BMs are the largest with an annual turnover in excess of $60 billion, accounting for approximately 40% of total global construction output and 20% of the UK's manufacturing output (USDOE, 2010).

In emerging economies such as in the continent of Africa for instance, BMs are estimated to account for 5-8% of the total value of the annual GDP (World Bank, 2012). Although the BMIs in LDCs account for an overwhelming majority of national economic growth, they have also been underperforming relative to BMIs in advanced economies (Adedeji, 2010). As economies within such regions experience population growth, housing infrastructure projects are most likely to evolve to match the level of income and demand. However, due to the implicitly apparent weak economic status of most HCIs and BMIs in LDCs, it is difficult to meet these demands, therefore imposing huge constraints on economic and housing development (Oluwakiyesi 2011). While BMs, which account for 50% - 80% of the total value of construction (USDOE, 2010) forms a key factor in the housing construction sector's response to the needs of human settlement, the impact of appropriate building material choice discourse in academia is resurgent despite numerous studies. As such there has been a revived growing debate on the need for energy efficient building materials as the demand for quality housing is now more critical in main urban centers (Abisuga and Oyekanmi, 2014). Following the high increase in demand for adequately sustainable and affordable BMs, various studies (Kibert, 2008; Seyfang, 2009a) have emphasised the appropriateness of locally- produced and recycled materials in meeting the growing demand for adequate housing. Despite this abundance, very little is known of their impacts on housing development when compared to their conventional imported carbon-embodied equivalents. As a result, the HCI is now replete with GHGs and unsustainable construction practices, which is often associated with the use of materials such as steel and cement (Malanca, 2010). Nevertheless, the global impacts of current housing decision-making practices are assumed to be severe (USDOE, 2010).

2.3 Resultant Effects of Poor Decision-Making Practices in the Housing Construction Industry

Since the beginning of the Industrial Revolution, the housing construction industry has engaged in a pattern based upon material goods, in which unlimited development, mass production, and ever-increasing consumption have been the order of the day (Ofori, 2004). Accordingly, industrialized and emerging nations throughout the world have implemented comprehensive policies to promote accelerated economic growth and manufacturers have responded by shifting their focus from quality to quantity as they continually strive for increased production and profits (Kyounghoon et al., 2008). Housing industrial activities are now known to be the principal cause of recent environmental and health crises through exploitation and pollution, and yet its activities rely heavily on a healthy environment for its sustenance and productivity. The following section provides an overview of the decision-making consequences resulting from housing construction activities.

2.3.1 Climate Change

Climate change has been known to be the greatest environmental challenge facing the world today (USDOE, 2010). Modern society is releasing unprecedented amounts of carbon into the atmosphere through the burning of fossil fuels (IEA, 2008). A subsequent report, published in 2001, confirmed that there is a climate change-induced effect, greenhouse effect and the increased atmospheric concentration of carbon dioxide caused by housing construction activities some of which include air pollution, allergen exposures linked to climate change, increased cardio-respiratory disease, and global warming (Meadows and Hoffman, 2003). The U.S. Environmental Protection Agency (USEPA, 2004) argues that total emissions from the developing world due to housing activities are expected to exceed those from the developed world by 2015 (as shown in figure 2.1).

These activities, it adds, will cause the global temperature to rise as increasing global temperature warms and expands the oceans, melts polar ice caps and, in turn, raises sea levels. To meet the housing demands of householders wishing greater self- sufficiency from expensive and potentially unreliable energy supplies, governments across the world are beginning to recognise the calamity of this situation and are currently working towards alternative environment friendly decision-making approaches (Copenhagen, December 2009). The imperative of climate change signifies that current housing activities and technologies need to develop in order to meet the demands of climate change predictions, while simultaneously reducing the contribution they make to CO_2 emissions. The concept of limiting greenhouse-gas emissions through responsible decision-making approach and housing practices is now widely accepted and embraced by governments as an increasingly important issue.

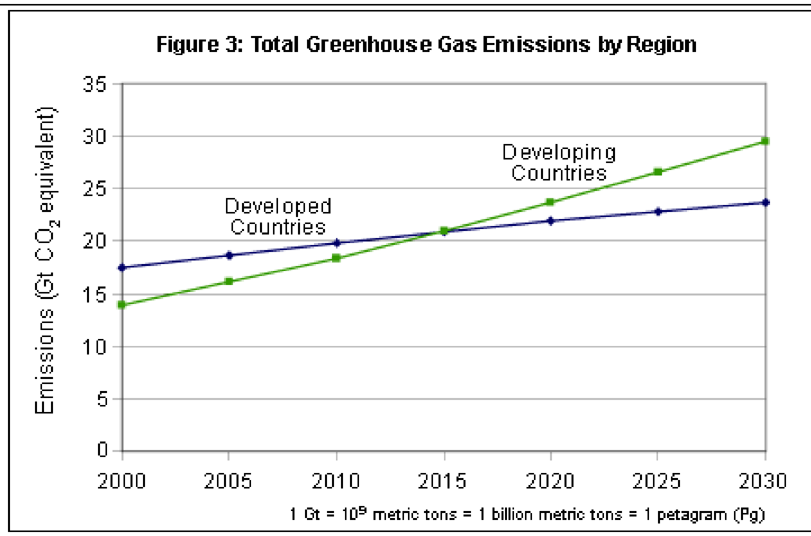


Figure 2.1. World greenhouse gas emissions by region: A projection of future greenhouse gas emissions of developed and developing countries

Source: United States Environmental Protection Agency (EPA).

2.3.2 Loss of Biodiversity

While further promotion of economic growth and housing activities worldwide are seen as the way to lift most developing countries out of poverty, they are also responsible for promoting resource depletion and reduction of biodiversity. Biodiversity refers to the variety of life of Earth (Kibert, 2008). A report by Kibert (2008) revealed that housing construction activities are destroying natural habitats and reducing it. The rate, at which species are disappearing due to these activities, he notes, is about 1,000 to 10,000 times the normal rate, adding that more than 25 percent of all species could disappear within the next two decades (Glasby, 2002). He noted that the extinction of one specie may eventually lead to the loss of many others dependent upon it, if no proactive step is taken to discontinue or alter current decision-making practices within the housing sector, and that it may eventually result in an accelerated loss of important genetic information.

2.3.3 Material Waste generation

The HCI has a major impact on the environment, both in terms of the resources it consumes and the waste it produces. The housing construction industry is responsible for producing a whole variety of different wastes, the amount and type of which depends on factors such as the stage of construction, type of construction work and practices on site (Du Plessis, 2002). One of the main barriers lies in the increasing amounts of material waste generated from housing construction activities and dumped in landfills. Although solid waste is generated by different economic activities, the HCI has always been considered as one of the major producers of waste (Du Plessis, 2007). The U.S. Environmental Protection Agency (USEPA, 2004) reported that 170 million tonnes have been generated in the US in 2003 and that 1900 Construction and Demolition (C&D) landfills are operating in the US to receive disposed material waste.

According to Eurostat report, 2 billion tonnes of waste is generated every year in European Union (EU-15) and the share of housing construction waste is 31% (DEFRA, 2007). Many factors such as poor decisions in the material choice, design, and handling of materials at the crucial stages of the design have been identified as primary contributors. This thus suggests an urgent need for an optimal decision-making approach to minimise or completely stave-off material waste when selecting building materials at the earliest stages of the design or undertaking construction activities in the HCI.

2.3.3 Social Change: Population Growth and Urbanisation

Population growth and urbanisation are clearly major threats to the environment (World bank 2012) and there is no doubt that the human population has been putting increasing pressure on the ecosystem through housing activities (Ofori 2006; USDOE, 2010). As a result, there have been constant increases in pressure on renewable and non-renewable resources, reducing the amount of capital and productivity per worker, and increasing the inequality of income. The United Nations (UN, 2012) report estimates the global population is to increase to eight billion in 2025 and nine billion in 2050 and approximately eight out of nine people will live in poor developing countries, hence creating more demand for housing within the urban centres due to social change in the life-style of persons within rural areas. In order to maintain housing production, professionals are enjoined to use highly-energy intensive building materials. Houses which are dependent on such materials, tend to affect the environment during production, transportation and use which, in turn, will require more of such materials in succeeding years to meet the rising demand for housing. This increased use of such products has increased the rate and effects of global warming, hence the need for alternative materials and housing models to harness a new approach to thinking about housing development so as to facilitate a renewed drive for greater performance improvement.

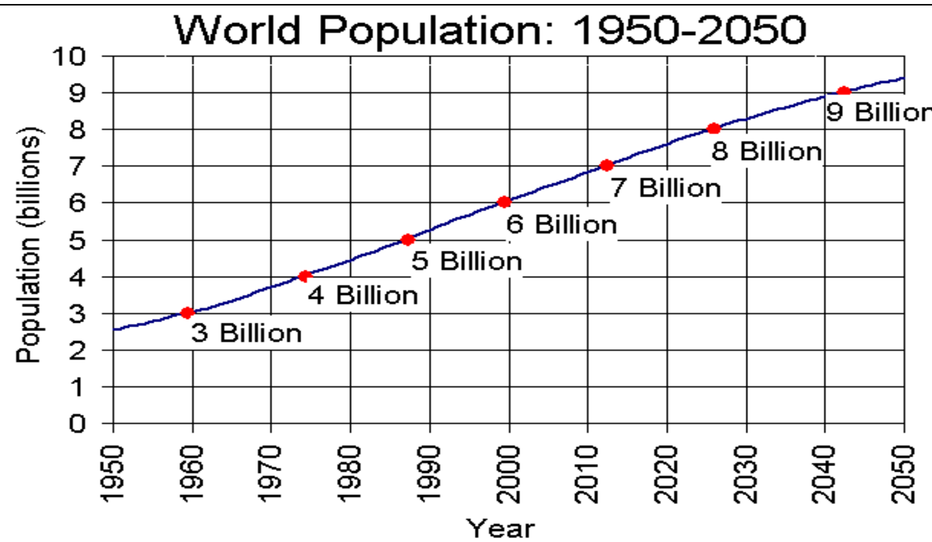


Figure 2.2. World population growth, actual and projected, 1950-2050

Source: WRI and Population Reference Bureau (2006) revision

With the identification of the underlying issues, it is thus evident that the HCI besides its economic benefits plays a major role in the current environmental and health crises. In pursuing the mission for change, many countries are now working towards maintaining a balance between developing the built environment and protecting the natural environment. Both scenarios point to the urgent need for new, more sustainable decision-making approaches to urban housing development. While housing strategies must be tailored to local conditions, they should be crafted with today's changing environmental, socio-cultural, and economic realities in mind. This therefore suggests that changes must be made in the manner that the HCI undertakes its activities, in order to create a balance between economic growth and environmental/health protection. The reviewed factors in the foregoing section, it is believed may have provided justification for the use of an alternative theory of housing construction, and as such, this study critically examines the case for a new form of housing construction and development practice.

"*We shall therefore require a substantially sustainable new manner of thinking if mankind is to survive.*" – Albert Einstein

2.4 Seeking an Alternative Decision-Making Approach to Housing Development

There is no denying that the HCI is responsible for the amount of pollutants dumped onto land, climate change, generation of hazardous waste, pollution, resource depletion and loss of biodiversity, which are the main causes of biologically and ecologically destructive phenomena (Kibert, 2008). Considering these issues, there is now a widespread directive that the housing industry finds an approach to balance population and economic growth with the protection of the environment to deliver a more responsibly conscious pattern of development. Due to the relative adverse effects of housing activities, the concept of sustainable development has now become a key theme in housing development (Ding, 2008), hence a review of its principles.

2.4.1 Sustainable Development Principles in Housing

Sustainable Development (SD) has become pre-eminent in the discussions on the relationship between humankind and nature. It has also evolved as a mainstream research focus and much attention has been devoted to the SD agenda from researchers of various backgrounds (Brundtland, 1987; Price et al., 2003; Du Plessis, 2007). As a result, there has been a proliferation of sustainable development policies, innovative technological, scientific and educational initiatives, and new legislative regimes and institutions.

However, the understanding of what constitutes the principles of "sustainable development" is now fairly well developed, and in some countries several definitions have been adopted based on specific criteria related to the use of materials, design, water, energy, and comfort (Trusty, 2003; Ding, 2008). Not surprisingly however, most countries lack such systems, as there is no universal consent as to which principle indicators constitute SD.

Cole (1999) argued that such a global definition would probably be quite meaningless because of the widely different conditions in different countries (particularly where the climate, the entire structure, need for heating/cooling, access to materials, culture and economic considerations are very different). As a result, a wide variety of institutional bodies, particularly within the housing sector have adopted the concept and given it their own particular interpretations. Nonetheless, there is a clear need (as would be demonstrated in this section) to quantify thematically, what factors constitute SD principles.

Popularly defined as "a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (Brundtland, 1987), numerous organisations-such as the housing construction industry, have proposed sustainable development as an alternative model for global economic development as a result of worldwide recognition of the negative effects of current and potential environmental degradation on social development. However, the broad recognition that the environmental principles matter, according to Brundtland's (1987) definition, often extends only as far as a belief that we can pursue economic growth without compromising the environment through a 'reorientation' of free-market capitalism.

Another definition of SD is the idea by Pinchot in the USA (Dryzek, 1997), which recognises that humans do need natural resources and that these resources should be managed, rather than rapidly exploited, in order to ensure maximum long-term use. This was seen as the key to humanity's well being and, through growth, poverty would be overcome: as everyone floated higher those at the bottom would be raised out of poverty. This principle of SD is usually due to associating development with economic growth. It can be argued that development and economic growth are mutually exclusive. For example, development could mean a general improvement in the quality of life, the surrounding environment or greater social stability. Hence, development is a qualitative change whilst growth is a quantitative change.

Postle (1998) however goes further suggesting that the principles of SD, as a concept, has a far wider reach than economic growth, encompassing a whole range of social, environmental and cultural factors such as employment, social welfare, culture, and infrastructure. He notes that SD achieves these outcomes by focusing on them from its conception and first stages of design, implementing them throughout construction, and by continually monitoring and measuring its performance in operation. Postle's linking of environmental and social concerns is however, based on a moral sympathetic outlook rather than seeing the two as materially and socially related and inseparable. Cole (1999) suggests that the principles of SD, as environmental, social and economic dimensions, embrace all facets of human activities (industry, transportation, food production among others), and spans local actions through to redressing the major inequities that exist between developed and developing nations. Given the political and economic interdependencies, where the actions of one nation profoundly affect others, the notion of `SD' from Cole's (1999) is meaningful only when applied on a global scale.

Priemus (2005) went on to criticise the global orientation of SD by Cole (1999) as being inadequate, in the sense that sustainable development takes place on different scales, and, as such, the quality and availability of say water, noise nuisance etc., all play various roles at different local and regional levels. Simply put SD principles are widely different depending on how the concept is developed in various countries.

Fiskel (2006) suggested that SD in the face of ever-increasing global complexity and volatility, will require resilience at many levels, including human communities and economic enterprises, and that it must move beyond a simplistic steady state model of the concept. He noted that policies and strategies must enable societal and industrial institutions to cope with unexpected challenges, balancing their need to flourish and grow with long-term concerns about human and ecological well-being.

Banfill and Peacock (2007) however think that the principles of SD deal with a lot more aspects than what Fiskel (2006) presumes, as it includes the use of energy and its effect; resources and materials; water and its disposal; pollution; waste; health; well-being, and the effects of human actions on the biosphere and habitats.
Sodager and Fieldson (2008) argue that tackling strictly environmental sustainability alone- as Banfill and Peacock (2007) seem to suggest, is not enough, as there is need for an integrated approach to address all three principles of sustainable development. The integrated approach according to Sodager and Fieldson (2008) must rely on the collaboration of all stakeholders in the building industry to quantify and interpret emissions throughout the building lifecycle. Their concept centered on three main issues: the relevance of sustainable housing, the constituent of a sustainable housing, and the process of obtaining such practice.

Pickerill and Maxey (2009) argue that the concept of SD by Sodager and Fieldson (2008) is a very weak interpretation of SD, in that the principles of sustainability is broad in terms of scope and context as well as practices, as it is simultaneously able to broadly encompass all aspects of life (social, economic, political, etc.) They note that the environmental benefits are improved air and water quality, reduced energy and water consumption, and reduced waste disposal. They added that the economic benefits are reduced operating cost, maintenance cost, and increased sales price and rent while enhanced health and occupants comfort, and reduced liability are the health and community benefit.
Construction Industry Environmental Forum (CIEF, 2009) suggests that SD is a solution for significant cost savings, to bring innovations and to enhance competitiveness for the long-term survival of any industry. Sustainable construction practices however, do not only provide increased market share and profitability but also bring many other intangible benefits such as quality in construction, and improved shareholder relations.

Sebake (2009) and Gibbered (2003) observed that SD in the context of the developed countries only addresses the conflict between protecting the environment and natural resources, and answering to the development needs of the society. They noted that SD particularly in the context of the developing countries would not be possible without tackling the problems of poverty and social equity both between people and nations. They contend that various definitions of SD are often hypothesized to be consistently and universally similar, therefore can always be readily adopted by any nation, suggesting that the economic emergencies of developed nations are typical of the less developed nations, thus ignoring national circumstances, value systems or current priorities. They suggest that the first step to achieving SD in LDCs is by raising standards of living through the identification of not only environmental issues but also the socio-cultural and economic challenges.

In summarising the discussions above, it is reasonable to state that SD is rarely a 'fixed' objective through time, therefore entails more than just eco-friendly measures in determining a successful outcome. The variety of definitions associated with SD therefore shows that the attractiveness (and the dangers) of sustainable development may lie precisely in the varied ways in which it can be interpreted and used to support a whole range of interests or causes. Although these themes provided many useful sustainability principle indicators in general, it is not sufficient to consider only the economic, and environmental dimensions of the concept, as there are numerous contexts- internal and external- that shape the process. A more comprehensive list of the sustainable principle indicators that should be addressed is therefore needed. However, in rapid housing development activity, low-impact green housing development concept has become a major housing strategic model and demonstrated considerable success when applied to new housing development for mass housing (Fairlie, 2008). Thus, the suggestion that the low-impact green housing concept displays a greater degree of sustainability than conventional house build approach merits further consideration and review.

2.4.2 Low-Impact Green Housing Development in Developed Countries: An Alternative Approach to Sustainable Housing

The increasing concerns about the sustainability of modern consumer lifestyles in the housing industry have led a number of professionals to seek for themselves different models of sustainable developments that are less demanding of resources. The complexity of providing sustainable affordable housing in sub-urban and urban dwellings is now evident from various research literatures (Fairlie, 2008; Maxey, 2009). For some (Kibert 2008; Seyfang, 2010), this has meant living in a dwelling, deriving energy from renewable resources, locally-sourced products, recycling waste materials (in accordance with the proximity principle), and/or avoiding pollutants. Tied to the concern of population growth, material waste, climate change and loss of biodiversity with sustainable development is a consideration of Low-Impact Green Housing Developments (LIGHDs). Research into LIGHDs has consistently found that it meets the criteria of economic, social and environmental sustainability (University of West England and Land Use Consultants 2002). The evidence to date suggests that LIGHDs have a better chance of achieving these aspirations than even the eco-towns in terms of location, materials used, scale and traffic generation (Fairlie 2009). LIGHDs have demonstrated sustainable solutions including low/zero carbon housing design, renewable energy generation, and waste minimisation (Maxey, 2009).

Pickerill and Maxey (2009) argue that the aspirations of SD are firmly embedded within LIGHD, which is a social as much as a physical model, reflecting current environmental, social, technical, cultural, emotional, political, ethical and economic concerns and aspirations of the growing population. They note that LIGHDs are a good vehicle through which to explore radical and innovative forms of SD and to critically assess their potential as a response to current environmental, social, economic and health issues.

It is therefore hard to avoid the conclusion that the housing industry has yet to fully grasp sustainable development as the strong sustainability performance of LIGHD is overlooked in planning decisions for housing design projects. An outline of what LIGHD is and what it offers in terms of its SD impact on housing development is presented below. By defining its purpose and concept as an evolving approach that offers practical housing solutions to the vast majority of the population, it explores its rationale, barriers, and its role as an alternative approach to sustainable development in the housing industry.

2.4.2.1 Definition and concept of low-impact green housing developments

Low Impact Green Housing Development (LIGHD) is a recent innovation pioneered in the UK (Fairlie, 1996). It has been characterised as an intrinsically sustainable form of development as it employs approaches that dramatically reduce humans' impact upon the environment, demonstrating that human settlements and livelihoods, when done appropriately, can enhance, rather than diminish ecological diversity (Pickerill, 2009). It is described in housing as a development that employs natural, reclaimed and/or local materials, and renewable technologies (Seyfang, 2010).

Fairlie (1996) describes it as: "a development which, by virtue of its low or benign environmental impact, may be allowed in locations where conventional development is not so often permitted". A revised version further exemplifies it as a development that, through its low negative environmental impact, either enhances or does not significantly diminish environmental quality. While this seems to be a broader definition than the former, it can be argued that Fairlie's (1996) concept of LIGHD is still mainly concerned with the environmental impacts of subsistence-based development in rural locations where residents draw many of their daily needs such as energy from the site.

Moyse (1999) provides a slightly different approach as; "settlements where the acreage is minimised, or, at the very least, brought below the national average by reducing the consumption of goods and materials and the production of waste" (p90), essentially reflecting the desire to minimise environmental impact through reducing the environmental footprint of development. Moyse's (1999) definition seems slightly restrictive to environmental concerns, and fails to acknowledge that LIGHD also directly responds to social needs for housing, an anti-capitalist strategy forging alternative economic possibilities, and a holistic approach to living that pays attention to not only personal issues but also political needs.

Steen (2000) notes that LIGHD integrates nature into its design, transgressing the nature/culture divide and blending with its surroundings, ensuring a low visual impact. His concept of LIGHD is closely associated with types of rural settlement typified by modest dwellings whose occupation is closely linked to the management of the land on which they stand.

Wrench (2001) notes that LIGHD often also increases ecological diversity, challenging dominant understandings of an inevitably antagonistic relationship between 'humans' and 'nature'. Vale (2001) goes a little farther to state that LIGHDs, in addition to its ecological impact, are designed to support sustainable livelihoods and lifestyles by minimising vehicle use, reducing costs (and, hence, the need to travel to earn money) and reducing consumption.

Maxey (2009) further expands on it by describing it as a "multi featured and intrinsically integrated form of development," and goes on to develop a detailed themed definition with detailed criteria such as: locally adapted, diverse and unique; based on renewable resources; of an appropriate scale; visually unobtrusive; enhances biodiversity; increases public access to open space; generates little traffic; linked to sustainable livelihoods; and coordinated by a management plan.

He adds that LIGHDs are buildings constructed from materials with low embodied energy and environmental impact, and preferably from locally sourced materials, unless environmental considerations or the use of reclaimed materials determine otherwise. He adds that LIGHDs must be such that it should be allowed in a wider range of settings.

From the analysis it can be deduced that the key strength of LIGHDs is one of an evolving nature that must be designed to innovate and adapt to changing environmental, technical, social, ethical, political, cultural and economic conditions. Therefore, a simple definition cannot capture the vast constituents of LIGHD. In other words, definitions and interpretations of LIGHDs need to be flexible to respond to its dynamic nature, not only where it employs natural, reclaimed and/or recycled products, locally sourced materials, renewable technologies, but also where the majority of the criteria are met.

Thus the definition adopted for this study does not distinguish locations where LIGHD should or should not take place. Rather, through the effective use of LCGBMCs -considering all the essential criteria, it recognises that development can take a variety of forms in different locations, and still fulfill the requirements of LIGHD. Following the feedback from empirical studies Low-Impact Green Housing Development (LIGHD) for the purposes of this study would be defined as:

"Any development- which through its effective and harmonious use of LCGBMCs, yields a low negative carbon-embodied life-cycle energy impact that either enhances or does not significantly diminish the economic, socio-cultural and environmental quality of the user or region it intends to serve".

The following sections exemplify the rationale, drivers, and barriers impacting LIGHDs and their implications for today's housing in developed regions.

2.4.2.2 Rationale for low-impact green housing in developed countries

Low Impact Green Housing Development (LIGHD) is a recent innovation pioneered in the UK (Fairlie, 1996). It has been characterised as an intrinsically sustainable form of housing that plays a significant part in the reduction of CO_2 emissions (CLG, 2007b). The Department for Environment, Food and Rural Affairs (DEFRA, 2005) further confirm how housing is responsible for over a quarter (28 per cent equivalent to around 150 million tonnes of carbon a year) of the UK's CO_2 emissions. Although varying across countries, there is a general need for more cost and energy efficient housing. Housing markets have become increasingly competitive, as middle class housing choices have shifted to properties in the sub-urban dwellings, combined with the desire for energy efficient structures. There is now a need to intelligently and intensively manage our surrounding environment in order to maximise return (in the forms of energy, water, food, shelter and products) and minimise waste (through recycling, composting and energy efficient systems). Thus providers of housing have increasingly had to turn to various mechanisms, such as housing policies (Shelter, 2004). In a bid to restore the balance between humanity and the environment, there have been planning campaigns that inspire a structured response to the situation, hence recognising the potential role of low-impact green housing developments in the transition to a sustainable built environment (Fairlie, 1996).

With the increasing numbers of people aspiring to live low-impact lifestyles, the need for the movement to express itself is growing. Low-impact green housing development is now being considered as having the potential to simultaneously address a whole range of issues including sustainability, affordable housing and rural-urban regeneration. A study by Shelter (2004) revealed that the shortage of affordable housing in rural and sub urban areas has been exacerbated by competing demands on the market from retired households and second home purchasers (Shelter, 2004).

Maxey (2009) pointed out that the lack of affordable housing for people who live and work in rural and sub-urban communities has been a serious problem for many years. This trend he adds, is likely to be one of the reasons why there is now an interest for alternative low-impact models of housing. Smith and Baird (2007) found that 'the need for reduced energy costs' is one of the primary drivers for low-impact green housing developments in developed nations. Miller, Spivey, and Florance (2008) estimate the productivity benefits from low-impact green housing designs to be as much as 10 times the energy savings from green efforts. Hence, understanding what main drivers affect the implementation of LIGHDs would be pertinent to the theme of this research.

Drivers for low-impact green housing, other than financial performance, are outlined, for example, by Yudelson (2010), and include: utility cost savings for energy, maintenance cost reductions, increased occupier productivity, improved health of occupants, and demonstration of commitment to sustainability and environmental stewardship. Fairlie (1996) acknowledges that most buildings will not meet all these requirements (referring to LIGHD as a rather ideal model being small-scale; unobtrusive; a building made from predominantly local materials; able to enhance biodiversity; a building that consumes low levels of non-renewable resources; a building used for sustainable purposes; linked to a recognised positive environmental benefit and a building with relatively low ecological footprint''), and argues that any truly low- impact green housing development (as opposed to conventional energy intensive housing developments) will conform to many of the aforementioned criteria.

In their current pursuit for sustainable development, Reddy and Mani (2007) argue that LIGHD structures hold enormous relevance and potential in providing solutions for environment-friendly buildings that are affordable, energy efficient, comfortable and recyclable.

Although there have been extensive literature as to the benefits of low-impact sustainable green housing in the last few years (Shelter, 2004; SOCR' 2007), and a number of quantitative studies on the drivers that impact on LIGHDs in developed countries (Boyle 2007; Smith and Baird, 2007; Fairlie, 2008), certain barriers still prevail.

2.4.2.3 Barriers affecting the implementation of low-impact green housing in developed countries

While a substantial amount of studies (Fairlie, 1996; Maxey, 2009; Seyfang, 2010) have discussed the SD benefits of LIGHDs over the last 10–20 years, many of their innovations have not been widely diffused in the developed regions (Seyfang, 2010). Evidence (Lovell, 2004; Smith 2007) has suggested that this may in part be due to the co-existence of fundamentally different discourses, practices and governance of sustainability between the mainstream system of housing provision and green researchers. Consequently the barriers to the transfer of such practices encompass ideological, cultural, social, political and ethical factors, as well as economic and technical ones (Smith, 2007; Shove, 1998; Lovell, 2004).

Smith (2007) states that LIGHDs have little compatibility with the mainstream system of housing provision, and as a result have little linking potential and growth prospects across all the socio-technical dimensions including guiding principles, technologies and infrastructure, industrial structure, user relations and markets, policy and regulations, knowledge base and cultural meanings (Smith, 2007, p. 429). In their study, Van Vliet et al. (2005) found that LIGHDs were limited by current regulatory frameworks designed for public housing provision, since such policies are infused with certain notions of what constitutes safe and efficient housing (Van Vliet et al., 2005, p. 93). Compounding this limitation are the facts that mainstream framings of sustainable housing continues to focus predominantly upon technical and environmental aspects, whilst overlooking the socio-cultural benefits and guiding principles underpinning LIGHDs (Smith, 2007, p. 437).

Another biggest barrier affecting the wide scale implementation of LIGHDs is the perception that they are the interest of a minority of people, and for the most part are temporary. Fairlie (1996) pointed out that LIGHD is most often mistakenly viewed as a niche or marginal area, and that the idea of it being small, muddy, temporary shelters/ shacks has consistently reinforced this notion. He further noted that current incentives are not yet strong enough to change the long-held perception of LIGHD by most professionals, and that its benefits are only evident over the longer period. Many articles on policy measures have also been discussed. Other barriers, either to illustrate the need for policy measures (Moyse, 1999: Vale, 200; Maxey et al., 2006) or to explain why LIGHD are not as successful as expected (Wrench 2001, Lovell, 2004; Seyfang, 2010). Barriers such as: economic/financial barriers, market failures, behavioral and organisational constraints, political and structural barriers and information barriers were recognised in Seyfang (2009a). Other specific circumstances that give rise to these problems as identified by Lovell (2004) relates to geography, climate, personality, economics, culture, politics and values.

Given the current need to develop low-impact sustainable housing in developed regions, it can be seen that a tension exists in mainstream housing provision, and therefore a supportive policy agenda could go a long way to help capitalise on the learning and experience of LIGHD, in answering that need. Thus, increasing regulatory pressure to improve building standards for low-impact green developments may help to reinforce or even force mainstream professionals to implement LIGHD models. In order to draw a comparative analysis, the drivers and barriers to LIGHDs are further addressed with regards to SD in the developing regions. Aspects of affordability, design decision-making, material selection, appropriate technology use, and cultural awareness are examined in details.

2.5 Low-Impact Green Housing in Developing Country

Current demand for housing worldwide has reached unprecedented levels due to factors such as human population growth, natural disasters and conflict (World Bank, 2012). This is felt no more so than in developing countries, which have experienced disproportionate levels of demand due to their innate vulnerability (UN, 2012). Many current approaches to housing delivery in developing countries continue to utilise inappropriate housing models that are often problematic and unsustainable. As such, affordability and sustainability are now vital considerations in the international development debate for housing the most disadvantaged population in developing countries in order to meet the long-term sustainable development goals and needs of housing inhabitants.

Low-impact green housing developments (LIGHDs) also meet more than human's immediate needs and has the potential to contribute significantly to a wider socio-cultural, environmental and economic context and to a better quality of life and personal fulfillment for its inhabitants through aspects such as employment generation, knowledge transfer and training, value and cultural continuity and improved health conditions (Erguden, 2001). Just like in the developed regions, there are also barriers and drivers that impact on the implementation of LIGHDs in developing countries

2.5.1 Key Barriers that Impact on the Implementation of Low-Impact Green Housing in Developing Countries

Despite the benefits of LIGHDs, the struggles for adequate and sustainable housing in many developing countries are considerable and still continue to rise. Low-impact green housing shortages within the context of the LDCs can often be traced back to three main sources as follows:

• Lack of government or political backing of low-impact green housing developments

While there have been efforts to implement low Impact green housing developments in DCs, current literature (Adedeji, 2012; Abisuga and Oyekanmi, 2014) assert that LIGHDs are yet to receive the same attention from the industries in LDCs (UNCHS, 2007). This means that the housing industry is not as involved in the participatory exercise of incorporating LIGHDs into mainstream housing as to the level that they should be to ensure that long term settlement needs are satisfied in an appropriate manner. Erguden (2001) highlights that policies and models for housing in developing countries have evolved over the past number of decades, with little or no interest in LIGHDs. Although the enablement-based approach has generally been considered to be the most appropriate, he argues that many approaches and models currently fall well short of the desired aspirations in relation to affordability and sustainability.

• Lack of training and education in sustainable design and construction of LIGHDs leading to lack of necessary design and building skills available;

Reffat (2004) states that the concept of LIGHD as a SD niche has only recently been introduced into the construction industries of the developing nations and that even sustainable construction is as yet not an essential part of the decision-making process. He noted that traditionally, affordability and sustainability in mainstream housing markets within the LDCs is associated with economic and social sustainability with little emphasis on environmental sustainability. He added that perceived higher costs and underlying socio-cultural factors also contribute to the lower levels of social acceptability of low-impact green housing construction in the mainstream affordable housing market.

- **Psychological and sociological perceptions ascribed to the associated building materials and their limited acceptability by people;**

A large number of studies (Zami, 2010; Abisuga and Oyekanmi, 2014) have stressed that local and recycled building materials serve as good alternative in low-impact green housing construction and that the use of them go along way in ameliorating the shortage of housing in LDCs, thereby reducing importation and cutting down the excessive cost and energy, which is often associated with conventional products. Yet, there have been uncertainties about the use of such materials in housing projects when compared with their imported counterparts. The reasons being that some professionals argue along the line that the status of such materials is deemed only for the poor hence are ill informed about their sustainability impacts and reticent towards their use.

2.5.2 Factors that Drive the Implementation of Low-Impact Green Housing in Developing Countries

While the analyses conducted in section 2.5.1 revealed the three main forces inhibiting the implementation of LIGHDs in developing regions, there are three main broad areas that offer the potential to significantly contribute to the provision of affordable and sustainable LIGHDs in developing countries. These areas are discussed as follows:

- **Need for Appropriate Design and Building Materials**

The UN Habitat (2011) suggests that efforts to address immediate housing needs should simultaneously address the long-term needs and sustainability of the communities that they intend to serve in terms of social, economic and environmental sustainability. The increasing demand for sustainable housing has resulted in an urgent need for crucial research into new design approaches and use of appropriate building materials in housing delivery (Malanca, 2010). Selecting locally-sourced and recycled building materials over conventional products have been recognized by many (Adeyemi, 2002;

Abisuga and Oyekanmi, 2014) as one of the main contributors to the provision of affordable and sustainable low-impact green housing, as BMs contribute up to 70% of the total direct costs of housing construction (UN Habitat, 2011). Sebake (2009) suggests that increasing the quality of life in developing countries requires optimum use of locally sourced and recycled materials over imported materials, so as to increase the potential for greater affordability. Adeyemi (2002) also noted that the use of localized materials is a key driving force for LIGHDs since it has the potential to dramatically reduce the cost of housing compared to imported materials, while simultaneously contributing to sustainable housing solutions.

- **Participation, Knowledge Transfer and Use of Appropriate Innovative Technology Specific to Developing World Contexts**

Evidence (UN Habitat, 2011; Adeyemi, 2002) has shown that sustainable development approaches and technologies established in the west are not always desirable and that if not implemented correctly, these approaches will prove unsuccessful. As such, the need for new approaches for the vastly different contexts within developing countries and local conditions have been emphasised; whilst given full recognition to knowledge and culture. However, participation by relevant stakeholders particularly from their developed counterparts in all stages of the design and delivery process has been recognized as an appropriate approach to housing provision in developing country contexts (Kibert, 2008). Knowledge creation, exchanging and sharing of skills, knowledge and experiences between the relevant stakeholders are now being recognized as effective approaches in ensuring that technical, cultural, economic and environmental aspects of low-impact green housing design and delivery are addressed in an appropriate manner. Ofori (2000) pointed out that the use of appropriate technology should work in conjunction with the available materials and should correspond to local conditions and culture and be durable, reliable, require a minimum of maintenance and be fit for modern living.

- **Informed Decision Making Assistance and Assessment Tools**

Decision-making in housing construction plays an important role in supporting sustainable development in developing countries, and as such is a significant issue that must be prioritised. However, it is recognised that decision-making is a complex one and that an assessment framework and structured approach are effective methods to integrate sustainability into the decision-making process of buildings in developing countries (Du Plessis, 2002). Reffat (2004) suggest that the problem with many responses to LIGHDs in the developing regions is that decisions are made with limited knowledge and information, adding that sustainable assessment tools to date have mainly focused on a developed world context. Aside from established assessment tools from developed nations, Nwokoro and Onukwube (2011) argue that there is little in the current literature that demonstrate the existence of any main assessment tool specifically directed to sustainable low-impact green housing in developing countries. However, the need to develop context specific assessment tools for developing countries that cater to the needs of a wider group of stakeholders has been recognised, given that existing developed country tools are deemed inappropriate to deal with issues that pertain to developing countries (Reffat, 2004; Sneddon et al., 2006).

It thus can be summarised from the analyses that many individual countries- within the developed and developing countries, will have region specific factors that will require more in-depth study by designers operating within that context. This is to fully establish issues associated with low-impact green housing in sufficient specific detail, and to ensure appropriate design responses for that specific region. As a case in point of the housing situation in developing countries, this study aims to investigate the current approaches to housing in Nigeria with focus on low-impact green housing developments. Amongst other issues, the barriers and drivers that impact on the implementation of low-cost green building materials are discussed, and factors that influence sustainable material selection are also examined.

2.6 The Nigerian Housing Construction Industry

2.6.1 Background and Context

The United Nations Fund for Population Activities (UNFPA, 2007) stipulates that 40% of urban growth between 2030 and 2050 is expected to occur mostly in Africa, and as a result, will increase from 13 to 27 million per annum (United Nations, 2006a). Current projection holds it that over 50% of the population in Africa is expected to live in urban areas by 2020 and most of this transition will occur in Nigeria (UN, 2010). It is argued that Nigeria's economic growth owes much to the sheer size of its population (UNDF, 2011). Despite their benefits, population growth and urbanisation have had their own share of socio-economic and environmental woes ranging from degradation of the physical urban environment— which exists in the nature of loss of biodiversity and green-house warming, waste of material resources, high energy consumption to housing congestion (Jiboye, 2009). These challenges are further complicated by changes in household composition and housing needs, and diversity of the population.

With a median age of 19 years and approximately 55% in working age bracket (15 – 64 years), Nigeria's population distribution portends strong potential for continuing growth in housing demand (Oluwakiyesi, 2011). As part of research and innovative development projects, the Nigerian housing industry, along with several housing institutions such as the State Housing Corporations, the Federal Mortgage Bank of Nigeria (FMBN), and other privately owned institutions have developed multi-sector housing reforms and policies to guide sustainable housing delivery processes. Despite a rise in the number of Public-Private Partnerships over the last 20 years, recent estimate puts the housing-price-to-income multiple for Nigeria at 20.45, six times the accepted affordability benchmark of 3.2, and considerably higher than even the benchmark in Hong Kong (FHA, 2012). Given the geographic, economic and cultural diversity, the Nigerian housing industry faces very different sustainable development challenges.

These challenges include disparities in social and economic welfare especially between urban centres and the rural countryside; social and environmental pressures from industrilisation and rapid urbanisation; and general degradation of the environment. And although every developing country faces serious housing affordability problems, variations in housing conditions and demographic trends in Nigeria create stark differences, calling for unique, locally crafted responses. Hence, ensuring sustainable housing delivery towards progressive urbanisation constitutes a critical challenge to the Nigerian housing industry. This section presents a general view of the Nigerian construction industry as in the context of a typical developing country. It provides insight into housing-related themes as a basis for understanding their impact on population and urbanisation. It examines the trends, challenges, and extent of the industry's role in climate change, and in attaining sustainable development in the built environment.

2.6.2 A Profile of Nigeria: Geographic Location and Setting

2.6.2.1 Location and size

Nigeria is situated in the west of Sub-Saharan Africa, north of the equator on the Gulf of Guinea, and lies between latitudes 4° and 14° to the North, and longitudes 3° and 14° East of Greenwich mean time (GMT) as shown in figure 2.3. The total area of the country is about 923,769.00 square kilometers, and about 13,878 square kilometers of water (National Bureau of Statistics, NBS-2010). Its distance from the Northern to the Southern regions covers about 1400 kilometers, and 1100 kilometers from the Eastern to the Western regions. Nigeria extends about 1690 kilometers from the Federal Republic of Cameroun on the East, bounded by the Republic of Benin on the West at about 773 kilometers, a distance coverage area of 87 and 90 kilometers to the Republics of Chad and Niger on the North, and bathed by the coastline of the Atlantic Ocean on the South. It lies along the southern coastline to the Atlantic Ocean stretching out at about 700 kilometers. Its eastern coastline stretches for 853 kilometers along the Gulf of Guinea.

Figure 2.3. Map showing Nigeria and its geographic location on the continent of Africa

Source: United Nations Fund for Population Activities (UNFPA).

2.6.2.2 Topography and climate

Nigeria has five major geographic regions: a low coastal zone along the Gulf of Guinea; hills and low plateaus north of the coastal zone; the Niger-Benue river valley; a broad stepped plateau stretching to the northern border that has elevations exceeding 1,200 meters; and a mountainous zone along the eastern border, which includes the country's highest point, Chappal Waddi (2,419 meters). Nigeria has two principal river systems: the Niger-Benue and the Chad. The Niger River, the largest in West Africa, flows 4,000 kilometers from Guinea through Mali, Niger, Benin, and Nigeria before emptying into the Gulf of Guinea. The Benue, the Niger's largest tributary, flows 1,400 kilometers from Cameroon into Nigeria, where it empties into the Niger River. Nigeria's climate is arid in the north, tropical in the center, and equatorial in the south. Variations are governed by the interaction of moist southwest monsoon and dry northeast winds. Mean maximum temperatures are 30º C–32º C in the south and 33º C–35º C in the north.

High humidity is characteristic from February to November in the south and from June to September in the north. Low humidity coincides with the dry season. Annual rainfall decreases northward; rainfall ranges from about 2,000 millimeters in the coastal zone (averaging more than 3,550 millimeters in the Niger Delta) to 500–750 millimeters in the north (UNHR, 2010).

2.6.2.3 Natural resources

Nigeria's primary natural resources consist of natural gas, petroleum, tin, iron ore, coal, limestone, niobium, lead, and zinc. Nigeria has proven oil reserves of 35.9 billion barrels, the tenth largest reserves in the world (Oluwakiyesi, 2011). Proven natural gas reserves are estimated at 185 trillion cubic feet, the seventh largest reserves in the world and the largest in Africa. Estimates for oil and natural gas reserves are as of January 2006 (World Bank, 2010). The country also has an abundance of arable land, and coasts.

2.6.3 Population Growth and Urban Projections in Nigeria

With just over 160 million people representing 2.46% of the world's population, Nigeria remains Africa's most populous country (UNHR, 2010). According to a World Bank report published in 2014, Nigeria makes up about 15% of the entire population in Africa. Population in Nigeria increased to 162.47 Million in December of 2011 from 158.42 Million in December of 2010, to over 178. 52 million in 2014, and as illustrated in **Figure 2.4** is expected to double by the year 2050 (UN 2012). The population of Nigeria represents 2.35 percent of the world´s total population, which arguably means that one person in every 42 people on the planet is Nigerian (World Bank, 2012). The United Nations, Department of Economic and Social Affairs, Population Division (2011) notes that Nigeria has one of the highest population and urban growth rates in the world, with its cities ranking amongst the fastest growing in the world. A UN Report on Nigeria indicates that the annual urban population growth rate is 5.8 percent, while the national population growth rate is 2.8 percent (UNHR, 2010).

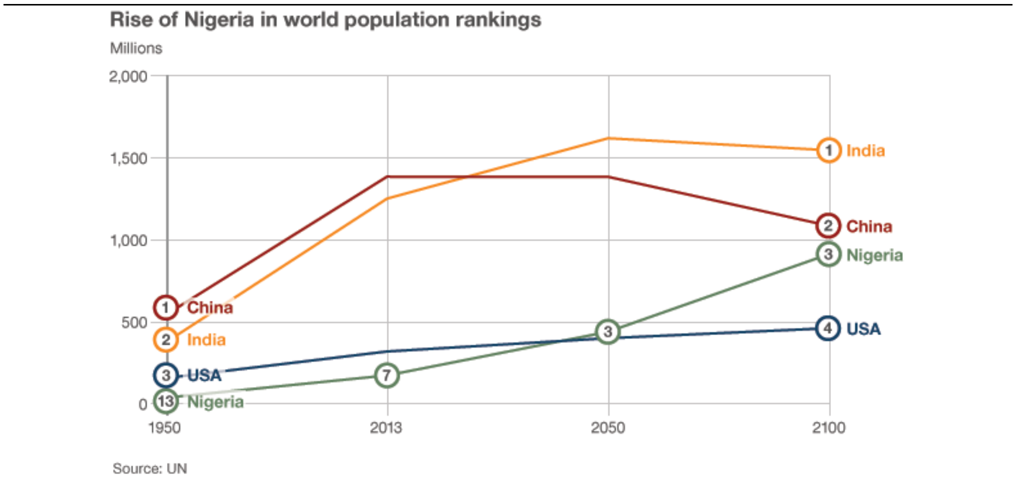


Figure 2.4. Nigeria's global population ranking (in Millions)

Source: National Bureau of Statistics

2.6.4 Urban Growth: Opportunities and Challenges in Nigeria

2.6.4.1 Emerging trend

One major challenge of contemporary and future urbanization derives from the fact that practically all urban population growth will take place in less developed countries, and that a large proportion of the future growth of the urban population will live in conditions of poverty (UNHR, 2010). The World Bank Report (2010) estimates that most of the urban growth will take place in developing countries, where the urban population is expected to double, from 2.6 billion in 2010 to 5.2 billion in 2050, signaling a massive decline of the world's rural population by about 0.6 billion (UNHR, 2010). By United Nation's projection, it is expected that 5.8 % of Nigeria's population will be urban by 2030 and over half the population in Nigeria will be urban by 2020 (UN, 2010). A recent report from UN-Habitat (2010) revealed that close to 50% of Nigeria's population now live in urban areas, compared to only 20% in 1980, 16% in 1970 and 13% in 1960 (**Figure 2.5**).

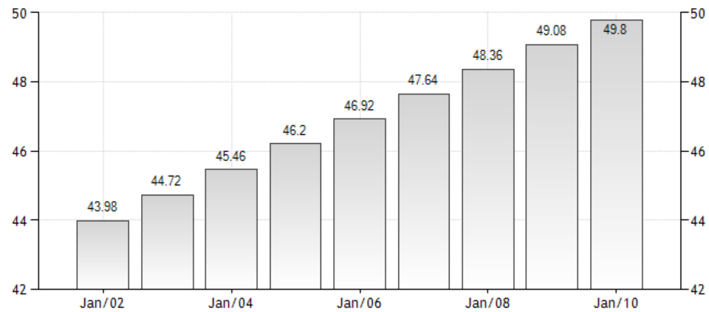


Figure 2.5. Urban population from 2002-2010 (% of total) in Nigeria

Source: National Bureau of Statistics

2.6.4.2 Opportunities and benefits of urban growth

Despite the commonly held negative views of population growth and urbanisation in Nigeria, several studies (Jiboye, 2009; Oluwakiyesi, 2011) have identified some of their important roles in economic and social development. This phenomenon is explained mostly by the presence of business opportunities, impressive economic growth, and expansion of infrastructural improvements within major commercial and administrative cities. Oluwakiyesi (2011) in his remarks on the Nigerian construction industry disclosed that urbanisation has fostered economies of scale in production and distribution networks, and favoured large facilities in more developed or economically buoyant states like Lagos, Abuja and Rivers State. He mentions that investors in cities generally appreciate accumulated advantages of urbanisation, ranging from urban amenities, to thriving economies. He describes urban cities as focal points of economic growth, innovation and paid employment, of which on average, urban residents tend to have better access to education and health care as well as other basic services such as clean water, sanitation and transportation than rural populations. Jiboye (2009) further notes that urban growth has done more to reduce rural poverty, and that the growth of domestic urban markets appears to be key to rural development. He mentions that migrants from rural areas gain access to better opportunities in cities and families left behind benefit from their remittances.

The advantages of large urban cities over smaller towns and cities in total factor productivity have been well demonstrated in the literature: World Bank (2000, p. 37). Urbanisation and population as important as they seem, also constitute major socio-economic and environmental threats to society.

2.6.4.3 Threats and challenges of urban growth

With increasing population and massive rural-urban migration accompanying the urbanisation process in Nigeria, there have been notable problems associated with the uncontrolled population and urban growth pattern. In conducting a detailed study of Nigeria's housing problems, Oluwakiyesi (2011) identified scarcity of productive land, congestion, proliferation of slums in the cities, increase in demand for urban services like housing, education, public health, and a generally indecent living environment as some of the issues associated with urbanisation. He notes that urban settlements in coastal areas such as Rivers and Cross Rivers States cause the destruction of natural habitats and consequently biodiversity loss, while also altering regional hydrology. He points out that the invasion of mangroves, coral reefs, sea grass beds and sand dunes destabilizes the coastline, leading to erosion or siltation, damaging infrastructure and increasing the vulnerability of local and regional populations to natural disasters while reducing resiliency to climate change and rising sea levels. Rapid population growth, high rural-urban migration, an expanding middle class and sustained macroeconomic expansion have resulted in a housing shortfall estimated at about 17million units (Adebayo, 2002, Oxford Business Group, 2011). A similar shortfall is equally replicated in public and commercial buildings as well as infrastructure (Jiboye, 2009). As a rapid response solution to chronic housing shortage and climate change due to population growth and urbanisation, the Nigerian housing industry is seeking ways to balance economic growth with environmental considerations in the decision-making process.

2.6.5 Nigerian Housing Construction Industry: Size and Forecast

Oluwakiyesi (2011) notes that a vigorous and buoyant housing sector is an indication of a strong programme of national investment and is indeed the foundation of and the first step to future economic growth and social development. He further indicated that the gross housing delivery is a major factor in the nation's gross domestic product (GDP) and indeed, a reflection of the state of economy of the Nation. In Nigeria, the housing construction industry is crucial to development as it accounts for millions of jobs while providing the infrastructure required for economic growth. It is renowned for its complex and dynamic building environment. The sector has posted impressive growth rates of over ten per cent in the last few years (Federal Republic of Nigeria, 2010, Central Bank of Nigeria, 2011). Each of the indicators examined below reveals part of the story that is relevant to the understanding of the current state and impacts of the Nigerian housing construction industry. These areas of discussion are a reflection and testimony of the future potential that the Nigerian construction possesses.

2.6.5.1 Number of housing construction firms

The Nigerian housing construction industry has in excess of 350 firms in total, of which over 190 are contractors (FHA, 2004). Statistics published by the Office of Nigerian Housing Authority (FHA, 2004) for the housing construction industry also give 3rd Quarter figures of approximately 192 private property development firms in Nigeria for the year 2007. In addition, the number of Licensed Primary Housing Mortgage Finance Institutions (LPHMFI) and other medium-size (based on scale of operation) housing constructions firms in Nigeria rose from 251 in 1993 to 276 in 1994 (Ajanlekoko, 2001; Nub1, 2008).

2.6.5.2 Housing construction output: current market trend, size and forecast

Another useful indicator of the economic significance of the Nigerian housing construction industry is its contribution to Nigeria's Gross Domestic Product (GDP). The World Bank Report (2010) estimates that Nigeria's housing construction sector accounts for 1.4% of its GDP. According to the United Nations' Human Development Index (2011), Nigeria has the second highest GDP in Africa (US$166.78 billion in 2007) after South Africa. While the Nigerian economy appears to be dominated by the petroleum sector, which generates about 70% of current account receipts and around 72% of government revenue, the Nigerian Economic Data Report (2011) has it that the petroleum sector's contribution to real GDP growth is relatively and surprisingly smallest compared to industries such as telecommunications, agriculture, manufacturing, and construction (Oluwakiyesi, 2011). Confirming the report released by the Nigerian Economic Data Report (2011), another study conducted by Oluwakiyesi (2011) revealed similar findings. The findings of his study revealed that the housing sector accounts for roughly 5.8% of Nigeria's GDP, making Nigeria's total GDP to rise to approximately 495 times its size, in the last three decades (see **Figure 2.6**).

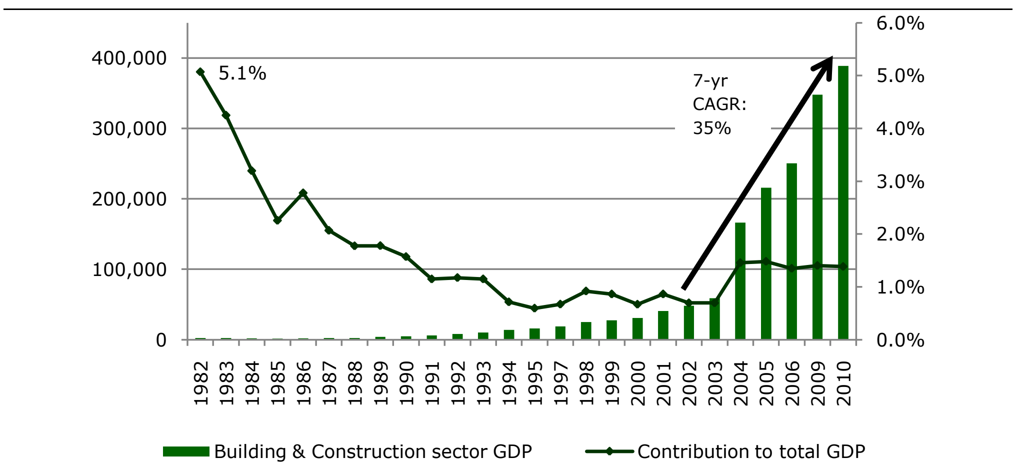


Figure 2.6. Nigeria's GDP growth rate

Source: World Bank Africa Development Indicators Database

2.6.5.3 Employment generation

The World Bank report on the wealth of nations (2010), notes that the output of any nation depends on its human resources — i.e. "the skill, dexterity, and judgment of its labour" (World Bank, 2010). Current estimates show that that between 0.4 – 2.5 million people are employed in the Nigerian housing construction industry (FHA, 2004; NBS, 2010). Nubi (2008) estimated that as at 2001, contractor employment within the housing sector was of the order of 1.8 million, accounting for about 6.2% of total employment in Nigeria. The Nigerian Housing Authority (FHA, 2009) also provides more current estimates of 2.6 million employees, representing over 8.5% of all jobs in Nigeria from highly skilled professionals through to lower skilled workers. According to Construction Skills Network (2009), lower skilled workers (trades and operatives) represent approximately 43% of the Nigerian housing construction workforce.

Though the Nigerian housing construction industry undoubtedly shares the responsibility of employment generation, creating investment opportunities, and improving the economy, the challenge of meeting the quantitative and qualitative demand for housing, especially for low-income earners who incidentally constitute the majority of the population, is still one of a major concern. The findings derived from the study ascribed the fundamental cause of this failure to the current issues associated with housing development in Nigeria housing industry.

2.6.6 Housing Development in Nigeria: Current Trend

The provision of housing lies silently beneath the rise and fall of the housing industry as well as its decision-making practices primarily because of its potential to create wealth, employment opportunities and industrilisation. Similarly, the design, development and use of housing are an evident medium to demonstrate the feasibility of sustainable concepts. Interestingly, housing development features as one of the objectives of sustainable development.

However, for many Nigerians, the desirability of owning or living in decent homes is as strong as the reality of its elusiveness. The inability to afford this prime asset is largely a root cause of the deficient housing situation. Common issues surrounding housing development in Nigeria are discussed as follows:

- **Health and Safety in Construction**

Occurrences of fatalities from construction injuries are far more common in developing countries like Nigeria than in the developed world and have remained high over the years (Ofori, 2004). Pesticide poisonings and provisions of clean water and air remain the major challenges within its regions due to the population concentration in urban cities.

Although the Nigerian housing industry has enacted regulations and established government agencies aimed at improving workplace safety and preventing occupational diseases and injuries, fatalities are still high (Oluwakiyesi, 2011). Resources focused on these goals are increasing significantly, but still fall far short of needs.

- **Waste Production**

The Nigerian Rural Urban Linkages (2004) reported that over 70 million tonnes have been generated in Nigeria in 2003 and that 900 housing construction and demolition (C&D) landfills are operating in Nigeria to receive disposed material waste. Although solid waste is generated by different economic activities, the Nigerian housing construction industry has always been considered as one of the major producers of waste (NRUL, 2004). This is clearly reflected in statistical and environmental reports by the Nigerian Rural-Urban Linkages (NRUL, 2004). According to a report by the United Nations Environment Programme (UNEP, 2005), almost 162 million tonnes of waste is generated every year in the continent of Africa, 62 million tonnes in sub-Saharan Africa, and the share of housing construction waste is roughly 21% (DEFRA, 2007). In Nigeria, over 1000 tonne per day of material waste is disposed of at landfills representing roughly 10% of total solid waste from housing (UNEP, 2005). Nigeria is no exception and it is considered as one of the biggest producers of waste, 45% of which is from housing construction waste (Oladipo and Oni, 2012) and it is ranked top in waste share per capita among the countries in Africa (Afon, 2007).

- **Depletion of non-renewable Resources**

The Nigerian housing construction industry is a major consumer of natural non-renewable resources such as metals, fossil fuel and non-renewable energy resources (Abisuga and Oyekanmi, 2014). It accounts for a large quota of material and energy consumption, biodiversity loss, and pollution. The need for alternative material and energy sources in line with statutory regulations has now become a vital option for the housing sector as it aims to either ensure the removal of any cost in material production energy or reduce any potential cost to an acceptable level.

- **Politics**

While tougher building regulations have been introduced, compliance with certain housing construction policies is weak, and actions to undertake such policies are slow and unresponsive to changing needs and demands (Nubi, 2008). In analysing the unchanged state of the Nigerian housing sector from a political perspective, Oluwakiyesi (2011) demonstrated how the dominant actors in the sector effectively withstand major changes in building regulations. He observed that the current practice in the housing sector favours more or less incremental change over radical change, and that technical decisions in the planning process are highly politicised. He reiterated on how the differences in the opinions of the parties involved in the housing chain are hardly reconcilable, as these tend to hinder sustainable innovative ideas.

- **Building Materials Shortage**

The local production of building materials in Nigeria is not sufficient to meet the demand for the housing sector (Oruwari et al., 2002). Being a country that relies heavily on cement, there are severe bottlenecks in the supply of materials due to fluctuations in demand and lack of capital for the build-up of supplies, or inputs. Here, cement is often regarded as a local product even when 60 % of the production cost results from imported energy. According to Oluwakiyesi (2011), the biggest factor influencing climate change is concrete and steel. Although cement makes up only 12-14 % of the final concrete mix, he argues that further embodied energy comes from the transportation and production of aggregates and in the case of reinforced concrete the manufacturing of steel. Shortage of other locally produced building materials such as; bricks, strawbale and earth are also experienced. In a country where there is a monopoly in supply, shortages have been deliberately created to force up the price, causing a scarcity of building materials, which invariably affects and alters the sustainable development plans in the housing sector. This steep rise of building materials has effectively removed decent housing from the reach of low and medium income groups in the region.

- **Construction Design Systems and Technologies**

  Nigeria like many other developing countries had systems or frameworks inherited from its colonial administrators and have found that some of these systems are inappropriate for their own current needs (Nubi, 2008). Conventional designs of these types suffer from various limitations for example, lack of thermal comfort and poor ventilation. Thus attention is now more focused to include building features appropriate to tropical and local conditions. Locally produced materials, systems and technologies have now been given more consideration in search of sustainable solutions. As such, many building design professionals are now beginning to get involved in "sustainable design" in response to expressed interest from their clients.

It can be argued from the above analyses that the emphasis on housing problems and needs in Nigeria differ considerably and so are the technologies and methods adapted in the housing industry. Analysis from the study suggests that it is of importance that sustainable practices be considered and integrated at various levels of housing development. Given the extreme supply-demand imbalance; the abundance of demand at the bottom end of the market; the high cost of conventional construction techniques and materials; and the reluctance of financiers to invest in alternative housing, it is therefore imperative that innovative building technologies and housing design models that drive down costs be explored if social housing and more affordable and energy efficient and low-impact housing in general – is to become a realistic possibility in Nigeria. Low-impact green housing has been described as an important model of sustainable development because of its contribution to the economy and the relatively significant environmental and social-cultural impacts (Fairlie, 2008; Maxey, 2009; Seyfang, 2010). Against this background, this study aims to examine LIGHDs as potential models for sustainable housing in Nigeria.

2.6.7 Low-Impact Green Housing Development: An Alternative Approach to Sustainable Housing in Nigeria

The quest for far reaching changes in the way housing construction should be carried out has been emphasised (Malanca 2010). As Nigeria pursues improvements in infrastructure and buildings, there are concerns over the manner in which these developments would occur especially considering the weak institutional forces at play. Nigeria's intense development pressure, the resulting rapid urbanisation and generally carbon intensive mediums of energy generation leaves the Nigerian housing industry and built environment under particular pressure to thoroughly embrace the sustainability imperative.

As a result, there is now need for new models of sustainable housing, to ensure the protection of the region's environment, the sustainability of its natural resources, and the high quality of life of its people (Malanca, 2010). While various literature (Fairlie, 1996; Seyfang. 2010) have stressed the economic, environmental and socio-cultural benefits of low-impact green housing, and identified several strategies and action plans in the pursuit of this concept in the broader context, there is a dearth of literature relating to the concept in Nigeria (Adegboye. 2009; Adeyemi, 2012; Anosike and Oyebade, 2012). The benefits of LIGHDs have been highlighted in various studies (Fairlie, 2008; Maxey, 2009). It therefore remains to be demonstrated what current drivers influence- or barriers hinder- the direction and capabilities of LIGHDs in the Nigerian context.

2.6.7.1 Factors driving low-Impact green housing in Nigeria

The drivers of LIGHD can be categorised into: environmental, industry, economic issues and legislation. From these broad categories, the following can be considered as the key drivers:

- **Climate change mitigation/environmental concerns/energy efficiency:** Since the adoption of the Unitary Development Plan (UDP) in 2005, climate change has become the single most important global priority (USDOE, 2010). The effects of global warming are already having severe effects on people and planet. As such, the Nigerian housing industry is beginning to adopt planning systems and strategies that will actively facilitate reductions in energy requirements, to address this global threat both from the perspective of adaptation to effects and impacts which it is already experiencing and those that the present and future generations will experience. Adeyemi (2012) reiterated the urgency with which climate change needs are to be addressed and planned. In response to this threat, he noted that a whole series of planning policy revisions and changes have been issued by the Federal Ministry of Lands, Housing and Urban Development (FMLHUD-2012) over the last 2 years. The requirements of the emerging local planning policy are designed to track best practices and sustainable low-impact housing models.

- **Government policies (Legislation/regulations): Peer pressure within the industry and increased realisation of the importance of LIGHDs construction image.** The reluctance to implement low-impact green housing developments has incited many governments to decree laws and policies guiding such ideas (Seyfang, 1996). Several policies have been designed to proactively and prescriptively promote LIGHDs, across its scope, in line with the priorities of Nigeria's sustainable development strategy (Nwokoro and Onukwube, 2011). Adeyemi (2012) said that strong legislation and clear regulations are vital in ensuring the success of the low-impact green housing agenda. He suggested that improving and tightening up regulations is one of the best ways of guaranteeing significant actions. He added that introducing policies that encourage low impact green developments in Nigeria could help to grow the region's economy in a sustainable way and produce a greater degree of social housing.

- **Biodiversity conservation:** The natural environment and landscape quality of Nigeria are precious assets, which should be preserved and enhanced for the benefits of both the current and future generations. The natural environment contains important and valuable habitats, biodiversity resources in an urban setting, as well as distinctive landscape in sub-urban zones. Recent legislative changes by the government now impose a duty on housing authorities to conserve biodiversity-one that aims to ensure that: construction, planning, development and regeneration have minimal adverse impacts on biodiversity and enhance it where possible.

- **Financial benefits/cost savings/operational efficiency**: Innovative housing models can be of considerable help in lowering the cost of construction (Ofori, 2004). Low-impact green housing concept has been addressed as one of the most frequently used alternative technique for rural and sub-urban dwellers worldwide due to its relatively low-cost approach (Fairlie, 1996). Several studies (Fairlie, 2008; Maxey 2009) have proven through case studies that the life-cycle cost of conventional housing is twice more than the cost for LIGHDs.

The identified drivers give some consideration to the notion that the LIGHD model displays a number of significant differentiators that distinguishes it from other conventional housing models. As yet, this study has failed to find any compelling evidence to confirm that the house build industry in Nigeria does indeed display a sufficient level of understanding and technical know-how to undertake such concept. Despite the country's demand for sustainable low-impact options in housing, the increased commitment in sustainability and environmental stewardship, certain barriers still undermine its benefits. The main issues underlying this setback are examined below

2.6.7.2 Barriers impacting Low-Impact Green Housing in Nigeria

Research conducted by a number of studies (Nwafor 2006; Nwokoro and Onukwube, 2011) suggests that although there is interest in the LIGHD concept, its frequency of application in Nigeria is poor. Three main barriers that hinder the implementation of LIGHDs are identified as follows:

- **Education and experience:** Generally, failure in low-impact green housing construction and the general unpopularity of the concept amongst professionals in the Nigerian housing industry are due to lack of knowledge of their sustainability impacts and inexperience in sustainable low-impact designs. A major theme evident in Nwafor (2006) and Sebake (2009) is the fact that there is still not enough clients or projects that could allow designers to gain much needed experience in low-impact green designs. Seyfang (2010) posited that a thorough understanding of the concept could ensure quality and proper performance of the building.

- **The client-perception factor:** Although clients often express interest in low-impact green design solutions, and are to some extent aware of the need for sustainable housing, it is rarely insisted on, due to clients' preference of choice. Abisuga and Oyekanmi (2014) explained that clients often find it hard to adhere to low-impact green designs partly due to a limited range of environmentally acceptable or responsible materials available to embark on such designs. They emphasised that the majority of clients object to LIGHDs for the sole reason that the materials used for such developments cannot satisfy the new needs of building forms and functions and, that it is impossible to provide enough of such materials to satisfy the level of housing demand. This is in agreement with the assertion of Nwafor (2006) who argued that the overall effect of the technical deficiencies of locally produced building materials creates acceptability barriers of LIGHD.

- **Poor selection approach in the use of Local and recycled building materials (LCGBMCs):** The development and selection of LCGBMCs remains frequently among the challenges of implementing low-impact green housing design. Nigeria is known to be rich with natural material resources required for the production of many LCGBMCs, but their exploitation has been severely hindered by numerous factors one of them being the selection approach. Generally, the selection of LCGBMCs in Nigeria is determined by their initial prices rather than considering the running costs attributed to those materials and their impacts on the environment throughout the entire life cycle of buildings. Abisuga and Oyekanmi (2014) also explained that suppliers ranges are often limited and do not accommodate LCGBMCs. This, they noted, is due to a number of factors, a few being research and development funding, the fact that these products are not mass-produced like their unsustainable counterparts. They maintained that there is as yet not a whole databank of LCGBMCs from which to choose from, hence creating a lack for professionals seeking to specify environmentally sustainable products for LIGHD projects.

While there are multiple benefits of LIGHDs, it is evident that barriers preventing clients and designers from committing to low-impact green design approach in Nigeria are presently surplus. Some of these include; lack of legislation, Ineffective information technology, lack of assessment tools, lack of education and knowledge in LIGHD design, higher risks based on unfamiliar techniques, and a lack of the associated material performance information. The lack of informed knowledge amongst building professionals thus suggests that there is need for data on such materials within which to view the management of the selection process, particularly in the early stages of the design when there are a greater number of unknown variables to consider. It thus can be argued that by utilising locally –sourced and recycled products, it is anticipated that clients would be more likely to consider a low-impact green housing solution.

2.6.8 Alternative Materials and Technologies: Drivers and Barriers Impacting the use of Low-Cost Green Building Materials in Nigeria

The erosion of earth's ability to sustain life has brought the issue of sustainable development practice into dominance in every aspect of human activities (Seyfang, 2010). The international community, through its different organisations, has devoted considerable efforts to assure that every human activity fulfills the requirements of this development (Fairlie, 1996; Wimbush, 2001). With increasing public and client awareness of the impacts of buildings and their associated materials, addressing environmental issues have become a normal part of the design and construction processes (Nwafor, 2006). Given the high level of public environmental awareness, " sustainable", which is a term commonly used to distinguish consumer building materials or products that are claimed to be in some way better for the environment than conventional products like cement and steel (Trusty, 2003), has become a catch phrase in the housing construction sector, as the cachet of being seen as a 'sustainable or green product' can have considerable market advantages (Nwafor, 2006).

Sebake (2009) noted that sustainable and green building material selection practices suggest a way to portray the housing construction industry's responsibility towards protecting the environment, which he claims urges the industry to pursue a balance among economic, social, and environmental performance when undertaking housing projects. Low-cost green building materials and components have been described as having considerable environmental, economic and socio-cultural advantage over their conventional counterparts (Fairlie 2008; Seyfang, 2009a; Adegboye 2009; Zami, 2010), given their relatively lower cost and energy requirements in their extraction, production, and transportation processes.

Anosike and Oyebade (2012) noted that LCGBMCs have the objective of doing less harm in their production, use, construction and operation by reducing local and global resource depletion and environmental degradation. They maintained that LIGHDs strive to reduce the negative environmental effects of materials by using more LCGBMCs (McDonough & Braungart, 2002; Reed, 2007). Nwafor (2006) claims that LCGBMCs respect the limitations of non-renewable resources, work with the pattern of nature's cycles, and inter- relate with the ecosystem. Kibert (2008) adds that they are non-toxic, energy and water efficient, made from local, recycled and recyclable materials. He noted that they exhibit certain characteristics including absence of environmental contamination during their life cycle.

Owolabi et al. (2014), while examining the effectiveness of gypsum board over conventional sandcrete block, revealed the benefits of using LCGBMCs in terms of time, ease of construction and handling. They added that using regionally extracted and manufactured LCGBMCs-unlike materials like steel and cement, which have relatively high-polluting processes, could help lessen the environmental impact of a building, by reducing environmental impacts of transport. Adegboye (2009) mentioned that LCGBMCs are minimally processed (e.g., uncut stone, earth materials, wood, bamboo), hence often pose fewer ecological impacts, have relatively low embodied energy, conserve energy use and potentially harmful emissions and waste, as well as protect the functional integrity, diversity and cultural identity of the place.

Jagadish (2007) writes, in addition to its political, economic, social and ecological advantages, that LCGBMCs have great cultural and architectural importance. He argues that the development of contemporary mass construction using LCGBMCs has the potential to revive lost cultural traditions, while contributing to the development of a progressive sustainable housing construction industry in both sub-urban and urban dwellings.

He adds that the emphasis on using LCGBMCs (such as mud, straw and recycled timber) for construction is a significant localisation impact of this type of building approach, quite distinct from mainstream building techniques. Although various studies (Kibert, 2009; Zami, 2010; Norton, 2004) have highlighted the benefits of using LCGBMCs in housing projects, certain barriers still limit their wider use in mainstream housing. Ofori (2004) notes that several factors account for this, including the efforts of professional institutions to enhance the awareness of their use through publications of policy documents and best practice guides in their selection process.

Abisuga and Oyekanmi (2014) noted that clients often refrain from low-impact green housing designs since designers often choose from a limited range of products that are sustainable, especially when there are so many other unsustainable options out there. They argue that this lack often results in clients relying heavily on imported materials. This, Anosike and Oyebade (2012) claim, is in part due to the fact that very few of these products are commonplace in the housing industry or have been widely established. They confirm that designers often expressed caution, with doubts that unaccredited products are inferior. This point is further established in Adegboye (2009), which explained not only how difficult it is to source LCGBMCs, but also how almost impossible it is to establish which products are authentically sustainable, intricately linking the problem to designers reticence in using such materials.

Nwokoro and Onukwube (2004) maintain that forward-thinking designers sometimes have trouble using LCGBMCs during the design process because of its failure to meet certain requirements, hence making them resort to unsustainable material selection practices. They further noted that although consideration is being given to the use of LCGBMCs, there is as yet no appropriate data guide from which designers could derive valuable information to conduct an effective decision-making process. They note that with sustainable low-cost green building products being relatively new, lacking regulatory building codes, and often manufactured by new small businesses, the majority of designers express wariness when specifying them.

Reddy and Mani (2007) identified lack of standardised local-based materials, rapid urbanisation, changing lifestyles and increased adoption of energy-intensive modern construction materials as some of the issues that have lead to a steep decline in adoption of LCGBMCs. They argue that most developing nations, under pressure for modernisation, have so far neglected the promotion of local construction methods and materials.

A similar study by Zami (2010) identified several barriers to the adoption of LCGBMCs, including the need for new legislation, technical training, public awareness of sustainability, and knowledge sharing. His study emphasised the lack of knowledge amongst the majority of construction professionals of their relative impacts on design-decisions as a key factor despite their enormous potentials. He added that LCGBMCs are perceived as ‘second class’, while modern construction methods and materials are seen as ‘civilised’ or ‘symbols of affluence’. His findings were that the inhibitors influencing the adoption of LCGBMCs depended on the context and situation of particular countries. Studies also identified clients’ resistance (Aye, 2003), knowledge of materials, limited materials and authenticity of suppliers (Mate, 2006), along with understanding of the impact of the materials (Kang & Guerin, 2009), accurate and accessible information and appropriate tools (Aye, 2003). Other barriers identified include client demands (Hes, 2005), designer and client poor knowledge (Davis, 2001), inaccurate and inaccessible information (Hes, 2005; Davis, 2001) and inappropriate tools (Hes, 2005), peoples mistaken perceptions and cultural problems (Morton, 2007, p377), lack of knowledge, skills, and understanding amongst professionals, government, donors, and users (Jagadish, 2007, p26), lack of technologies and resources (Jagadish, 2007, p26-27), lack of building codes, policies to adopt LCGBMCs (Morton, 2007), and difficulties in obtaining insurance (Morton, 2007).

Undoubtedly, the use of LCGBMCs in construction presents some benefits as well as challenges that undermine their use. While marginal progress is being made in the area of advancing the use of LCGBMCs in mainstream housing, selection of such products remains a challenging, confusing, and sometimes even contentious issue as majority of design and building professionals within the Nigerian housing sector are still locked in to old traditional practices of material selection. It is thus evident that existing approaches presented for material selection in the Nigerian housing sector may not be sufficient to aid Sustainable Material Selection (SMS).

2.6.9 Current Approach to Material Selection in the Nigerian Housing Industry

Historically, conventional literature about the Nigerian housing industry has largely remained peripheral to discussions on material selection within design practice (Nwafor, 2006; Abisuga and Oyekanmi, 2014). Despite an evolving culture of sustainability in the housing industry, there are limited methods or processes to support the management and synthesis of material knowledge to stimulate sustainable material selection during the design process (Nwokoro and Onukwube, 2011). As environmental decision-making requires consideration of sustainability principles in housing, understanding material selection from this perspective has become important. There is now discourse on how material decision-making methods could support designers in the sustainability aspects of material selection. Such aspects include the understanding of how material selection influences a design considering embedded design team knowledge, and stakeholder influences, which are key to supporting environmental decision-making around materials.

While crucial studies have been undertaken to improve the material selection process in industrialised as well as emerging economies, there is currently less understanding around the process of material selection amongst designers in the Nigerian housing sector (Nwafor, 2006; Nubi, 2008).

Presently, material selection in Nigeria is poorly understood and fraught with burden shifting, as current approaches are incapable of adaptation to meet new situational requirements. This is partly because material selection is mostly done after designs are finalised (Nwafor, 2006). This is problematic as extra costs and time are incurred when changing a building's component during the later stages of its development (Gluch and Baumann, 2004).

Oluwakiyesi (2011) further explains that the basic problem associated with the material selection process owes much to whether or not designers are very knowledgeable about such products. He observed that the knowledge of most professionals who are responsible for making key decisions in the Nigerian housing industry are sometimes negligible, as their decisions are based on the information of other colleagues or what they recommend. He stated that material choices for some designers often means them sifting through catalogues of competing suppliers and manufacturers. Nwokoro and Onukwube (2011) also see the lack of information as a potential cause, giving examples of resources such as handbooks, and advisory services from material suppliers as the readily available sources. They found, through interviews with designers, that material selection tends to originate primarily from experience. They suggest that the industry set up a system for information so product information is readily available, to ensure that design and building professionals develop a clearer understanding of the nature and characteristics of the materials and products they specify.

In Abanda et al's (2014) case, finding information, which is relevant and up-to-date to enable material selection, was identified as the most common problem in the housing industry. They maintained that the format suppliers provide information with is usually not in line with the information designers require. The research found that although most designers were aware of issues of sustainability, it was rarely a factor when selecting materials, as they were rarely asked by clients to factor it in, with some having never been asked.

They note that designers are most concerned with the aesthetics and so find it very challenging to understand everything. They suggested that technical experts work in tandem with designers to help them understand sustainability and to ensure feasibility. They emphasised the importance of a wide range of material-selection decision factors with comparable information of material properties that could enable designers to see the benefits and drawbacks of the available materials. Adedeji (2010) went on further to state that material selection in Nigeria till this day still faces a fundamental problem of how to assess the suitability of a product. He notes that designers within the housing sector find it difficult to delineate material choices because of the amount of contradictory information being portrayed. He claims that in practice, it is also nearly impossible, or at least impractical to make a list of sustainable products, as there is an overall lack of knowledge and understanding in terms of sustainable materials due to the dearth of information.

Adobo and Kolo (2009) provides a slightly different view as to the sustainability of the current material selection approach. Another factor they claim was often personal and related to the individual's awareness of the issues and desire to factor them in when selecting materials. They noticed that many designers express a desire to know more about sustainability and the desire to try new materials but that designers often stick to a few materials that they are familiar with. Tied into this belief by some is that appropriate material selection systems are not fully in place and so material choice makes little or no impact at the end of life. They noted that many designers perceive the idea of pushing sustainable materials or alternative selection approach as a way to lose clients and, in some cases, have been turned down for proposing such ideas. They add that there is a general consensus that clients are not interested, thus sustainability in the material selection approach is often not a consideration. It was suggested in their study that designers and engineers be supported by applications that provide material information, guidance and help during the design process

Although emerging material resources to support design practitioners such as material libraries, databases and material selection software have been developed as resources to supplement designers choice of materials at the design stage, Abiola (2002) found strong evidence that such support systems are not currently available to designers within the Nigerian housing industry. He confirmed that there has to date been no adequate support system to assess the contribution of LCGBMCs to sustainable housing development, despite a growing need, adding that designers' material selection processes are very often based upon experience either personal, colleagues or experts opinions. He maintains that most designers occasionally use experts in the form of moulders, suppliers and manufacturers whom they contact for advice. He suggested that a new qualitative evaluation framework, which is designed to incorporate the information associated with LCGBMCs and other key elements be provided to aid informed decision-making at the earliest stage of the design. He adds that designers require a multi-level approach to material information as their information needs vary through the design process.

From the analysis, it therefore can be argued that the current problem with material selection for the design of housing projects in Nigeria is a problem of decision-making, which in most cases is determined by either clients' preference or unquantified professional judgment (Oruwari, et al., 2002). This in addition has put pressure on the outcome of the design as the cultural, technical, environmental issues are left out at the outset of the material assessment process. A number of studies have attempted to assess material choice by using various network generators (Adedeji, 2010; Adegboye 2013). Others (Abanda et al, 2014) have explored personal approaches by using a checklist approach that requires the designer to keep a personal log of all previous products for future reference. A major drawback however, in all these methods are that they lack appropriate multi-criteria assessment techniques, and thus cannot be so efficiently utilised.

Ofori (2004) states that the success of material selection management at the early design stages is primarily determined by the level of awareness of the benefits of assessing multiple key influential factors in the decision-making process. He adds that the inclusion of such criteria in the adoption of appropriate materials ensures the fulfillment of sustainability principles in housing construction. It therefore suggests that material selection management models should comprise a measure of the sustainability, wherein materials are selected based on a wider range of decision factors.

2.7 Moving Towards Sustainable Material Selection

Material selection is a complex problem often tackled by designers in a number of ways, and in most cases not similar to those used by other practitioners. It involves a complex number of considerations, which can be conflicting upon each other. Many studies (Karana et al. 2008; Ding 2008; Castro-Lacouture et al. 2009; Spiegel and Meadows, 2010) have identified materials selection as a key factor in the sustainability of any housing project, and yet considerations for sustainability attributes have only recently been introduced in the material selection decision-making process (Ashby and Johnson, 2006). The selection of a material for a specific design necessitates that many criteria are satisfied at the same time (Chick and Micklethwaite, 2011; Zarandi et al., 2011; Quinones, 2011). This can be a lengthy and expensive process, and often the final selection is based on compromise between advantages and disadvantages of candidate materials. Kibert (2008) argue that it is often difficult for designers to cut through the hype and determine just how sustainable low-cost green building materials are, let alone when compared with numerous alternatives, as evaluating multiple products for a given housing project can be a complex process. Although there is no clearly adopted definition as to what sustainable building materials entail, several studies (Ashby (2009a; Florez 2010; Bayer et al. 2010) have characterized various qualities that describe them.

In selecting sustainable building materials for instance, one product may pose global warming impacts while another may involve a known human carcinogen; a third product may require large amounts of fossil fuel, but may be more durable with the potential to last twice as long as the first two alternatives. Florez et al (2010) have stated that the appropriate materials for sustainable low-impact green housing design vary by impact priorities, regional issues, project budgets, and performance requirements. Some designers, they note, emphasize materials that conserve resources by being reused without remanufacturing, by being extremely durable, or by closing material loops with high-recycled content as being sustainable.

Others (Castro-Lacouture et al. 2009; Quinones 2011) place great emphasis on low toxicity of products and emissions throughout their life cycle when selecting materials, while others (Florez 2010; Bayer et al. 2010) regard low ecological impacts or conservation of water as the highest priority.

Castro-Lacouture et al. (2009) tell us that Portland cement concrete for instance may appear to be a "green or sustainable" material for those with durability or regionally produced materials as a priority, whereas it might be rejected by those who are concerned about the global warming impacts of material manufacture or high embodied energy materials. Composite lumber (a mix of recycled plastic and wood fibers) on the other hand may seem like a good alternative to wood lumber for those concerned with the ecological impacts of clear- cutting forestry practices, but noted that it may be rejected for its mixed material composition by those concerned with the closed-loop recyclability of materials. In addition to varying priorities and goals in sustainable building material selection, Quinones (2011) also expressed that the ideal sustainable or green building material might be a natural, renewable, local and indigenous, nontoxic, low embodied energy material, which she notes are very familiar attributes of LCGBMCs, but however argued that these materials may not be feasible in all situations pending on a number of factors.

She noted that LCGBMCs- despite their varied potential benefits, may for instance not be able to perform to current construction standards, or may not be appropriate for the scale of construction or performance requirements. With a wide variety of priorities that determine what sustainable materials entail comes an even wider issue of what sustainable material selection is.

Asif et al. (2007) maintain that what drives sustainable material selection is influenced by a number of factors. They note that material selection before the advent of sustainable development was determined mostly by cost, appearance, availability and ease of use, but that sustainability concept has now broadened the factors for SMS in recent times. Likewise, Bayer et al. (2010) argue that SMS is not only dependent on the qualities of that product but also the influencing factors that determine its choice as the most appropriate option, hence the overall performance of that material. SMS, according to Nwokoro and Onukwube (2011), entails accounting for all inputs and outputs through a product's life cycle. They argue that SMS considers all aspects of materials entire life cycle. Ashby (2009a) and Chick and Micklethwaite (2011) cite extensive research literature as to what factors constitute SMS. A number of studies have looked at what factors influence and necessitate SMS for designers aside from technical properties some of which are; values (Trimingham, 2007; Pedgley, 1999), intangible aspects (Karana et al., 2008), meanings (Ljungberg and Edwards, 2003; Karana, 2009; Ashby and Johnson, 2006), sensory vocabulary (Allione et al., 2012) and perceptions (Ashby and Johnson, 2006). Other factors that influence SMS include life span, reliability, recyclability, and resistance to damage or decay (Trusty, 2003).

Nwokoro and Onukwube (2011) further asserted that materials selection could play a key role in achieving ecological sustainability if it is done in such a way as to minimise adverse impacts on natural environmental systems as a result of using the materials.

They added that by using LCGBMCs, transportation costs is reduced, and at the same time the local economy is sustained. Their argument was that availability of regionally manufactured materials depended on the project location, and that Ideally, heavy materials whether aggregate, concrete, or brick should be procured within 100 miles, medium-weight materials within 500 miles and lightweight materials within 1000 miles of the project site. They mentioned that distances between raw material extraction locations and manufacturing/processing facilities also determine SMS. They argued that using available regional materials and products could save time on future projects within the same location.

Some other factors mentioned for when selecting materials include amount of pollution generated over the life of the material as a result of its use and availability of environmentally sound disposal options (Nwafor, 2006). Bonnema (2006) argue that SMS will mean designers taking more notice of the ingredients which make up a material as there are numerous potential negative effects, such as: Toxic to human and ecological health, Cancer-causing potential, Reproductive system disruption, Endocrine system disruption, Sensitizer, and Mutagenicity (damage to DNA).

Kibert (2008) writes that housing projects are made more economically sustainable through minimising the total life cycle cost of projects by selecting material components with the lowest life cycle costs. The principal factors identified as key to SMS in Kibert (2008) are a material's life cycle costs, including costs of manufacture, transport, assembly, maintenance, and disposal or recycling. Attributes associated with SMS according to Trusty (2003) include degree to which using the material represents depletion of natural resources, cultural background or integrity of place, reusability of the material, and substitutability of the material with respect to nonrenewable resources.

Trusty (2003) listed some factors such as availability of materials, budget, design brief, health and safety, design for disassembly and disposability, land longevity. Similarly, Lewis et al. (2001) give four key factors which the designer should aim to achieve SMS namely; abundant and non-toxic, natural rather than synthetic, minimise materials, process and service, and maximise use of recyclates. Ashby (2009a) give strategies for the sustainable-selection of materials by focusing on energy and carbon breakdowns, identifying the life phases and adopting simple metrics of environmental stress. Ashby (2011) states that SMS means conserving material stock and enabling its reuse. More recently, there is an evolving body of literature on intangible aspects of materials such as material form or meaning and emotional associations. Wastiels and Wouters (2009) provide a comprehensive list of the key factors a designer must consider when selecting materials into seven categories namely: (1) physical aspects, (2) appearance, (3) subjective, (4) cultural context, (5) physical context, (6) time, and (7) money.

While there is no universally acceptable definition as to what constitutes SMS, it is safe to say that SMS is contextual, and is influenced by numerous factors. Therefore, the sustainability impact of LCGBMCs is determined by what key influential factors are at play when selecting such materials. With the complexity and confusion associated with sustainable material selection, it is to be expected that designers require support to aid informed choices. It therefore extends the argument by advocating the use of LCGBMCs, with emphasis on the necessity of establishing performance assessment mechanisms and indicators for LCGBMCs if their improved performance is to be targeted for wider use in housing construction.

2.8 Summary

This chapter has demonstrated the relationship between housing construction activities and economic growth. It was revealed that the nature of the causality relationship between economic activities in the housing sector and their adverse effects on the environment differ among countries due to the differences in their geographic contexts, socio-technical settings and value systems. Drawing extensively on the theoretical foundations of SD in the literature studied, this paper has critically examined the importance, level of knowledge of SD and the potential challenges of implementing SD principles in the Nigerian housing industry. It showed that the Nigerian housing construction industry has been rising up to the challenge of sustainability as they are under increasing legal and commercial pressure to become more sustainable, since past failure of professionals to adhere to the principles of SD has resulted in the construction of housing projects of questionable quality. A subsequent review further highlighted the need for LIGHD as a strategic niche with the potential for wider transformation of mainstream housing in Nigeria, with emphasis on the impacts of LCGBMCs.

Further study was conducted to gain insights into the understanding of sustainable material selection, and to explore if and how sustainable materials are determined, and identify what key sustainability principle indicators (factors) influence the selection of LCGBMCs in the design of LIGHDs. It was revealed that a wide range of factors largely influence sustainable material selection, even though a large amount of literature still adhere to environmental matters. One key barrier was that the data sources available for LCGBMCs were quite limited in the adequacy of the information provided, possibly more useful for inspirational purposes than for engaging in an effective trade-off exercise. It was revealed that the assessment of sustainability principles had different conflicting criteria, which suggested the need for multi-criteria decision assessment tools.

Chapter III

Investigating current technology available for assessing building material performance in industrialised and emerging economies

CHAPTER 3: TECHNOLOGY IN MATERIAL SELECTION

3.1 Introduction

Proven and commercialized technologies have been developed within the last ten years to promote environmental awareness amongst built environment professionals (Cole, 1999; Cooper, 1999; Ding, 2008), and encourage the sustainable use of building materials in the housing construction industry. Since then, various studies on building material selection support systems have developed in size and specification (Trusty, 2003; Seyfang, 2009a). Yates (2001) notes that the application of building material assessment tools has been widely accepted as an effective and useful way of promoting sustainable housing construction in the house build industry (Cole, 1999; Ding, 2008). While various research institutions have developed assessment tools that attempt to quantify and qualify the potential environmental impacts and performance of various conventional building materials, there have been little systematic efforts to examine the general validity and applicability of these tools to LCGBMCs in the design of LIGHDs.

Chapter two highlighted the environmental impacts of housing construction activities with focus on the theoretical principles for understanding the impacts of LCGBMCs on low-impact green housing developments. The existing practices impacting their use in housing construction, as well as their socio-cultural, economic, environmental, ethical, and technical importance in achieving a sustainable built environment were also discussed. Conclusions drawn from the literature review indicated that the main bar to the use of LCGBMCs was a lack of relevant information presented in a style familiar and explicit to designers. Following a further review, there were requests of how designers within the Nigerian house build industry could be supported to integrate sustainability into the material selection decision-making process.

This chapter investigates the current technology used in both developed and developing countries to assess the performance of building materials beginning from section 3.2. The objectives of this section are to identify ways to improve the methodology used in the Nigerian house build industry for selecting low-cost green building materials, and examine the quantifiable and comparable features of some selected decision-support systems so as to identify appropriate strategies that are needed to develop the proposed integrated modular-oriented system for the evaluation of LCGBMCs. Section 3.3 further examines the benefits and limitations of current models in ascertaining material sustainability. Section 3.4 demonstrates the concept of multi-dimensional approach in the assessment of material sustainability, and thereafter discusses a conceptual framework for building material evaluation based on a multi-dimensional approach. Section 3.5 concludes the chapter. This chapter fulfills Objective 3 of the research study

3.2 A Review of Existing Assessment Tools

With the advent of sustainable material selection and sustainable housing, numerous resources and tools have been created to aid informed decisions (Cole, 2003; Ding, 2008; USDOE, 2010). This section explores what information designers require to make sustainable material selection decisions when formulating decisions regarding the selection of low-cost green building materials and components at the crucial stages of the design process, and analyses what support resources exist to enable this. In this section, some of the very few but popular assessment methods and expert tools used in both developed and developing economies are examined in details.

3.2.1 Decision Support Tools in Developed Countries

ENVEST - Envest is the first UK software for estimating the life-cycle environmental impacts of a building from the early design stage. It enables architects and designers to evaluate the environmental impacts of different design option for a chosen building, and considers the environmental impacts of materials used during construction and maintenance. Envest has been created principally to help designers compare different material options in terms of environmental performance from the early design stages. Using minimal data entered through simple input screens, Envest allows designers to quickly identify those aspects of the building that have the greatest influence on the overall impact. All impacts are assessed using Eco points, a measure of total environmental performance, which allows the designer to compare different designs and specifications directly. Although Envest covers the whole phase of a building's life cycle, it is limited to the assessment of materials for office buildings and has more limited groups of users. Unspecified input data and non-credible input data are the other issues identified with Envest and its lack of flexibility in alternatives or categorisation of materials.

BEES - (Building for Environmental and Economic Sustainability), is a computerised tool for choosing environmentally preferable building materials (Lippiatt and Ahmad, 2004). The BEES environmental performance assessment is based on the LCA standards, including categorising in impact categories, normalising by dividing by the U.S. emission per year per capita, and weighing by relative importance. The overall evaluation involves the environmental score and the economic score being weighted together to achieve the most appropriate balance between environmental and economic performance using relative importance decided by the decision maker's values. BEES Online, aimed at designers, builders, and product manufacturers, includes actual environmental and economic performance data for 230 building products (see model in **Figure 3.1**).

The BEES system however, is not capable of providing data for a full LCA of a complete building, as it only produces data for a limited amount of building products (Lippiatt 2007, Bayer et al. 2010). From those products, it only considers materials that are significant in weight, energy or cost. It categorizes a minimal set of impact categories, hence limits the flexibility, accuracy and performance of any building product in terms of maximising its full potentials.

BEES 4.0

Figure 3.1. Sample of BEES model

Source: Adapted from The National Institute of Standards and Technology (NIST, 2011)

<u>ATHENA</u> - ATHENA is an LCA tool developed at the ATHENA Sustainable Materials Institute in Ontario, Canada (Clements-Croome, 2004). The ultimate goal of this system is to encourage the selection of material mixes of over 1200 building materials and assembly combinations (Trusty et al., 1998). ATHENA Impact Estimator for buildings is the only software tool that evaluates whole buildings and assemblies based on internationally recognized life cycle assessment (LCA) methodology. The model breaks down the selected assemblies comprising a design into their respective products for the purpose of applying the model's life cycle inventory (LCI) databases that contain estimates of the environmental effects per unit of each building product (see **Figure 3.2**).

A limitation of this tool is that it only allows the evaluation of assembly options given that they also come with fixed dimensions (Bayer et al. 2010). Another Major drawbacks to this tool are the cost and required skills to use it, and the limited options of designing high-performance assemblies.

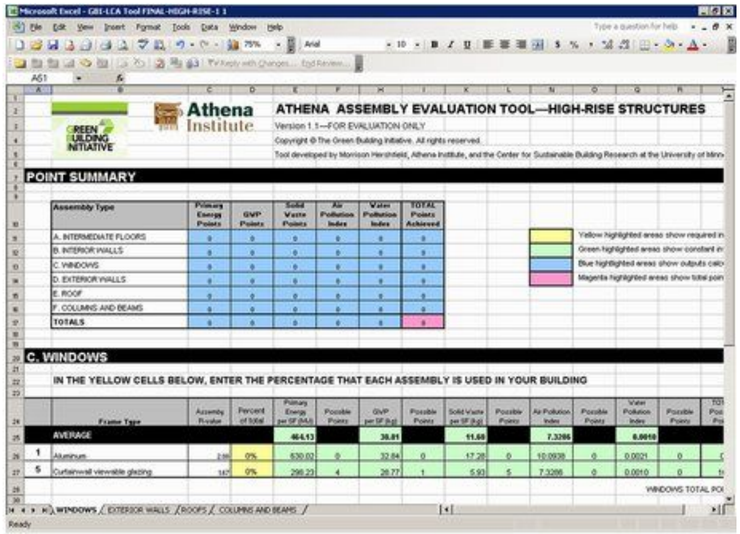


Figure 3.2. Sample of ATHENA reporting documentation

Source: Adapted from HK Buildings Department, 2005

EPM- Environmental Preference Method (EPM) was developed by Wood /Energy, in the Netherlands in 1991, within the program on Sustainable living at the Dutch Steering Committee on Experiments in Housing (Anderson et al., 2009). The main goal of the model is to construct a ranking of building materials according to their environmental impacts by positively labeling or blacklisting a product using the matrices approach (Anderson et al., 2009). The principle of this method takes into account different factors, such as various damages of eco system, consumption/exhaustion of resources, energy consumption (in all phases of production, including transport), environmental pollution with different waste and hazardous materials, waste disposal problems, hazardous emissions into the atmosphere, global warming, impact on human beings, re-use and recycling possibilities, etc.

The result is a list of preferable materials and products, made on the basis of evaluation of the environmental impacts of each of them, and adjusted to typical positions within a building (Anink et al, 1996). The matrices in EPM are however not published, and no detailed description is given of how a specific product is assessed. This model includes environmental aspects, but the second and third elements of sustainable materials (social and economic considerations) are not included (as shown **Figure 3.3**).

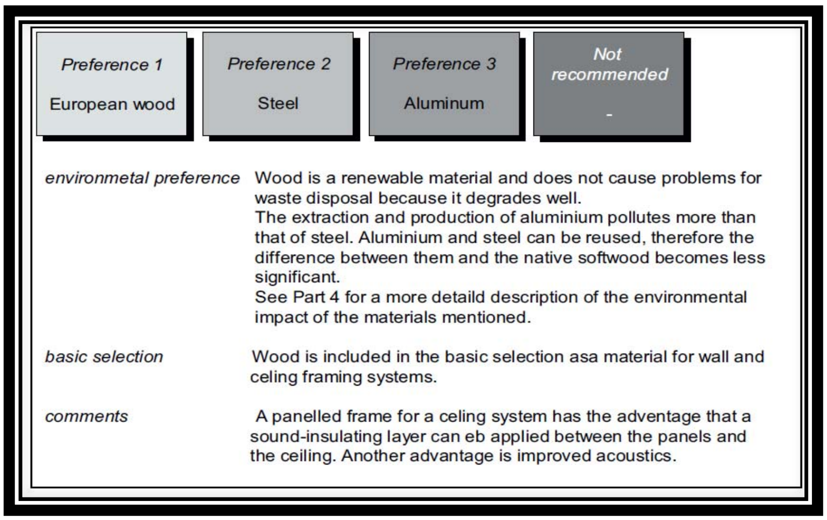
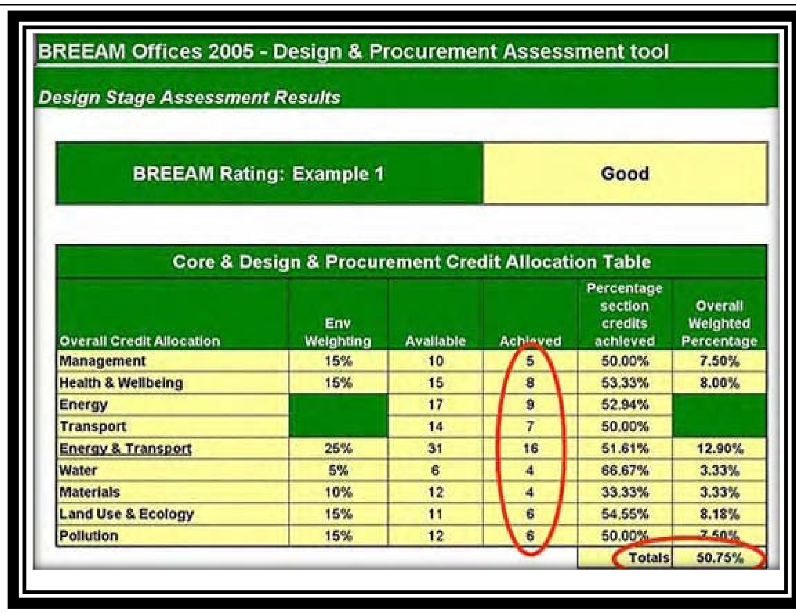


Figure 3.3. Relative ranking of wall and ceiling frame systems in the EPM method

(Source: Anink, et al., 2008)

<u>BREEAM—</u>BREEAM (Building Research Establishment's Environmental Assessment Method) was developed in the United Kingdom in 1990 and is the building environmental assessment method with the longest track record (Peter & Somervell, 2004). BREEAM covers a range of building types including: offices, homes, industrial units, retail units, and schools. Material selection is based on awarding points for each criterion and the points are added for a total score calculated based on the credits available, number of credits achieved for each category and weighting factor. The overall building performance is categorised as Unclassified (<30%), Pass (30%), Good (45%), Very Good (55%), Excellent (70%) and Outstanding (_85%). **Figure 3.4** shows sample reporting and certification pages for a BREEAM. The results of the investigation are fed into the design development stage of buildings and changes can be made accordingly to satisfy pre-designed criteria (Crawley and Aho, 1999; Kibert, 2008).

Although there is no disputing that the BREEAM rating tool aid corporates and developers improve a project's sustainability status and enjoy sustainability credentials, it requires capital expenditure to invest in this costly tool. Another draw back is that the energy performance assessment adopts the U.K Building Regulation as a benchmark to rate the level of performance improvement, which may not necessarily apply to other regions with an entirely different assessment structure.


BREEAM Offices 2005 - Design & Procurement Assessment tool

Design Stage Assessment Results

BREEAM Rating: Example 1	Good

Core & Design & Procurement Credit Allocation Table

Overall Credit Allocation	Env Weighting	Available	Achieved	Percentage section credits achieved	Overall Weighted Percentage
Management	15%	10	5	50.00%	7.50%
Health & Wellbeing	15%	15	8	53.33%	8.00%
Energy		17	9	52.94%	
Transport		14	7	50.00%	
Energy & Transport	25%	31	16	51.61%	12.90%
Water	5%	6	4	66.67%	3.33%
Materials	10%	12	4	33.33%	3.33%
Land Use & Ecology	15%	11	6	54.55%	8.18%
Pollution	15%	12	6	50.00%	7.50%
				Totals	50.75%

Figure 3.4. Sample reporting and certification for BREEAM

(Source: Peter & Somervell, 2004)

GREEN-STAR—Green Star is the most followed voluntary building environmental assessment scheme developed in Australia to accommodate the need of buildings in hot climates where cooling systems and solar shading are of major importance (Cole, 1999). It is similar to BREEAM in that it evaluates the environmental merits of building products using the credit rating system based on a number of points allocated to the credits in order to determine the total scoring and hence the level of certification (Crawley and Aho, 1999; Kibert, 2008). It has a set of environmental criteria related to management, indoor environmental quality, energy, transport, water, materials, land use & ecology, emissions, and innovation. The building certification is expressed as a number of stars: 1-3 Stars (10-44 points; not eligible for formal certification), 4 Stars (45-59 points; Best Practice), 5 Stars (60-74 points; Australian Excellence) and 6 Stars (_75 points; World Leadership).

The disadvantage with this tool is that its use is limited to the evaluation of lettable areas within office buildings, hence excludes areas that are not offices or supporting the office. Moreover, the assessment structure is delineated in Australian standards and perhaps may not apply to other regions with different socio-technical background-given the differing views on impact assessment. **Figure 3.5**, below, is a screen shot from the actual assessment tool.

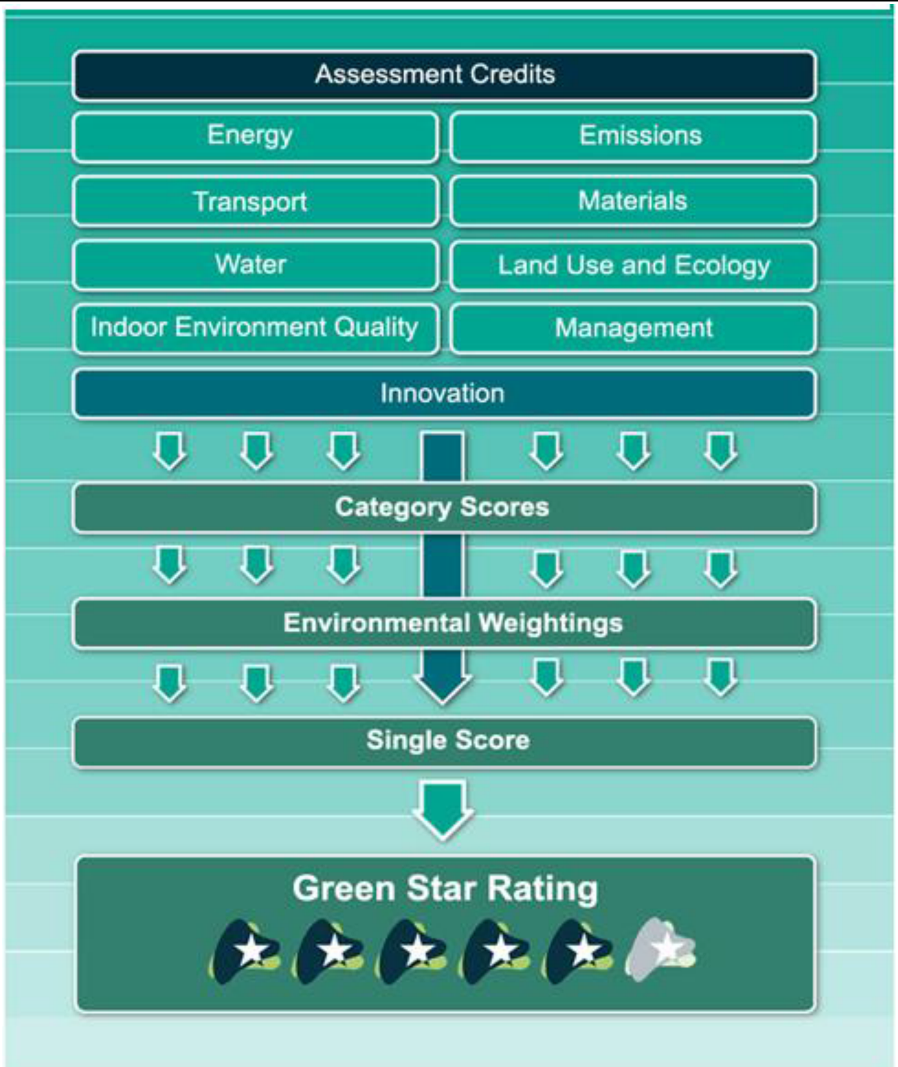
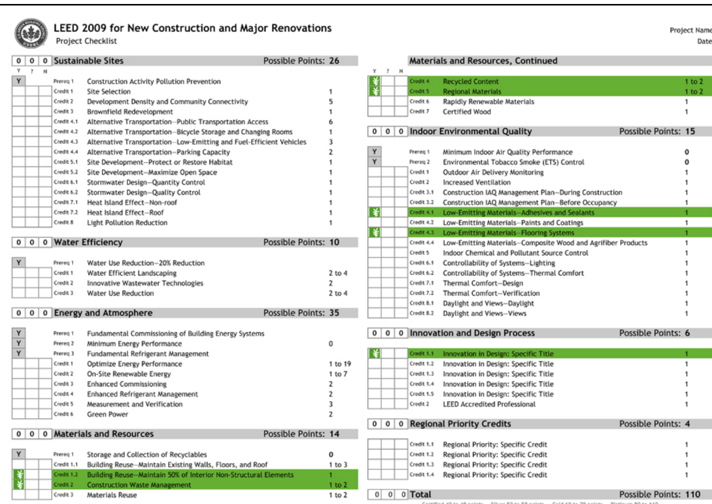


Figure 3.5. Screen shot from the actual assessment tool

<u>LEED—</u> Leadership in Energy and Environmental Design (LEED) Building Assessment System is a performance-based tool for determining the environmental impact of building products and facilities from the whole-building perspective (Kibert, 2008). LEED was developed and piloted in the U.S. in 1998 as a consensus-based building rating system based on the use of existing building technology (Crawley and Aho, 1999; Kibert, 2008).

It is a green building rating system for commercial, institutional and high-rise residential new construction and major renovation in five areas of sustainability: sustainable sites, water efficiency, energy and atmosphere, innovation and design process, materials and resources, and indoor environmental quality (Zhou et al., 2010). The four levels of certification are: Certified (26-32 points), Silver (33-38 points), Gold (39-51 points) and Platinum (52-69 points). Figure 3.6 shows an example of LEED® Version 2.0.

Without a doubt the greatest concern regarding the LEED model is the apparent overemphasis on environmental benefit without an equal concern for the durability of the products employed to achieve this environmental benefit. Unfortunately, the current LEED model makes little or no attempt to reconcile the need to meet new and emerging environmental needs. Given the increasing popularity of the LEED concept and the rating system's disjointed approach, the potential for confusion may be significant, especially for a building owner or designer wanting to apply the LEED concept to the billions of square feet of say roofing projects.


LEED 2009 for New Construction and Major Renovations
Project Checklist

Project Name
Date

Y	?	N	Item	Title	Points
0	0	0		**Sustainable Sites**	Possible Points: 26
Y			Prereq 1	Construction Activity Pollution Prevention	
			Credit 1	Site Selection	1
			Credit 2	Development Density and Community Connectivity	5
			Credit 3	Brownfield Redevelopment	1
			Credit 4.1	Alternative Transportation—Public Transportation Access	6
			Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
			Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
			Credit 4.4	Alternative Transportation—Parking Capacity	2
			Credit 5.1	Site Development—Protect or Restore Habitat	1
			Credit 5.2	Site Development—Maximize Open Space	1
			Credit 6.1	Stormwater Design—Quantity Control	1
			Credit 6.2	Stormwater Design—Quality Control	1
			Credit 7.1	Heat Island Effect—Non-roof	1
			Credit 7.2	Heat Island Effect—Roof	1
			Credit 8	Light Pollution Reduction	1
0	0	0		**Water Efficiency**	Possible Points: 10
Y			Prereq 1	Water Use Reduction—20% Reduction	
			Credit 1	Water Efficient Landscaping	2 to 4
			Credit 2	Innovative Wastewater Technologies	2
			Credit 3	Water Use Reduction	2 to 4
0	0	0		**Energy and Atmosphere**	Possible Points: 35
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	0
Y			Prereq 3	Fundamental Refrigerant Management	
			Credit 1	Optimize Energy Performance	1 to 19
			Credit 2	On-Site Renewable Energy	1 to 7
			Credit 3	Enhanced Commissioning	2
			Credit 4	Enhanced Refrigerant Management	2
			Credit 5	Measurement and Verification	3
			Credit 6	Green Power	2
0	0	0		**Materials and Resources**	Possible Points: 14
Y			Prereq 1	Storage and Collection of Recyclables	0
			Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
			Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1
			Credit 2	Construction Waste Management	1 to 2
			Credit 3	Materials Reuse	1 to 2
				Materials and Resources, Continued	
			Credit 4	Recycled Content	1 to 2
			Credit 5	Regional Materials	1 to 2
			Credit 6	Rapidly Renewable Materials	1
			Credit 7	Certified Wood	1
0	0	0		**Indoor Environmental Quality**	Possible Points: 15
Y			Prereq 1	Minimum Indoor Air Quality Performance	0
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	0
			Credit 1	Outdoor Air Delivery Monitoring	1
			Credit 2	Increased Ventilation	1
			Credit 3.1	Construction IAQ Management Plan—During Construction	1
			Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
			Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
			Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
			Credit 4.3	Low-Emitting Materials—Flooring Systems	1
			Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products	1
			Credit 5	Indoor Chemical and Pollutant Source Control	1
			Credit 6.1	Controllability of Systems—Lighting	1
			Credit 6.2	Controllability of Systems—Thermal Comfort	1
			Credit 7.1	Thermal Comfort—Design	1
			Credit 7.2	Thermal Comfort—Verification	1
			Credit 8.1	Daylight and Views—Daylight	1
			Credit 8.2	Daylight and Views—Views	1
0	0	0		**Innovation and Design Process**	Possible Points: 6
			Credit 1.1	Innovation in Design: Specific Title	1
			Credit 1.2	Innovation in Design: Specific Title	1
			Credit 1.3	Innovation in Design: Specific Title	1
			Credit 1.4	Innovation in Design: Specific Title	1
			Credit 1.5	Innovation in Design: Specific Title	1
			Credit 2	LEED Accredited Professional	1
0	0	0		**Regional Priority Credits**	Possible Points: 4
			Credit 1.1	Regional Priority: Specific Credit	1
			Credit 1.2	Regional Priority: Specific Credit	1
			Credit 1.3	Regional Priority: Specific Credit	1
			Credit 1.4	Regional Priority: Specific Credit	1
0	0	0		**Total**	Possible Points: 110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

Figure 3.6. Sample reporting and certification for LEED

(Source: USDOE, 2009)

GBTool- The International Framework Committee for the Green Building Challenge in Canada developed the GBTool in 1998 (Todd, et al, 2001). It is designed to reflect regional conditions and context (Crawley and Aho, 1999; Kibert, 2008). It includes criteria in categories such as Site Selection, Project Planning and Development; Environmental Loadings; Energy and Resource Consumption; Indoor Environmental Quality; Functionality; Long-Term Performance; and Social and Economic Aspects. Criteria are assessed using scales that are based on local benchmarks of "typical" practice; buildings can score -1 if below typical practice or from +1 to +5, representing good to very high performance. The tool itself comprises two spreadsheets, one for data entry (to be completed by the project team) and one for establishing weights and benchmarks and completing the assessment (to be completed by third party sponsors or assessors).

However, since GBTool is not integrated with the life-cycle process of a project, it is difficult for the construction professionals to use the assessment indicators at the planning, design and construction stages of the building process, since it is limited to use in post-construction assessment. (**Figure 3.7** shows an example of CASBEE reporting documentation)

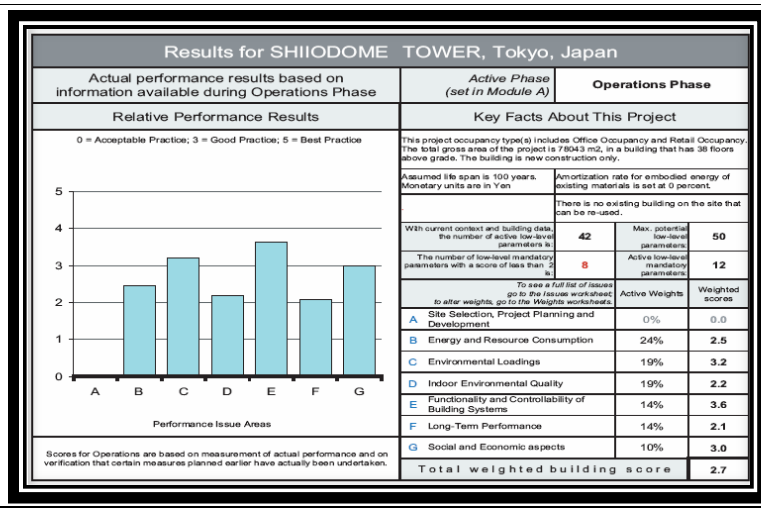


Figure 3.7. Sample reporting and certification for GBTool

(Source: Todd, et al, 2001)

3.2.2 Decision Support Tools in Developing Countries

Since the variance in the problems of natural resource depletion and global environmental degradation has become evident, the interest for the cross-cultural transferability of assessment methods is now of particular importance to those in developing countries (Cole, 1999, Kibert, 2007). Several recent assessment tools within the developing regions moreover, show structural features that differentiate them from the first generation of tools in the developed regions (Gibberd, 2002).

Gibberd (2003) mentions that since developing countries are confronted with pressing social and economic concerns, their domestic constraints on environmental progress have been found to be qualitatively different from those in developed countries (Cooper, 1999). Hence, the following tools suggest a transition towards a generation of tools that may enable assessment of the extent to which buildings can contribute to supporting an entirely different sustainable pattern of living in developing regions.

CASBEE- CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) was developed in Japan, beginning in 2001. This family of assessment tools is based on the building's life cycle: pre-design, new construction, existing buildings, and renovation. It is a relatively new system developed for the Japanese market that is available in English, but has not been tested in the U.S.

Results are plotted on a graph, with environmental load on one axis and quality on the other – the best buildings will fall in the section representing lowest environmental load and highest quality. Each criterion is scored from level 1 to level 5, with level 1 defined as meeting minimum requirements, level 3 defined as meeting typical technical and social levels at the time of the assessment, and level 5 representing a high level of achievement as shown in **Figure 3.8.**

This system unfortunately requires documentation of quantifiable sustainable design achievements, which are assessed by only trained, first-class architects, which have passed the CASBEE assessor examination.

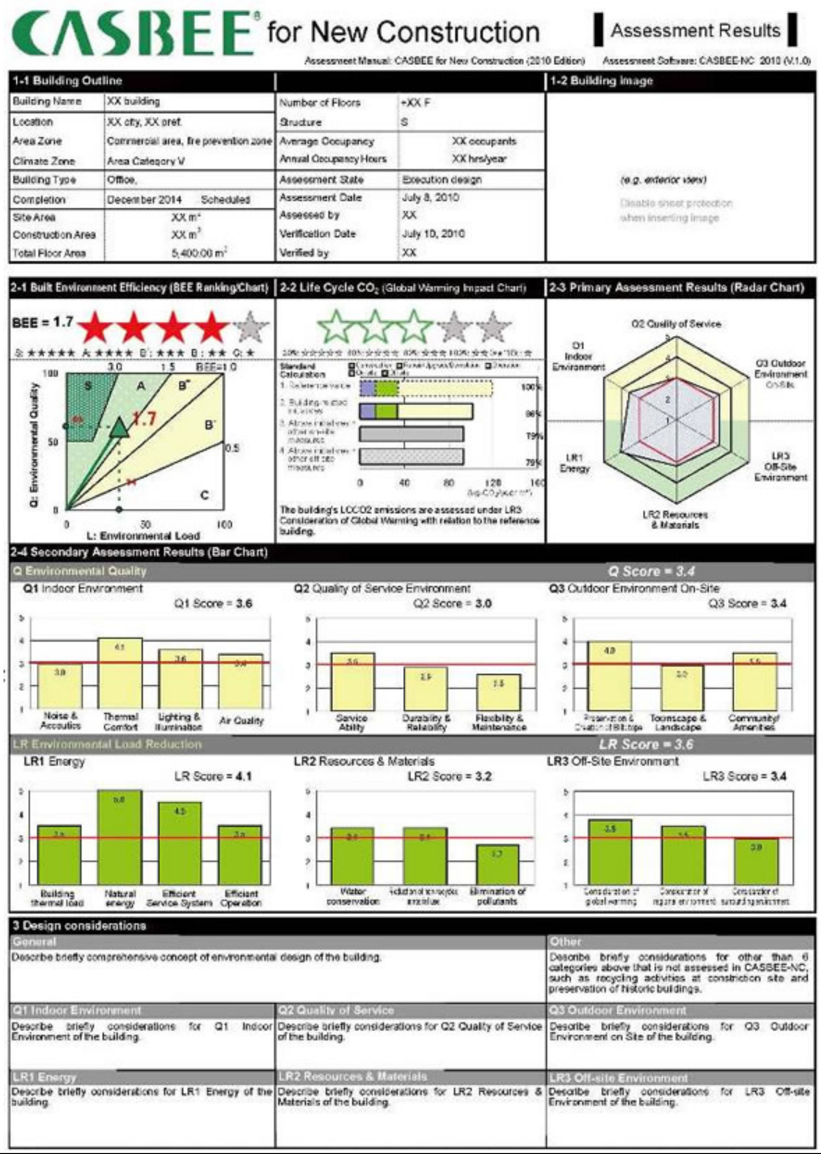


Figure 3.8. Sample of CASBEE reporting assessment result and documentation sheet

Source: Adopted from HK Buildings Department, 2005.

CEPAS- The Comprehensive Environmental Performance Assessment Scheme for Buildings (CEPAS) is a holistic assessment tool for various building types with clear demarcation of the entire building life cycle that covers the pre-design, design, construction, demolition and operation stages. It employs an additive/weighting approach, which introduces and organizes performance criteria that make a clear distinction between "human" and "physical" performance issues as well as "building" and their "surroundings (Crawley & Aho, 1999). This manifests as eight performance categories: Resource Use; Loadings; Site Impacts; Neighbourhood Impacts; Indoor Environmental Quality; Building Amenities; Site Amenities and Neighbourhood Amenities (Cole, 1999).

However, for the CEPAS assessment model, only single-ownership buildings are eligible for assessment. **Figure 3.9** shows an example of CEPAS Version

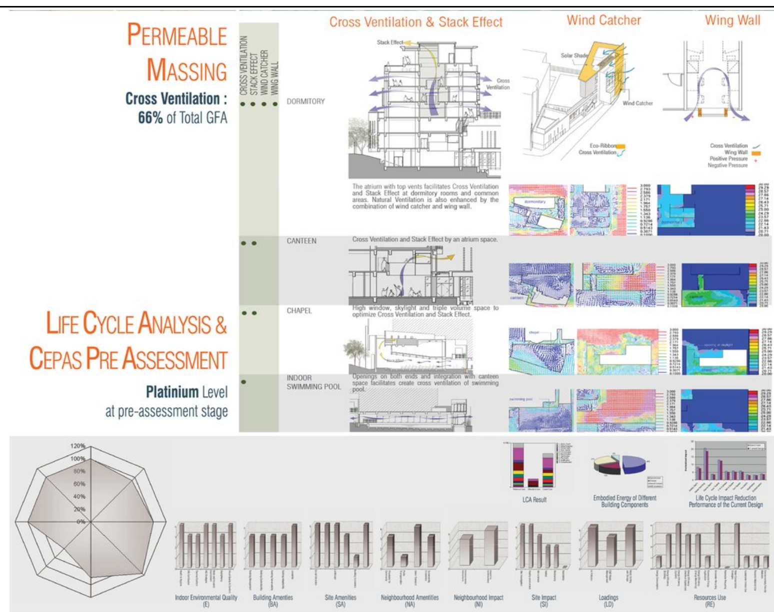


Figure 3.9. Sample of CEPAS reporting documentation

Source: Adopted from Cole, 1999.

<u>SBAT-</u> The Sustainable Building Assessment Tool (SBAT) was created in South Africa by the CSIR (Council of Scientific and Industrial Research) in 2001 (Gibbered, 2002). SBAT provides an indication of the performance of a building or the design of a building in terms of sustainability, and explicitly introduces performance criteria that acknowledge social and economic issues (Gibbered, 2003). A total of 15 performance areas are identified – equally divided within the overarching sustainability framework of environmental, social and economic as shown in **Figure 3.10**. These performance areas are each described through 5 performance criteria in three steps namely: 1) Setting the Project Up, 2) Entering Measurements, and 3) Reading the Report. It also considers to a nine-stage process based on the typical life cycle of a building: Briefing, Site Analysis, Target Setting, Design, Design development, Construction, Handover, Operation, Reuse/recycle, is explicitly defined in this context.

The current tool however mainly assesses building performance with little recourse to material indicators. Since the tool is based on the overall performance of the building, any differences in the materials used do not affect the decisions with the result that the scheme is almost entirely unable to differentiate between choices of materials except for indirect consequences.

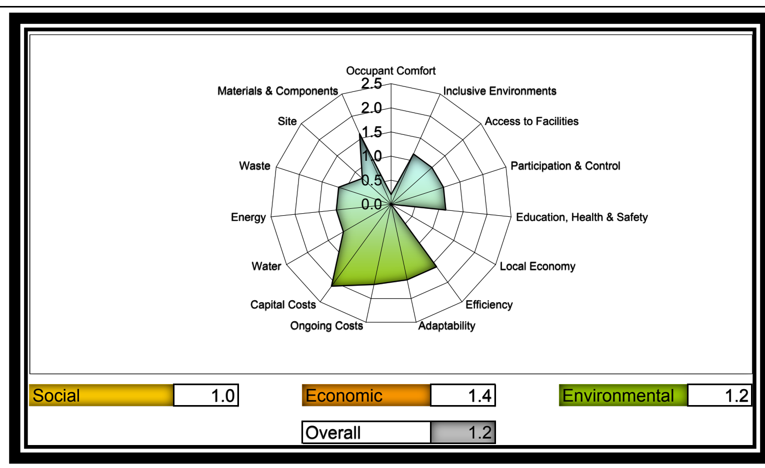


Figure 3.10. Sample of SBAT reporting documentation

Source: Adopted from Gibbered, 2001.

Although the reviewed tools in both developed and emerging economies have an extended use in the built environment, various authors (Ding 2008; Zhou et al., 2008) have established a strong credibility amongst expert/knowledge-based tools and emphasised their need in dealing with material selection problems using different assessment techniques. The following section examines some examples of existing expert/knowledge-based tools.

Appendix O presents a comparative analytical summary of the reviewed building assessment tools. It offers comparative details on each of the rating systems based on a range of criteria

3.2.3 Building Assessment Methods: Knowledge-Based Tools

In recent years, expert/knowledge-based tools have dominated research in computerised housing construction management in a bid to supplement first and second generation decision support models.

Some examples like Mahmoud et al's (1996) work is accredited as being one of the pioneers of DSS applied to materials selection problems. They developed a multi-criteria knowledge decision model for quantitative cost analysis. This system was designed for the selection of finishing materials such as floors, walls and ceilings with the objective to operate at the least cost. What this study does not provide are links, information or tools to aid the designer with material decision-making. Although it gives a very brief introduction to floor, wall and ceiling materials, some of the common material types are listed but with little information. No specific information methodology was given for evaluating such materials but strategies are explained as to how to improve materials selection choices.

Other influencing reviews within the scope of this study include Mohamed and Celik (1998) who proposed a computerised framework that is responsible for evaluating alternative design options, and cost estimation of materials for residential buildings. The program's data utility enables users to intuitively choose their most preferred option from list of materials. No mention was however made as to the MCDM technique used for evaluating the list of materials selected. It was also found that the existing framework is limited to the cost considerations of material choice and fails to include values such as aesthetics, and cultural aspects.

Lam et al. (1999) took Mohamed and Celik's (1998) work a stage further and suggested that materials management systems should be integrated into appropriate computer systems, which could assist in the design of the project. It was suggested that the decision-making process in the choice of materials could be quantified, measured and improved by using a software package. The Methodology structure employed was proposed to be the most appropriate method to develop an efficient and effective materials selection system. It was emphasised that because simulation tools emulate human decision making skills, the recommended outcomes of the system more accurately reflect real life solutions. What Lam et al.'s (1999) study fail to acknowledge is the huge and long-term impact of professional judgment on overall building performance, as limiting the choice of materials to just the specification of systems would impede the discovery of design opportunities inherent in designers judgment.

Perera and Fernando (2002) reinforced Lam et al.'s (1999) proposal by developing a computer-based cost modeling material management system for roofing material selection. This software was claimed to include 35 to 50 percent of decision-makers input, over and above normal computerised materials management systems. Evidently, this work indicates that supplementing designers' decision using DSS can reduce management time and subsequently decrease associated materials selection management problems at the crucial stage of the design. Although the model acknowledges the input of the designer in the selection of materials it does not encourage the integration of a broader range of factors into the material selection process. Further results however, demonstrated large inconsistencies in the evaluation process, as no particular reference was made as to the MCDM selection methodology employed.

Ashby and Johnson (2002) proposed a knowledge- based system for assessing aesthetic attributes such as transparency, warmth, and softness in the material properties list for product designers. Within the discipline of architecture, however, the intangible qualities of materials are not described and mapped within the current design models. No selection framework was provided to support the implementation of the system. Although it gives a little information on each of the material types outlined, it however does not demonstrate how to source these materials.

Keysar & Pearce (2007) demonstrated in their study how material selection tools could facilitate the innovation diffusion process and radical decision-making transformation. They developed a Decision Support Tool (DST) for green building to facilitate selection of material selection tools among new adopters on public sector project for architects and engineers selecting materials for designs. Their research seem to imply that designers choice of an appropriate DSS determines informed decision in material choice, hence do not choose for materials but rather for material systems. The system does not provide assistance for material comparisons, advice on material properties or recommendations for tools to assist in the evaluation of sustainable materials.

Zhou et al. (2008) developed a decision support multi-objective optimization model for sustainable material selection. The material selection tools and material data sheets provide extensive information that include factors such as cost, mechanical properties, process performance and environmental impact throughout the life cycle. The tool however, lacked the considerations or descriptions to evaluate the intangible aspects of building materials, which are also important to architects. Although the tool tended to be defined to include both technical and non-technical aspects, generally the former was covered more

Wastiels and Wouters (2008) proposed a qualitative and quantitative framework to support informed decisions based on ‘physical’ and ‘sensorial’ aspects of building materials, but without the tools integration and computerisation. In the presented framework, no pronouncement is made upon how sustainable considerations from these different categories could influence each other, and what MCDM approach could possibly be used if developed.

Ashby and Johnson (2006) further developed a creative framework to aid industrial designers select materials which should enable material and process information to be captured, presented creatively, allowing browsing and searching along with the ability to identify technical and perceived material, process and product attributes. Although the technical dimension of the material selection process was discussed, it was surprising to find more focus given to technical considerations. Designers are required to consider many factors as determining the choice of materials using the single-criterion approach would mean depriving designers of the use of diverse materials available.

Gehin et al. (2008) created and developed a tool designed to assist designers to optimise end of life considerations of materials, providing information tailored towards remanufacturing. It is designed to enable designers to evaluate the environmental impact of the products and its components. Its presentation style lacks graphics and would appeal more to engineers than designers or architects, as the majority of the products appear to suit an engineering application.

More recent concepts introduced and utilised in the materials evaluation domain include the combination of a Decision Support System (DSS) with knowledge-based MCDM techniques, The research by Rahman et al. (2009) developed an integrated knowledge-based cost model for optimizing the selection of roofing materials and technology for residential housing designs.

It was hypothesised that using Technique of ranking Preferences by Similarity to the Ideal Solution (TOPSIS) could deal better with uncertainty that is naturally present in decision-making processes when selecting roofing materials at the early stages of the design. The framework presented is only designed as an evaluation tool to assess the cost sustainability of roofing materials once they have been selected. Very little precise information is given about the technical, socio-cultural and environmental issues.

A process framework for building design was further proposed in Loh et al., (2010). They developed an ICT system to support multi-stakeholder decision-making which facilitates inclusion of energy issues when selecting building products at the early design phase of buildings based on users preferred weightings. Preliminary results would suggest that the AHP approach used could make a significant impact upon the choice of materials. The model proposed by Loh et al. (2010) rank-orders a set of preselected, technically feasible materials using different decision factors with and without tangible values, such as a clients favour over a particular building design, publicity potential of the building design, life cycle cost, capital cost and energy performance of different materials and building layouts. Issues of sustainability are covered by a number of criteria but what is lacking is the information on how to select sustainable materials.

A similar study by Ding (2010) developed a comprehensive assessment decision support system that measures the life-cycle environmental characteristics of a building product using a common and verifiable set of criteria and targets for building owners and designers, to achieve higher environmental standards. Upon analysis it was found that her study appears to only direct sustainable material selection towards environmental issues.

Hornbuckle (2010) presents a visualisation designed to map the links between designers, other actors involved in secondary material supply, secondary material types and the material cycle. The framework gives methods to source secondary materials, on a scale from quite easy (ask distributor) to particularly challenging (investigate and experiment with problem secondary material and close the loop) /the methods are each linked to the necessary supplier; such as distributors, manufacturers, and factories. The secondary material is presented hierarchically depending on the quality, with high quality closed loop at the top and problematic contaminated at the bottom. The understanding of material sustainability amongst designers was found to be limited to the material production and end-of-life phases.

The Building Information Modeling System (BIM, 2013) was developed as the most common denomination for a new way of approaching the design, construction and maintenance of buildings. It is designed to aid decision-makers in the planning and design phase of the project, extending throughout the building life cycle, supporting processes including cost management, construction management, project management and facility operation. The most benefits of applying BIM in design phase are cost reduction and control and time saving by improving productivity, better coordination and reduced error, and rework (Bryde et al 2013). Although the potential of using BIM models for energy simulation is well known, a systematic approach that can be used to share the necessary information is still lacking (Young, et al 2009).

From the above analyses it is clear that the starting points and expectations of the reviewed expert/knowledge-based assessment methods are qualitatively and quantitatively different from those of the first and second generation of tools used in industrialised and emerging economies. By highlighting the different sustainable building material assessment tools, it can be deduced that there was very little consistency in the methodologies used from one tool to another.

Although reference is made to sustainability criteria and issues in each of the reviewed tools, the fundamental underpinnings regarding relative and separate scoring of the individual criteria are different from those currently deployed in assessing sustainable performance in developing countries. While few may still query the proliferation of assessment tools in the housing construction industry, it can be noted that each of the individual tool reviewed is dispersed and founded on individual initiatives without a unified consensus based framework. The following section highlights some of the problems common to the reviewed tools.

3.2.4 Limitations of the Reviewed Assessment Tools

In relation to the existing tools, this research presented an extensive review of the characteristics for a number of material evaluation tools used in both developed and developing countries. It also identified the different material selection indicators used in each tool. From the analysis the following issues were identified as part of the problems associated with existing DSS.

- **Regional Variation:** One of the weaknesses identified with the reviewed tools is that most of them were developed for local use and so, do not allow for international, national or regional variations. Potential DSS models often have to be adjusted according to the background of the intended region, since the variance of climate, natural resources and economic situation in different regions do not permit a universal or standard approved material assessment system. However, the proposed integrated modular-oriented model is to be developed for flexible use so that users who intend to apply such model to a different environment are able to do so with minimal adjustments.

- **Complexity:** Most of the reviewed assessment tools required large quantities of detailed information to be assembled and analysed, which can be very confusing to use and hard to understand due to the complexity of the information displayed and calculated. Having too many information to deal with as in the case of the BEPAC and GBTool could jeopardise their usefulness in balancing between completeness in the coverage and simplicity of use. The databases of the proposed model would be split into modular units or compartments to allow for ease during the evaluation process.

- **Life cycle approach:** Some of the reviewed tools from the literature are only applied at a specific point in time, as most tools fail to take a life cycle approach, and target conditions only during the final design or operation stage. The envisaged model will be designed to accommodate issues relevant to the decision-making process from the earliest stages of the design, since decisions made at the initial stages of the design have greater impacts on the performance of the building than when considered at the final design stage

- **Financial and Socio-Cultural issues:** Most building material assessment tools such as; BREEAM, BEPAC and LEED focus on the evaluation of building products against a set of environmental criteria but do not include cost and socio-cultural considerations in the evaluation framework. This often contradicts the ultimate principle of building projects, as minimizing the cost of materials is fundamental to all building projects. Attention will be given to both the economic and socio-cultural dimensions of the SD principles, since a project that may be environmentally sound could be very much expensive to build and most often not compatible with the life-style of its users.

- **Evaluation of quantitative and qualitative data:** Quantitative criteria such as energy and water consumption can be readily evaluated based on the total consumption level and points awarded accordingly. In using models such as BREEAM, and LEED, qualitative criteria such as aesthetics, health and safety, are difficult to evaluate.

In most existing tools, quantitative and qualitative data are normally evaluated on a `feature- specific' basis where points are awarded for the presence or absence of desirable features, which largely undermines the importance of qualitative criteria within the decision-making process. This study is to examine various assessment techniques and adopt the most appropriate material assessment technique that can adequately deal with both quantitative and qualitative elements of the material selection process.

- **Weighting alteration:** Generally, most existing building material selection frameworks provide a default weighting system, which encourages users to change the weights based on regional differences. Individual country teams often establish scoring weights subjectively when evaluating building products, which is often a problem when applied to other regions. Since the default weighting system can be altered, there is likelihood that users may manipulate the results to improve the overall scores in order to satisfy a specific purpose. The weighting of the criteria would thus be derived on a project-by-project basis and reflect the objective of the potential users and relevant stakeholders.

- **Clarity of intentions:** The notion of "material assessment" implies uncompromised accuracy, objectivity and transparency in defining the performance indicators and matched by an equally rigorous process of evaluation. However, the need for clarification and distinction between the role of a tool as an assessment model measuring performance and progress from their role as encouraging market transformation is symptomatic of a wide range of existing support systems. This suggests the need for greater clarification of the overall goals and objectives when developing the envisaged resource for LCGBMCs.

While there may seem to be claims that existing building assessment tools provide limited pre-processed rules of thumb (Selkowitz et al. 2009), there are great advantages to their application in the housing construction industry. The points in the following section primarily relate to the lessons learnt from the reviewed tools and their potential role in facilitating the development of the envisaged model.

3.2.5 Strategies Derived from the Reviewed Assessment Tools

The following have been identified as potential strategies that will be implemented during the development of the envisaged model

- **Holistic/ Integrated modular-oriented approach:** The review of the tools in the contexts of both the developed and developing countries in sections 3.3.1-3.3.3 suggests that interventions to support sustainable development in developing countries must address environmental, social, and economic issues as a holistic priority. It is thus suggested that the resource to be developed for the evaluation of LCGBMCs in the design of LIGHDs must ensure maximum beneficial environmental, technical, socio-cultural, sensorial and economic impacts in the decision-making process, rather than concentrating on the more conventional approach of minimising either environmental or economic impact.

- **Participation:** From the reviewed literature it was observed that some of the stakeholders had little to contribute in how development of existing assessment tools may have occurred. In order to ensure that the proposed assessment support tool and invariably, the development reflect the needs and priorities of the target groups it will benefit, this study is to ensure that they are appropriately involved in the development process through interviews and surveys.

- **Indigenous systems:** The study revealed that developing countries have highly evolved indigenous systems that are sustainable and relevant to the development of any system. These include technological, organisational, cultural and knowledge systems. These can provide highly valuable models for sustainable development as they would provide working models that can be drawn on during the development process. Developing of the system therefore would not be created in isolation to potential users and local communities hence would be designed to be responsive to local needs, knowledge and opportunities.

- **Sustainability principle indicators (Key decision/influential factors):** Sustainability Principle Indicators are used to measure progress towards achieving the sustainability objectives. One of the overarching goals from the reviewed studies is that design and building professionals must ensure that the decisions made at the crucial stages of the design process are able to support sustainable development through the identification of multiple key decision factors. A range of indicators has been identified from the literature and professional practice, which would be used to measure the sustainability of LCGBMCs in the design of LIGHDs. A representative list of potential indicators is to be compiled in chapter 5. In the sustainability index, stakeholders will have the opportunity of identifying the criteria and sub-criteria that concern them most in the evaluation framework. Additionally, stakeholders will also participate in deriving weights and ranking factors through questionnaire surveys to reflect the level of importance of criteria and sub-criteria during the feasibility stage of the system. A separate set of contextual considerations would also be developed as a heuristics base to facilitate specific feasibility and appropriateness testing of each material choice. Algorithms would be made available in the literature to determine the authenticity of each heuristic.

- **Weightings:** Users weightings will be employed to supplement their decision-making process but not to supplant human judgment so as to determine the importance of each sustainability attribute or factor. Weightings are included to authenticate the final material choices. It remains the ultimate material selection criteria, as no laws or process currently exist that determines sustainable material selection and design. By incorporating user weightings into the selection process, the methodology would gain greater acceptability to the user who supplies the weightings, so that a customisation of the sustainability of the final design product can occur.

- **Modular concept:** The assessment framework aims to ensure that the right sustainable development objectives are set in terms of the state of knowledge and technology, the context, project, and stakeholders. This study aims to make sustainable material selection directly relevant to buildings and construction by breaking the components down into easily implementable steps and processes, which in turn would be integrated into a holistic model of low-cost green building materials and components. Since the components of the framework would consist of distinct information and features, each database may be developed independently into modular bits, so that data may be added as they are acquired to supplement the knowledge and databases. This is to ensure that each component of the framework is accurately and independently updated without disruption or interference of other units.

The foregoing section has identified some of the strategies and features that will be implemented in the development of the envisaged evaluation decision support model for LCGBMCs. The following section elaborates on different existing evaluation techniques in material selection and management.

3.3 Existing Techniques in Material Selection

Godfaurd et al. (2005) has stressed that the use of a proper material assessment or evaluation technique can be a powerful resource for builders and designers in sustaining the decision process and supporting an assertive choice. As a result, numerous material selection and assessment techniques have been developed to support the decision- making process. Some of the pros and cons of various evaluation techniques in use are examined below in order to identify the most appropriate option for this study.

3.3.1 Environmental Valuation Techniques

Van Pelt (1994) has noted that valuing environmental resources means using market forces to determine resource allocation and ensure less wasteful consumption. He explained that putting value on environmental assets limits environmental degradation and promotes its protection. One of such methods used to assess the selection of materials as the environmental costs and issues are considered during the decision-making process is the environmental valuation technique. In this process a monetary value is put on the environmental effects of economic decisions, to provide a framework for comparing the environmental loss with economic gains (van Pelt, 1994; Boyd, 2007). The various techniques of assigning monetary values to environmental benefits include:

- Market valuation of the physical effects method: Here, the market valuation of physical effects observes environmental changes in physical terms and the differences are estimated accordingly.

- Stated Preference: This method is used to obtain values of environmental assets by asking people directly to place monetary values on environmental issues such as the value of preserving a forest.

It is often a questionnaire-based social survey used to obtain individuals' willingness to pay for an environmental gain or to accept compensation for a loss (Turner et al., 1994).

- The revealed preference method: This method involves the examination of people's behaviour to the environment. It is based on surrogate markets, which act as a proxy for the missing environmental goods and services in the market. Some of the advantages of the environmental valuation technique are as follows:

- Can help to stimulate environmental awareness, justify a decision, and evaluate regulation so as to indicate relevance to macroeconomic objectives and to determine compensation.

- This approach helps to place an upper limit on resource usage and allows a trade-off process to establish market prices by which resources are allocated.

- It allows the decision-maker and general public to realise the potential damage and, in the process, highlights the importance of environmental conservation and its incorporation into the decision- making process.

Despite their advantages, several issues still plague the environmental valuation technique. Below are some of the weaknesses of the environmental valuation techniques:

- The usefulness and accuracy of environmental valuation techniques is highly controversial. Environmental effects have no natural units of measurement, as it is difficult to translate them into economic valuations and bring them into national account calculations

- Environmental damages are multidimensional and too complex to be evaluated using these techniques. In other words the benefit of the environment to society is too complex to be captured by a single dollar value and any attempt to do so may underestimate the importance of the environment

- Most environmental valuation techniques are single-dimensional, therefore unsuitable for evaluating multifaceted ecological impacts. For a technique to be useful and adequately address environmental issues, such technique needs to be more diverse to embrace and address the complex nature and issues of the environment.

- Since the techniques rely heavily on an individual's view rather than actual market behaviour, there is likelihood that such approach may result in biased assessment

- Most valuation methods require extensive data collection, which is lengthy, costly and time-consuming

3.3.2 Life Cycle-Cost Analysis (LCCA) Technique

Life Cycle Costing (LCC) according to Boyd (2007) is an economic evaluation technique used when quantifying the cost related to a product during its life cycle. The concept covers the total cost performance of an asset or product over time, including the acquisition, operating, maintenance and disposal cost (van Pelt, 1994). The development of LCC has its origin in the normative neoclassical economic theory which states that firms seek to maximise profits by always operating with full knowledge (cited in Gluch and Baumann, 2004). This theory seeks consistent preferences from decision makers and reminds them of the need to know the long-term economic effects of their preferences (Caroll and Johnson, 1990). Following are some of the advantages of environmental valuation techniques:

- LCC aims at translating all impacts (including environmental impacts) into a single unit of measure -monetary unit.

- LCC covers the total cost performance of an product over time

There is however some problems associated with the LCA method of analysis. The identified weaknesses are that:

- Life cycle cost analysis, as a single dimensional tool is insufficient to consider environmental effects, as it is limited to dealing with quantitative data for discrete choice problems.

- LCC in its present form is too limited for efficient use and the input data is not sufficient for a complex assessment approach with the wide-range of available materials on the market

- The money value attached to LCCA results in bias and loss of important details which in turn limits the decision maker's possibility to obtain a comprehensive view of environmental problems

- It over-simplifies multi-dimensional environmental problems since it assumes that everything can be expressed as a one-dimensional unit, such as monetary figures.

3.3.3 Life-Cycle Assessment (LCA) Technique

Life-cycle assessment, or LCA, is a methodology that evaluates the sustainability of products by identifying and quantifying energy and materials used and wastes released over its entire life-cycle (Trusty 2003). In building construction, an LCA is generally conducted over the full building life cycle, including materials manufacturing, construction, operation, and decommissioning. LCA is generally accepted as a functional tool that quantifies environmental impacts and performance of systems (Trusty 2003, Ljungberg 2007, Abeysundara et al 2009, Bayer et al. 2010, and Florez 2010).

Although LCA is relatively new to the building sector, it has been used extensively since its conception in the 1960s.The International Organization for Standardization (ISO) 14040 series describes four general steps to be performed in any LCA: goal and scope definition, inventory analysis, impact assessment and interpretation. The goal and scope definition phase defines the process or product to be assessed, and identifies the level of detail of the analysis to be performed, and the impact categories to be evaluated (Bayer et al. 2010, BDC 2005).

The inventory analysis step quantifies and categorizes the inputs and outputs of a system, that is, energy and materials used and the emissions to air, water, and land. This phase is also known as the life-cycle inventory (LCI) phase (Bayer et al. 2010, BDC 2005). The impact assessment portion of the LCA process translates LCI information into specific environmental indicators or impact categories, such as global warming, eutrophication, and smog formation. Impact assessments differ from one LCA tool to another since it is based on the judgment and value of impacts.

One important advantage is that LCA is highly advocated because it is transparent and multi-dimensional in demonstrating the trade-offs required to properly select product, components, systems, and assemblies of a project (BDC 2005). As it follows, there are certain disadvantages of LCA

- At its current stage of development, there are not enough economic incentives for the building community to accept it as a selection support system, as it generally consumes more time and resources than it saves for building projects;

- Databases can be inaccurate, incomplete or too generalized, requiring the decision-maker to use multiple sources while drawing more assumptions to the analysis;

- In addition, many LCA experts debate the impact assessment methods and the practice of weighing them. Since the methods used to translate and quantify inventories into impacts vary by the complexity of the impact category, information can be interpreted with inconsistency;

- More than 75% of users are identified to be lacking experience in bid estimating. This can heavily influence the reliability of results as the learning curve for the majority of the students is at its origin

- Finally, the lack of benchmarks limits data available, resulting in unnecessary repetition of complex work;

An extensive study of the LCA method of analysis, its benefits, consequences and limitations can be found in Quinones (2011)

Consequent of the need to incorporate both quantitative and qualitative issues into the material selection decision-making process, applying market prices to determine the suitability of a product has become more and more questionable. Ding (2008) has noted that much advantage lies in the rigour of a technique that is able to evaluate different scenarios (whether quantitative, qualitative or both) using a range of variables that are significant to the analysis. Given the limitations of the previously reviewed techniques, the following section draws a comparison between the two most commonly used assessment techniques in order to identify and choose the more appropriate and effective material assessment methodology relevant to this study.

3.3.4 Single or Multiple Dimensional Evaluation Technique?

Single criterion evaluation techniques have dominated project appraisal since World War II and were mainly concerned with economic efficiency (Nijkamp et al., 1990; van Pelt, 1994). Cost benefit analysis (CBA) has been described as one of the leading models in this respect and a well respected appraisal technique widely used in both private and public development to aid decision-making, since its decision-making process is based on finding the alternative with the highest net monetary value. This approach has however been criticised by many scholars (Van Pelt, 1994; Hobbs and Meier, 2000) who consider it inappropriate, since it regards financial return as the only concern in project development, knowing that the project or product that exhibits the best financial return does not necessarily mean the best option for the environment. Van Pelt (1994) noted that using only one assessment criterion should not be regarded as a correct approach, as decision-making in reality is rarely based on a single dimension. He argued that since there are many environmental and social considerations underlying sustainable development, it is impossible to quantify such elements in monetary values.

Due to a strong tendency towards incorporating multiple criteria and objectives in product appraisal, there is now a need for more appropriate analytical tools for analysing conflicts between objectives. Multi-Criteria Analysis (MCA) has become one of the most powerful methodologies in optimisation analysis (Papadopoulos and Karagiannidis, 2008). Unlike the single-criterion approach, MCA techniques offer the possibility of accounting for non- efficiency criteria as well as non-monetary building impacts, and can address subjective views of various parties in society (Van Pelt, 1994; Hobbs and Meier, 2000). It is particularly useful for those environmental impacts that cannot easily be quantified in terms of normal market transactions.

MCA, according to Van Pelt (1994), transfers the focus from measuring criteria with prices, to applying weights and scores to those impacts in order to determine a preferred outcome thus, avoiding the ethical debates surrounding the issues of monetary valuation, as environmental matters are largely priceless and unique. It is a more flexible methodological approach as it can deal with quantitative, qualitative or mixed data for both discrete and continuous choice problems and does not impose any limitation on the number and nature of criteria. MCA as a utility approach has been structured in such a way that public participation can be readily included to review the results and identify areas of agreement and disagreement in terms of criteria selection, alternative evaluation and weighting assignments through questionnaires. Undoubtedly, the use of single dimensional approach in determining the choice or performance impacts of a material presents some challenges that undermine its use.

Since this study intends to deal with multiple-dimensional arrays of data, where externalities and intangibles would be common, and given that the engagement of conventional single dimensional evaluation techniques such as LCC and credit award systems are insufficient in assisting decision-makers evaluate the complex nature of sustainability in the material selection decision-making process, the Multi criteria analysis (MCA) approach would be adopted for use in this study, as a more realistic and ideal assessment methodology in dealing with the increasingly complex nature of the material selection problems. The Principles and concept of MCA are discussed hereafter.

3.4 Adopted Technique: Multi-Dimensional Approach

A multiple dimensional model comprises a set of techniques dedicated to the examination of relationships amongst multiple variables, which are random but interrelated so that their different effects can be meaningfully interpreted (Singh et al., 2007). Ding (2008) notes that most of the differences between the various multi-criteria evaluation methods arise from the arithmetic procedures used as a means to aggregate information into a single indicator of relative performance. She added that the use of such mathematical models to predict impact on each of the attributes lies at the heart of the MCA process. Figure 3.11 shows the conceptual framework of a multiple dimensional decision model of building material evaluation and selection process.

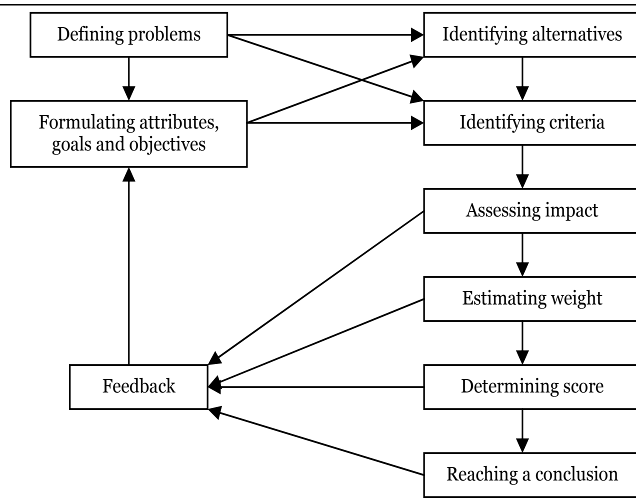


Figure 3.11. Multiple dimensional decision model of building material evaluation and selection

Source: Adopted from (Nijkamp et al., 1990)

The diagram above gives a step-by-step description of a multiple dimensional approach of material selection. In the MCA process, each stage supplies additional information and participate in the feedback loop to provide further information for a more precise consideration for the forthcoming stage(s). Each of these stages is described as follows.

3.4.1 Defining Problems

Building material evaluation usually starts by defining a problem then formulating material attributes, objectives and goals (van Pelt, 1993; RICS, 2001). At this stage, the problem is structured to provide adequate specification of objectives, so that attributes can be identified. Nijkamp et al. (1990) and Ding (2008) note that early identification of material constraints is critical to developing a more precise set of alternatives in order to optimise the best solutions.

3.4.2 Identifying Alternatives

The next step of the MCA process is to identify alternatives, based on the identified problem. At this stage, the list of feasible alternatives is identified. Alternatives may include design alternatives, location options, material options and technology.

3.4.3 Identifying Criteria

Next, the evaluation criteria are defined following the identification of material alternatives. The decision model eliminates those that are less important based on their weighting scores. The criteria are used as guidelines to analyse impacts from each material alternative (Nijkamp et al., 1990; Ding, 2008).

3.4.4 Assessing Impacts

At this stage, each criterion is measured using the most appropriate method for its nature to reflect its relative importance against each alternative (Saaty, 2001). It involves expressing impacts in numeric terms and information may be presented in an evaluation matrix with alternatives set against criteria in a spreadsheet (Saaty, 1994).

3.4.5 Estimating Weights

In material evaluation, choosing an option from a list of alternatives means that priorities must be set and weights assigned to each criterion, reflecting each criterion's priority. Nijkamp et al (1990) and Saaty (2008) suggest that various methods of estimating criteria weighting include direct estimation-which involves the expression of relative importance of the objectives or criteria in a direct way through questionnaire surveys, or the indirect approach where Weights are obtained through estimating actual previous behaviour derived from ranking alternatives or through an interactive procedure of obtaining weights by questioning the decision-maker and other involved parties.

3.4.6 Reaching Conclusions

Finally, decisions are made according to the score of each alternative. This stage provides further information to select the most appropriate of all ranked alternatives that satisfies or meets the ultimate objective(s) (Ding, 2008).

Given the previous discussions on the trend towards multiple criteria in material appraisal, it is therefore necessary that this study identify a Multi-Criteria Assessment technique (MCA) that facilitates multiple dimensional assessments of criteria to aid informed decision-making when selecting LCGBMCs for LIGHDs. In order to avoid inconsistencies across jurisdictions regarding what MCA techniques may be properly applied to a particular problem, and identify the technique that most applies to this study, detail description of various MCA methods available is provided in chapter six. The rationale for choice of the MCA method is also discussed in the same chapter.

3.5 Summary

This chapter has fulfilled the second objective of this research. It reviewed some selected collection of publications to establish the key integration perspectives that current material DSS have embraced, and to establish an initial view on how integration has improved decision support performance and sustainable thinking in the building development processes, not only in the sense of what support DSS can provide, but also in the way how the decisions are made in a sustainable manner. While the primary purpose of existing DSSs is to improve the performance of individual decision maker, the study demonstrated its advantages in providing consistent, coordinated, active and global support for multiple users to fast respond to varied decision requirements resulting from dynamic situations in various contexts. It also established the ambiguity and limitation of traditional approach to material selection, along with a critique on the existing assessment tools.

A further study examined the emergence of valuing material choice using a non-monetary approach in lieu of the conventional market-based approach. The inherent weaknesses in the conventional market-based approach suggested that the MCA approach was an ideal model for this study since it allows information from heterogeneous qualitative sources as opposed to the single assessment approach. The reviewed studies however, revealed little literature that exists on how designers could apply MCA techniques when selecting LCGBMCs for LIGHD projects. The identified lack showed that there were requirements for greater communication between members of the various design teams, since most of the tools reviewed had no direct indicators that were specifically relevant to the impacts of LCGBMCs. This indicated the need for an alternative resource that will provide designers with a range of appropriate informed data with which to aggregate the sustainability impacts of considered options with regard to the key factors, so as to resolve complex materials selection problems. The next chapter thus elaborates on the research methodology adopted to fulfill this objective.

Chapter IV

Research design, methods and strategies

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

A broad, but focused literature review was carried out in chapters 2 and 3, with the aim of gaining new knowledge and generating new directions to further the study. One of the established critiques was that most existing tools are established on the case- based reasoning of the developer and the country in question. It was also found that current knowledge within the context of this study is limited and purely theoretical. Unfortunately there were many research questions that could not be answered by the literature review alone. Following this lack, it was decided that it will be useful to engage with relevant stakeholder groups within the housing industry to explore in more detail what other key pieces of information were required to address the research question posed in chapter 1, and how this could be achieved.

This chapter outlines the research design and methods applied throughout the research, including the participants' information and data analysis techniques applied. It discusses the philosophical assumptions and the design strategies underpinning this study. The chapter discusses the ethical considerations in section 4.2; examines the research paradigm in section 4.3; and highlights the research design and rationale for the selected approach in section 4.4. The research methodology discussions in this chapter are presented in two parts. The first part in section 4.5 focuses on the sampling procedure, measurement scales, data processing procedures and the data collection methods employed in the study, while the second part in section 4.6 describes the methods of data analysis employed for the study. Section 4.7 concludes the chapter.

Table 4.1 gives five key areas to be considered to develop a framework for the research design. The framework enabled the study to structure each research stage.

Table 4.1. Research design model (Robson, 2002: 81)

Purpose	• What is the study trying to achieve? • Why is it being done? • Are you seeking to describe, explain or understand something? • Are you trying to assess the effectiveness of something? • Is it in response to some problem or issue for which solutions are sought? • Is it hoped to change something as a result of the study?
Theory	• What theory will guide or inform your study? • How will you understand the findings? • What conceptual framework links the phenomena you are studying?
Research Questions	• To what questions is the research geared to providing answers? • What do you need to know to achieve the purpose(s) of the study? • What is it that is feasible to ask given the time and resources available?
Methods	• What specific techniques (e.g. semi-structured interviews, participant observation) will you use to collect data? • How will the data be analysed? • How do you show that the data are trustworthy?
Sampling Strategy	• From whom will you seek data? • Where and when? • How do you balance the need

4.2 Ethical Considerations

Gibson and Brown (2009) suggest that a checklist of ethical considerations outlining the necessary actions needed to undertake any study should be provided to avoid any potential harm to the participants, whether directly or indirectly involved, so as not to violate accepted research practice or community standards in conducting research. They stressed that the research ethics committee should assess all the survey instruments before deployment, to ensure validity and reliability of the information, and to build the researchers confidence in the questionnaire the researcher administers.

To avoid any harm to potential respondents who consented to participating in the study, a duly signed application form containing a checklist of actions to be strictly adhered to in the process of gathering data was sent to the University of Westminster's Research Ethics sub-Committee (refer to **Appendix B**).

The following actions were undertaken to ensure that this research complied with the accepted ethical guidelines contained in the University of Westminster's Ethic document.

- Contacted the University of Westminster's Ethics Committee to receive approval to conduct both the initial exploratory and main survey involving human subjects;

- Listed out detailed instructions in the instruments used to confirm the processes in place, so as to ensure participants confidentiality and anonymity;

- Deployed cover headed letters to subjects emphasising discretional measures in the field exercise. All conduct details were given in the covering letter accompanying the questionnaire (refer to **Appendix B**);

- Obtained written consents from the subjects involved in the survey.

With all these in place, there was an approval from the Ethics Committee to carry on with the main study.

4.3 Research Paradigm

The research paradigm is a strategy of enquiry, which moves from the underlying assumptions to the research design, and finally to the data collection and analytical methods (Myers, 2009). Creswell (2003) states that all research are based on some underlying philosophical assumptions about what constitutes a 'valid' research, and which research method(s) is or are appropriate for the development of knowledge in a given study (Yin, 2003; Creswell, 2003). Yin (2003) suggests that to conduct and evaluate any research, it is important that the researcher knows what the assumptions are and what they entail, before they embark on any research.

Robson (2002) has also argued that the way in which research is conducted may be conceived of, in terms of the research pattern subscribed to, the research strategy employed and so the research instruments utilised (and perhaps developed) in the pursuit of a goal or an objective. He noted that research methodologies can either assume a quantitative approach, which is usually concerned with theory verification using figures and statistics or qualitative approach, which lends itself to understanding and providing richly descriptive reports of the individuals' perception, attitudes, beliefs, views and interpretations given to a problem. However, the strength in combining both qualitative and quantitative research methods to improve the quality of the research have been widely acknowledged (Yin, 2009), hence the rationale for choice of the research design approach adopted for this study.

4.4 Adopted Research Design Approach and Rationale for Choice

Research design, according to Yin (2003), is a basic step-by-step plan that guides the data collection and analysis phases of the research project. It provides a framework that specifies the type of information to be collected, its sources, the collection procedure and justification for the procedure used (Creswell, 2003). Making successful predictions of building materials and components is a complex process that requires objective and logical reasoning, as well as rigorous evaluation of a wide-range of possible alternatives (Ding, 2008). Similarly, sorting of alternatives into classes arranged into a priority order, ranking of alternatives from best to worst, and selecting the most desirable alternative, can only be achieved if proper and adequate information are made available (Yates, 2001). Therefore, providing adequate data on the material properties, and selection parameters that will inform the decision-making process in the selection of LCGBMCs, entails eliciting information from various sources by using suitable varieties of data collection methods, and sometimes-good intuition in the choice of the collection methods (Myers, 2009).

Hofstede and Neuijen (1990) however suggest that every research should be designed to start with a qualitative orientation and then followed up with a quantitative verification. This approach, they note, helps the researcher to determine which dimensions can be used to measure them, and to know how the dimensions relate to what is known about the subject from existing theories and/or research. They argued that the reverse order forces the researcher to impose a theoretical structure on the data before it is examined- a structure that could leave out some important variables or include some non-essential ones.

Hence, the broad nature, complexity of the research problem, variability of the information needed to develop the proposed material selection decision support system, and the perceived deficit of each research method in addressing the different aspects of the research question, informed the use of multiple data collection methods, which suggests the combining of qualitative orientation methods with quantitative verification techniques. The preference for the mixed-method approach was to obtain as much information as possible from a variety of sources. The method helped to achieve the objectivity, rigour, and logical reasoning required to address the different aspects of the research question, and eliminate any likely sources of bias, given the variability of the research question and diversity in the types and sources of data required for answering the key research question posed in section 1.4 of chapter 1.

The 4-phase research design adopted for this study is illustrated in **Figure 4.1**, which exemplifies each of the stages and the tasks each undertakes within the research study.

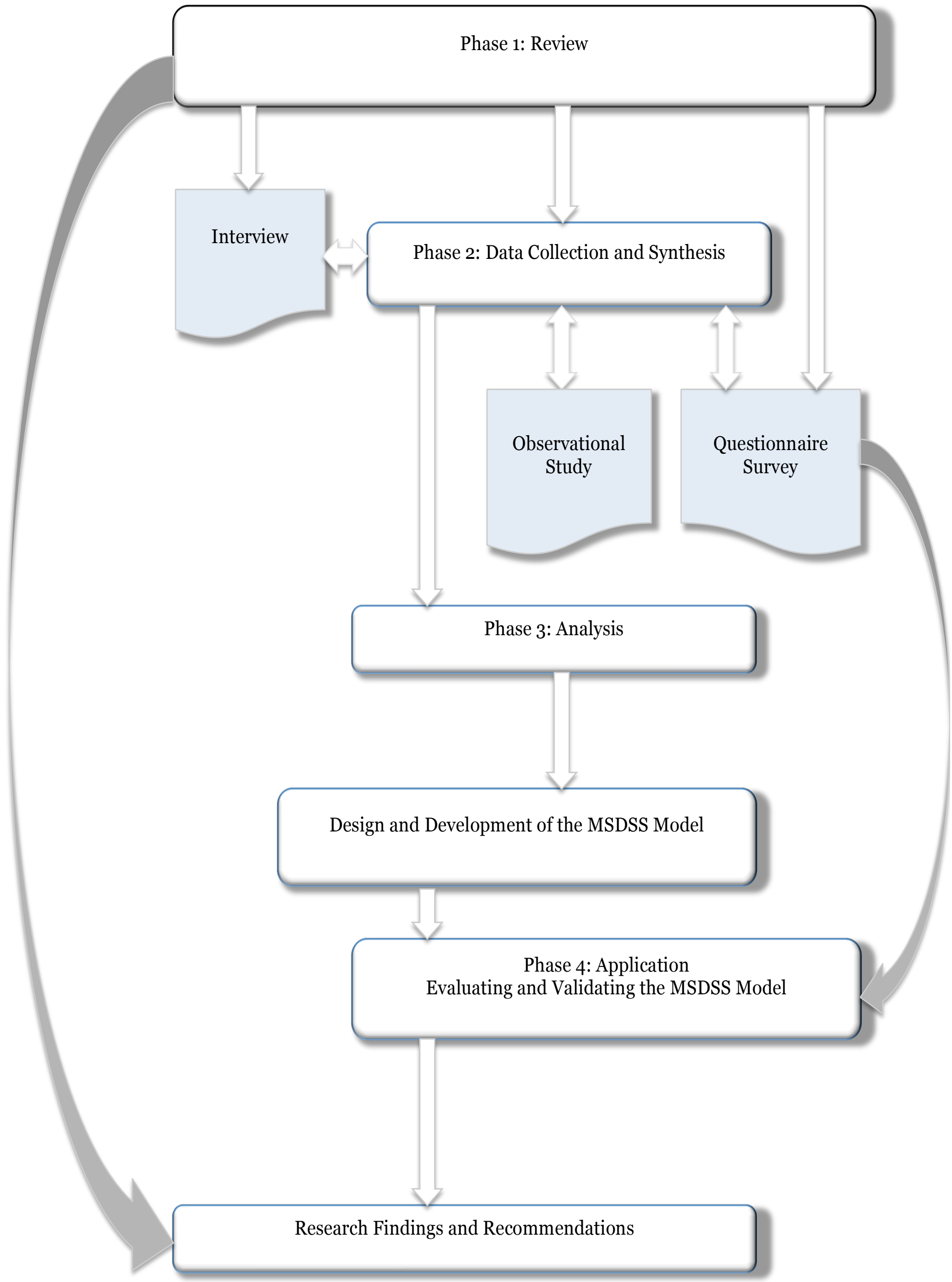


Figure 4.1. Research methods in phases

4.5 Data Collection Techniques

This section discusses the overall research methods used for the study and the justification of the reasons for using them. The four stages of the research methodology are broadly discussed as follows:

4.5.1 Phase 1 [Review]: Crossed Referenced Analysis

Providing a clear theoretical framework for a relatively new area of study is the basis, upon which the desired study could be developed (Yin, 2009). Hofstede and Neuijen (1990) note that exploratory review enables the researcher to better understand the theme understudy, assess the feasibility of the study, suggest hypothesis and mechanisms that can serve as the basis for quantitative research, and even determine the best data collection and analytical methods appropriate for the main study.

- To address the fundamental issues associated with the first, second and third objectives outlined in section 1.5 of chapter 1, the following steps where undertaken:

Step 1

Explored and examined relevant literature through synthesis and analysis of recently published data, using a range of information collection tools such as; books, peer-reviewed journals, articles, and dissemination notes, from libraries and internet-based sources.

This task helped to confirm initial observations, and develop preliminary ideas on issues specific to the research theme relating to the impacts of decision-making on the selection of LCGBMCs for LIGHDs, and their role in sustainable housing. It also provided insights into knowledge deficits of various decision support systems (DSSs) currently available for assessing building material performance, which helped the study to identify appropriate strategies needed for the development of the proposed integrated modular-oriented Material Selection Decision Support System.

Step 2

Conducted a preliminary study to further examine views and current thinking from leading researchers and practicing practitioners of relevant building professional groups who influence material choice decisions, and possess enough industry and product knowledge relating to LCGBMCs, using a semi-structured questionnaire.

The need to include industry views arose due to a lack of academic references and an acknowledgement that the industry often provides more current and insightful information. The respondents who included mainly building professionals from targeted regions such as the UK, USA, Canada, South Africa, and China where selected because of their long-standing experience, and versatility in the use of building material assessment tools, and on the grounds that knowledge on materials sustainability was however, found to vary significantly between participants when compared- due to different geographies, areas of interest and variations in the technical nature of participant's roles. The choice of an online semi-structured questionnaire at this stage was informed by the constraints of distance, time, budget, and sample size. The inclusion of both closed-ended and open-ended questions provided an opportunity to validate prior assumptions in the background section, and elicit more information from respondents willing to express and elaborate on their views. This method allowed for a large number of other potential material selection decision-making factors and relevant information not found in the literature base to be further explored.

4.5.2 Phase 2 [Synthesis]: Collection of Primary Data

Creswell (2008) stated that primary research is particularly useful when you want to learn more about a problem that does not have a wealth of published information, and serves as an efficient means of looking at a far greater number of variables than is possible with literature review. Considering the different facets of the underlying research problem in chapter 1, and that the broad nature of the information needed for the study would not have been possible with just one research method, the study took the form of an initial questionnaire survey, followed by a range of interviews and observations with key personnel in the Nigerian housing industry to address specific areas of the study.

- To further elaborate and expand on the first, second and third objective outlined in section 1.5, the following tasks were undertaken:

Step 3

Conducted primary research with building professionals who possess a wide range of research experience and industry knowledge in the use of LCGBMCs, given the limited sources available for the Nigerian component of the research.

This helped the study to identify other missing variables not found in the literature and preliminary studies and ascertain whether the choice of variables derived from both the literature review and preliminary study could be justified as input variables in the proposed decision support system. It also examined the level of consistency of information gathered from the primary study with that of respondents' views from the literature and preliminary studies on issues relating to the use of LCGBMCs, current material assessment resources and the influence of sustainability in material selection. The following sections exemplify each data collection method and process used in this stage starting with questionnaire survey

4.5.2.1 Questionnaire survey

Yin (2009) has expressed that questionnaire surveys are one of the most cost effective ways to involve a large number of people in the process if one is to achieve generalisable results. He however, stressed that the accuracy and success of questionnaire surveys largely depend on the careful design of its content, structure and the response format. In order to gain an overall insight to the topic area that fits with applying questionnaires, and to explore as many variables as there could be, the questionnaire approach was considered ideal for this purpose. The choice of questionnaires sent and returned by emails over interviews at this stage was due to time, budget, distance and resource constraints, as well as its efficiency and effectiveness in sampling a large audience of the respondents who were widely dispersed all over the country. Moreover, for a single researcher, such as in this case, it would have been impossible to interview the large number of building practices in Nigeria to cover a wide geographical area. Table 4.2 shows the framework used for the design of the questionnaire based on the five components given earlier by Robson (2002) in Table 4.1.

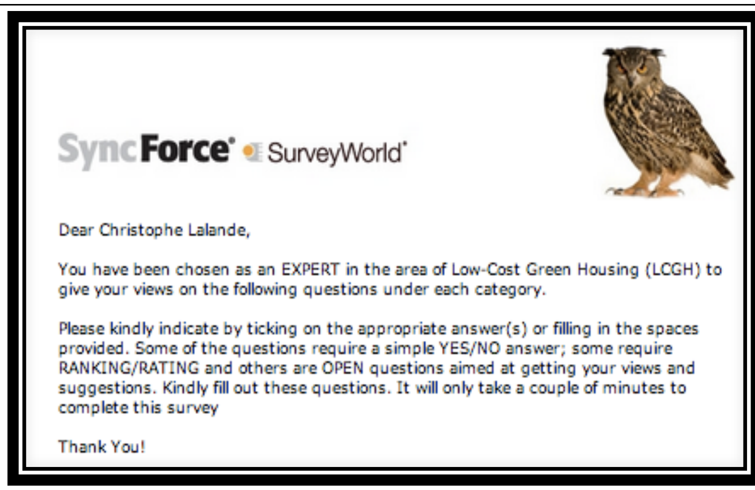
Table 4.2. Questionnaire scoping study model

Purpose	Study how low-cost green building materials are assessed and identify the resources currently used. Also understand what type of resource is required to encourage the wider use of low-cost green building materials in house build projects
Theory	To carry out this study a wide level of background knowledge is required to understand how LCGBMCs are considered in the material selection process along with knowledge pertaining to low-impact green housing design, material selection tools and resources.
Research Questions	• What resources currently exist for information on LCGBMCs? • What information do designers need when making sustainable material selection choices? • How do designers make decisions about LCGBMCs? • What are the drivers and barriers for using LCGBMCs? • How can individuals be supported to integrate sustainability principles into the material selection process? • Do design and building professionals in Nigeria need, or want, a resource to support the selection of LCGBMCs for LIGHDs?
Methods	Questionnaire designed with a predominantly flexible approach giving quantitative and qualitative responses. Study shall focus data collection on semi structured approach with respondents
Sampling Strategy	Data will be collected for the questionnaire from databases of several building professional institutions in Nigeria and posted to contacts. Purposeful and random sampling techniques were used to identify participants who had experience of working with sustainable materials. Participants were also asked to suggest relevant colleagues, following a snowball strategy.

To avoid inconsistent and bias responses the Delphi technique was used intermittently when and where appropriate, and other precautionary measures were also taken into consideration when designing the questionnaires for both surveys 1 and 2. Details of the survey instrument are given in the following sections and a copy of the questionnaire is attached as Appendix D.

4.5.2.1.1 Survey 1

The first survey was hosted at SyncForce.SurveyWorld.com and was launched via email between mid March 2011 and mid May 2011 including 22 questions (see Figure 4.2). An invitation letter was attached to the email with a link to the survey web page (see Appendix D). The first survey attracted over 150 interested visitors with 50 eligible respondents. The questionnaire's home page clearly stated the questionnaire's purpose, target group and approximate survey duration (see Figure 4.3). An open-ended question followed every part of the questionnaire in order to allow respondents to share their thoughts and comments. As an incentive to increase response rate (Malhotra et al., 2002), the respondents were assured to receive the summary report of the final survey.



SyncForce SurveyWorld

Dear Christophe Lalande,

You have been chosen as an EXPERT in the area of Low-Cost Green Housing (LCGH) to give your views on the following questions under each category.

Please kindly indicate by ticking on the appropriate answer(s) or filling in the spaces provided. Some of the questions require a simple YES/NO answer; some require RANKING/RATING and others are OPEN questions aimed at getting your views and suggestions. Kindly fill out these questions. It will only take a couple of minutes to complete this survey

Thank You!

Figure 4.2. Survey 1: (mid March 2011- mid May 2011

Source: Adopted from the survey tool

4.5.2.1.2 Survey 2

The second survey was launched between November 2012 and January 2013. It was closed after three months to ensure a balanced participation. The automatic report filtering generated only 210 eligible respondents, out of 480 participants. Both the first and second surveys were structured to include the same introduction entailing 22 and 20 questions respectively.

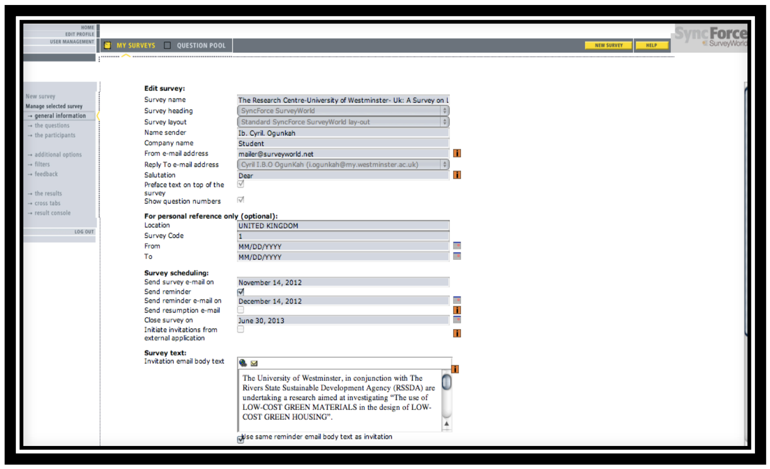


Figure 4.3. Survey 2: (mid November 2012- Mid January 2013)

Source: Adopted from the survey tool

The first stage of the process was to determine the research objectives that would influence the structure of the questionnaire. The literature review explored the area from which sets of research questions were developed. Having identified the key variables that would be included in the questionnaire, the next step was to design a questionnaire. The respondents, who were mainly building and construction professionals in the housing construction industry, were the source of information chosen on the basis of their expertise in the area of study.

The second stage of the questionnaire design involved determining the question content, type and distribution process. Despite the cultural and ethnic differences in Nigeria, the major advantage of the respondents was the relative homogeneity given that all were experienced building professionals. Optimum consideration was given to the design of the questionnaire and the type of questions to minimise any potential bias or errors in responses arising from cultural, language, ethnic and other differences among respondents.

4.5.2.1.3 Questionnaire design format

The format of the questionnaire was an adaptation based on Likert's (1932) scale: a psychometric response scale primarily used in questionnaires to obtain participant's preferences. Respondents were asked to indicate their level of agreement with a given statement by way of an ordinal scale of 1 to 5 (where 5 depicted a stronger opinion, and 1 a lesser opinion). The reasons for the likert scale were due to its ability to produce attitude measures that could reasonably be interpreted as measurements on a proper metric scale, its simplicity in design, its likelihood to produce a highly reliable scale and its ease to read and complete by participants giving that respondents are more likely to reply to a more convenient, and less-time consuming data collection format (Yin, 2009; Creswell, 2008). The questionnaire was divided into three main sections for easy analysis and reporting as follows:

- General information concerning the demographic study and related actions:

The first part of the questionnaire contained 10 questions aimed at obtaining responses with regard to respondents' general knowledge and views concerning the use of LCGBMCs in the Nigerian housing construction industry. The responses were based on desired ideal expectations of choice followed by the list of options to choose from, since the desired expectations are considered to have better explanatory power than the predictive expectations (Spreng et al., 1996).

- Development of material selection criteria:

The second part of the questionnaire comprised 8 questions seeking respondents comments on the "most important" and "least important" factors or variables under the view and expectations of the informed selection of LCGBMCs. Some parts of the questions were open-ended and the objective of this part of the questionnaire was to provide an opportunity for respondents to elaborate on any issue that was of concern to them. Very simple wordings were used in these statements to get the actual content of the information-avoiding misinterpretation of the wordings (Yin, 2009).

- Application of the proposed material selection decision support system:

The third and final part of the questionnaire contained 2 questions. This section of the questionnaire was used to gather other relevant information. It investigated commitments to sustainable design practices, as well as drivers and barriers impacting on the use of LCGBMCs.

4.5.2.2 Response format

The questions were direct and responses were expected on a likert scale, which has been well validated by a number of studies (Likert, 1932; Creswell, 2008; Yin, 2009). Given the strong arguments for the validity of the likert scale, along with the scale's acceptance and use by many researchers, an adaptation of the refined LIKERT scale was considered appropriate for this study.

The scale was based on 5 point bipolar scales labeled " 1= strongly disagree to 5 = strongly agree". The respondents were expected to indicate their choice by checking a number along the scale. If the respondents considered that the factor was not relevant to the selection of LCGBMCs at the design stage, they were requested to check the not applicable (n/a) box. The choice of the 5-point scale was in view of its ability to minimise skewed responses.

4.5.2.3 Pre-testing the questionnaire

Munn and Drever (1990) argue that carrying out a test run on a questionnaire survey before embarking on the main study is a very crucial step that is necessary to demonstrate the methodological rigour of a survey. In order to assess the clarity and comprehensiveness of the questionnaire, and the feasibility of the survey, the questionnaire was pretested on a randomly selected sample of researchers (precisely 75 in number) who were broadly representative of the type of respondents targeted by the main survey.

A total of 75 research institutions and practicing small to medium scale organisations were sent questionnaires to complete the survey, taking into consideration the number of low-impact green housing projects executed, their role in the construction industry, their experience in low-impact designs, and age of organization. Of the 75 pilot questionnaires sent out to the selected sample, 35 were returned representing a response rate of 46.7%. This compares favourably with the 20% response rate achieved in the pilot survey reported in Xiao (2002). Although the results of the pilot study were not used as part of the data required for the development of the proposed model, pre-testing the survey enabled the study to:

- Test whether the questions were clear and understandable;
- Test the wording, sequence, form, and layout, question difficulty, question and survey instructions;
- Identify any flaws in the design, which were corrected prior to its administration to a much more larger sample of the Nigerian population;
- Test the comprehensibility of the list of proposed decision selection factors/variables;

- Ensure that the wordings of the questionnaire could be reliably interpreted. This provided an opportunity for checking and correcting potential errors on time, so that the data obtained during the main survey fully addressed all aspects of the issues raised, and were internally consistent and coherent for analysis;
- Identify additional variables that broadened the range of decision selection factors;

Following the feedbacks from the respondents of the pilot study, there was evidence on the need to revise the questionnaire and vary item wording to suit different service settings for the main study, hence informed the use of the Delphi technique.

4.5.2.4 Revision of the questionnaire

Given the feedback from the respondents of the pretested questionnaire, a number of possible amendments were identified towards improving the format, content, and appearances of the questionnaire. While the respondents did not have a problem with a 5 point scale format, they suggested that the introduction of the “not applicable” (n/a) and “please tell us what you think” options were necessary for every question, given that low-impact green housing construction was an area that attracted so much interest, and required expert suggestions that would likely inform the development of the proposed model. This was rectified and incorporated into the revised questionnaire for the main study. This suggestion of incentives was taken into consideration as respondents were provided with the result consoles at the close of every survey for their individual studies.

4.5.2.5 Reliability of the instrument

Several suggestions were strictly followed to ensure the reliability of the instrument for the main survey, following the feedback from the respondents of the pretested questionnaire. Having satisfied the requirement to pre-test the questionnaire and having completed the revision of the questionnaire, it was ready for deployment for the main survey.

4.5.2.6 Sampling issues

As mentioned above in section 4.5.2.1.1, the questionnaire was administered via email survey, given the impossibility in reaching all the respondents in person, and the distance of their respective locations. There were issues of going through multiple databases of several building institutions, and in ensuring a sample size that was statistically adequate to achieve maximum response rate. Amongst the major obstacles were the difficulties in obtaining permission from the Universities in Nigeria and private construction firms to retrieve email contacts, and convincing them to participate in the study.

An official request signed by the research ethics department was sent to all the institutions involved, seeking their consent to participate in the study. Although this process took several weeks, some interested members of various Universities and construction firms consented to the request, which boosted the number of respondents in the survey. For those who did not want their identity to be made known, an anonymous link was sent to such individuals.

4.5.2.7 Sampling strategy

The target population for the study was defined as registered and experienced building design and construction professionals from various housing construction firms and top accredited Universities such as Ahmadu Bello University, Covenant University, University of Lagos, Federal University of Technology Minna, as well as registered/licensed private construction firms in Nigeria. Apart from having a sample representative of the population in Nigeria, the main objective of the sampling strategy was to achieve sampling equivalence between the researchers and professionals of the various building professions both in higher institutions and practicing building design and construction firms.

Hair et al. (1995) warned that it is important to consider not only the statistical significance, but also the quality and practical significance of the results for managerial applications, when analysing data. They argue that uneven sample sizes amongst different professional groups could also influence the results. They add that the equality of variance could be achieved with groups of approximately equal size (if the size of largest group divided by the size of smallest group is less than a ratio of 1.5).

Given that this study involved various building professional groups, the purposive, stratified random, and snowball sampling research methods were adopted where applicable to avoid biased results. The underlying reasons for adopting these sampling methods are discussed in section 4.5.2.9.

4.5.2.8 Sampling frame

Yin (2009) described sampling frame as a list of sampling units or a pool of all eligible members of a population from which a sample of interest is drawn. To validate the sample frame corresponding emails where sent to potential participants to verify their email addresses with the help of a confirmatory consent letter.

A total of 480 respondents of different institutions and organisations in Nigeria were sent questionnaires to complete the survey, taking into consideration the size, project type, annual turnover and age of institution and organisation. The sampling frame that was adopted for the selection of the sample- informed by Xiao (2002) was a list from the Building Professionals Registration Council Board Register of Nigeria, the directory of the Building Design and Construction Consultants, and the directory of various universities. The sampling frame used in this survey was drawn from databases of several building professional institutions as listed below.

- The Nigerian Institute of Architects (NIA),
- Nigeria Institute of Estate Surveyors & Valuers,
- Nigeria Institute of Quantity Surveyors,
- Nigerian Institute of Town Planners,
- Nigerian Society of Engineers,
- Nigerian Institute of Builders,
- Nigeria Institute of Civil Engineers,
- Society of Construction Industry Arbitrators of Nigeria,
- Nigerian Institution of Surveyors, and
- Several top ranking Universities in Nigeria offering building and construction related courses.

4.5.2.9 Sampling method

Creswell (2003) notes that ultimate responsibility for producing reliable analytical results lies within the sampling technique, and the characteristics of the subjects. Therefore, to ensure uniformity, quality and validity of data, this study assumed the purposive, stratified random and snowball-sampling techniques where appropriate, to select subjects based on their level of expertise, experience, academic and professional qualifications in the field of housing construction. The sampling methods adopted for this study involved three techniques at different stages as highlighted in section 4.5.2.7. The expert sampling within the purposive or judgmental sampling method- in the form of a consent letter, was used to determine the initial selection process which suggests that only experienced respondents who had first-hand knowledge in the area of study where legible to participate, to ensure the reliability and validity of the data (Creswell, 1997, Yin, 2009).

The stratified random selection method was used to ensure that the specific sample groups of various design and building professionals were evenly represented, which created balance of group sizes amongst multiple groups that were selected. This method ensured homogeneity, and improved quality of the data gathered. Stratified random sampling, by Creswell's (2008) definition, is where each member of a population has a known and non- zero probability of being included in the sample. It was utilised because of its advantage in achieving sampling equivalence amongst different groups. On exceptional occasions where the need arose to facilitate response rate and achieve reasonable sample size, the snowball sampling method was also adopted, as the approached respondents were asked to distribute the questionnaire to their colleagues and partners with similar background.

4.5.2.10 Sample size

According to Creswell (2007), determining the sample size of a study area is a complex process that involves several qualitative and quantitative considerations which include: the nature of the research, the number of variables, nature of analysis, incidence rates, completion rates and resource constraints. Given the paucity of literature in the area understudied, and considering that a large number of variables were to be analysed, a reasonably large sample was required. The main strategy used to select the sample was to request the administrative offices of the respective Universities and housing construction firms to extract all registered and qualified members belonging to the targeted groups from their staff databases, which was done as instructed. In order to determine a suitable size for the sample, the following formula from Czaja and Blair (1996) and Creative Research Systems (2003) was applied.

$$ss = \frac{z2 \times p(1-p)}{c2}$$

Where: *ss* = sample size, *z* = standardized variable, *p* = percentage picking a choice, expressed as a decimal, *c* = confidence interval, expressed as a decimal.

As has been suggested by other researchers, a confidence level of 95% was assumed (Munn and Drever, 1990). For 95% confidence level (i.e. significance level of $\alpha = 0.05$), $z = 1.96$. Based on the need to find a balance between the level of precision, resources available and usefulness of the findings, a confidence interval (*c*) of ±10% was also assumed for this research (Czaja and Blair, 1996).

According to Czaja and Blair (1996), when determining the sample size for a given level of accuracy, the worst-case percentage picking a choice (*p*) should be assumed. This is given as 50% or 0.5. Based on these assumptions, the sample size was computed as follows:

$$ss = \frac{1.96\,(1.96) \times 0.5(1-0.5)}{0.1 \times 0.1}$$

$$ss = 96.04$$

Therefore the required sample size for the questionnaire survey is 96 respondents. However, the figure requires a further correction for finite populations. The formula for this is given in Czaja and Blair (1996) as:

$$\text{new } ss = \frac{ss}{1 + \frac{ss - 1}{pop}}$$

Where: *pop* = *population*

$$\text{new } ss = \frac{96.04}{1 + \frac{96.04 - 1}{176000}}$$

$$\text{new } ss = 95.99$$

The Nigerian housing construction industry and Building professionals in higher institutions because of their very busy schedule are known for their poor response rate to questionnaire surveys. Based on this, it was necessary to adjust the sample size to account for non-response. By assuming a conservative response rate of 20%, the appropriate sample size that was to be surveyed was calculated as:

$$\text{survey } ss = \frac{\text{new } ss}{\text{response } rate}$$

$$\text{survey } ss = \frac{96}{0.20} = \text{480 design and building professionals}$$

Thus, each respondent of each professional group within the targeted populations had an equal probability of being selected.

Step 4

4.5.2.11 Questionnaire administration for the main survey

Following the agreement with the University of Westminster's Research and Ethics Committee, a total of 480 online questionnaires attached with cover letters were deployed to participants of various institutions as listed in section 4.5.2.8 (See **Appendix D** for questionnaire). The selection of respondents followed the sampling methods discussed in section 4.5.2.9. The idea of an online approach was due to the fact that the subjects would be widely dispersed around the country, the possibility of a larger sample size, and that they were more likely to reply to a more convenient, and less-time consuming data collection method, since the majority of them were practicing professionals. A duly signed attached letter, and a statement of the objective(s) of the study to guide the respondents on the potential contribution they could make to good practice in terms of LCGBMCs, accompanied the questionnaire. To ensure a good response rate, three steps were followed in administering the survey:

- The first step involved a mail-out of an advance-notice letter to all the members of the sample population, notifying them of the questionnaire they were to be receiving shortly and encouraging their participation by suggesting incentives.
- The second step was deploying the actual questionnaire with an accompanying personalised, signed cover letter (Babbie, 1990). This was undertaken on November 14, 2012, roughly one week after the advance-notice letter as recommended in Creswell (2003).
- The final step involved re-sending another set of questionnaires to all pending respondents with an accompanying personalised attached signed cover letter, three weeks after the initial deployment.

The returned questionnaires were progressively recorded through the SyncForce.SurveyWorld.com site, and data entered into the SPSS v.20 file.

Step 5

4.5.2.12 Interviews

Creswell (2003) suggests that it can be helpful to consult knowledgeable researchers in the field to ask for more details, when sometimes the information reported in the questionnaire is insufficient to verify or clarify specific issues. To deepen understanding in the areas of interest and obtain as much useful qualitative data as needed from small numbers of people who agreed to elaborate on less detailed responses received on the questionnaires, this study conducted in-person interviews with building professionals who influence material choice decisions in the housing construction industry. Before starting each interview the interviewer gave a briefing, introduced the project, explained how the data would be used and asked if the interviewee was willing to be recorded. The questions were divided into sub topics to ensure that all points were covered.

Table 4.3. Interview scoping study model

Purpose	Study whether LCGBMCs are considered during material selection by practicing designers. Understand designers' attitude, and identify drivers and barriers towards the use of such materials. Seek to understand what could lead to the wider use of LCGBMCs in mainstream housing and what could be involved in getting such products into mass use.
Theory	This study is guided by the findings from the questionnaire study, preliminary study and literature reviews.
Research Questions	• What information do designers need when making sustainable material selection choices? • What information is needed to enable sustainable material selection during the design of LIGHDs? • What are the drivers and barriers for using LCGBMCs? • What resources exist to support sustainable material selection? • How do designers make decisions about LCGBMCs? • How can individuals be supported to integrate sustainability principles into the material selection process? • Do design and building professionals in Nigeria need, or want, a resource to support the selection of LCGBMCs for LIGHDs?
Methods	Semi-structured interviews shall be conducted by the researcher and recorded for later transcription. Transcriptions shall be analysed using Nvivo software via coding and clustering and also thematic analysis.
Sampling Strategy	Purposeful and convenience sampling were used to identify design consultancies with varying awareness of sustainable design by searching their websites for any mention of sustainable design or material selection. Participants were identified either from having previously completed the questionnaire study, and stating they would be willing to participate in future research, or via internet searches. The design directory website was used to identify a number of design consultancies and agencies

Since this study did not have the resources and time to interview larger groups of respondents, a total of 10 in-depth in-person interviews were conducted after the questionnaire survey. The non-probability cross sectional convenience sampling method was used to select subjects thus ensuring a diversity of views on matters concerning the use of LCGBMCs in the Nigerian housing sector. A convenience sample is a study of subjects taken from a group that is conveniently accessible, and known to a researcher given their level of expertise (Creswell, 2007). One advantage of this sampling method is that it was easy to access respondents, and it required little effort and time (Yin, 2009). The choice of a semi-structured approach of interview was that it allowed for a flow of conversation whilst also retaining the structure enabling research questions to be answered.

Each interview lasted between 45 minutes and an hour (see full analysis of the interviews in Appendix G). Online telephone interviews were mostly carried out using Skype Voip software due to time, resource, privacy and budget constraints, particularly for respondents who had access to Internet services at their respective work places and declined the idea of face-to-face interview. Information gathering involved the use of digital Dictaphone audio recorders, and in most cases transcripts to avoid alteration of information, and to re-contact the respondent should there be need to confirm certain issues about the study.

Step 6

4.5.2.13 Observation

Observation consists of physically observing or inspecting a subject, an object, system or group of tools, by taking closer note of their behaviour, characteristics or functionality (Yin, 2004). In order to understand how the framework could be developed further into a tool, an observatory workshop was designed in order to observe individual and team participation with existing tools. The need for an "observatory workshop" was to understand the interactions of designers with the inner workings of existing tools.

Table 4.4. Observatory scoping study model

Purpose	To evaluate the use of the tool in a real-life material selection team scenario. To probe designers participation in the material selection process, how building materials are considered and if, or how, they utilise current tools and resources.
Theory	This study is carried out to observe whether and how the tool increases the individuals understanding and confidence of selection sustainable materials
Research Questions	• Does the tool improve the individuals understanding of sustainable material selection? • What factors influence the selection of materials? • Are the factors that determine sustainable material selection clear to understand • What information do designers need when making sustainable material selection choices? • How easy do the designers find the tool to use?
Methods	Participants will take part in a workshop observatory interview session with a Semi-structured survey given for feedback and any additional comments. During the workshop the researcher shall make notes of observations and these will later be clarified using the audio recordings where applicable.
Sampling Strategy	Purposeful and convenience sampling to identify design consultancies with varying experience with material selection tools.

Observational studies at 2 green building firms in the UK helped to inform the development of the proposed Material Selection Decision Support System (MSDSS). The firms were first contacted and informed about the objectives of the study and their roles as participants. Each company was researched, prior to the first visit and throughout the study, to gain an understanding of the company ethos, specialties, and products. Participants had to be based in the UK knowing that they have had long-standing experience of working with assessment tools and given the resource and time constraints. The process involved interviewing experts, who had between 10 to 35 years of experience in the industry, qualified in their respective fields, and who had implemented or used such systems by directly observing and inspecting how they were developed and how effective they were against some criteria such as comprehensibility and flexibility when in operation. The study adopted the purposive and convenience-sampling method, being familiar with the organisation’s interest and role in material evaluation. In attempts to obtain their informed consent and enhance trustworthiness of the study, a duly signed covering letter with the University of Westminster’s letterhead was used to support the observational study, thus ensuring credibility of the study. Each observational study was condensed significantly to fit within two hours.

To provide essential triangulation of data gathered through reviews, questionnaires survey and interviews, and to get first-hand knowledge of how existing tools work(ed), an observational study was conducted on Environmental Assessment Trade-off Tool (EATT) -an expert system used to select the final material-building design combination, and whose trade-off criteria are based on BRE Green Guide to Specification- known to be one of the most commonly and widely used systems in the UK. The second study was with participants with the National Green Specification and GreenSpec firm. Unlike the one-on-one interview, where information gathering involved the use of audio recorders, information gathering in this case was based on written records and notes since some of the respondents did not welcome the idea an audio recorder-for reasons of anonymity (Yin, 2009).

An architectural technician and a designer from each firm, with over 20 years of experience, tested the interface of the existing model. The initial interviews conducted took the form of a face-to-face interview while subsequent ones were conducted over the telephone via Skype to clarify certain issues. One of the users (designer from the GreenSpec) spent time at the architectural practice explaining the way in which work was conducted during the early design of buildings, mainly to test the 'user friendliness' of the interface.

The architectural technician (using the EATT) gave a short presentation about the functionality and material input procedure of the EATT model, and performed a test on the tool. The test began with the selection of material alternatives from the model database. During this process, the technician only considered the performance and structural qualities of the materials. He said this was because an architectural technician usually focuses on structural suitability when selecting a material. Where possible, the researcher completed the transcriptions and observations as soon after the interviews as possible to improve accuracy and to be closer to the data collected.

4.6 Data Analysis and Application Techniques

4.6.1 Phase 3 [Analysis]: Analysis of Primary Data

This section outlines the methods employed by the researcher to analyse the data collected from the literature, surveys, and interviews, and discusses the various application methods required for assembling the analysed data for the development of the Material Selection Decision Support System (MSDSS).

4.6.1.1 Data analysis strategy

Prior to undertaking the quantitative analysis, a five-stage process was followed to prepare the data for analysis, which included (a) checking the response rate, (b) editing of completed questionnaire, (c) coding of responses, (d) screening of data and checking margin of error(s), (e) sampling splitting

(a) Checking the response rate

Chinyio et al. (1999), Akintoye (2000), Dulami et al. (2003) and Takim et al. (2004) acknowledged that the ideal and acceptable response rate required for further analysis must fall within the range of 20% and above. They reported that the normal response rate in the housing construction industry for postal or email questionnaires fall within the range of 20-30%, given the low-response rate that is common within the housing construction industry. Similarly, Black et al. (2000) reported that a response rate of 26.7% is ideal for a questionnaire survey conducted within the housing construction industry, stating that low response rates in most building construction industry surveys are not unusual. For example, studies conducted by Ofori and Chan (2001) received a response rate of about 26%, Vidogah and Ndekugri (1998) received a response rate of 27%, and Shash (1993) received a response rate of 28.3%. Given that 210 questionnaires were returned out of the 480 dispatched copies from the selected sample in this study, a response rate of 43.75% was achieved, which was in line with and well above the required standard.

(b) Editing of completed questionnaires

According to LoPresti (1999), analysis of missing data is required to improve the validity of the study. Therefore, to end up with a more reliable data set and to be able to use all the data collected in the analysis (since the responses received from participants contained some missing data), some time was spent investigating and resolving the missing data problem. Checks were done to ensure that the data received through returned questionnaires were complete, and free of inconsistencies. In situations where partly completed questionnaires were found, The SPSS v.20 Missing Values Analysis option was used to analyse the patterns of missing data, and organise it in a format suitable for analysis.

(c) Coding responses

The questions in the questionnaire and interviews where pre-coded prior to administration for easy analysis. To facilitate the analysis of this data, the responses were categorised under different constructs generated from the factor analysis.

(d) Screening data and checking for margin of error(s)

Sutrisna (2004) has stressed that a large sample of the target population must be considered for inferential statistical analysis to be properly undertaken. Munn & Drever (1990) note that as a rule of thumb, any sample with size greater than the threshold of 30 ($n > 30$) should be considered as a large sample. Therefore the sample size of 210 obtained in this survey was considered adequate for the purpose of inferential statistical analysis, given the low-response rates common with housing construction surveys (Ankrah, 2007). Using the SPSS v.20, the frequencies procedure was run for every variable to check for errors in data entry. With this method, every error detected was rectified. To ensure accuracy of the data, the questionnaire was randomly checked for any impossible correct entries using the formula below.

$$E = z\alpha/2\ (\sigma/\sqrt{n}) \text{ OR } MoE = 0.98\sqrt{(1/n)} \ldots\ldots 4.0$$

When the margin of error was computed using **Equation 4.0**, an estimate of 6.76% margin of error due to sampling was obtained at 95% confidence level. This interpretation is that 95% of the results obtained from this survey fell within ± 6.76% range. This means that we could be 95% sure that a repeat survey would yield results that only differ by about 6.76% in either direction.

(e) Sample splitting

Good & Hardin (2003) note that sample splitting is a process that involves halving of a sample, to estimate the model parameters, and verify that the data gathered for developing the model is valid. Since there were anticipations that the model would be evaluated towards the latter phase of the study, a proportion of the data collected was selected and held back. This approach has been described as an effective method of evaluation when it is not practical to collect new sample to test the model (Snee, 1977). The recommendation in Picard and Berk (1990) suggest that an ideal range that should be set aside for evaluation purposes should fall between a quarter (1/4) and a third (1/3) of the overall sample size. However, in terms of how much was set-aside for this study; the differences in the variations and evidence from previous studies suggests that there is no standardized percentage required for sample splitting. Whilst Xiao (2002) set aside 12.20%, Omoregie (2006) set aside 9.03%. This appears to suggest that there is no fixed number or percentage required for validation, as the number required for data splitting depends on the number of responses (Good & Harding, 2003). Going by Good & Harding's (2003) analogy, 10% of the sample was therefore randomly selected in SPSS and excluded from the main analysis. The 10% was equivalent to roughly 20 cases (refer to **Table 4.5**). The approach adopted further helped to eliminate uneven sample sizes amongst different professional groups, given that a sample of 210 could achieve a ratio equivalence of 1.48, which is very much in range with Hair's et al. (1995) limit of 1.5.

Table 4.5. Number of case-samples held for calibration and validation

Overall Questionnaire Received		Percentage of Samples (%)
Analysed Sample	210	90
Sample Held Back for Calibration and Evaluation	20	10
Total	230	100

Source: Results of the study

4.6.1.2 Rationale for data analysis technique

Several studies (Siegel & Castellan, 1998; Orme & Buehler, 2001) have suggested that researchers check the underlying assumptions that apply to the data gathered before proceeding with any relevant statistical procedure.

Orme & Buehler (2001) noted that making any conclusion about the normality of the data as to whether or not a particular data follows a normal distribution (i.e., requires parametric statistical procedures) or non-normal distribution (i.e., requires non-parametric procedures) is a decision that must be considered to avoid violating the normality of the assumption. They noted that understanding the type of data gathered is very important in letting the analyst or researcher know the appropriate method for analysing the data collected, as failure to do so may result in conclusions that are likely to be invalid.

In selecting the appropriate data analytical technique for this study the various steps highlighted in the flowchart (shown in **Figure 4.4**) were taken in to consideration to avoid false positive results or "type one error", often associated with applying a parametric test to nonparametric data (Siegel & Castellan, 1998).

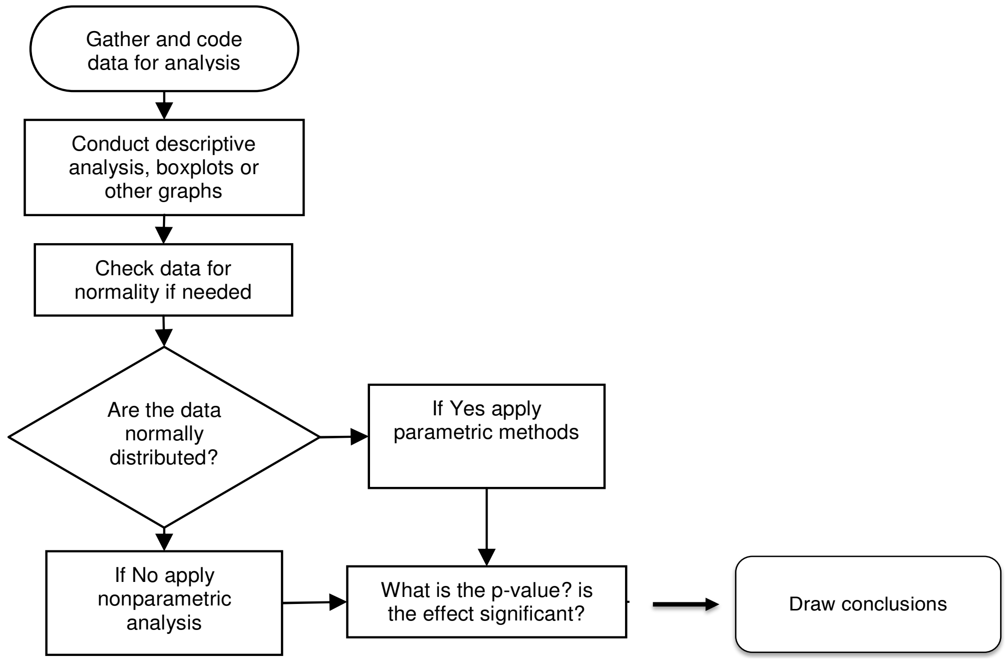


Figure 4.4. A step-by-step flowchart of the data analytical technique

Source: Adopted from (Baranoski et al., 2001)

Given that the data would draw on views of experts with different perspectives, and that the information gathered would contain both quantitative and qualitative data, there was likelihood that the sample distribution may be skewed (Yin, 2003).

In order to address this uncertainty, check that any of the 'assumptions' incurred on individual tests were not violated, and provide conclusive evidence that the underlying assumption holds, a normality test (following the principles of the Kolmogorov-Smirnov and Shapiro-Wilk) was undertaken to assess whether or not the sample came from a population with a normal distribution. The Kolmogorov-Smirnov test, and Shapiro-Wilk test were adopted because of their simplicity, and to compensate for their individual weaknesses. The performances of the tests were evaluated under various spectrums of the sample distribution and size as shown in **Table 4.6**.

Table 4.6. Tests of normality results for sampling distribution

Tests of Normality							
	Job Affiliation	Kolmogorov-Smirnova			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Level of Experience	Architect	.198	43	.000	.914	43	.003
	Builder	.221	47	.000	.872	47	.000
	Engineer	.326	33	.000	.824	33	.000
	Quantity Surveyor	.271	46	.000	.878	46	.000
	Urban Designer	.232	27	.001	.797	27	.000
	Other	.214	14	.083	.895	14	.096

a. Lilliefors Significance Correction

Source: analysis of surveyed data, 2013

The above table presents the results from two well-known tests of normality, namely the Kolmogorov-Smirnov Test and the Shapiro-Wilk Test. Orme & Buehler (2001) have argued that the Shapiro-Wilk Test is one of the most sensitive and appropriate tests for determining the assumptions of normality given that it can handle small sample sizes (< 50 samples), and sample sizes as large as 2000.

For this reason, the Shapiro-Wilk test was considered the most relevant numerical means of assessing normality for the sample distribution. Given that the result analysis of the P or Significant values for a confidence interval of 95% for both tests were < 0.05 as shown in the **Table 4.6**, there was enough evidence to reject the claims that the sampled population was of a normal distribution.

Step 7:

- To help address the fourth objective outlined in chapter 1, the study applied several techniques associated with nonparametric method of data analysis following the normality test results in section 4.6.1.2.

4.6.1.3 Descriptive statistics analysis

Descriptive statistics are used to describe the main features of a collection of data in quantitative terms (Chinyio et al., 1998; Omoregie, 2006). This technique was employed for analysing data related to the characteristics of the respondents, their affiliations, and open-ended questions/comments. Graphical techniques utilised for presenting the results from these analyses included pie chart, bar chart and tables.

4.6.1.4 Relative index analysis

This technique was used to further analyse and aggregate the scores of the variables rated on an ordinal scale. The SPSS was first used to determine the valid frequencies (in percentage terms) of the variables rated, which were then fed into **Equation (4.1)** to calculate the variables' respective rank indices (RIs).

$$RI = \frac{\sum w}{A \times N} \qquad \text{4.1}$$

Where w, is the weighting as assigned by each respondent on a scale of 1 to 5 [with 1 implying the least and 5 the highest]. A is the highest weight (i.e 5 in the case of this study) and N is the total number of the sample. Based on the ranking (R) of relative indices (RI), the weighted average for the six groups of factors were determined.

4.6.1.5 Kendall coefficient of concordance and chi-square tests

Kendall's coefficient of concordance (W) was used to determine the degree of agreement among the respondents in their rankings. This coefficient provides a measure of agreement between respondents within a survey on a scale of zero to one, with '0' indicating no agreement and '1' indicating perfect agreement or concordance. Using the rankings by each respondent, W was computed using **Equation (4.2)** (Siegel and Castellan, 1988).

$$W = 12\sum \frac{R_i^2 - 3k^2N(N+1)^2}{k^2N(N^2-1) - k\sum T_j} \quad \text{...4.2}$$

Where$\sum R_i^2$ is the sum of the squared sums of ranks for each of the N objects being ranked; k is the number of sets of rankings i.e. the number of respondents; and gj is the number of groups of ties in the jth set of ranks, and Tj is the correction factor required for the j^{th} set of ranks for tied observations given by:

$$T_j = \sum_{i=1}^{gj} (t_i^3 - t_i)$$

Where t_i is the number of tied ranks in the j^{th} grouping of ii Gj ties, and gj is the number of groups of ties in the j^{th} set of ranks

To verify that the degree of agreement did not occur by chance, the significance of W was tested, the null hypothesis being perfect disagreement. The Chi-square (x^2) approximation of the sampling distribution given by Equation (4.3) with (N-1) degrees of freedom is used for testing this hypothesis at a given level, for N>7 (Siegel and Castellan, 1988). Calculated x^2 value greater than its counterpart table value implied that the W was significant at the given level of significance and as such the null hypothesis was not supported hence, rejected.

$x^2 = k(N-1)W$ 4.3

4.6.1.6 Factor analysis

Factor analysis is a data reduction methodology that serves to define the underlying structure of interrelationships (or correlations) among a large number of variables (Hair et al., 1998). This technique was used to reduce large number of variables to a smaller set of underlying factors that summarise the essential information contained in the variables.

Hair et al. (1995) argue that a sample size of 100 is adequate to calculate the correlation between variables. Since the total number of subjects in this study was 210, it therefore conformed to the required ratio of subjects as noted by Hair et al. (1995). This analysis was performed with the assistance of SPSS Statistics v20. Kaiser– Meyer–Olkin (KMO) measure and Bartlett's Test of Sphericity were conducted to examine the sampling adequacy, ensuring that factor analysis was going to be appropriate for the research. Bartlett's Test of Sphericity states that if the variables are perfectly correlated, only one factor is sufficient. If they are orthogonal, we need as many factors as variables. If the correlation matrix is the same then they are an identity matrix. A simple strategy was to visualize the correlation matrix.

If the values outside the main diagonal are often high (in absolute value), some variables are correlated; if most these values are near to zero, then PCA is not really useful. Maximum likelihood approach was then employed to extract six groups of factors with eigenvalues greater than 1, however, suppressing all other factors with eigenvalues less than 0.3 based on Kaiser's criterion (Kim and Mueller, 1994; Field, 2000). To interpret the relationship between the observed variables and the latent factors more easily, direct oblimin rotation was selected as the most ideal rotation method (see **Appendix G** for more details).

4.6.2 Phase 4 [Application]: Assembling, Developing, Testing and Validating the Proposed MSDSS Model

This stage involved the physical data modelling that formed the final step of the research methodology where the internal storage structure and file organisations were carried out. The physical data model describes how data items are put into storage locations so that they could be retrieved (Miles et al, 2000). This phase dealt with system configuration: hardware devices (storage, display and peripherals), file structures, access methods and location of data.

- To help address the fifth objective outlined in section 1.5 of chapter 1, the following tasks were undertaken:

Step 8

4.6.2.1 Assembling data for the MSDSS model

The researcher employed relevant Database Management Systems (DBMS) to assemble the key components and data gleaned from the results of the surveyed questionnaire and interviews, as part of the initial design and development process. Macro-in-Excel Visual Basic for Applications and Microsoft Excel 2012 were selected as ideal spreadsheets for developing the algorithms of the DSS model and storing the data used for developing the algorithms, given the large amount of information.

Step 9

4.6.2.2 Developing the MSDSS model

Once the basic design was established, the individual components of the system were then built. Macro-in-Excel VBA was used as the ideal programming language, and MS Excel was used to develop the database for the main structure workflow of the proposed system. For satisfactory operation, the software requirements of the system included the following specifications: Intel Celeron processor; 2 GB of RAM; approximately 120 GB of hard disk space required for storing large files and a 15 inch monitor

Step 10

4.6.2.3 Testing and evaluating the MSDSS model

Miles et al. (2000) consider performance evaluations involving potential end-users as the best way to establish the usefulness of a given system. Obonyo et al (2005) state that evaluation is a process of determining the overall value of the software system, to ensure that the prototype model satisfies the performance criteria defined in the functional specification including its usability and limitations.

- To help address the first part of the sixth objective, the following steps were undertaken:

The researcher tested the internal links to know what was to be measured within the system, by inputting relevant data into the system using the black-box test run control approach, which included functional and regression tests. The objective of these methods were to check and verify whether or not the outputs of the results against easily calculated values tallied, and were consistent with random input variables after modifications.

Since the aim of this study was to validate the model for industry-wide application in the Nigerian housing construction industry, expert opinion evaluation was also used to assess the feasibility of the model in terms of its adequacy and clarity, and to ensure that the model was reasonably robust and acceptable to users (see full illustration in chapter 5 and **Appendix K**). To achieve this goal, feedback questionnaires were developed and deployed to a select few who partook in the previous study via email contacts to seek their expert views concerning the accuracy, completeness, comprehensibility and cost effectiveness of the model. The use of the previous survey respondent's list as a sample frame had two main advantages:

- First, most of the practitioners in this list were individuals in senior positions from building and design firms with relevant expertise and experience in material assessment and selection.
- Second, their prior involvement in the earlier survey made them familiar with this research, which ensured good response rate.

To further build a modified prototype version of the system, necessary changes were made afterwards based on the feedbacks from the survey. Some of the changes included categorizing the material types, and modularizing the various aspects of the model.

Step 11

4.6.2.4 Validating the MSDSS model

Validation of a system is a process of applying formal methods to ensure that the system design is achieving its intended functions correctly within pre-established conditions in order to increase confidence in the model (Heesom, 2004; Kennedy, et al, 2005). However, validation based on a case study allows an empirical inquiry into the real-life context of a research work, and differs to other qualitative research studies in the sense that the focus of attention is on individual cases as opposed to the whole population of cases. In view of the complex nature of this research, the case study approach was deemed to be the preferable method to generate the essential data for analysis and assess the robustness of the model.

- To address the final part of the sixth objective, the following steps were undertaken:

The model was applied to a case study building project in Nigeria, to check and confirm the effectiveness and robustness of the system. Here, the outputs from the algorithms of the system were compared to monitored data from the completed case study building, to review the potential savings of the new materials proposed. Further descriptions of the validation exercise are covered fully in chapter 6.

Table 4.7. Summary of the adopted research design road map

<table>
<tr><td>AIM</td><td colspan="3">To explore and evaluate the significance of an integrated modular-oriented mode of assessment that is able to assist designers in developing an improved capability to make early-informed choices, when formulating decisions to select LCGBMCs at the early conceptual stages of the design.</td></tr>
<tr><td>STAGE</td><td>OBJECTIVES</td><td>TASKS</td><td>METHOD</td></tr>
<tr><td rowspan="2">1: REVIEW</td><td>1. Elicit current views and background information on themes related to the economic, environmental and social impacts of housing construction activities, with emphasis on the role of material selection decision-making in sustainable housing</td><td>Step 1. Examined relevant literature through synthesis and analysis of recently published data, using a range of information collection tools such as; books, peer-reviewed journals, articles and dissemination notes from libraries and internet base sources</td><td>AA,</td></tr>
<tr><td>2. Compare and contrast various technologies currently used at national and international levels for modeling decision-making in the selection of building materials and components to highlight their strengths and weaknesses</td><td>Step 2. Reviewed relevant literature and subsequently, conducted preliminary study with leading researchers and practicing professionals who influence material choice decisions in the housing industry.</td><td>AA, QS,
INT</td></tr>
<tr><td rowspan="4">2: SYNTHESIS</td><td rowspan="4">3.Identify the key influential factors that affect the selection of building materials</td><td>Step 3. Conducted a pilot study, by deploying a test-questionnaire to a small sample of researchers in Nigeria who possess relevant knowledge on issues specific to the use of low cost green materials via email</td><td rowspan="4">AA, QS,
INT, OBS</td></tr>
<tr><td>Step 4. Conducted the first part of the main study by administering the revised questionnaire to targeted and interested registered building professional groups, who influence the selection of construction materials from throughout the construction value chain in Nigeria.</td></tr>
<tr><td>Step 5. Subsequently, conducted in person interviews with interested building professionals who influence material choice decision in housing construction using audio recording systems and writing tools to avoid misinformation</td></tr>
<tr><td>Step 6. Finally, carried out inspection on most commonly used tools in the UK by directly observing how they function when in operation and interviewing professionals who had implemented such systems</td></tr>
<tr><td>3: ANALYSIS</td><td>4. Establish and specify the impact weight of each key influential factor</td><td>Step 7. Analysed the data gathered from the surveyed exercise(s) using a suite of statistical analytical techniques</td><td>AA</td></tr>
<tr><td rowspan="4">4: APPLICATION</td><td rowspan="2">5. Develop a Multi-Criteria Decision Support System for aggregating the weighted factors needed for the assessment of LCGBMCs</td><td>Step 8. Assembled the key components and data gleaned from the analysis of the surveyed questionnaires and interviews</td><td rowspan="2">AA, QS,
M</td></tr>
<tr><td>Step 9. Developed the conceptual framework of the proposed system into a refined model using relevant Database Management System (DBMS)</td></tr>
<tr><td rowspan="2">6. Test and validate the developed system</td><td>Step 10. Inputted relevant data to test the output of the system against easily calculated values using the black-box control approach. This was followed by an expert-survey with participants who had participated in the study, using feedback questionnaires to get their judgments about the system. Made necessary adjustments based on the feedback from the survey.</td><td>M, QS, AA</td></tr>
<tr><td>Step 11. Validated the modified decision support system using a case study in Nigeria by comparing the outputs from the algorithms of the model to monitored data from the ongoing building project</td><td>M, CS</td></tr>
<tr><td colspan="4">KEYS: AA (Archival analysis) QS (Questionnaire Survey) INT (Interview) OBS (Observation) CS (Case study) M (Modeling)</td></tr>
</table>

4.7 Summary

This chapter has presented an outline of the research methodology adopted for carrying out this research. A four-phase research method was adopted to provide rich insights and enable triangulation of the data in order to fulfill the research aim and objectives as summarised in the Research Road Map in **Table 4.7**. This involved first, a comprehensive literature review followed by a pilot survey for fine-tuning the questionnaires for a subsequent nation-wide survey, and then interviews with key stakeholders in Nigeria, to confirm initial observations and to investigate current knowledge of design and building professionals regarding the concept of the sustainability principle-particularly, as it affects the selection and implementation of low-cost green building materials in the design of LIGHDs, and associated barriers towards implementing it.

The data collected were analysed with the aid of SPSS v.20 and Excel, using various forms of non-parametric techniques given the nature of the sample distribution. Information gathered from literature review, the survey and subsequent interviews were used to draw deductions and conclusions in respect of the research objectives, which formed the basis for developing a multi-criteria decision support model that met the requirements of the participants. **Appendix G** outlines the research work undertaken and outcome using the adopted research methods.

The next chapter is dedicated to making the most substantial contribution to the study by addressing the key research question posed in section 1.4 of chapter 1.

Chapter V

Developing the conceptual framework and testing the usefulness of the proposed MSDSS model for the evaluation and selection of low-cost green building materials and components

CHAPTER 5: DEVELOPMENT AND TESTING OF THE MSDSS MODEL

5.1 Introduction

The quest for adequate information presented in a format that gives designers a more informed view of the impacts of LCGBMCs was highlighted in chapters 1, 2 and 3. Following this request, the study engaged key stakeholders within the Nigerian housing industry to provide vital industry and practice-based information, using the relevant research methods adopted for the study in chapter 4. Throughout the analyses of the empirical studies (in **Appendix G**) there were further demands by participants for a new resource that would ensure the provision of up-to-date informed data relating to LCGBMCs, in order to support designers in the early stages of the design.

This chapter draws together the findings from both the literature review and the empirical studies to address the key research question posed in section 1.4 of chapter 1. As a response to participants' request, it seeks to develop a model, designed to aid and facilitate better-informed decision in the selection of LCGBMCs. Section 5.2 outlines the framework of factors required for sustainable material selection, section 5.3 examines the key factors of each group that make up the framework of the sustainability principle, while section 5.4 examines the adopted analytical model for the proposed MSDSS system. The concepts of the Analytical Hierarchy Process (AHP) and its advantages over other traditional material selection techniques are discussed in section 5.5, while section 5.6 illustrates the design and development of the prototype version of the MSDSS model. The full details of the steps involved in the workings of the MSDSS model are presented in section 5.7. Finally, the testing of the prototype MSDSS for selecting LCGBMCs is demonstrated in section 5.8, while a summary of the entire chapter is presented in section 5.9. Overall, Chapter 5 fulfills Objective 5 of the research.

5.2 Outline of the Framework for the Key Factors

The main study provided relevant industry and practice-based information, which was the predominant source of information for the framework structure of the key factors that make up the sustainability principle index. Reviews conducted on existing tools (in chapter 3) identified a number of sustainable material selection factors. The factors, strategies, drivers and barriers towards sustainable material selection identified from the literature review in chapters 2 were used as a starting point to sketch out ideas and work out which factors were key for inclusion.

Figure 5.1 presents a visual map of the key factors (the sustainability principle indices) that influence designers' decisions when selecting LCGBMCs for LIGHDs (see **Appendix G** for full analysis of factors). The framework has been sub-divided into six (6) key areas. Each box represents a group of factors that the participants had identified as key attributes that they consider when selecting building materials.

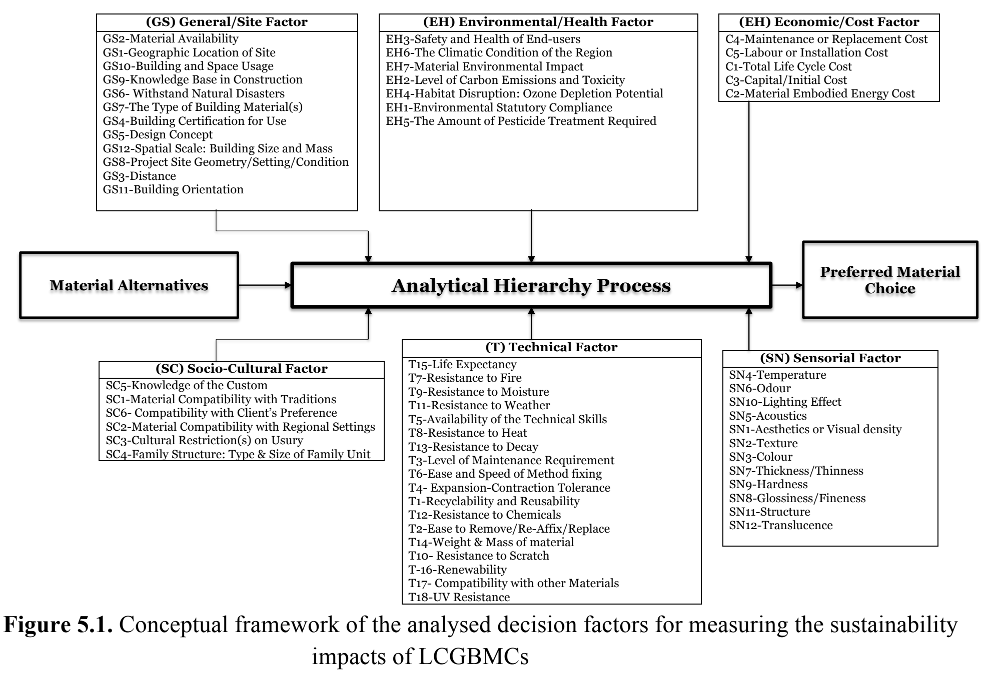


Figure 5.1. Conceptual framework of the analysed decision factors for measuring the sustainability impacts of LCGBMCs

5.3 Analysis of the Material Selection Factors

The analysis of the interviews and surveyed questionnaires identified 55 key sustainability principle indicators (influential factors) as important components of the material selection process (see **Appendix G** for full analysis). As part of an exercise to maintain consistency in the material selection decision-making process during crucial stages of the design, and to clarify the similarities and differences in properties and functions between various factors, the 55 factors were further compressed into six categories as follows:

5.3.1 Factor 1: General/Site (GS) Suitability

One of the fundamental aspects of housing design is the characteristic of the building site. Zhou et al. (2008) pointed out that factor such as soil characteristics, location and topography for instance, can influence design and material selection decisions. They argue that consideration of the site context of use is essential in determining the suitability of a building product in any housing project, since even projects located on neighboring sites differ in their characteristics. This group of factors includes: location, distance, site layout, and geographic information of the region.

5.3.2 Factor 2: Environmental/Health (EH) Impact

In addition to the easily quantifiable issues in the decision-making process, the long-term ecological footprint and health impacts of a material are equally important in the selection of LCCGBMCs, hence in achieving a sustainable low-impact green structure (Behm, 2005). Bubshait & Almohawis (1994) defined health and safety as the degree to which the general conditions promote the completion of a project without major accidents of injuries to users.

To reduce or eliminate any form of environmental hazards resulting from the production and transportation of building products, and to improve safety performance during occupancy, designers must address environmental and health issues when selecting materials at the early stages of the design. This group of factors includes; environmental statutory compliance, toxicity, ozone depletion potential, embodied carbon emission, fossil fuel/habitat depletion, pollution and air quality.

5.3.3 Factor 3: Economic/Cost (EC) Efficiency

Goh and Yang (2009) argue that the financial constraint is still one of the prime concerns to many building clients because of the huge capital requirement for housing construction. Historically, material selection decision-making has been based largely on the first-cost mentality approach (Goh and Yang, 2009). With increasing pressure to provide affordable housing, design and building professionals are focusing on the early identification of the long-term financial impact of housing projects when selecting building materials at the initial stages of the design (Cole, 1999).

Since the cost of operating a building is consequent of the choice of materials at the early stages of the design, decisions based solely on initial cost often undermines the log-term impacts of the products. This means that designers must consider a long-term economic assessment approach that is able to predict the costs of a building from its inception, operation, maintenance, and replacement until the end of its lifetime to ensure that the green development objectives are achieved. The group of factors that fall under this category include: material embodied energy cost, capital cost, labour cost, material replacement cost, material maintenance cost, and total life-cycle cost.

5.3.4 Factor 4: Socio-Cultural (SC) Benefits

Socio-cultural variables are much difficult to quantify and as such have not received as much attention in the architecture literature as other groups of factors (San-Jose et al, 2007). San-Jose et al. (2007) argue that the socio-cultural variable forms an implicit part of the design decision-making process, as it helps to define the architecture of the region, as well as promote the image of the community. Likewise material choice also must be compatible with specific regional and local cultural and aesthetic conditions. For example, the Southwestern adobe and flat roof residential construction would not export well to New England, where the widespread use of wood framing, clapboard siding, and pitched roofs is climatically appropriate, as well as culturally embraced. Hence, considerations must be given to socio-cultural factors during the early stages of the design to conserve the cultural asset. Factors within this group include: material compatibility with traditions, and cultural restriction on usury.

5.3.5 Factor 5: Technical (T) Performance

Wong and Li. (2008) note that one vital aspects of housing design is to find trade-offs that satisfy a multitude of technical objectives, since they provide a rational framework for building design and construction that is flexible and amenable for accommodating innovations and change. The technical concept enables the execution of buildings that are highly suitable for the functions and activities of their occupants. Therefore, failure to recognize the significance of technical criteria during material selection at the early stages of the design, may lead to building system incompatibility, malfunctioning, and risk of obsolescence (Wong and Li., 2008). In other words failure to match the technical criteria with occupants and clients' expectations at the crucial stages of the design may eventually lead to malfunctioning of the building systems, which could result in loss of confidence in the building structure, hence, affect the business operations of occupants in the long run.

Factors such as; fire resistance, resistance to decay, life expectancy of material (durability), ease of construction and maintainability must be considered at the initial stages of the design when selecting LCGBMCs, in order to attain the desired service life of the building product without excessively increasing its life-cycle cost.

5.3.6 Factor 6: Sensorial (SN) Performance

Factor 6 focuses on sensorial impact such as visual density, texture, colour, temperature, acoustics and hardness. This group of factors expresses the quality of the actual material used in a specific building element in relation to human senses or feelings. Ashby & Johnson (2002) note that choosing materials for an architecture project is not only about meeting technical requirements, but also the material's appearance and sensory behaviour.

Wastiels and Wouters (2009) argue that limiting the assembly of buildings to environmental, economic, or technical aspects impede the discovery of design opportunities inherent in materials themselves. They note that sustainability in a material can also be related to the material quality itself, appearance, texture, acoustics, thermal capacity and odour.

The following section is to review some of the well-known multi-criteria decision techniques that are commonly used to assess sustainable principle indicators in the building industry, in order to identify the most ideal model that will apply favourably to the context of this study.

5.4 Multi-Criteria Decision Support Models for Material Selection

Numerous techniques for multi-criteria decision-making have emerged (Trusty, 2003). According to Singh et al. (2007; 2009), the sole reliance on univariate or bivariate analyses has been found to be inadequate. Consequently, the use of the multivariate analysis has become more acceptable in deciding the choice of materials due to its ability to address both objective and subjective variables. As the name implies, multivariate analysis comprises a set of techniques dedicated to the assessment of relationships between more than two variables, which are random but interrelated so that their different effects are meaningfully and uniformly interpreted (Singh et al., 2007). However, the question remains as to which of the existing MCA techniques is most suitable for the articulation of composite indices when evaluating competing material options.

In the following sections a range of available MCA analytical techniques are examined, in hopes of identifying the MCDA approach most applicable to this study. The rationales for the most preferred technique are also discussed.

5.4.1 Scoring Multi-Attribute Analysis (SMAA)

This technique is used for evaluating multi-criteria decision problems to identify the best decision alternative from several well-defined alternatives. Anderson et al. (2005) spelt out the analysis involved in this technique in clear steps as follows:

Step1. Develop a list of the criteria to be considered. The criteria are the factors that the decision maker (DM) considers relevant for evaluating each decision alternative.

Step 2. Assign a weight to each criterion that describes the criterion's relative importance. Let wi = the weight of criterion i.

Step3. Assign a rating for each criterion that shows how well each decision alternative satisfies the criterion. Let r_{ij} = the rating for criterion i and decision alternative j.

Step 4. Compute the score for each decision alternative as follows:

$S_j = \sum w_i r_{ij}$; where S_j is the score for decision alternative j………..….....5.1

Step 5. Order the decision alternatives from the highest score to the lowest score to provide the scoring model's ranking of the decision alternatives. The decision alternative with the highest score is the recommended alternative. The simplest form of SMAA is expressed as $S_j = \sum r_{ij}$ (i.e. without any weightings (W_i) and is termed simple scoring MAA. Anderson et al. (2005) however, note that this method has major weakness, as r_{ij} is often a very subjective measure.

5.4.2 Multi-Attribute Utility Theory (MAUT)

This technique is similar to SMAA except that it uses "utility" to quantify the subjective components of the attributes. The term "utility" is used to refer to the measure of desirability or satisfaction of an attribute of the alternative under consideration. It gives an abstract equivalent of the attribute being considered from natural units such as years, or £ into a series of commensurable units (utiles) on an interval scale of zero to 1 (Holt, 1998). As in SMAA, utility values can be used in conjunction with weightings, Wi, to give a more reliable aggregate score for the various alternatives. MAUT is expressed mathematically as:

$$S_j = \sum_{i=1}^{n} W_i U_{ij};$$

……………..…………..……………………………………..5.2

Where Ui represents the abstract equivalent expressed in utiles for the ith attribute of the jth alternative and n is the attributes considered by the decision maker.

5.4.3 Multiple Regression (MR)

This is a statistical technique used to develop a model for observing and predicting the effect of a number of independent variables upon a dependent variable. In general, a MR model for predicting an outcome Y, a function of independent variables, X_1, X_2,…..X_n is given by equation of the form:

$Y = a + b_1(X_1) + b_2(X_2) + ... + b_n(X_n)$ ………...………...…………………..…5.3

Where a is the constant representing the y-axis intercept of the regression line; b_1,b_2,…..b_n are the partial regression coefficients representing the amount the dependent variable Y changes when the corresponding independent variable changes 1 unit and n is the number of independent variables.

In applying MR as a decision-making technique, the various attributes or criteria will be represented as independent variables and the dependent variable will represent the total score obtained by each alternative. Associated with multiple regression is R^2, coefficient of determination, representing the percent of variance in the dependent variable explained collectively by all of the independent variables. The higher it is, then the more accurate the model is able to predict.

5.4.4 Multivariate Discriminant Analysis (MDA)

MDA is also a statistical analysis technique concerned with separating distinct set of objects (or observations) based upon their observed independent variables (Anada & Herath, 2009). The technique begins by finding the most discriminating variable, which is then combined with each of the other variables in turn until the next variable is found which contributes most to any further discrimination between the groups. The process continues in a similar manner until such time as very little discrimination is gained by inclusion of any further variable (Holt, 1998).

The criteria which best discriminate between groups and which are most similar is confirmed by computing the ratio of between-group variation to within-group variation, simultaneously for all the independent variables. The discriminate factors are then used to develop a linear discriminate function of the form:

$Z= C_0 +C_1 V_1+ C_2 V_2+ ....C_n V_n$……………………..........................…5.4

Where Z is the score of the discrimant function; V_n is the nth discriminating variable; C_n is coefficient of V_n and C_0 is a constant.

5.4.5 Weighted Sum Method (WSM)

The Weighted sum method often called the decision matrix approach is perhaps the earliest and the most commonly used approach, especially in single dimensional problems. This evaluates each alternative with respect to each criterion and then multiples that evaluation by the importance of the criterion. This product is summed over all the criteria for the particular alternative to generate the rank of the alternative. Mathematically it is represented as:

$$R_i = \sum_{j=1}^{N} a_{ij} w_j$$ …………………..……………………………………………..5.5

where R_i is the rank of the i^{th} alternative, a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion, and w_j is the weight or importance of the j^{th} criterion. Difficulty with this method emerges when it is applied to multi-dimensional decision-making problems. In combining different dimensions, and consequently different units, the additive utility assumption is violated

5.4.6 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is widely acceptable technique among practitioners and it is easily conceivable method and its calculations can easily be performed (Schinas, 2007). It can easily incorporate fuzzy approach. It may use any weight scale selected by decision maker and it can use the same decision matrix. It can also handle a larger number of alternatives that is considered in this research. TOPSIS is based on the idea that the chosen alternative should have the shortest distance from the positive ideal solution and farthest from the negative ideal solution (Hwang and Yoon 1981; Schinas, 2007). The assumption of the utility of each attribute tends to increase (or decrease) monotonically. Then it is easy to locate the ideal solution, which is defined as the sum of all best attribute values attainable, and the negative-ideal solutions composed of all worst attribute values attainable.

5.4.7 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is perhaps the most commonly used for prioritization of decision alternatives. Developed by Saaty (1980), the essence of the process is decomposition of a complex problem into a hierarchy with goal (objective) at the top of the hierarchy, criterions and sub-criterions at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy. Elements at given hierarchy level are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level. Ratio scale and the use of verbal comparisons are used for weighting of quantifiable and non-quantifiable elements. The method computes and aggregates their eigenvectors until the composite final vector of weight coefficients for alternatives is obtained. The entries of final weight coefficients vector reflect the relative importance (value) of each alternative with respect to the goal stated at the top of hierarchy. A decision maker may use this vector due to his particular needs and interests, to calculate the consistency index which must be lower than 0.10.

When all criteria are combined, an indexing algorithm termed the 'sustainability or green utility index' is created to rank options of competing material choices on their contribution to sustainability. Each criterion is then measured and combined using AHP technique to give an overall index score. The higher the index, the more sustainable is the outcome. **Table 5.1** gives a summary of the various tools based on the levels of information on the decision-making environment and the nature of output results as described by Holt (1998).

Table 5.1. A comparative analysis of the characteristics of MCA techniques (Holt, 1998)

Technique	Nature of input data	Nature of output
Scoring Multi-attribute analysis	Interval and ordinal but Subjective	Numeric score and ranks and hence rank amongst alternatives
Multi-attribute utility theory	Raw data is often qualitative, utility achieves interval data	Numeric score and ranks and hence rank amongst alternatives
Multiple regression	Interval predictive	Numeric; further value
Linear programming	Value judgment on the importance of an over-all objective	Maximisation of objective function
Multivariate discriminant analysis	Multivariate	Group membership/group characteristics
Weighted sum method	Interval and ordinal but Subjective	Numeric score and ranks and hence rank amongst alternatives
TOPSIS	Raw data is often quantitative	Numeric score and ranks Alternatives from the positive ideal solution
Analytical hierarchy process	Raw data is often qualitative and quantitative, utility achieves interval data	Numeric score and ranks and hence rank amongst alternatives

5.5 The Multi-Criteria Assessment Technique Adopted

Nijkamp et al. (1990) note that selecting an ideal MCDA for a particular study means that the selected method must allow for the weighted aggregation of quantitative individual factors, which requires that the method is utility or value based, quantitative in format and provides a cardinal measurement of the weighted differences amongst factors and not merely ordinal difference. They add that the method must be such that it is transparent so that the method of construction can be disseminated for robustness, and formalises explicitly the logical thought processes that are implicitly carried out by the designer when faced with a material selection problem. Given the complex range of considerations associated with the selection of LCGBMCs and having full knowledge of all possible consequences of all potential material alternatives, the AHP model of decision-making was adopted to demonstrate the concept of the selection methodology for the proposed MSDSS model. The following section explains the rationales for selecting the AHP model of decision-making.

5.5.1 Rationale for Selecting Analytical Hierarchy Process (AHP)

The following are the various contexts for which AHP was selected as the ideal selection/assessment methodology for the proposed MSDSS model over other available techniques.

- Most multiple objective programming techniques face the problem of dealing with a large (if not infinite) number of alternatives (Singh et al., 2007). Since the proposed MSDSS model would require significant amount of quantitative and qualitative data input including: numeric, descriptive, and categorical data, using AHP model would ensure the resolution of conflicts between tangible and intangible factors as decision making in reality engages with solid, verbal, objective and subjective elements;

- There were anticipations that choosing an ideal product from a range of competing alternatives in the MSDSS model might involve multiple step analytical method of judgment. With the AHP technique, potential users are able to break down complex unstructured problems into component parts, and arrange these parts into a hierarchy of a much simpler and more logical judgments by simply assigning numerical values to represent each of their preferred choice of materials and variables;

- The components of the MSDSS framework are modular, and as such each may be developed independently or require future modifications. Since data may be added subsequently to supplement the knowledge and databases, the AHP model- given its flexible nature of accommodating inordinate number of considerations, would be capable of handling extra attributes as they are acquired.

- Unlike other MCDA models, the AHP model can be easily implemented using any simple and very familiar spread sheet or software application such as the MS Excel, MS Access and MSWord;

- It was anticipated that comparing LCGBMCs will involve the use of numerical logics and will include attributes that are measured on a number of different numerical scales or user-specified weightings. AHP was selected to enable the formulation of the mathematical models required for computing the Green Utility Index (GUI), since numerical calculations and algorithmic procedures are an essential requirement for the proposed MSDSS model.

The computational assessment procedure associated with the Analytical Hierarchy Process (AHP) is fully discussed in Appendix H. The following section describes how the MSDSS model for LCGBMCs is developed and how the internal storage structure and file organisation are specified including the system configuration procedures.

5.6 System Design and Development: Physical Data Modeling of the MSDSS Model

5.6.1 Introduction

The overarching aim of this research has been to explore how designers can be better enabled at the earliest stages of the design to incorporate sustainability principles into the material selection decision-making process when formulating decisions to select LCGBMCs for their mainstream use. This section describes the development process of the MSDSS model, and examines the various functions and types of database management software/hardware applications relevant to this study.

Section 5.6.2 establishes the primary function and underlying rationale for choice of each software and hardware along with their relative advantages and disadvantages. Section 5.6.3 discusses the steps followed in the design and development of the MSDSS analytical system including data modeling development techniques, which include the conceptual, logical, and physical data modeling process.

First, it details the system architecture of the MSDSS analytical system user interface, and establishes where each database module is going to be located, and what function each module is to perform in section 5.6.4. Section 5.6.5 demonstrates the selection methodology adopted for LCGBMCs. It describes the operation of the system to give an overall understanding of the workings and application of the system; showing the logic, functions, and relationships between the various data organized in different modules, and compatibility between the various sources of information collected in section 5.6.6.

5.6.2 Database Management Software for Modeling the MSDSS

The choice of the specific database management applications for the design and development phases was one of a strategic nature. Several database management software choices were considered to build the MSDSS databases such as Java script, MS Excel, and MS Access. In the MSDSS analytical system, the main software packages considered include Microsoft Excel 2013 version, Microsoft Access, Microsoft Word, and Macro-in-Excel Visual Basic for Applications. MS Excel 2013 was selected as the core storage software as it provides capabilities in information processing, managing complex/multiple databases, spatial analysis, graphic user interfacing, and mainly because of the presence of several enhanced plugs and extensions capable of improving functionality of the system. The following sections discuss the underlying rationale for choice of each database management application along with their relative advantages/disadvantages.

5.6.2.1 Microsoft Excel

The Monitoring database of the MSDSS model was initially organised by using Microsoft Excel 2013, which is the most basic of the current versions of Microsoft Excel software (Microsoft, 2013). The software was chosen because of its capabilities to retrieve, store and query non-spatial/attributes information efficiently and ability to handle the relatively large data. This software allows enforcing key constraints and referential integrity constraints thus, guarding against errors in the database. In the designed database, the properties of the desired data for each modular unit are specified and in other cases automatically rejected by the DBMS, if data with wrong properties are entered. Excel also allows integration of different data formats e.g. Excel Data base file can be converted to other formats like Access and word files. In addition, Microsoft Excel possesses a powerful macro language that is essential since a menu driven interface had to be developed. MS Excel has the ability to upgrade itself as current versions of the software are released.

5.6.2.2 Microsoft Word

The MSWord 2013 version was selected as the ideal data-editing tool for inputting material data from various sources. Microsoft Word was used in most data integration steps because of its user-friendliness and ease in creating intermediate text based data formats.

5.6.2.3 Programming Language (1): Visual Basic for Applications 6.0

Chapra (2007) describes Visual Basic for applications (VBA) 6.0 as an example of a graphical-based language and Microsoft Widows programming language used to create the graphical user interface (GUI). Visual Basic 6 programs according to Halberg et al. (1997) are created in an Integrated Development Environmental (IDE), which allows the programmer to create, run and debug Visual Basic programs conveniently, and create working programs in a fraction of the time that it would normally take to code programs without using IDEs. The following are some of the advantages and disadvantages of the VBA 6.0 program.

Advantages of Visual Basic for Applications 6.0

- Easy to install
- Faster compiler
- Allows database integration with wide variety of applications
- Additional internet capabilities
- Easy to Back up and restore

Disadvantages of Visual Basic for Applications 6.0

- Poor visual appeal –most models based on the application are visually unattractive
- Only works in a Local Area Network, therefore requires installation on every computer to launch model

- Much more difficult to upgrade if updates are needed, as user has to manually upgrade the software.
- Applications built using the 32-bit version of Visual Basic 6.0 only runs with Windows 95 or Windows NT (Version 3.5.1 or higher), but not compatible with Macintosh operating systems
- System is too complex to run
- May not be able to handle complex problems as much as VB.Net or Macro-in-Excel, since the proposed model involves large amount of logic

5.6.2.4 Programming Language (2): Macro-in-Excel Visual Basic for Applications 6.0 (MEVBA)

Macro-in-Excel VBA has a wide array of unique and useful features that are the best and only reason for using VB in programming. Compared to other programming language such as C++, or Java, Macro-in-Excel VBA is an object-oriented programming language that is considered a step up from older versions of Microsoft Visual Basic Applications (VBA).

Advantages of Macro-in-excel Visual Basic for Applications

The following outlines the advantages of Macro-in-Excel VBA (MEVBA).

- A powerful object-oriented programming language: Macro-in-Excel Visual Basic for Applications has many language features that allows users to easily create multi-threaded, scalable applications using explicit-multi threading. This aspect enabled more detailed consideration of a larger number of factors and material alternatives in the MSDSS model.

- Makes application easier to maintain: Since the MSDSS was designed to contain large number of macros that would respond to events on reports, there was a likelihood of potential difficulties in maintaining the system. With MEVBA, codes were easily built into form, causing the system to handle and manage the large volume of data typically associated with LCGBMCs.

- Enables the developer to improvise functions: The MSDSS contains a series of mathematical model and computational algorithmic procedures that provides a basis for improvising new functions or logic. With MEVBA, it was easy to transform data by performing arithmetic and logical operation, and formulate the mathematical model for computing the green utility index (GUI). This enabled the MSDSS model create unique functions to either perform calculations that exceed the capability of an expression or replace complex expressions written in the model application.

- Mask error messages: Applications used by a variety of people almost always require some code for handling errors. Using MEVBA helped to automatically detect error during tests run without having to create its unique code systems for detecting and handling errors.

- Skilfully create or manoeuvre objects: The MEVBA application enables the developer to skilfully create and modify objects using unique codes. This facilitated the manoeuvering of all the objects within the database of the MSDSS model.

- Flexible coding: Coding an argument simply means supplying the additional information that some actions require. With Macro-in-Excel VBA, it was easy to pass arguments to the code at the time it ran, allowing a great deal of flexibility on how the codes were run.

- The primary strengths of the MSDSS framework are its modularity and expandability. Since the components of the framework were modular, Macro-in-Excel VBA enabled the splitting of the databases into modular units, which allowed for each unit to be developed independently without having interfering with the entire system.

- It has the ability to write scripts and automatically convert raw material data to an appropriate and usable condensed graphic data format

- Macro-in-Excel VBA is able to encapsulate much of the basic functionality that used to have to be built using other programming languages such as VBA 6.0. The Macro-in-Excel VBA Framework has the code that makes Windows Forms work, so any language can use the built-in code in order to create and use standard Windows forms;

- Macro-in-Excel VBA applications could be run on any operating system hosting the VBA Framework. In other words, the user could achieve true cross-platform capabilities simply by creating Macro-in-Excel VBA applications, provided the VBA Framework is available for other platforms;

Disadvantages of Macro-in-Excel Visual Basic for Applications

- The one thing not suitable to make programs in Macro-in-Excel VBA is that it uses lots of processing time (CPUs).

- More memory space is usually required to install and work in Macro-in-Excel VBA, since it contains Graphical components that need more space. To address this problem, the system was made to run on higher specifications of 2 to 4 GB of RAM, and approximately 80-500 GB of hard disk space.

5.6.2.4 The Rationale for programming language adopted for developing the MSDSS Model

Copeland (2004) noted that although each programming language has its own strengths and weaknesses, the reason for choosing a particular language might ultimately be based on a range of factors (IEEE, 1990). Beizer (1995) noted that the appropriate program to use for developing a DSS model mainly depends on the contextual components of the system. In order to identify a more reliable program for developing the proposed MSDSS model, certain factors were considered.

Some of the factors considered during the review include; the availability of potential users familiar with the program, how well the language fits in with the model, life-cycle costs of development and use, portability, safety and reliability, ability to handle complex logic and numeric expressions, flexibility, ease of coding and reading, ease to compile and identify bugs, and tendency to run codes on any windows platform. Recent studies, including several by Walkenbach (1999) and others by Halberg, et al. (1997), and Chapra (2007) cover Macro-in-excel VBA extensively. Since it was envisaged that the development process would involve constant modification and subsequent expansion of the database to accommodate more information, consideration of the factors suggested "Macro-in-Excel VBA" as the ideal program for developing the proposed model, given that its advantages (listed in section 5.6.2.4), outweighs those of other reviewed programs.

5.6.3 Database Management Hardware for Modeling the MSDSS

Database management hardware is any physical device used as part of a computer system to enhance a program or software (IEE, 1999; Bertolino, 2001). Generally, the main hardware components include the processing unit and the peripheral unit. Given the advantages of Macro-in-Excel VBA, the MSDSS model was designed to run under all forms of Disk Operating Systems (DOS) including Windows 95/98/NT/2000, Microsoft Windows 8, 7, Vista, XP; Windows Server 2012, 2008, 2003; Windows Embedded Standard 7; Windows Embedded Standard 2009 Operating Systems, and Macintosh. For satisfactory operation, the software requirements of the system include the following specifications: Intel Celeron processor or compatible or higher specification; 2 GB of RAM; approximately a minimum of 80 GB of hard disk space in addition to space required for storing large files in the system folder and a 15 inch monitor to present information in a highly visual manner. Below is a schema illustrating the interrelationship of the various features/components of the automated material selection decision support system for assessing LCGBMCs selection process.

5.6.4 System Architecture of the MSDSS Model

Figure 5.2 shows the overall schema or architecture of the MSDSS analytical system, which consists of an extensive modeling of the interactions between the various components of the system as described in section 5.6.6. The system consists of a number of interconnected modules/features that are also described in **Table 5.2**.

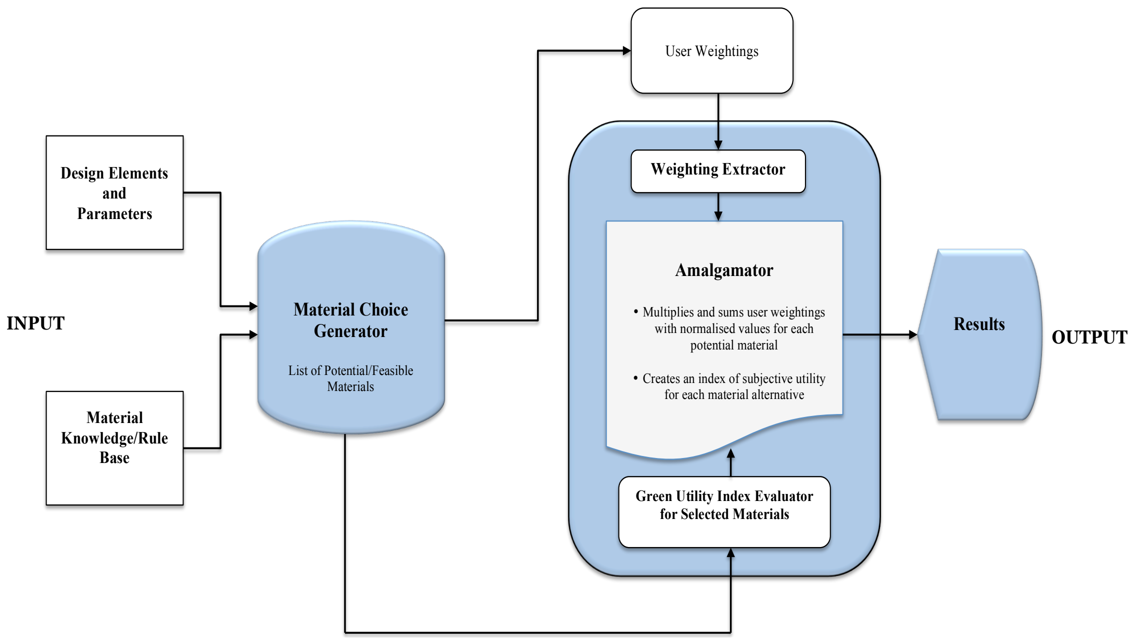


Figure 5.2. Modified conceptual model of the Material Selection Decision Support System (MSDSS)

Table 5.2. Individual functions of the various features/components of the conceptual framework

FEATURES OF THE MSDSS MODEL	FUNCTIONS OF THE VARIOUS FEATURES/COMPONENTS
1. Design Elements and Parameters Module	This unit consists of a range of building design elements, their respective attributes, parameters, description, dimensions (including size, colour shades, form, and thickness) and other performance requirements specific to all candidate materials and components. The elements include: External Wall, Internal Wall, Beam, Column, Floor & Slab, Pavement, Skirting, Door &Window, Stair, Ceiling, and Roof. It also responsible for generating the initial set of all potential competing material alternatives specific to the elected design element. Here, the decision-maker is able to input the relevant dimensional values of various building materials for each design element.

2. Material Selection Decision Rules/Heuristics Module	This unit consists of a collection of set-rules used in current practice(s) for measuring the project-specific minimum requirements during material selection. It is used to define the boundaries, and the consideration of the context of use, and describes the Material Selection Rules to test the suitability of each material selected by the user. It involves listing of context-specific materials of an elected design element, by gradually srcutinising and eliminating candidate materials based on their inability to meet stated material selection heuristics/rules.
3. Material Choice Generator Module	This unit consists of all eligible material alternatives that are available for the intended task.
4. Users' Weightings Module	This unit enables the user to sort out preferred weighting value(s) for specific factors.
5. Weighting Extractor Module	This feature enables the user to assign different weighting values to each factor, according to the subjective importance, which that factor/variable holds for the user against a set of competing materials eligible for the intended task.
6. Green Utility Index Evaluator Module	-The Green Utility Index Module is responsible for performing logical queries by sorting out input values for each factor against corresponding values of competing materials using the AHP model of decision-making.
7. Amalgamator Module	-The amalgamator module is responsible for calculating the weights (usually numeric figures given to each material by the user). Here both the weighting value for the material and the value for the factors are multiplied and summed to create a list of preference for the material alternative(s) selected by the user. -Finally it ranks each material by sorting the alternatives according to the utility value of the calculations for all the materials that were compared.
8. Results Module	- This feature views the MSDSS APP data, and generates reports. It allows the MSDSSAPP User Interface to communicate with the user, and also connects all the reports and queries that are generated in the Monitoring databases to the corresponding project files. -This unit is responsible for generating results in form of graphs, quantitative and descriptive reports, showing variance of materials suitability in relation to the relevant factors inputted by the user

5.6.5 Selection Methodology of the MSDSS Model

The diagram shown below (in **Figure 5.3**) demonstrates the conceptual framework of the selection methodology for the decision support system. **Table 5.3** describes a step-by-step procedure of the selection methodology for the material selection decision support system.

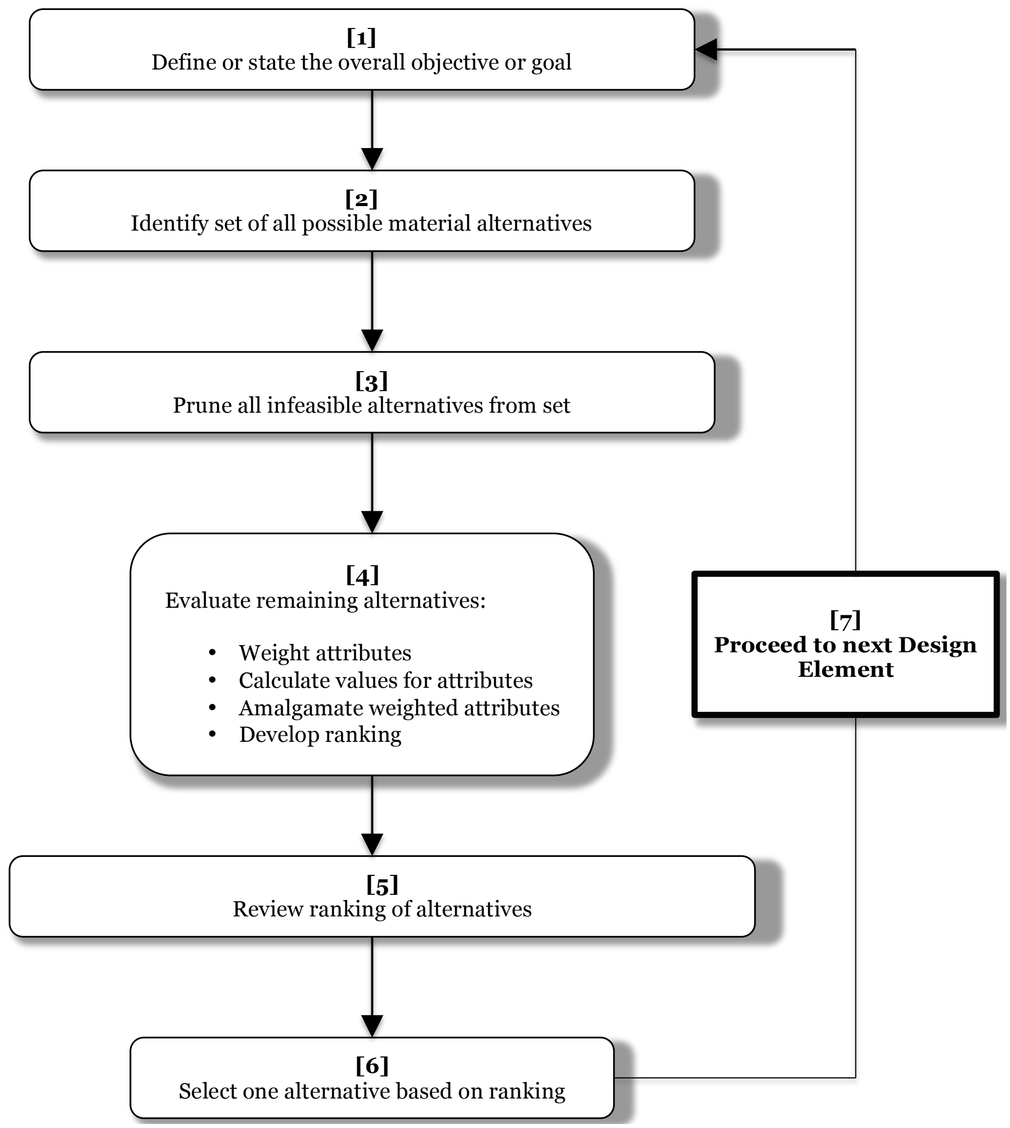


Figure 5.3. Materials selection methodology of the MSDSS model

Table 5.3. Step-by step approach of each objective and task of the material selection methodology

OBJECTIVE	TASK
1. Define or state overall objective/goal	The first step of the methodology is to define the main goal of the intended task.
2. Identify Sets of all Potential Material Alternatives	After defining the main goal of the task, the next step is to generate a set of all possible alternatives. In the material selection process, this comprehensive set of alternatives includes all the construction materials and components currently in the database, or manufacturer's webpage.
3. Prune all infeasible alternatives from set	The third step is to reduce the complete set of alternatives by eliminating/pruning those alternatives, which are clearly infeasible/unsuitable for the intended application according to the Construction Standards Institute (CSI) Divisions. For example, if the element under consideration is a structural beam, materials such as roofing sheet and glass are automatically pruned from the set of possible alternatives under consideration, since none of these materials fall under the CSI structural divisions. This should result in a subset of alternatives specific to the elected design element under consideration, all of which would be feasible choices for the intended application. The "pruning" approach is used rather than allowing the user to select feasible materials from the whole set since users tend to overlook alternatives which might be unfamiliar to them but are feasible.
4. Evaluate Remaining Alternatives	The fourth step in the methodology is to evaluate the feasible alternatives using the AHP model such that a ranking can be developed according to the relative importance of the material in relation to the key factors.
• Weight Attributes (Decision Factors)	• First, the decision maker weights each factor according to the relative importance that the decision factor or variable holds for the decision maker, in order to supplement, not replace, his judgment.
• Calculate Values for Attributes	• Second, values for each of the factors are determined for each material based on the AHP model of decision-making and then, a normalized value between zero and one is calculated for each factor value.
• Amalgamate Weighted Attributes	• Afterwards, the weights and normalized values are multiplied and summed to create an index of preference for the set of alternative(s).
• Develop Ranking	• Then, a list of alternatives ranked according to the relative importance of the factors is presented.
5. Review Ranking of Alternatives	When the indices of factors have been calculated for all eligible alternatives, a ranking is developed sorting the alternatives according to each utility value. The alternative with the highest utility value is recommended from the ranked list of potential materials for each design/building element.
6. Select Alternative Based on Ranking	The decision maker may then either elect/decide to select the highest ranked alternative, or choose another alternative from the set based on his/her professional judgment.
7. Proceed to Next Design Elements	The decision maker then proceeds to the next design/building element.

5.6.6 Working Procedure of the MSDSS Model

The modified system architecture of the conceptual model presented in **Figure 5.5** of section 5.6.4 illustrates the workflow and interactions between various components of the MSDSS model. The following steps further explain how the MSDSS model operates. To use the system as illustrated in **Figure 5.5** the following steps are undertaken:

I. The load manager first launches the MSDSS application and instructs the user to enable macros, which then activates the operational process;

II. The system automatically provides user with a list of design elements from the "List of Design Elements" module, and then queries/prompts the user to select his desired building design element for the intended task;

III. The User then selects the particular design element needed for the intended task from a list of conceptual design elements (broken down by Construction Standard Institute Division); and then prompted by the system to provide dimensional values for the selected design element;

IV. User enters dimensional values to answer prompts about areas and dimensions of the elected design element;

V. The system validates the dimensional values entered by the user, and then generates the set of all relational building material alternatives that are available for selection within the 'materials' database;

VI. The system with the help of a set of material selection heuristics/rules along with the details provided by the user- generates a list of feasible materials relevant to the elected design element. Here, the system automatically narrows down the list of available materials to a few eligible candidate materials that fulfill a set of user-defined queries/requirements;

VII. After the set of feasible material alternatives has been generated, the user is then prompted to assign factor weightings according to the relative importance that each factor or variable holds, and a normalized value between zero and one is calculated for each factor in relation to the set material alternatives;

VIII. Then, the normalised value of each factor is amalgamated (multiplied and summed) with the normalised values for each potential material alternative, which then results in a relative ranking of the feasible materials for the elected design element, hence creating an index of subjective utility for each material alternative;

IX. When the indices of utility have been calculated for all feasible material alternatives, the system displays in a descending order of ranking, a list material alternatives according to their utility values;

X. The system prepares the output graphical results and a layout, leaving the user with the option of either selecting the highest ranked alternative recommended by the system, or another alternative from the set based on his professional judgment;

XI. The user may elect to generate a printout report of the list of selected materials;

XII. The user then proceeds to the next design element.

Figure 5.4 below shows an illustration of the workflow system architecture of the Material Selection Decision Support System (MSDSS). The full details of the steps involved in the workings of the actual prototype MSDSS model are presented in section 5.7.

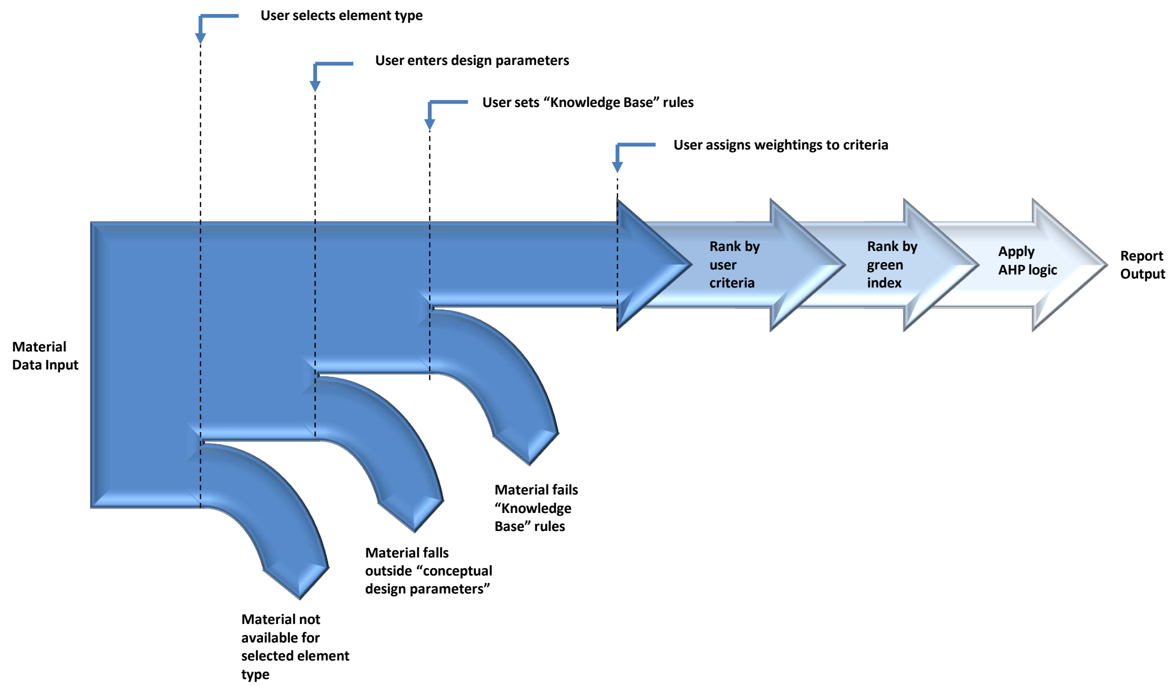


Figure 5.4. Illustration of the workflow showing the material selection decision-making process with the help of the MSDSS experts' knowledge tool

5.7 Prototype of MSDSS User Interface Menu

This section of the chapter illustrates the various working procedures of the actual prototype model. It describes how the various components of the MSDSS are managed during the material evaluation and selection process.

STEP 1

In the MSDSS main menu the user has the option of whether to proceed or discontinue with the task.

-To discontinue, the user clicks on the < Exit> button.

-To proceed, the user double clicks the <MSDSS ICON> to launch the MSDSS application

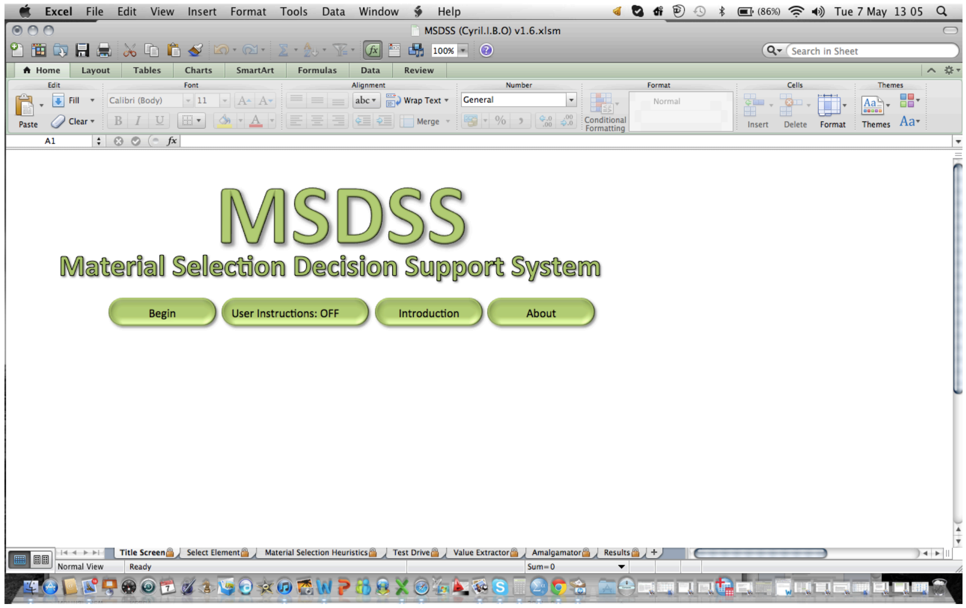


Figure 5.5. User interface of the prototype MSDSS analytical system main menu

-The user then clicks on the <BEGIN> tab/button to initialize a project task (**Figure 5.5**).

-To activate the instruction manual, the user is prompted to click the <USER INSTRUCTIONS ON/OFF> tab. This guides the user as (s) he progresses through the set task.

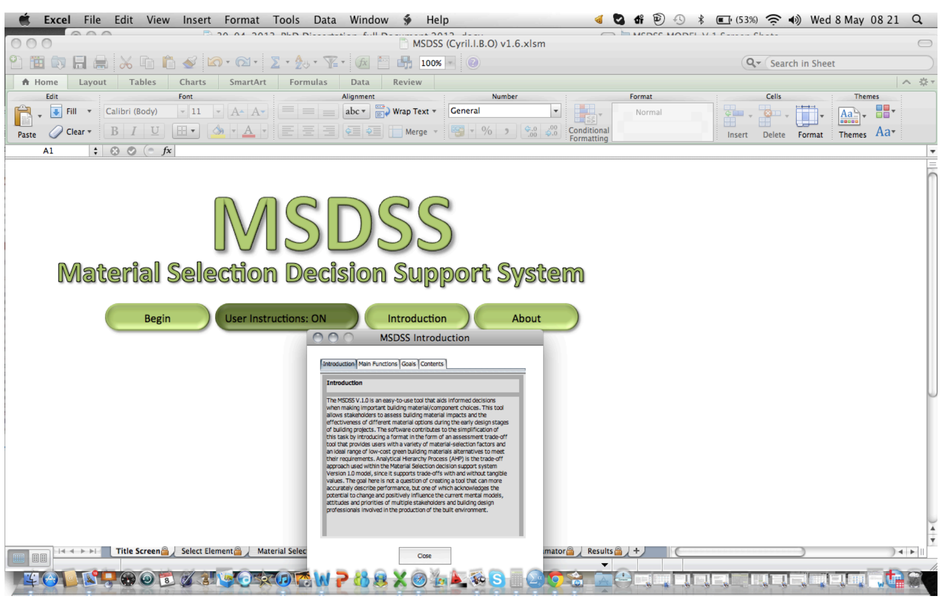


Figure 5.6. Shows sample of the introduction table

-The <INTRODUCTION> tab/button introduces the main functions and ultimate goals of the MSDSS model (**Figure 5.6**).

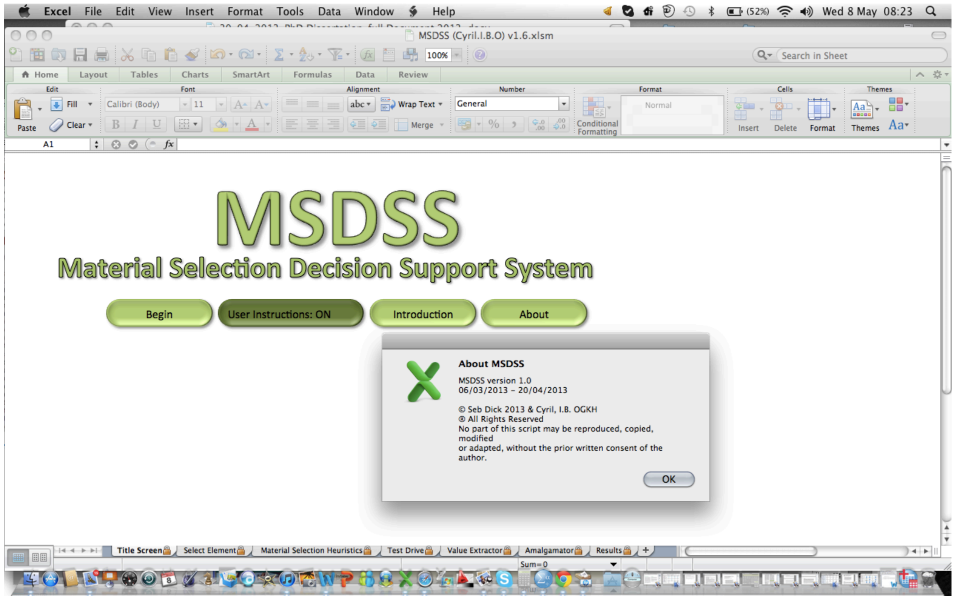


Figure 5.7. Sample of the copyright instructions

-The <ABOUT> tab/button provides the copyrights instructions about the model version (**Figure 5.7**).

-To proceed to the next window, the user clicks on the <USER INSTRUCTIONS ON/OFF> button to activate the instruction guide and then the <BEGIN> button to commence the task.

STEP 2

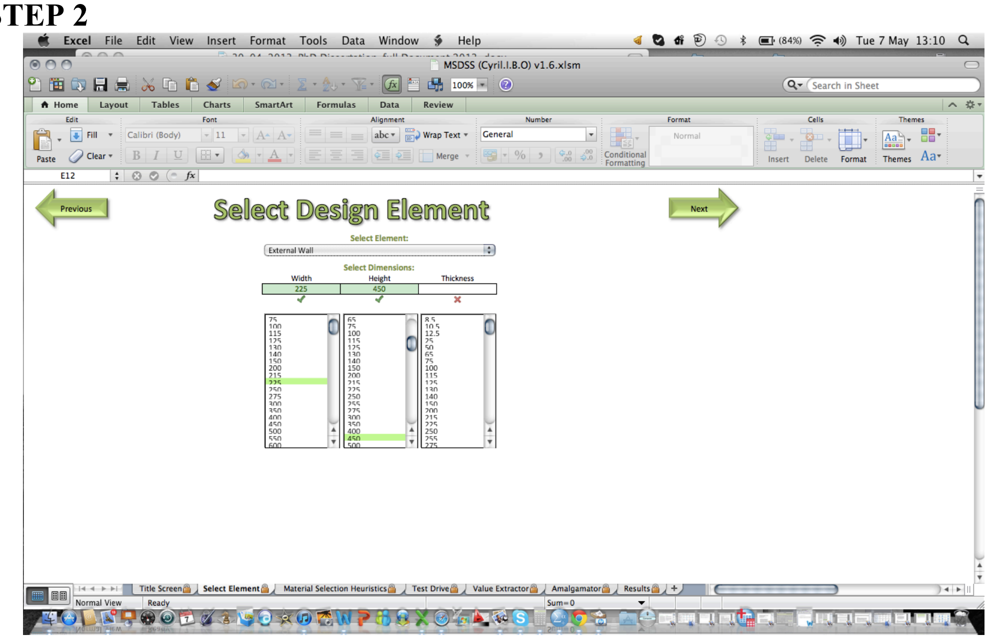


Figure 5.8. Sample of the design element user interface menu

-This phase displays the dimensional scales for the available DESIGN ELEMENTS (**Figure 5.8**).

-Here, the user is provided with a list of design elements and a range of dimensional values.

-User is prompted to select the particular design element required for the intended task (broken down by Construction Standard Institute Division); and assign dimensional values (**Figure 5.8**).

-User enters dimensional values using the dropdown list of the <SELECT DIMENSION> tab, to answer prompts about areas and dimensions of the elected design element

- After system validates the dimensional values for the elected design element, the user then proceeds to the next task by clicking on the <NEXT> button.

STEP 3

- This phase displays the <MATERIAL HEURISTICS>, which consists of a collection of set-rules used to define the minimum requirements or threshold of each material or component (**Figure 5.9**).

-User is prompted to assign threshold values under each category of the <MATERIAL HEURISTICS>.

-User assigns values to a range of thresholds associated with the material properties using the scroll down tab/button, prompting the system to generate and display the set of all eligible building material alternatives associated with the elected design element.

- After the set of feasible material alternatives has been generated, the user then proceeds to the next task by clicking on the <NEXT> button.

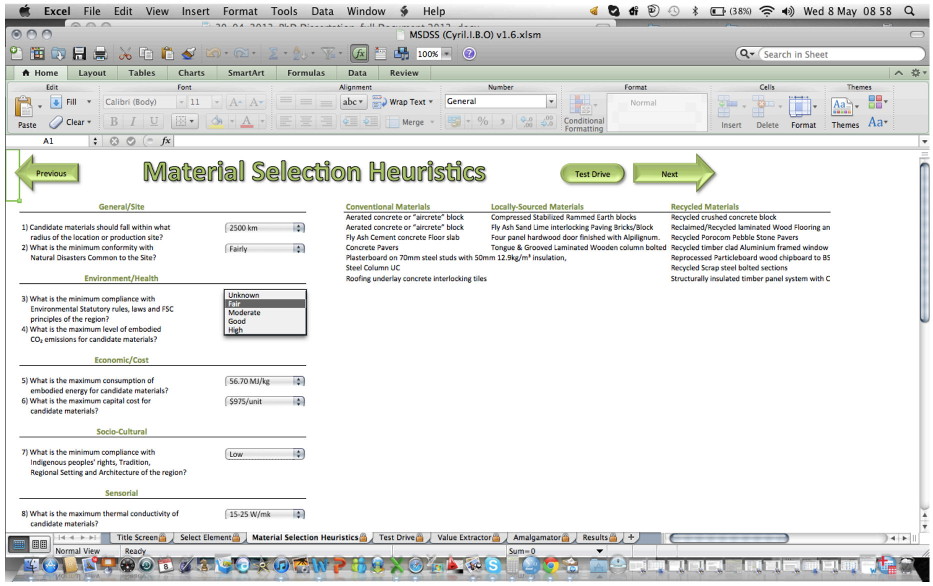


Figure 5.9. Menu for the knowledge base

STEP 4

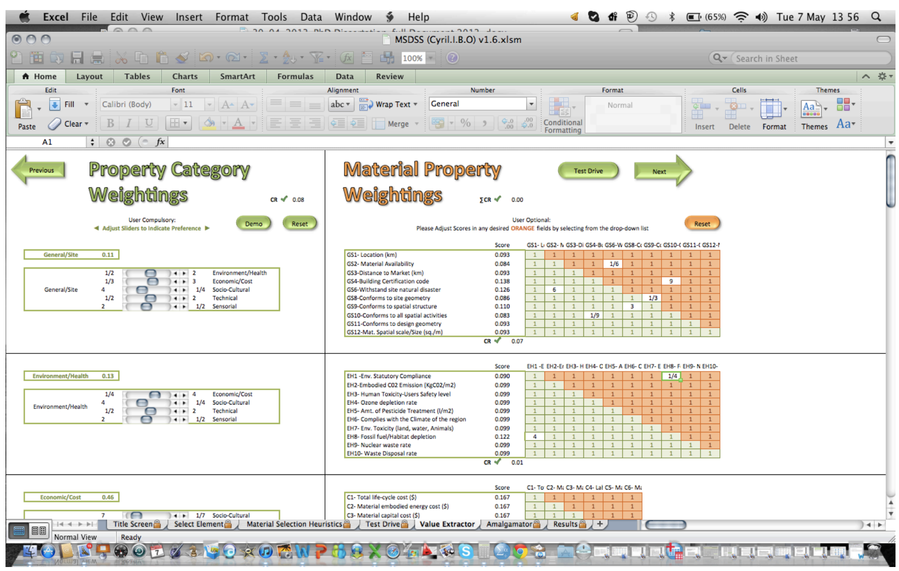


Figure 5.10. Sample of the value extractor user interface menu for the property category weightings

-This phase displays the <VALUE EXTRACTOR>, which consists of a set of property category weightings on the left column.

-This option enables the user to access the dynamic weighting values from 1-9 and calculate the relative importance of each main factor such that Consistency Ratio (CR) is less than 0.10 (**Figure 5.10**)

-The user is given the option of either using the <TEST DRIVE> to engage in a quick comparison between pairs of materials as to determine the relative worth of one against another, OR

-The user is prompted to assign weightings to the parent factors according to their subjective importance, as to determine their relative importance.

-In cases where the CR of each parent factor exceeds 0.10, the user is either prompted to readjust the weightings OR reassign the weightings using the <RESET> button to netralise all weightings.

STEP 5

- This phase displays the <MATERIAL HEURISTICS>, which consists of a collection of set-rules used to define the minimum requirements or threshold

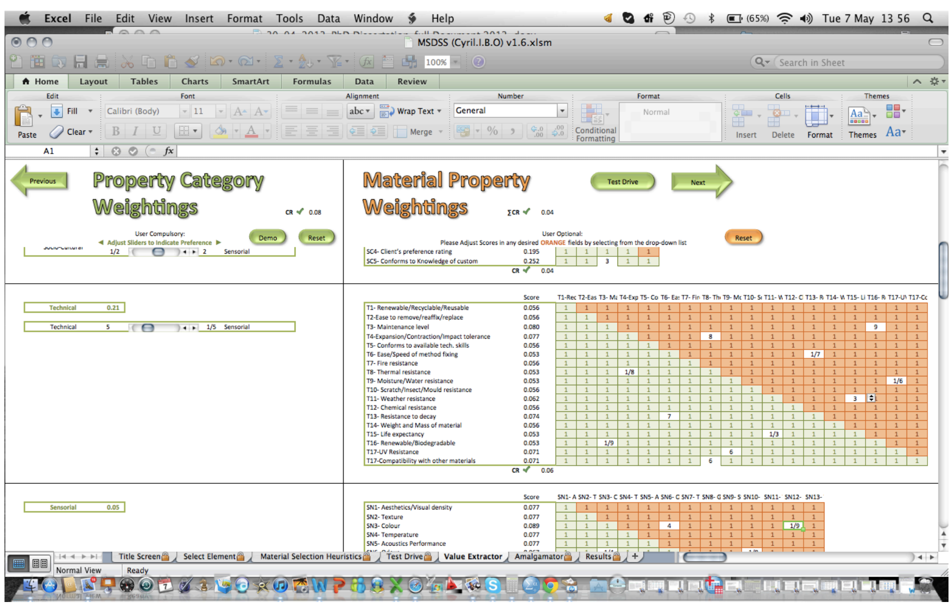


Figure 5.11. Value extractor user interface menu for the sub-material property weightings

-This phase also displays the <VALUE EXTRACTOR>, which consists of a set of material property weightings. This option enables the user to access the dynamic weighting values from 1-9 (**Figure 5.11**)

- User is prompted to assign factor weightings according to the relative importance that each sub-factor holds,

-User assigns weightings to a set of sub -factors, and a normalized value between zero and one is calculated for each category of the sub-factors in relation to the set material alternatives using the ORANGE fields on the right column. After pairwise comparison of each sub-categorical factors, the user then proceeds to the next task by clicking on the <NEXT> tab

STEP 6

-This phase displays the <AMALGAMATOR>, responsible for calculating the overall final/global weightings (**Figure 5.12**).

-System amalgamates (multiplies and sums) the normalised value of each factor and sub-factors with the normalised values for each potential material alternative,

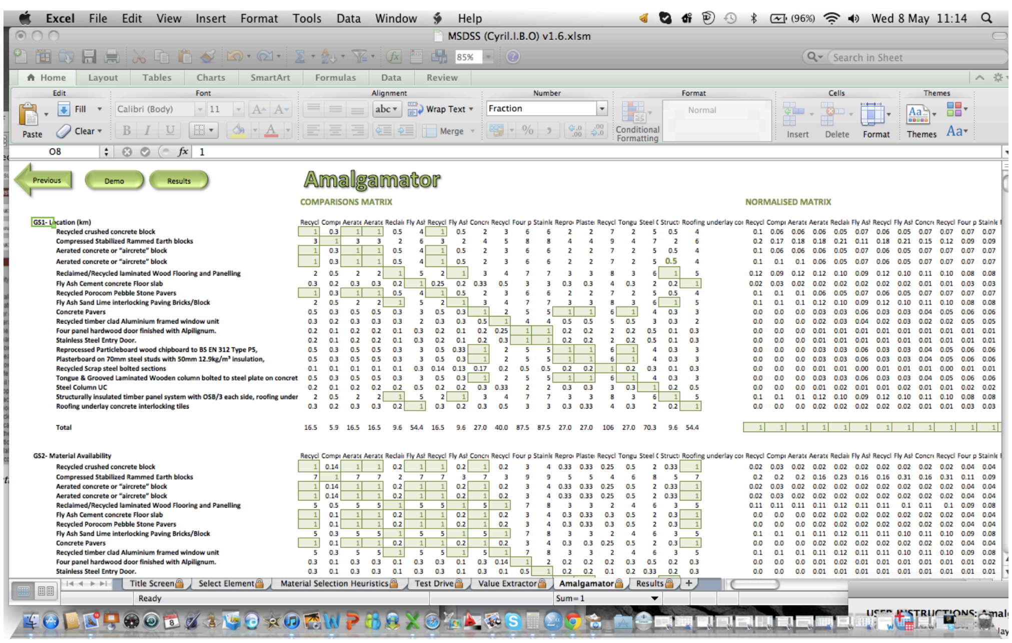


Figure 5.12. Amalgamator generating matrix results based on the calculations performed

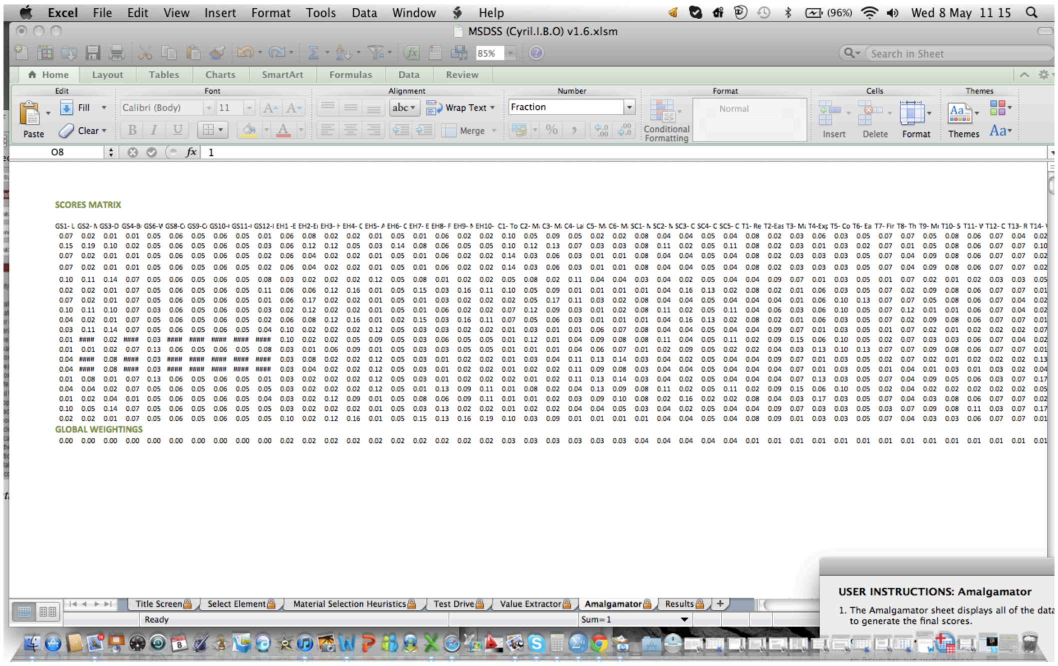


Figure 5.13. System showing trade-off values of each factor category against others 1

STEP 7

-The system logic TRADES-OFF the values of each criteria category against the others (see **Figure 5.13**).

-System performs the pair-wise comparison for the elected factors to create the scores of the COMPARISON MATRIX (see **Figure 5.14**)

-System NORMALISES the comparison matrix so that all values in the columns totals 1 (see **Figure 5.15**).

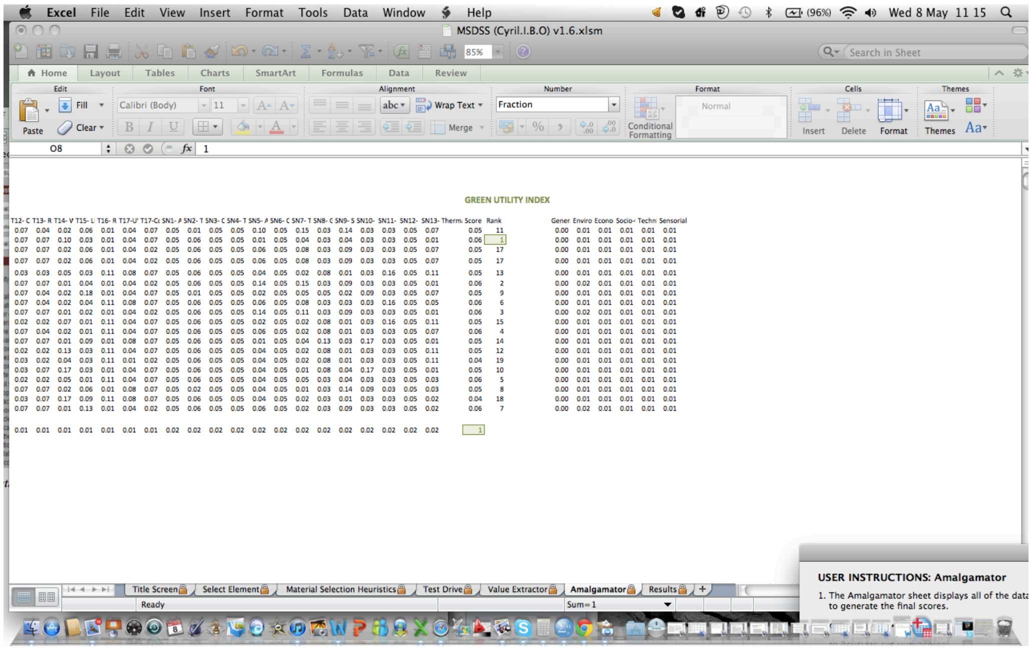


Figure 5.14. System showing scores of the comparison matrices

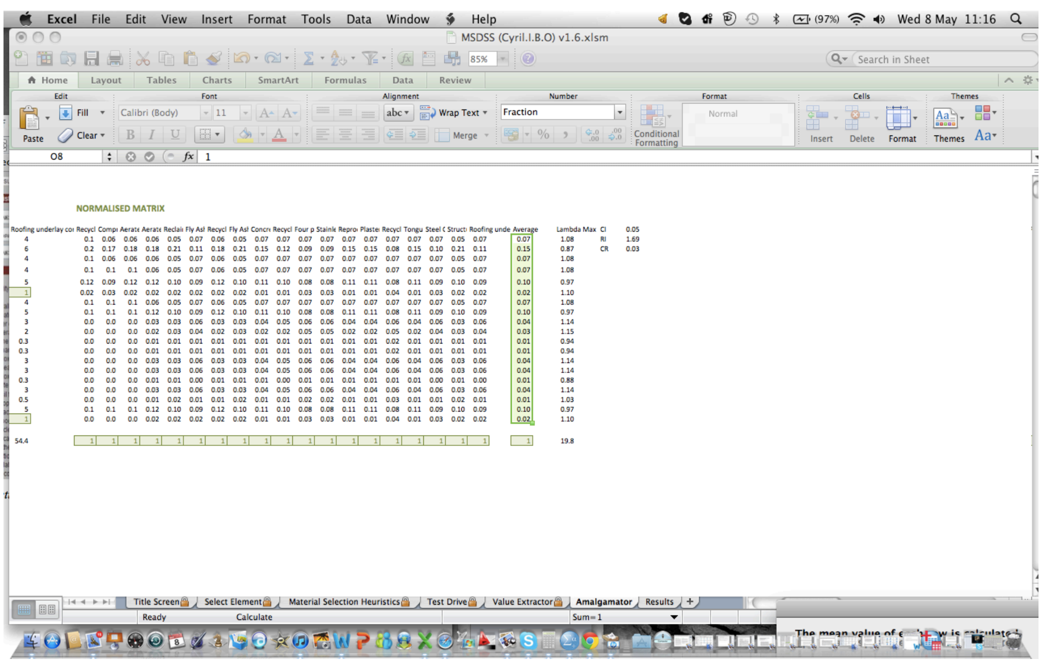


Figure 5.15. System displaying the normalised scores of the comparison matrices

STEP 8

-System performs PAIR-WISE COMPARISON for the selected materials as shown in **Figure 5.16**.

-The system generates the normalised scores of the pair-wise comparison for the selected materials (**Figure 5.17**).

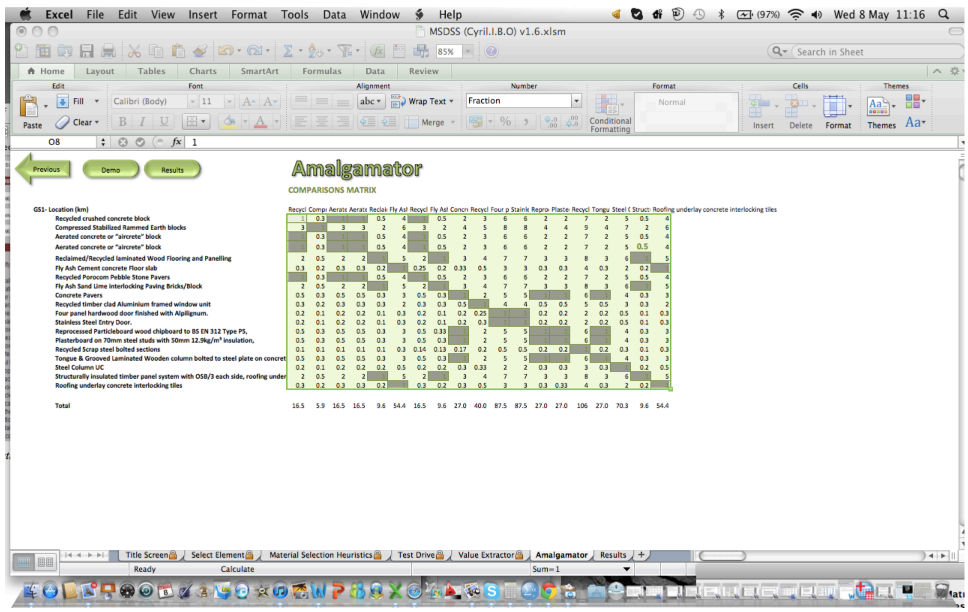


Figure 5.16. System displaying the pairwise comparison scores for the selected materials

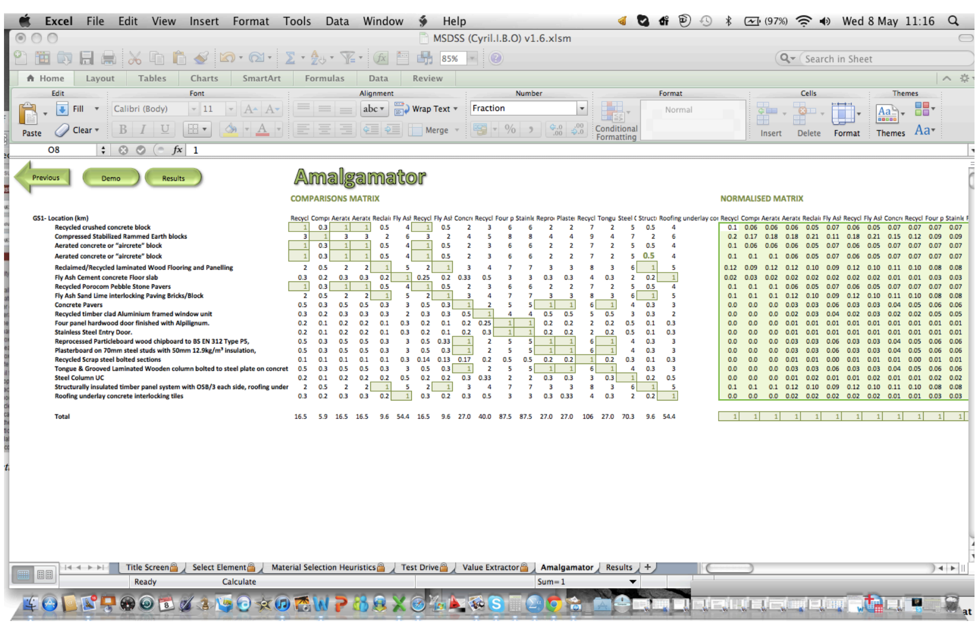


Figure 5.17. Normalised score of the comparison matrices for the selected materials

STEP 9

-System calculates the MEAN VALUE of each row (**Figure 5.18**)

-System carries over the column of AVERAGES to create the SCORES MATRIX (**Figure 5.18**).

-System displays the score data for each material alternative (**Fig. 5.19**).

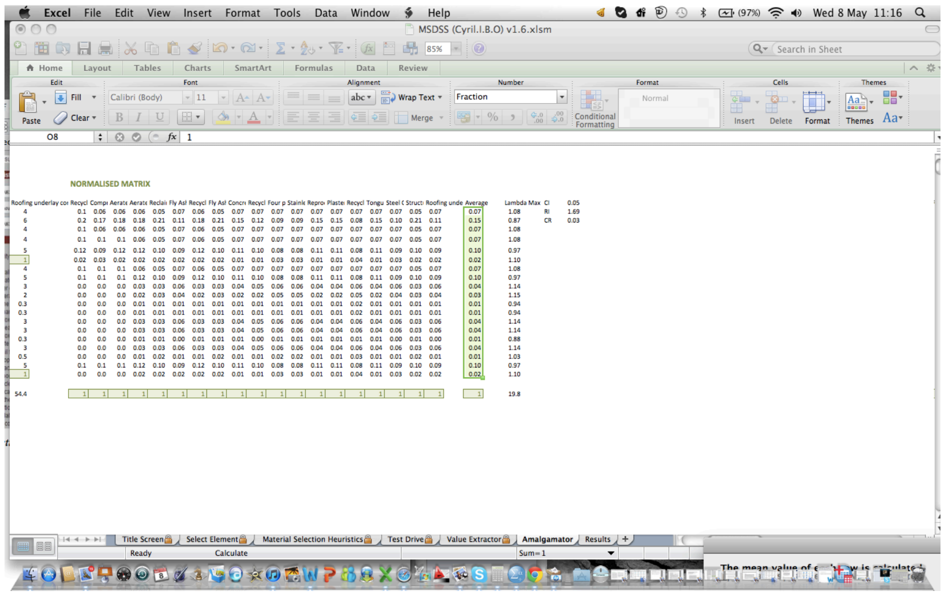


Figure 5.18. System displaying the calculated mean value of each row

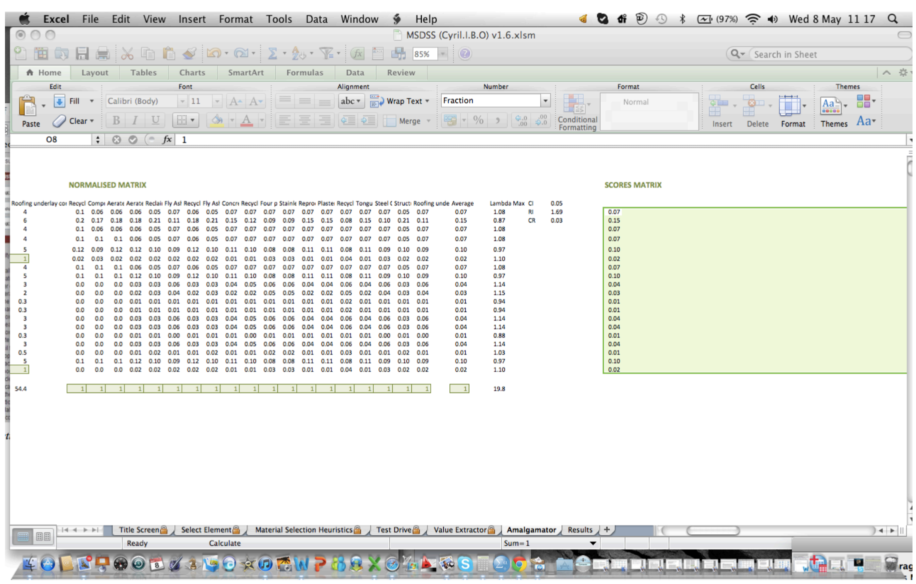


Figure 5.19. System displaying the calculated mean value of each row

STEP 10

-System generates The GLOBAL WEIGHTINGS and creates an index of SUBJECTIVE UTILITY for each material alternative

- After creating the subjective utility for each material alternative, the user then proceeds to the FINAL task by clicking on the <NEXT> button

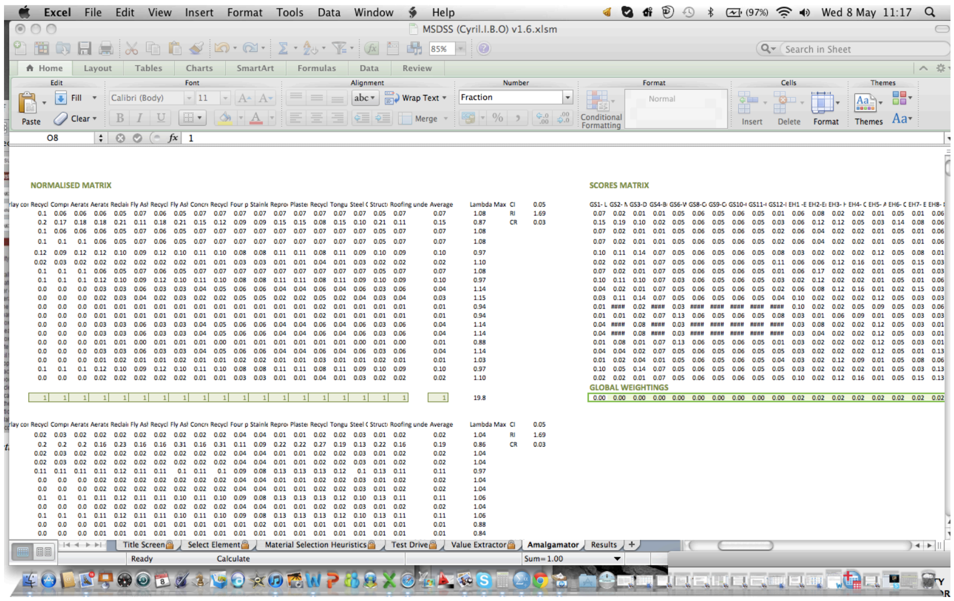


Figure 5.20. Calculated global weighting results from the products of the factors

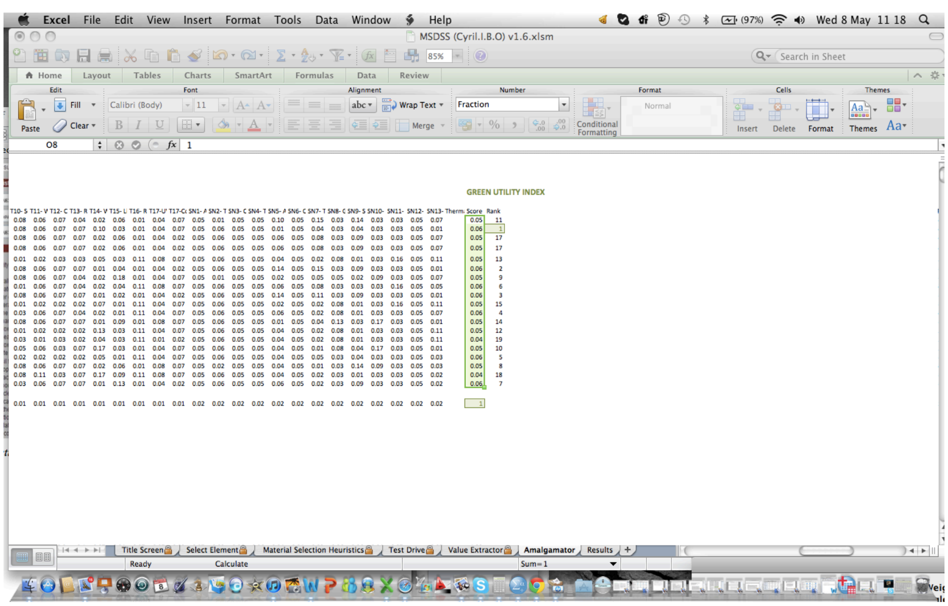


Figure 5.21. Calculated global weighting results from the products of the factors

FINAL STEP

-This phase displays the <RESULTS> of the overall tasks undertaken

-System displays a GRAPHICAL LAYOUT of the material alternatives with their relative utility values in a descending order of ranking (**Figure 5.22**).

-User either selects material with the highest UTILITY VALUE as recommended by the system, OR, User decides on an alternative product using his professional judgment (**Figure 5.23**)

-User is prompted to the click on the <SHOW FULL DATA FOR SELECTED MATERIALS> button to view the various properties of the selected building material/component (**Figure 5.24**)

-User may elect to either preview the electronic copy of the REPORT on the screen, print, or send it to a Word or Excel file for further analysis and formatting (**Figure 5.25**).

-Finally, user may proceed to printing, to retrieve a hardcopy of the report (**Figure 5.26**)

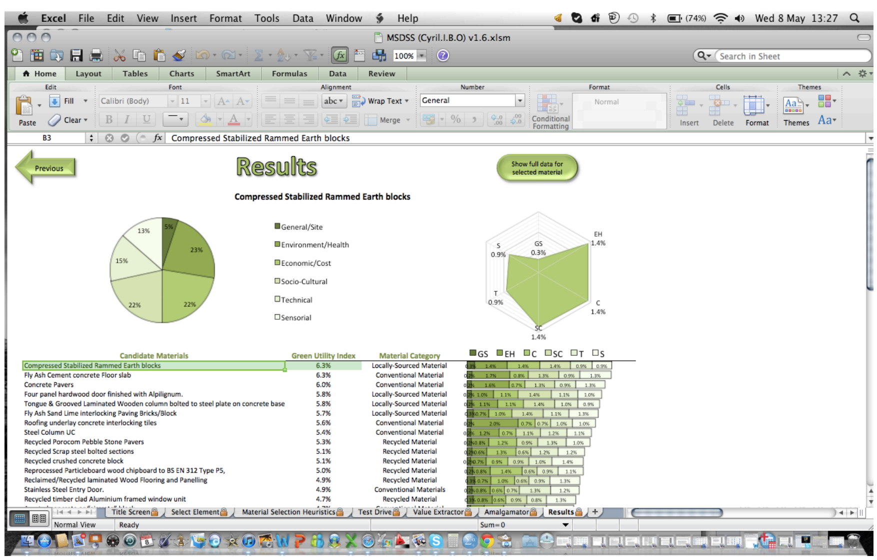


Figure 5.22. Sample menu from which the results are generated and how they are displayed

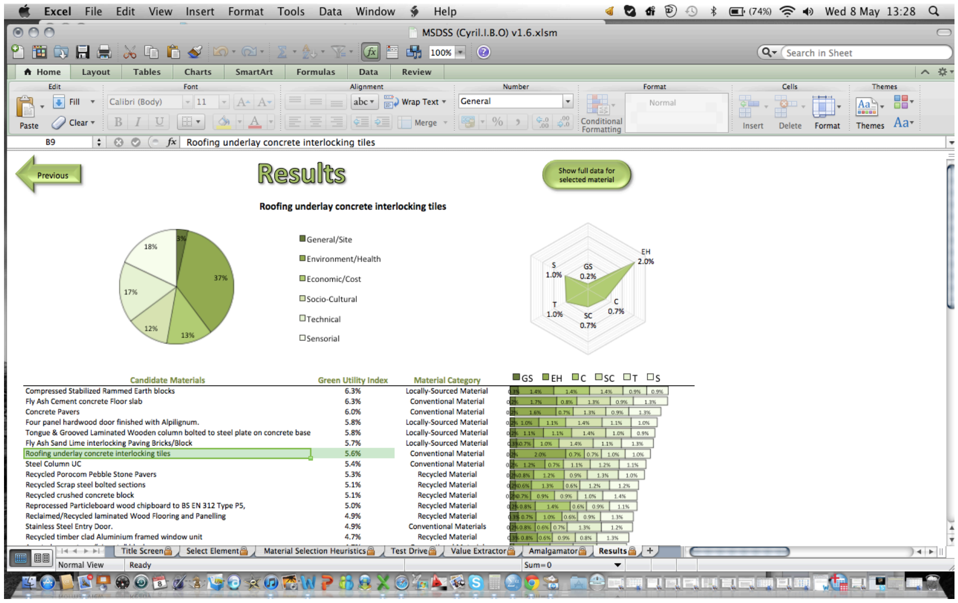


Figure 5.23. Sample of the MSDSS analytical system report of user's preferred choice

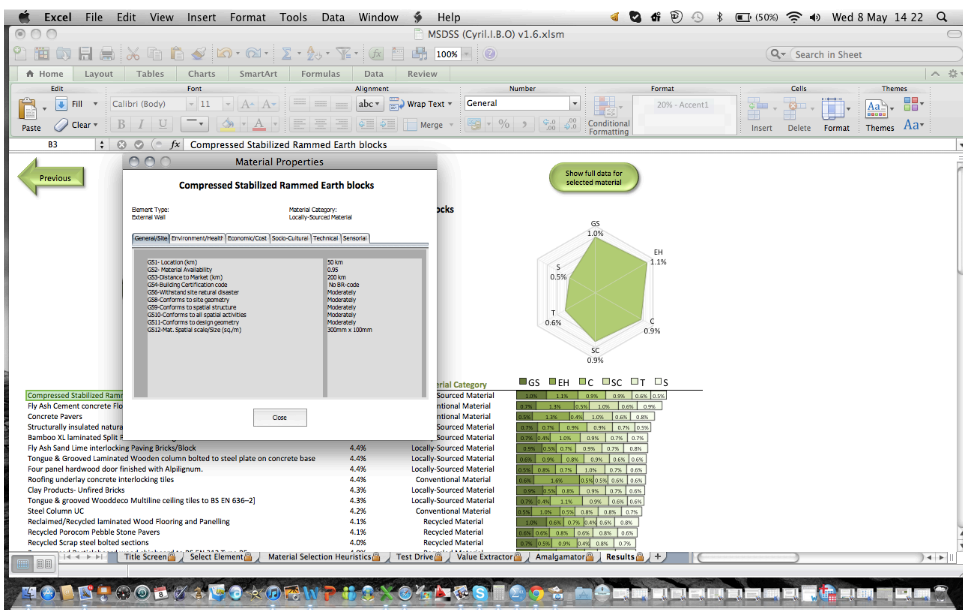


Figure 5.24. Generated reports of the material properties from the MSDSS reports menu

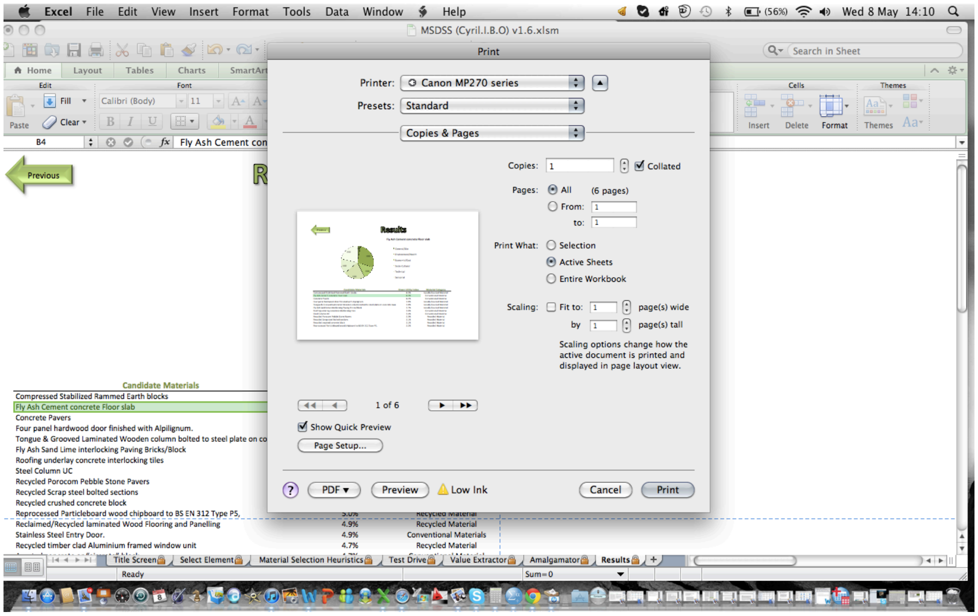


Figure 5.25. Generated printout details of the selected materials

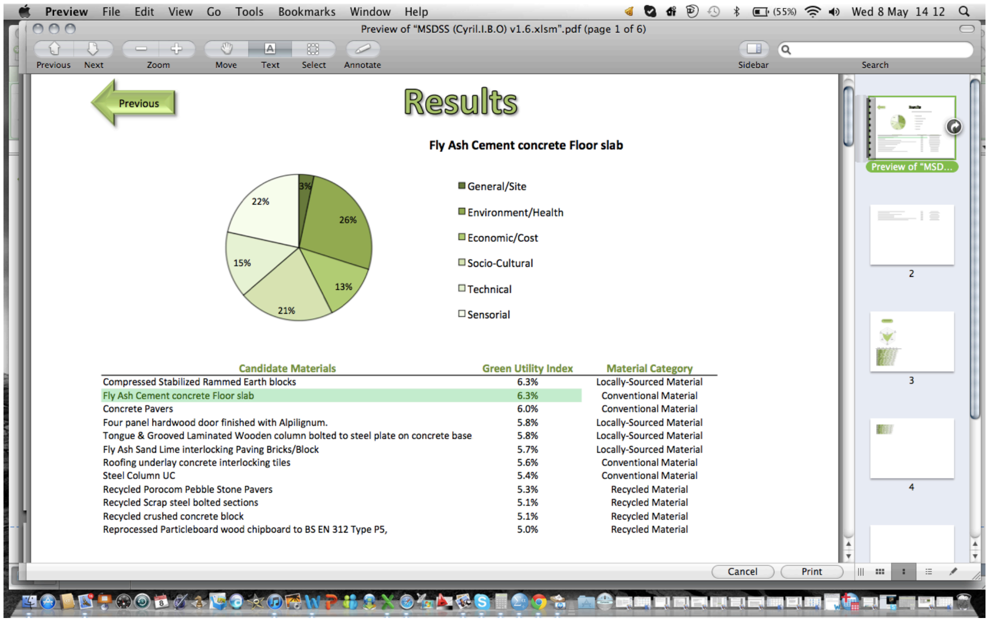


Figure 5.26. Sample printout preview in PDF format

5.8 System Testing: Physical Assessment of the MSDSS Model

This section describes the various testing methods adopted for this research. It focuses on testing the specific components and operations of the MSDSS model to identify potential errors, in order to fix notable faults detected in the cause of development. The following section describes the testing processes of the MSDSS model, the various types of testing procedures used in this study and the rationale for their choice.

5.8.1 Testing of the MSDSS Model

Copeland (2004) defined software-testing ss the process of analysing a software item to detect the differences between existing and required conditions (otherwise known as debugging) in order to evaluate the features of the software item. According to Bertolino (2001), software testing is an activity that should be done throughout the whole development process (IEEE, 1990: Bertolino, 2001).

To assess the quality of the prototype MSDSS model and determine whether the model satisfied the conditions proposed at the start of the development phase, an initial test run was conducted to check the internal mechanism of the links and source codes for any bugs or unidentified errors. The initial test run undoubtedly detected some errors and bugs (as shown in **Figures 5.27; 5.28;** and **5.29**), which were later corrected to improve the system usability. To further check the consistency of the result outputs of the model against easily calculated values of some random input variables, the black box method was also employed as ideal test method during and after the development processes of the model.

Section 5.8.2 presents the details of the black box methods of testing as applied to this research, and rationale for adopting the approach.

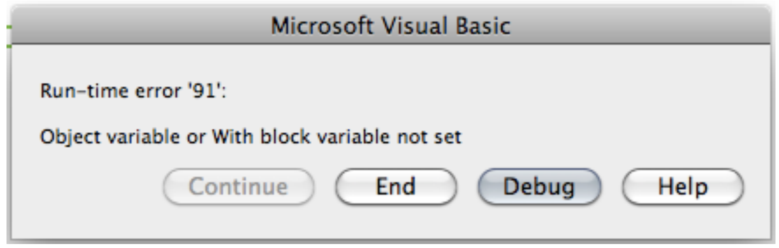


Figure 5.27. Debugging template

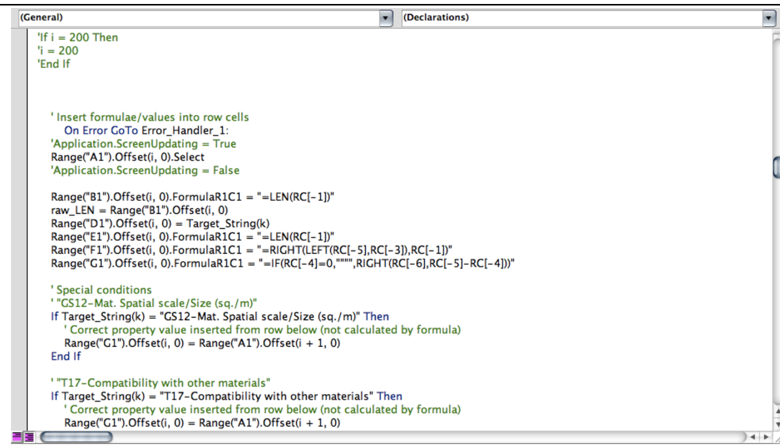


Figure 5.28. Test result of the debugging process

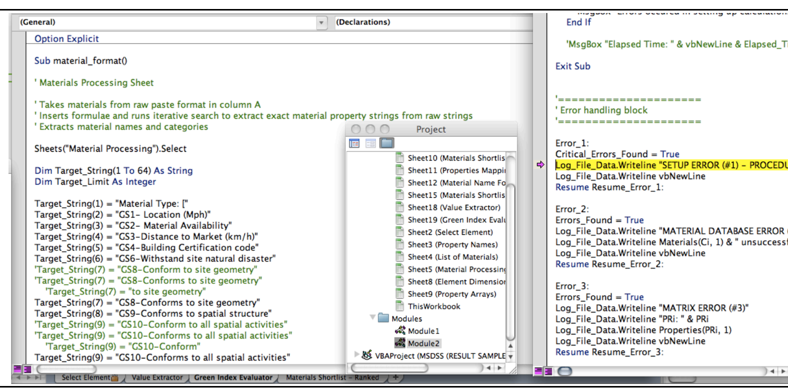


Figure 5.29. Template showing a list of detected errors after initial test runs of the internal links

5.8.2 Black Box Testing Approach and Rationale for Choice

Beizer (1995) defined black box testing as a testing system that ignores the internal mechanism of a system, but focuses solely on the outputs generated in response to selected inputs, variables and execution conditions. He argues that the users do not have access to the source code, since they are privy only to the input and output data. The following are reasons for which the black box test run method of assessment was adopted.

- Easier and less time consuming method of comparing and checking the consistency of the outputs of the developer with the random input variables of independent testers since it does not permit assessing the internal mechanisms of the model;

- Well suited to handle large code segments since the MSDSS contained several source codes;

- Less expensive method of testing compared to white box, given the limited resources of this research and that it does not necessarily require software experts to perform the tests;

- Easier to detect misinterpretation of requirements and unpredictable behaviour;

Given the nature of the model, two types of black box test run approaches: the functional and regression test-run methods were employed. An extensive study of the black box and white box method of analysis can be seen in Beizer (1995).

5.8.2.1 Functional and system testing

To ensure that the functionality of the MSDSS model specified in the requirement specification- at the start of the model development- complied with the envisaged standards, the functional/system testing method was applied due to its human-computer ability to interpret and display results through the Graphical User Interface (GUI).

Stage of Application: The test was conducted during the various phases of the development process using a test case planning document (see sample in **Table 5.4**). This was extended through further cycles of evaluation and refinement, where the prototype model was tested with various versions and types of operating systems and/or applications.

Assessors: This test was undertaken by a handful of independent testers in the UK and USA, all of whom had no knowledge of the internal structure and workings of the programs.

Table 5.4. Test case planning template

Test Case #:	**Test Case Name:**	**Page:** 1 of ..
System:	**Subsystem:**	
Designed by:	**Design Date:**	
Executed by:	**Execution Date:**	
Short Description:		

Pre-conditions

Step	**Action**	**Expected System Response**	**Pass/ Fail**	**Comment**
1				
2				

Post-conditions

Requirements and Tasks: To avoid bias and validate the result outputs, test runs were undertaken by five (5) neutral testers from the UK and USA- (particularly those who had participated in the preliminary study and were verse in the AHP concept), using the test case-planning template shown in **Table 5.4**. This enabled the study to easily compare the results of the independent testers with the test results of the programmer/developer to correct any noticeable error before they were sent to design and building practitioners in Nigeria. The template provided the necessary instructional guide on use, in terms of the time required, speed, and extent to which a user can learn to operate, prepare inputs for, and interpret outputs of the MSDSS model. The model was assessed based on the following requirements:

- Incorrect or missing functionality;
- Interface errors;
- Errors in data structures used by interfaces;
- Behaviour or performance errors; and
- Initialization and termination errors.

Findings: The outcome of the results of independent testers showed seemingly similar outputs but slight differences regarding incorrect functionality from the results of the programmer, which proved that the components of the model were in a fairly stable condition, given that the model did not exhibit most of the underlying errors listed above (see **Table 5.5**). Following the identification of some minor errors, changes were made, which culminated in an operationally stable system, to meet the requirements for low-cost green building material information analysis.

Table 5.5. Test case template showing the result analysis of the model after a test-run by an independent assessor

Test Case #: 2.0	**Test Case Name:** Material Selection
System: MSDSS MODEL	**Subsystem:** Select Ideal Materials
Designed by: Researcher	**Design Date: 15/03/2013**
Executed by: Anonymous Independent Assessor	**Execution Date: 28/05/2013**
Short Description: Test the Selection Methodology and Performance of the MSDSS Model	**Page: 1 of 2**

Pre-conditions
The user has a system installed with Windows XP, Windows 7, Vista, or Macintosh; Intel Celeron processor or higher specification; 2 GB of RAM; approximately a minimum of 80 GB of hard disk space, a minimum of 13.3" monitor
The user has a valid and current version of Macro-in-Excel VBA or Microsoft Excel 2010 or higher version installed on his system
The user has accessed the MSDSS model by clicking on the "Enable Macros" button to activate macros
The system displays the main menu

Step	**Action/Instruction**	**Expected System Response**	**Actual System Response as Identified by the assessor**	**Pass/ Fail**	**Independent Assessor's Comment**
1	Click the 'USER INSTRUCTION' button	The system responds to the command by highlighting the button	The system did respond to the command by highlighting the button	P	The system responded to the command in time
2	Click the 'BEGIN' button	The system displays a message of successful operation requesting that the user: 1] Selects a category of the design element, 2] Enters dimension values	The system displayed a message of successful operation and requested that I: 1] Select a category of the design element, 2] Enter dimension values	P	Successful operation
3	Click 'OK' button	The system asks the user to select the desired attribute threshold from each drop-down list	The system instructed that I select my desired attribute threshold from each drop-down list	P	Successful operation
4	**Check post-condition 1**	The system displays a message of successful operation	√	√	OK
5A	Click 'PROPERTY' button Click 'OK' button for Demo Operation Click 'CANCEL' button to Exit Demo Operation	The system asks the user to perform a demo operation.	The system asked if I wanted to perform a demo operation. I clicked the 'OK' button and a demo was performed showing the value elicitation steps.	P	OK
5B	Select 'VALUES 1-9' from the dropdown list button	After the demo operation, the system displays a message asking the user to enter values for each parent factor on a scale of 1-9	At the end of the demo, the system displayed a message asking that I enter values at my discretion for each parent factor on a scale of 1-9	P	OK
6	Click 'OK' button	The system displays a message of **successful** operation if the Consistency	The system displayed a message of **unsuccessful** operation and then	F	Failed operation Error

		Ratio (CR) < 0.10	instructed that I re-confirm the Consistency Ratio (CR)		identified CR > 0.10
7	Repeat steps 5A, 5B and 6 by adjusting weighting values and Click 'OK' button to continue	The system displays a message of **successful** operation	The system displayed a message of **successful** operation after readjusting the values.	P	Consistency achieved CR< 0.10
8	Click 'MATERIALPROPERTY' button	The system asks the user to enter values for a specified set of sub-factors on a scale of 1-9	The system instructed that I enter values for a specified set of sub-factors on a scale of 1-9	P	Successful operation
9	Click 'OK' button to continue.	The system displays a message of **successful** operation if Consistency Ratio (CR) < 0.10	The system displayed a message of **unsuccessful** operation and instructed that I re-confirm the Consistency Ratio (CR)	F	Failed operation Error identified CR > 0.10
10	Repeat steps 8, and 9 by adjusting weighting values and Click 'OK' button	The system displayed a message of **successful** operation	The system displayed a message of **successful** operation after readjusting the weighting scale	P	Consistency achieved CR<0.10
11	**Check post-condition 2**	The system displayed a message of successful operation	√	√	OK
12	Click 'NEXT' button	The system performs an 'AMALGAMATION' of the values entered in steps 5A, 5B, 6, 7, 8, and 9, and finally displayed the results	The system displayed a message of **unsuccessful** operation and instructed that I re-confirm the Consistency Ratio (CR) and total score of Utility Green Index (UGI)	F	Error identified Sum of values > 1.0000
13	Repeat steps 5A, 5B, 6, 7, 8, 9, 10 11, and 12 by re-adjusting weighting values and Click 'OK' button	The system displays a message of **successful** operation	The system displayed a message of **successful** operation	P	Sum of GUI value = 1.0000
14	Click 'NEXT' button	The system displays a range of shortlisted materials in a ranking order	The system displayed a range of shortlisted materials in a ranking order. I saved the results in the database and exited after a successful printout.	P	Successful operation
15	**Check post-condition 3**	The system displayed a message of successful operation	√	√	OK

Post-conditions	
1	The system displayed a list of selected low-cost green building materials based on user's preference for the intended task
2	The system confirmed the Consistency Ratio (CR) of all assigned values
3	The system displayed the a range of shortlisted materials in a ranked order

Benefits of Functional Testing: Below are the rationales for adopting and running functional tests.

- The black box functional test run approach allowed a mock test of the MSDSS model to be undertaken even before the actual databases were fully designed and created. This helped improve the operational quality of the model before building experts in Nigeria carried out further testing.
- It is less expensive compared to the white box test run approach;
- It also enabled the assessment of the non-functional properties of the MSDSS model such as the appearance and format of the result output

A regression test-run was further conducted to verify whether or not the functionality of the MSDSS model complied with its original specified requirements after several modifications.

5.8.2.2 Regression testing

Knowing that the MSDSS model had undergone several changes during the development stages, regression tests were carried out to check the overall functions of the various components. The Institute of Electrical and Electronics Engineers (IEEE, 1990) defines regression testing as selective re-testing of a system or component to verify that modifications have not caused unintended effects and that the system or component still complies with its specified requirements (IEEE, 1990).

Stage of Application: The regression test was run throughout the testing cycles, as this ensured the consistency of the system's functionality. To demonstrate stability of the system, a re-run test of the various features of the entire system was undertaken whenever changes were made, which ensured that every component of the MSDSS model was in stable condition and that all major functionalities were present and worked under "normal" conditions.

Assessors: This test was undertaken by the developer/researcher.

Requirements and Tasks: The following tasks were undertaken during the regression test-run of the system:

i. Evaluated the Open Database Link between MS Excel and VBA database.
ii. Accessed Query attributes extraction in relation to Macro-in-Excel VBA central database.
iii. Corrected processing within the central database in terms of schemas and logic relationships.
iv. Corrected numerical calculations where necessary.
v. Performed Database Queries – Macro-in-Excel and VBA.
vi. Assessed final Reports of Proposed Analytical Procedures.
vii. Assessed the Overall system integration
viii. Checked the stability and consistency level of the User Interface configurations and reports,

Findings: The cumulative results of this evaluation process showed that the MSDSS model was in a stable condition following consistent test-runs. Appendix K discusses in details the application procedure used for assessing the prototype MSDSS model. It demonstrates the applicability of the proposed system to material selection problems- in accordance with the impact of any assumption, simplification and method used during the assessment exercise. The second phase of the evaluation process was however, undertaken at the later stage of development. It involved eliciting feedbacks from respondents (both academics and housing industry practitioners) that previously participated in the study given their familiarity with the system development process.

5.9 Summary

The findings in chapters 2, 3 and 4 emphasised the inefficiency of conventional single-dimension evaluation models. It implied that the assessment of building products using evaluation monetary techniques are inadequate for addressing wider sustainability issues associated with the use of LCGBMCs. This reinforced the significance of a model capable of taking into consideration a multi-attribute approach. Based on the observed need, a Multi-Criteria Material Selection Decision Support System (MSDSS) was developed and discussed in this chapter, to fulfill objective five of this study.

This chapter has described the process undertaken to develop a prototype model that helps designers predict which decisions most critically determine the selection of LCGBMCs. Variables within the model were further discussed within six dimensions which are: site suitability, environmental/health impacts, cost effectiveness, socio-cultural benefits, technical performance and sensorial impact. Illustrations of the MSDSS physical data modelling processes and working procedures were also demonstrated. The MSDSS was built using data from several sources of the case-based documents analysis, and additional information from number of experienced building professionals in Nigeria, and builder/developer companies in the UK. A further test was undertaken to ensure the usefulness and reliability of the model. The test exercise started off with a trial run of the internal links and was followed by an independent verification approach consisting of third party users. The iterative feedbacks culled from independent assessors were used to compare and check the accuracy of the simulation results, which informed subsequent readjustments (see **Appendix K** for full analysis of expert evaluation exercise).

The next chapter discusses the procedures adopted for validating the prototype MSDSS model using an on-going case study project.

Chapter VI

A case study reference for validating a prototype of the MSDSS model

CHAPTER 6: VALIDATION OF THE MSDSS MODEL

6.1 Introduction

The key research objective posed in chapter 1 includes developing a Multi-Criteria Decision Support System for aggregating the weighted factors needed for the assessment of LCGBMCs. This was covered in detail in chapter 5. Therefore, the aims of this chapter are to demonstrate this in practical application to material selection problem, establish the computational correctness of the software, and evaluate the reliability of the decisions made by the system when formulating decisions regarding the selection of low-cost green building materials and components at the crucial stages of the design.

This chapter first begins in section 6.2 by briefly surveying techniques developed in building construction and engineering to identify the most suitable technique(s) that can be utilised to validate the model. It then provides the characteristics of the participants in section 6.3; subsequently, discusses the background to the selected case study and then describes the input data collection procedures for the sustainability model in section 6.4. In view of the complex nature of the research, a case study is further presented in order to show how designers can understand which building component decisions consistently contribute the largest to a building's impact. Case study was chosen as the best means to validate the model and show how incorporating the sustainability principle indices (i.e. weighted decision factors) works to rank building materials. The result analysis and findings of the validation exercise are discussed in section 6.5, and conclusions presented in section 6.6. This chapter fulfills Objective 6 of the research.

6.2 Techniques Adopted for Validating the MSDSS Model

Various validation techniques have been devised to optimise advanced system models in relation to different classes of materials, as well as material tailoring for specific designs (Macal, 2005), each of which has been used either subjectively or objectively, the latter referring to the use of some type of statistical or mathematical procedures. Gass (1983) and Qureshi et al. (1999) cite extensive research literature and practical evidence on various types of validation techniques. Although a number of different approaches to validating Decision Support Systems (DSS) have been reported (Macal, 2005), Winter and Johnson (2000) argue that "validation" is not a single, fixed or universal concept, but rather a contingent construct, inevitably grounded in the process and intentions of particular research projects and methodologies. Therefore, analysis and reflection of the various techniques in Gass (1983), Qureshi et al. (1999) and Winter and Johnson (2000), and the contextual component that is being analysed in this research—in terms of assessing the credibility of the MSDSS model based on a list of proposed variables, suggested "expert" and "criteria" validity as the most appropriate techniques for this study.

6.2.1 Research Design Approach Adopted for the Exercise

Suitable clusters of research approaches such as focus group discussions, and knowledge-mining interviews with domain experts were considered as the main data-gathering instruments for this exercise. The validation exercise was done using potential end-users perceptions, since the study needed participants to record accurately, live observations about the model whilst comparing their results to monitored data from the case study project.

6.3 Demographic Analysis of the Sample Population

Since the assignment of weights in this research required logical and analytical thinking, and knowing that a larger sample may subsequently affect the viability of the data (Reza et al., 2010; Wong and Li, 2008), only a small sample of the relevant building professionals (at the stakeholders' meeting) were highly valuable to this empirical inquiry, and deemed capable of providing deeper insights.

To validate the model decision-making capabilities, 25 willing stakeholders with design and construction background, and well versed in the technical aspects of their respective domains were invited. Ten (10) out of the Twenty-five (25) stakeholders were randomly selected and assembled into different focus groups for role-play— most of whom hold senior positions in the building construction firms with relevant experience in material assessment and selection. To avoid incurring unnecessary costs, and eliminate any likely sources of bias, the study assumed the convenient and random sampling techniques for the group selection of the target population, hence, giving each member of the various housing units a fair chance of being included in the exercise.

Although most of the participants were those who had participated in the initial surveys, and had full knowledge of the study, the contents of each activity were clearly explained to the group members. Each of their profiles is assigned as follows in **Table 6.1**.

Table 6.1. Profile of Participants for the validation exercise

S/ NO	Position /Designation	Type of Organisation	Area of Expertise	Years of experience	No. of housing projects undertaken
1.	Material Specifier and Program Designer	Building and construction firm	Material analyst and Programmer	15	> 10
2	Researcher and Senior Building Construction Consultant	Research and urban development firm	Research and Development	27	> 20
3	Building Engineer	Housing construction firm	General practice	7	>10
4	Material Specifier	Architectural and construction firm	Material analyst	23	>25
5	Project Architect and engineer	Housing development and urban design firm	General practice	30	>12
6	Senior Architect and Chief designer	Architectural and sustainable design firm	Full architectural service	26	> 45
7	Senior Quantity Surveyor	Quantity surveying outfit	Material advice	35	>30
8	Architect and Builder	Lands and Housing Firm	General practice	17	>13
9	Building Sustainability Consultant	Building Research and development firm	General practice consultant	25	> 40
10	Material Software Developer	Material Specification firm	Research, ICT and development	15	25

6.3.1 Instrumentation and Data Collection Procedures

Primary data was used as the main source of the research instrument for this exercise. The main sources of primary data were the data elicited from the focus group discussants and monitored data from the proposed on-going case study project. Documents that explained the overall aim and objectives of the study were first issued out to the participants. In order to generate sufficient and valid information from the participants, a PowerPoint demo was used to illustrate a practical exercise of the AHP method of analysis using the MSDSS prototype model. This process enabled the participants to get a general overview of the model before the main exercise. At the end of the session, participants where clarified on areas that proved to be difficult during the exercise, to avoid arbitrary results in the main exercise. The analyses and results of the actual exercise are discussed in the following sections

6.4 Analyses and Results of the Validation Output

The following tasks were undertaken to validate the MSDSS model:

- Selection of the case study project
- Site visitation,
- Collection of relevant data for the validation exercise
- Material identification,
- Factors/criteria selection,
- Assignment of weights to factors/variables/criteria
- Comparative analysis of selected materials/components

6.4.1 Selection of the Case Study Project

The first stage of the validation exercise was to select an appropriate case study. The case study was an on-going 3-bedroom residential housing project situated in the sub-urban area of Rivers State in Nigeria (see **Figure 6.1**)

6.4.2 Site Visitation

The next phase was to visit the site to identify what materials were selected and what means were used to determine the choice of materials for each design element. The observations were carried out right from the onset of the design up to the construction stage.

6.4.3 Collection of Relevant Data

After site visitation, relevant pieces of information needed to support the exercise were obtained. The information consisted of the full set of working drawings, bill of quantities, specifications (material finish scheduling information) and portraits of the project in stages of development (refer to Appendix L). The exercise was conducted on an on-going 3-bedroom housing project managed by Kanex Engineering. This case study was chosen since it was at the time of the study, still at the earliest stage of possibly incorporating sustainability principles. AutoCAD and ArchiCAD were selected to support visualisation. Table 6.2 gives a full profile of the case study project.

Table 6.2. Case study profile

Project Name	A 3-Bedroom Private Residential Housing Project
Applied Material Technology	Graded Sand Mix with Cement, Aluminium and steel
Project General Information	
Region	Southern Nigeria
Location	Port Harcourt Province in Rivers State, Nigeria
Project Budget/Cost	$28,565 [N4997445.95]
Finance Provider	Privately Financed
Number of Units	1
Consultant/Project Designer	AK & Associates
Contractor	Kanex Engineering and Housing Construction Company
Project Description	
The project is a privately owned 3-bedroom residential housing unit, located within Port Harcourt metropolis in the Southern part of Rivers State in Nigeria. The housing unit is composed of the mini sitting lounge, a main family sitting/living lounge, three bedrooms all en suite, an open-air carport, a back garden, an open porch, a security post and a generator house with a total built area of 215.325m2.	
Project Technical information	
Project Type	Private Housing Project
Unit Area (m2)	215.325 m2
Actual Start Date of Project	July 2014
Scheduled Date of Completion	Scheduled to be fully completed in March 2015
Technology Specific Information	
Type and Description of Materials and Technology Introduced	The materials used for external walls and fences was a mix of fine or sharp sand which is available in most parts of the country in addition to other imported additive materials like cement, steel, and aluminium. The project benefited from the availability of suitable sand mix adjacent to the site where a seasonal stream passes by. The simple 600mm wide strip foundation was selected as the ideal alternative for the foundation due to the plain topography, although additional reinforcement bars were laid horizontally at 1-metre intervals in areas that required certain amount of permissible load such as the open-air carport. The 20mm plaster cement block dimensions were (W=150mm x H=225mm x L=450mm) and the weight of each block was 10kg. The mix ratio for the concrete floor slab was 1:3: 6 consisting of 1 part cement, 3 parts fine aggregate, and 6 parts coarse aggregate. 12mm Steel bars were used as lintels for doors and windows openings.
Source of Materials (Local or Imported)	Local (sand, stones, fine and coarse aggregates) + Imported (cement, steel, aluminium, corrugated iron sheets, door & window units, machineries and equipment)
Building Technology Enabler	Individual Architect-Private Company (AK & Associates Consults)
Technology Enabler Sector	Kanex Engineering and Housing Construction Company
Knowledge and Technology Transfer	The workers had knowledge of the project through years of practice.
Total Number of Workers	15 workers, excluding the project architect, contractor and foreman

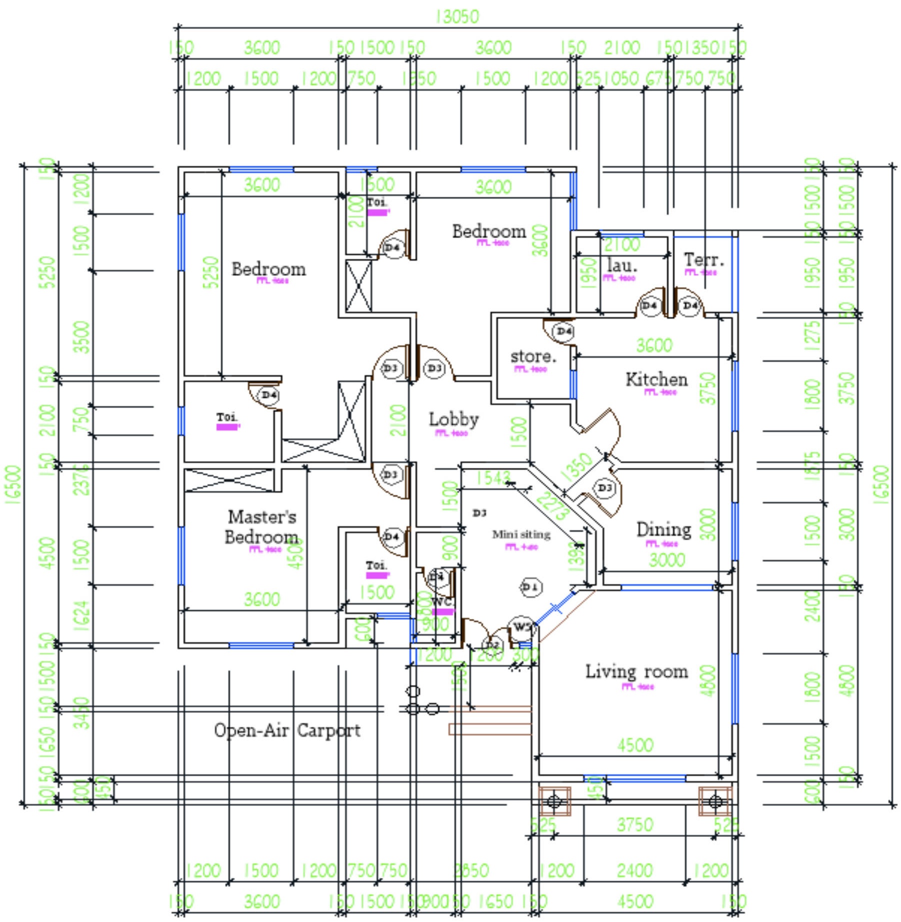


Figure 6.1. Design layout of the proposed case study project

6.4.4 Material Identification

At this stage, the groups of stakeholders were instructed to select material(s) for each design element according to the relative importance for which the material(s) held. Three sets of materials were selected for every design element from the material's data table of the MSDSS guide specification manual, which consisted of flooring, external wall, window, ceiling and roofing as shown in **Table 6.3**. It should be noted that every material enlisted by Group 'C' was the exact prototype that was used for the proposed case study. Final selection choice of each stakeholder's group was based on compromise between advantages and disadvantages of candidate materials.

Table 6.3. Participants' preferred choice of materials/components

Design Element(s)	Group A (1, 2, 4, 10)	Group B (6, 7, 9)	Group C (3 5, 8)	Stakeholder's Generated Materials
Flooring	50mm x 600mm, Reclaimed/Recycled laminated Wood Flooring and Paneling	230mm x 150mm, Bamboo XL laminated Split Paneled Flooring	900mm x 900mm Fly Ash Cement concrete Floor slab	
Wall (External)	150mm x 225mm, Recycled Crushed Concrete Block	75mm x 125mm, Compressed Stabilised Rammed-Earth Block	225mm x 225mm Aircrete Hollow Block	
Door/Window	900mm x 2100mm, Recycled Timber-Clad Aluminium Framed Door/Window Unit	900mm x 2400mm, Stainless Steel Door	900mm x 2100mm, Four-Panel Harwood Door Finished with Alpilignum	
Ceiling	900mm x 900mm, Reprocessed Particle Wood Chipboard	1200mm x 1200mm, Tongue & Grooved Wooddeco Multiline Ceiling Tiles	600mm x 600mm, Plaster Board on 70mm Steel Studs	
Roofing	420mm x 330mm, Structurally insulated Natural Slates	420mm x 330mm, concrete interlocking tiles	420mm x 330mm, Long-Span Corrugated Aluminium Roofing Tiles	

6.4.5 Factors/Criteria Selection

The next stage of the exercise was to identify a set of decision factors that would determine the choice of the elected building material(s). Each category of the parent factors consisted of a range of decision sub-factors, hence were grouped as follows: GS-General/Site Suitability, EH-Environmental/Health Impact, EC-Economic/Cost Efficiency, SC- Socio-Cultural Benefits, T-Technical performance, and SN-Sensorial Effects/Impacts. The participants of Group 'B' were more concerned about factors such as: life cycle cost, capital cost, maintenance cost, and restriction on usury.

The participants of Group 'A' were more particular about factors consisting of: the level of CO_2 emissions, ecological toxicity, ozone depletion and the recyclability potential of the product, while the participants of Group 'C' concentrated more on the level of tolerance to external impacts from natural occurrences, and acoustic performance. All these factors were taken into account during the analysis. **Table 6.4** shows the alternative factors/variables/criteria generated in the stakeholders' focus group meeting.

Table 6.4. Criteria for Material Selection

Participants' Group		Stakeholders' choice of Factors/Variables/Criteria	Design Elements
A	1, 2, 4, 10	EH2-Level of CO_2 emissions/Eco-toxicity, EH4-ozone depletion, T1-Recyclability	Flooring, Wall (External), Door/Window, Ceiling, Roofing
B	6, 7, 9	C1-Life cycle cost, C3-Capital cost, C4-Maintenance cost, SC3-Cultural Restriction on usury.	
C	3 5, 8	GS5-Tolerance to impacts of natural occurrences, SN5-Acoustic performance	

Table 6.5 shows a comparison of the selected material alternatives based on both the proposed decision criteria/factors/variables listed in **Table 6.4** and the information contained in the MSDSS guide specification manual.

Table 6.5. Comparison of the selected materials attributes

Material Data Origin	MSDSS Model Specification Manual		Case Study Project
Participants' Group	A	B	C
Floor Material Choice	50mm x 600mm, Reclaimed/Recycled laminated Wood Flooring and Paneling	230mm x 150mm, Bamboo XL laminated Split Paneled Flooring	900mm x 900mm Fly Ash Cement concrete Floor slab
Proposed decision Factors			
GS5-Level of tolerance or resistance to impacts from Natural Disaster (earth tremor)	Moderately Prone	Highly Prone	Moderately Prone
EH2: Rate of CO_2 Emissions ($KgCO_2/m^2$)	0.07 $KgCO_2/m^2$	0.023$KgCO_2/m^2$	0.2$KgCO_2/m^2$
C1: Life-Cycle Cost ($) (N)	$30, 000 @ 60 yrs.	$353, 367 @ 60 yrs.	$316, 702 @ 60 yrs.
C3- Material Capital Cost ($) (N)	$8.50/sqft	$15.36/sqft	$17.89/sqft
C4- Maintenance Cost ($) (N)	$2, 925 @ 30 yrs.	$10, 350 @ 20	$30, 925 @ 20 yrs.

		yrs.	
SC3: Cultural Restriction on Usury	Very Low Restriction	Very Low Restriction	High Restriction
T1-Recyclability Level	Highly Recyclable	Highly Recyclable	Highly Recyclable
SN5-Acoustics	Moderate	Good	Very Strong

Participants' Group	A	B	C
Wall Material Choice	150mm x 225mm, Recycled Crushed Concrete Block	75mm x 125mm, Compressed Stabilised Rammed-Earth Block	225mm x 225mm Aircrete Hollow Block
Proposed decision Factors			
GS5-Level of tolerance or resistance to impacts from Natural Disaster (earth tremor)	Moderately Prone	Moderately Prone	Moderately Prone
EH2: Rate of CO_2 Emissions ($KgCO_2/m^2$)	0.073 $KgCO_2/m^2$	0.02 $KgCO_2/m^2$	0.3$KgCO_2/m^2$
C1: Life-Cycle Cost ($) (N)	$316, 702 @ 60 yrs.	$150, 367 @ 60 yrs.	$481, 619 @ 60 yrs.
C3-Material Capital Cost ($) (N)	$17.90/sqft	$5.04/sqft	$28.60/sqft
C4- Maintenance Cost ($) (N)	$14, 398 @ 30 yrs.	$4, 400 @ 25 yrs.	$30, 925 @ 30 yrs.
SC3: Cultural Restriction on Usury	Low Restriction	Very Low Restriction	Low Restriction
T1-Recyclability Level	Highly Recyclable	Highly Recyclable	Highly Recyclable
SN5-Acoustic Performance	Strong	Poor	Good

Participants' Group	A	B	C
Door/Window Material Choice	900mm x 2100mm, Recycled Timber-Clad Aluminium Framed Door/Window Unit	900mm x 2400mm, Stainless Steel Door	900mm x 2100mm, Four-Panel Harwood Door Finished with Alpilignum
Proposed decision Factors			
GS5-Level of tolerance or resistance to impacts from Natural Disaster (earth tremor)	Highly Prone	Moderately Prone	Fairly Prone
EH2: Rate of CO_2 Emissions ($KgCO_2/m^2$)	0.7$KgCO_2/m^2$	For making new steel door- 6.15$KgCO_2/m^2$	0.87$KgCO_2/m^2$
C1: Life-Cycle Cost ($) (N)	$650/unit @ 20 yrs.	$795/unit @ 20 yrs.	$565/unit @ 20 yrs.
C3- Material Capital Cost (£) (N)	$325/unit	$975/unit	$275/unit
C4- Maintenance Cost ($) (N)	$425/unit @ 30 yrs.	$350/unit @ 25 yrs.	$249/unit @ 30 yrs.
SC3: Restriction on Usury	Low Restriction	Highly Restricted	Low Restriction
T16-Recyclability Level	Highly Recyclable	Highly Recyclable	Highly Recyclable
SN5-Acoustic Performance	Fair	Poor	Good

Participants' Group	A	B	C
Ceiling Material Choice	900mm x 900mm, Reprocessed Particle Wood Chipboard	1200mm x 1200mm, Tongue & Grooved	600mm x 600mm, Plaster Board on 70mm Steel Studs

		Wooddeco Multiline Ceiling Tiles	
Proposed decision Factors			
GS5-Level of tolerance or resistance to impacts from Natural Disaster (earth tremor)	Fairly Prone	Highly Prone	Fairly Prone
EH2: Rate of CO_2 Emissions ($KgCO_2/m^2$)	$0.12KgCO_2/m^2$	0.0238KgCO2/m2	0.38KgCO2/m2
C1: Life-Cycle Cost ($) (N)	$300/unit @ 20 yrs.	$59/unit @ 20 yrs.	$160/unit @ 20 yrs.
C3- Material Capital Cost ($) (N)	$11.7/unit	$15.3/unit	$94.0/unit
C4- Maintenance Cost ($) (N)	$65/unit @ 30 yrs.	$35/unit @ 30 yrs.	$265/unit @ 30 yrs.
SC3: Restriction on Usury	Very Low Restriction	Very Low Restriction	Low Restriction
T1-Recyclability	Highly Recyclable	Highly Recyclable	Highly Recyclable
SN5-Acoustic Performance	Moderate	Moderate	Moderate

Participant	A	B	C
Roof Covering Material Choice	420mm x 330mm, Structurally insulated Natural Slates with Timber trussed rafters and joists with insulation, and roofing underlay	420mm x 330mm, Timber trussed rafters and joists with insulation, roofing underlay, counter battens, battens and concrete interlocking tiles	420mm x 330mm, Structurally insulated timber panel system with plywood and roofing underlay, Long Span Corrugated Aluminium Roofing Tiles
Proposed decision Factors			
GS5-Level of tolerance or resistance to impacts from Natural Disaster (earth tremor)	Fairly Prone	Highly Prone	Fairly Prone
EH2: Rate of CO_2 Emissions ($KgCO_2/m^2$)	$0.0235KgCO_2/m^2$	$0.5KgCO_2/m^2$	$8.24KgCO_2/m^2$
C1: Life-Cycle Cost ($) (N)	$350/sqft @ 20 yrs.	$316/sqft @ 20 yrs.	$475/sqft @ 20 yrs.
C3- Material Capital Cost ($) (N)	$7.5/unit	$17.80/unit	$15.10/unit
C4- Maintenance Cost ($) (N)	$15000/sqft@ 30 yrs.	$30,425/sqft @ 30 yrs.	$45,425/sqft @ 30 yrs.
SC3: Restriction on Usury	Low Restriction	Low Restriction	Highly Restricted
T1-Recyclability	Highly Recyclable	Highly Recyclable	Fairly Recyclable
SN5-Acoustic Performance	Poor	Good	Poor

N/B: Please note that the cost of the materials presented in **Table 6.5** was the approximate value of the materials as at the time and stage of the project development therefore, might not necessarily hold as the current cost or naira/dollar value for the building materials.

6.4.6 Assignment of Weights to Factors/Criteria

After materials were selected, the stakeholders were instructed to set the standard criteria priority based on their aprioristic knowledge and individual weighting preference(s) -as each member within the groups was able to present his/her judgment independently. Each group assigned weightings based on the mean relative importance that the factors held using the verbal scale of 1-9 as proposed by Saaty (2007), and calculated the consistency ratio not exceeding 1.0 ($0.1 \leq x \leq 1.0$). This enabled individual groups to obtain the comparative prediction of the utility indices for each elected building material based on the proposed factors.

To obtain the corresponding consensus/overall pair-wise comparison matrices, the results of the pair-wise comparison matrices obtained from each group of stakeholders were combined using the geometric mean approach. The data from the pairwise comparison stage were then entered into the MSDSS software to simulate the performance of the different material combinations in relation to the corresponding priority vector for each factor. The data entered were then automatically translated into the corresponding largest eigenvalue problem, generating a normalised and unique priority weights for each factor against each material- attached to the dominance of each alternative, relative to other alternatives under that sub-factor (assessment logic was based on the AHP model of decision-making). As a result of the material trade-offs, the best, second and third best material combinations — consisting of material preference(s) from the three groups of stakeholders, were generated. As there was multi-stakeholder involvement, the best material combination was the accumulated result from stakeholders— evidenced by the relative utility scores of each material. The results of the analyses are displayed, illustrated and analysed in the following sections

6.4.7 Comparative Analysis and Interpretations of Results

Using the results generated from the analyses in **Figures 6.2** and **6.3**, the materials proposed by Group 'B' (Bamboo XL laminated Split Paneled Flooring and Compressed Stabilised Rammed-Earth Block [CSEB]) for the design elements "FLOOR" and "WALL", had higher utility scores of 49.1% and 40.8% respectively, when compared with the results of the materials suggested by Group 'C' for the case study project (Fly Ash Cement concrete Floor slab and Aircrete Hollow Block), with lower scores of 32.3% and 29.8% respectively. This meant that the materials proposed by Group 'B'— given their higher utility scores, performed better than the materials proposed by Group 'C' on CO_2 emissions, global warming, ecological toxicity, ozone depletion, cultural restriction on usury, rate of recyclability, human health and user safety. However, based on the same analyses in **Figures 6.2** and **6.3** as derived from the MSDSS guide specification manual, it was observed that the materials suggested by Group 'A' (Reclaimed/Recycled Laminated Wooden Floor and Recycled Crushed Concrete Block) for the design elements "FLOOR" and "WALL" performed far less - with utility scores of 18.7% and 29.4% respectively, than the materials proposed by Group 'C'. This means that over their life cycle, the materials suggested by group 'B' – since they emit less toxicity with an average of $0.0215KgCO_2/m^2$ would on a ratio scale of 3:1, cost far less in the long-term and do far less damage to the environment compared to materials suggested by Group 'C' with an average emission rate of $0.25KgCO_2/m^2$.

Selected Shortlisted Materials	Green Utility Index
Bamboo XL laminated Split Paneled Flooring	49.1%
Fly Ash Cement concrete Floor slab	32.2%
Reclaimed/Recycled laminated Wood Floori	18.7%

Figure 6.2. Illustration of the utility indices for the proposed floor materials

Selected Shortlisted Materials	Green Utility Index
Compressed Stabilized Rammed Earth block	40.8%
Aerated concrete or "aircrete" block	29.8%
Recycled crushed concrete block	29.4%

Figure 6.3. Illustration of the utility indices for the proposed wall materials

For the design element "DOOR/WINDOW", the material suggested by Group 'B' (Recycled Scrap Stainless Steel Door with bolted sections) —having arrived at a utility index of 46.4%, performed better than the materials suggested by Group 'A' (Recycled Timber-Clad Aluminium Framed Door/Window Unit) and Group 'C' (Four-Panel Harwood Door Finished with Alpilignum) on habitat alteration, durability, recyclability, life-cycle cost, maintenance cost, cultural restriction on usury, acoustic performance, thermal resistance, and water resistance with their utility scores arriving at 29.3% and 24.2% respectively. This means that "Recycled Stainless Steel Door with bolted sections", considering all the proposed factors and the utility indices in **Figure 6.4**, would on a ratio scale of 2:1 be more energy and cost efficient in the long-term than "Recycled Timber-Clad Aluminium Framed Door/Window Unit " and the material used for the case study project—"Four-Panel Harwood Door Finished with Alpilignum", since the material proposed by Group "B" requires less energy and cost for recycling and perhaps has a longer-life expectancy.

Selected Shortlisted Materials	Green Utility Index
Recycled Scrap steel bolted sections	46.4%
Recycled timber clad Aluminium framed wi	29.3%
Four panel hardwood door finished with Al	24.2%

Figure 6.4. Illustration of the utility indices for the door/window Materials

Using the results in **Figure 6.5** for the design element "CEILING", the material suggested by Group 'A' (Reprocessed Particle Wood Chipboard) with a utility index of 45.4% performed better than the material proposed by Group 'B' (Tongue & Grooved Wooddeco Multiline Ceiling Tiles) and that of Group "C" (Plaster Board on 70mm Steel Studs) on habitat alteration, recyclability, life-cycle cost, maintenance cost, cultural restriction on usury, acoustic performance, thermal resistance, and water resistance, having arrived at the scores 33.1% and 21.5% respectively. This means that "Reprocessed Particle Wood Chipboard" and "Tongue & Grooved Wooddeco Multiline Ceiling Tiles", would on a ratio scale of 2:1 perform better than "Plaster Board on 70mm Steel Studs", considering the proposed factors.

Selected Shortlisted Materials	Green Utility Index
Reprocessed Particleboard wood chipboard	45.4%
Tongue & grooved Wooddeco Multiline ceil	33.1%
Plasterboard on 70mm steel studs with 50m	21.5%

Figure 6.5. Illustration of the utility indices for the proposed ceiling materials

Similarly, using the results in **Figure 6.6** and applying the same parameters to the design element "ROOF" resulted in a higher utility score of 57.2% for the material proposed by Group 'B' (Timber trussed rafters and joists with insulation, roofing underlay, counter battens, battens and concrete interlocking tiles) hence, showed better performance than the material proposed by Group 'A' (Structurally insulated Natural Slates with Timber trussed rafters and joists with insulation, and roofing underlay), with a score of 25.5%, and the material proposed by Group 'C' (Structurally insulated timber panel system with plywood (temperate EN 636-2) and roofing underlay, Long Span Corrugated Aluminium Roofing Tiles) with a score of 17.3%. This means that the material proposed for the project "Structurally insulated timber panel system with plywood (temperate EN 636-2) and roofing underlay, Long Span Corrugated Aluminium Roofing Tiles" would on a ratio of 1:3, perform worse than "Structurally insulated Natural Slates with Timber trussed rafters and joists with insulation, and roofing underlay" and far less than “Timber trussed rafters and joists with insulation, roofing underlay, counter battens, battens and concrete interlocking tile” on habitat alteration, CO_2 emissions, recyclability, life-cycle cost, maintenance cost, cultural restriction on usury, acoustic performance, thermal resistance, and water resistance

6.5 Discussion of Findings

Given the overall analysis, it is evident that the materials suggested by the stakeholders in Group “B” —on the average, performed better than the materials suggested by the stakeholders in Group “A”, as well as the materials suggested by the stakeholders in Group “C”, since a higher utility score in the MSDSS model suggests lower energy, environmental, and cost impacts. In relating the total amount of each material’s impact contribution to the total amount of greenhouse gases released every year, per metre square, —according to the participants’ panel importance weights, the materials suggested by Group ‘B’ proved to be more environmentally, economically, sensorially, technically and socio-culturally sustainable than the materials proposed by the stakeholders in Groups ‘A’ and ‘C’. Furthermore, it can be deduced from the analysis that the materials suggested by the stakeholders’ in Group ‘C’ for the case study project had the cheapest capital cost when compared to other materials. However, the materials proposed by stakeholders of the Group “B” was better in life cycle cost assessment when compared to the materials suggested by stakeholders in Groups ‘A’ and “C”. This means that by investing extra capital cost on the materials from the MSDSS guide specification manual, the building would yield less energy and environmental impacts by at least 25%, and generate more cost savings of roughly 30%-50% per year in the long-term. The results therefore, demonstrate that based on equal importance weights, the materials proposed by stakeholders of Group “B” would perform better than others in economic, technical, sensorial, environmental and socio-cultural value.

6.6 Summary

Designing, developing, and implementing Decision Support Systems (DSS) to aid informed choices requires analysing the knowledge base and decision making capabilities of the system (Quinones, 2011). Consequently, for models to work properly in practice, the components and algorithms must also be assessed correctly (Florez et al., 2010).

This chapter has presented a method for testing the correctness and the decision-making capabilities of a Multi-Criteria Material Selection Decision Support System. The outcome of the MSDSS model was validated for its efficiency in suggesting informed choices of LCGBMCs to potential users, using an on-going case study project located in Port Harcourt, Nigeria. The resulting inferences were based on the sample data of the stakeholders measured against the monitored data of the proposed case study in relation to the set of sustainability principle indicators (decision factors) proposed by the stakeholders. The results show how the range of embodied impacts is steadily reduced as decisions are made in order- from those achieving the greatest embodied impact reductions to those achieving the least reductions. The results of the comparative analysis revealed that the life cycle cost, sensorial, socio-cultural and environmental impacts of the materials proposed for the case study was less evident in value than that of the materials generated by the MSDSS model. This study has therefore proposed a prototype model that could be used by designers as a basis from which to perform informed trade-off analysis that reflects all the key characteristics of LCGBMCs.

Chapter VII

Summary, conclusions, and recommendations

CHAPTER 7: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter presents the general summary of the research. It discusses the findings from chapters two to six, and draws conclusions to cover achievement of the original objectives used to address the research question posed in chapter 1. A reflection of the major works undertaken in the study is summarised and conclusions are drawn to finalise the study. It further highlights contributions of the study to knowledge, and identifies the research limitations. In the final section, it provides recommendations to software developers, practice, research communities, and policy makers, and suggests other avenues for further research. The remainder of this chapter has been divided into sections to discuss the research findings as follows:

- 7.2. Review of Research Aim and Objectives;
- 7.3. Reflective Summary;
- 7.4. Conclusions;
- 7.5. Contributions to Knowledge;
- 7.6. Dissemination of Research;
- 7.7. Research De-limitations and Challenges; and,
- 7.8. Recommendations for Future Research

7.2 Review of Research Aim and Objectives

The aim of this study has been to address the research question set out in chapter 1. It has identified six categories of the sustainable development principle indicators (factors) applicable to this study, and developed a Multi-Criteria Material Selection Decision Support System (MSDSS) that enables designers to assess the applicability and potential impacts of LCGBMCs for their promotion and adoption in mainstream housing. The objectives are restated in this section and the extent to which they have been met are summarised along with the research methods used to achieve them.

Objective 1: *Elicit current views and background information on themes related to the economic, environmental and social impacts of housing construction activities in the Global and Nigerian contexts, with emphasis on the role of material selection decision-making in sustainable housing;*

This aspect of the literature review generated a number of important insights that explained the socio-economic significance of the decision-making process on housing and its reverse effects on the environment, from the global perspective and in the Nigerian context. There were clear indications that rising costs and demands for housing, and their resultant impacts could be addressed through careful designs of LIGHDs and sustainable use of LCGBMCs. A further study identified some drivers that informed the need for LCGBMCs and factors that limit their mass use in mainstream, one of which was the lack of informed knowledge. Findings from the study revealed that current material information systems lacked the capacity to adequately assess the impacts of different LCGBMCs in a sustainable manner, taking into account a range of key sustainable principle indices/indicators (factors), hence identified the need for a more appropriate resource, which in turn fulfilled objective 1 of the research.

Objective 2: *Compare and contrast various technologies currently used at national and international levels for modeling decision-making in the selection of building materials and components: to highlight their strengths and weaknesses*

In understanding the problems associated with the mass use of LCGBMCs in housing, it was envisaged that improving knowledge sharing about current best practices could be realised through Technology Transfer (TT). The literature review highlighted the viability of technology in fulfilling sustainable development principles and requirements in the material selection decision-making process. In this exercise, existing material assessment tools used in both developed and developing countries were examined and found wanting.

The findings were premised on the fact that most existing tools are culturally implicit, as such treat the sustainability impacts [of the] wider built environment as simply a matter of energy and mass flows with little or no consideration to other dimensions of the concept. This was met through a comprehensive review of both academic and industry references to sustainable material selection. This was then further explored through a preliminary survey, of which the majority of the respondents emerged with a relatively strong degree of commitment in terms of the need for more current and up-to-date information. This exercise also formed significant basis upon which the model was conceptualised, hence fulfilling objective 2.

Objective 3: *Identify the key influential factors that affect the selection of building materials*

Following the need for more current and relevant information, suitable clusters of data collection methods were used to elicit valuable information from both academics and practicing professionals who influence material choice decisions in the Nigerian housing industry. In achieving this, the study identified shortcomings in the current practice, and provided a means of understanding the practitioner's view of conventional systems and their expectations for a new model. The outcome of this exercise led to subsequent re-evaluation of the proposed sustainability principle indices/indicators (decision factors) and further modifications of the conceptual DSS model to meet practitioners' requirements, which in turn fulfilled objective 3.

Objective 4: *Establish and specify the impact weight of each key influential factor*

The fourth research objective was to establish the key influential factors required for working out the relative impacts of the different choices of materials.

A list of sustainable principle indictors (factors) was gleaned from the analysis of the surveyed questionnaire and ranked according to their weighted importance using a suite of statistical analytical methods. To ease the decision-making process and avoid mixing up the vast array of factors, the factors were narrowed down into six categories as follows:

- General/Site suitability (GS)
- Environmental/Health impact (EH)
- Economic/Cost efficiency (EC)
- Socio-Cultural benefits (SC)
- Technical performance (T)
- Sensorial impact (SN)

By identifying and ranking the factors in their order of importance using the factor analysis approach, this section thus, fulfilled objective 4 of the research.

Objective 5: *Develop a Multi-Criteria Decision Support System for aggregating the weighted factors needed for the assessment of LCGBMCs*

The fifth objective was to further develop the proposed conceptual framework into a scalable prototype Material Selection Decision Support System (MSDSS) using the data gleaned from the analysis. This phase provided an overview of the hardware devices (storage, display, etc.), and database management systems used including the system configuration techniques, its mechanisms, file structures, access methods and data location procedures. It provided the opportunity to assess the potential capabilities of the proposed programming language needed to develop the conceptual model schema. Following the development of the MSDSS model, preliminary test runs were conducted during the various stages of the development process to regularly check the internal mechanism of the links, and the consistency of the result outputs. Therefore, the development of the model into a scalable and functional prototype system enabled the fulfilment of objective 5.

Objective 6: *Test and validate the developed system*

The final objective of this research was to validate the applicability, effectiveness and usefulness of the developed model, using a case study project located in Port Harcourt, in which a comparative analysis was performed to show how optimal choices could change with changing user weightings and variables in real life practice. This was followed immediately after the user evaluation exercise in **Appendix K**. This procedure was useful in demonstrating the overall value and possible limitations of the software, hence suggesting areas for further improvements. This exercise thus, enabled the fulfilment of the research objective 6.

7.3 Reflective Summary

The purpose of this research has been to address current issues associated with the provision of quality low-impact green housing developments in Nigeria by employing sustainable practices in the selection of LCGBMCs. The response to the research question posed in chapter 1 commenced with a dual stage scoping study consisting of comprehensive reviews of both academic and industry references, and preliminary studies with design and building professionals currently engaging with building materials. Some consensuses were identified from the reviews and surveys, which were then used to cover the theoretical aspect of the research, hence fulfilling objective 1 towards realisation of objectives 2 and 3.

In chapter 2, the study discussed issues surrounding the housing construction industry with emphasis on the impacts of sustainability principle indicators on the material selection decision-making process. It highlighted drivers and obstacles affecting the implementation of LCGBMCs in the design of LIGHDs, and identified factors that are critical in determining their relative impacts at the design stage.

Chapter 3 reviewed various material assessment tools in developed and developing regions, to identify knowledge deficits and potential benefits associated with their use. This exercise provided the foundation for the development of the conceptual model, which formed the major part of this research.

In chapter 4, the study explained the various data collection and analytical methods used in this research. Subsequent survey exercises with leading experts in the field helped to identify the principal sustainable principle indicators/decision factors that were included in the MSDSS model.

The analysis of the surveyed questionnaire and responses from personal interviews (in **Appendix G**) enabled the development and testing of the prototype model in chapter 5.

The discussion of research findings from the evaluation exercise was presented in Appendix K, while the validation exercise, used to determine the adequacy of the MSDSS model was addressed in chapter 6.

Chapter 7 provided the study with the necessary data to make necessary recommendations that will help to ensure more delivery of sustainable low-impact green housing, through the wider use of LCGBMCs.

7.4 General Conclusions

Many developing cities around the world are facing the problems of increasing urban density and energy demand. As housing represents a significant source of growth in global energy demand, their energy use, and associated environmental impacts also create great pressure to our planet. The yardsticks for the measurement of housing development for rapidly growing and urbanising nations is hinged upon not only the extent to which the housing industry is able respond to either the socio-economic challenges or environmental issues but how well it holistically engages with the economic, socio-cultural, and environmental conditions of that region (Ofori, 1991). Building materials have been identified as one of the principal components of housing development, as they constitute the single largest input in construction- often accounting for as much as 5.8% of a nation's GDP (UN, 2010). Likewise, the deterioration of the physical environment due to housing construction activities is traceable to the choice of building products at the early design stages (Gluch & Baumann, 2004). As more consideration is given to socio-economic and environmental concerns, interest in the use of LGCBMCs is experiencing a renaissance (Seyfang, 2010).

With the objective to encourage the increased supply and use of energy efficient and cost effective building materials, this study underscored the need for improving understanding of relevant data associated with LCGBMCs, being identified as partly responsible for their current lack of use in mainstream housing. The information needs of designers were researched within the literature review, followed by empirical studies to understand what support system designers needed. Critical appraisal of the current approach to selecting building materials showed that most of the existing studies and tools reviewed had no direct indicators that were specifically relevant to the impacts of LCGBMCs.

It emerged that there was a need to explore how designers could be supported to facilitate the integration of sustainability principles in the decision-making process to aid better-informed decisions when selecting LCGBMCs for LIGHDs. The findings from the empirical studies and the literature review were combined to develop the proposed conceptual model into a working prototype Multi-Criteria Decision Support System (MSDSS) that is well suited to perform effective trade-off analysis at the early stages of the design.

Consequently, the primary objectives of this research- to provide designers with a model that aims to facilitate the selection of LCGBMCs appropriate to the scale, lifecycle, location and context of a development project and to integrate their outputs in a meaningful manner to augment their limited capacity to deal with complex material selection problems, has been achieved. Thus, the exploration that led to the development of the MSDSS model has proven to be a worthy contribution to housing design and housing construction management. It is clear that a need existed for a tool specifically tailored to address the unique challenge of housing in Nigeria. It is therefore hoped that the model- through a combination of local action and national enabling policies, can help to narrow the gap identified in this study.

7.5 Contributions to Knowledge

Insights identified from addressing the research aim and objectives in section 1.5 represent part of the original contribution to knowledge made by this study. The following are itemised as other key contributions of the study to research and practice:

- Frameworks for sustainable material selection already exists (see chapter 3) but these only focus on either one single aspect of sustainable materials, or developed for specific conventional materials, or with many presented in a format too detailed or with engineers in mind, or is designed to be applied at the latter stage of the design process.

Applying a material assessment tool at this point in the process conflicts with the literature, because it is widely acknowledged that sustainable considerations need to occur before design decisions have been made in order for the most significant improvement to be achieved. More so, there was no compelling evidence that suggested any form of integration that deals with the assessment of the sustainability impacts early in the design. Throughout all the empirical studies a confusion and lack of understanding regarding LCGBMCs was evident, due to the complex issues and contradictory information. In order to encourage the use of such materials, Seyfang (2010) came to a similar conclusion with the consideration of a holistic framework that incorporates sustainability principles to improve understanding of the relative impacts of each product to better inform designers. This lack of a holistic presentation and a need for a quick visual representation were the drivers for the holistic framework presented. There is currently no documented study, so far, that performed similar analysis on the capacity of a model to adequately capture, store, analyse and present data that are accessible to designers in usable forms and formats to better inform material choices in the design of LIGHDs, hence makes a valuable contribution. The novelty of the framework thus lies in the visual overview of sustainable material impacts and selection factors. The framework is designed to visually present the impacts of sustainable material considerations in order that trade-offs can be identified.

- The majority of literature and resources focused solely on either environmental aspects of material selection (Zhou et al., 2008; Ding, 2010) or technical considerations (Ashby and Johnson, 2006), or sensorial aspects (Wastiels and Wouters, 2008), or the selection of materials based on economic requirements (Rahman et al, 2009). There was, however, a lack of reference to social-cultural implications in the reviewed studies, which indicated the need for further study to incorporate not just the social-cultural aspects of the sustainability principle but also the aforementioned dimensions of the concept.

Within previous empirical studies there has been little mention of social-cultural considerations as it has historically been left out of the conventional sustainable development agenda. The inclusion of social-cultural, and sensorial issues is often lacking, within both literature and material selection resources. However, this framework was designed to reflect this in order to enable mainstreaming of some of the cultural dimensions such as pride of place, symbols, and sense of belonging.

- The research presents a detailed understanding of the drivers and barriers, which influence the selection of LCGBMCs in the design of LIGHDs, a topic that is lacking within current literature. Thus, this research can help to inform building practitioners on low-energy building material research and housing policy development dialogue, and it is hoped will make a significant contribution to the on-going debate.

- Historically, conventional literature about the Nigerian housing industry has largely remained peripheral to discussions on sustainable material selection within design practice. Despite an evolving culture of sustainability in the global housing industry, there are limited studies within the context of Nigeria that discussed extensively the management and synthesis of material knowledge to stimulate sustainable material selection during the design process, hence enriches current body of knowledge on the Nigerian component of the research.

7.6 Dissemination of Research

The key aim of dissemination of research is to reflect the multidisciplinary nature of the study by publishing in the widest range of sources. Both theoretical and empirical findings within the scope of this research have been published in peer reviewed journals, and international conference(s) as the research progressed (publications are attached in Appendix M). More publications are also in preparation and under review.

7.7 Research De-limitations and Constraints

The research carried out in this study is significant to design and building stakeholders, and the findings from the study are useful in terms of incorporating sustainability principle in the assessment of LCGBMCs. This research is however, subjected to the following de-limitations and constraints:

7.7.1 Delimitations of the MSDSS Model

The following are itemised as the delimitations of the MSDSS model.

- Even though the selection methodology of the MSDSS model remains appropriate for any building type, the scope of this tool for now is limited to selecting building components for residential housing for which each material impact can be predicted at the early stages of the design process.

- The model development is restricted to a scalable prototype, which is only used for demonstration purposes of the selection procedures. Therefore, most interfaces of the model are saddled with default outputs.

- The model provides reports on some of the available LCGBMCs, and so there is currently very little flexibility for a user to query reports, as they would prefer.

- The hypothetical scenario of a case study was undertaken on 3-floor materials used in a 3-bedroom residential building. The research results of the case study may only be valid for the characteristics and culture of design and building professionals in the Nigerian housing industry. There are, of course, limitations to the case study as it is not possible to generalise with such results given the cultural, social, economic, and geographical diversity of other regions.

7.7.2 Delimitations of the Study

The following are identified as the delimitation of the overall study.

- It is important to express that the results provided by this study are not necessarily exhaustive. What it provides is a solution that meets the requirements of the stakeholders who participated in this study (i.e. certain criteria were compromised, and decision making process largely depended on the stakeholders' priority assigned to the sustainability principle indicators/factors). Clearly the opinions presented in this study are those of the individuals interviewed and cannot be taken to be representative of other design and building professionals. It needs to be recognised that the participants interviewed were chosen specifically because they showed in-depth knowledge of the area of study and not that this understanding and interest is not necessarily to be found among all participants within Nigeria, the UK or elsewhere.

- For those interested in research in LCGBMCs, it should be noted that the study is quite exceptional, in that the outcome of this study is not likely to be the case with subsequent studies.

- It is important to also emphasise that this research is written from the Nigerian perspective. There is no claim that the outcome presented will completely address the underlying gap identified in the study. Neither is it claimed that the findings of the study are exhaustive. The results are not meant to suggest that making decisions in a certain sequence – from those achieving the greatest impact reduction to those achieving the least – can help designers arrive at a best or improved design in terms of lowered embodied impact. Rather, the results are meant to help designers visualize the potential reductions for each building material so that they can understand how incorporating sustainability principles into the material selection decision-making process at the early design stage could contribute to minimising a building's embodied impact.

7.7.3 Research Constraints

There were few setbacks that this research faced during the course of this study. The following constraints are hereby listed for future consideration.

- The process of developing the overall research study was faced with critical issues that led to several changes in the research topic, methodology and its objectives in order to achieve the main aim of this research. Submitting papers for peer-review in conferences/seminars and publishing articles in journals helped to restructure and clarify the overall research study.

- There were reservations regarding the currency and scope of the research information, as there was no compelling evidence of prior research that applied to the context of this study, therefore having to rely on the most current reports, and data elicited from interviews with experienced participants in this field. This brought about the need for continuous checking, comparison and updating of the available information, hence posed a serious challenge to this research.

- It remains true that sample sizes that are too small cannot adequately support claims of having achieved valid conclusions, and the same is true that sample sizes that are too large or uneven do not permit the deep, naturalistic, and inductive analysis that defines qualitative inquiry (Creswell, 2003). Getting an adequate sample size for each group of professionals was demanding, hence posed a serious challenge. However, the sampling methods specified in section 4.5.2.9 of chapter 4 made it possible to achieve sampling equivalence amongst professionals of the various building professions.

- Getting a list of the sample population for the study was very discouraging, and having access to people and organisations also posed a serious challenge due to their time differences and tight-schedules.

Constantly reminding the subjects using any available means including contact e-mails, social media (LinkedIn, Facebook, Twitter) and phone calls helped to minimise this problem.

- The fact that most of the participants had little or no exposure to AHP quantitative-based decision-making concept was rather discouraging, as they were not used to considering the choice of materials based on user-specified weightings. Manuals sent to participants prior to evaluation exercises helped to reduce the complexities associated with the MCDM technique adopted.

- It is also acknowledged that there were time, personal, administrative and financial constraints. However, the importance of the study remains, for the limitations do not detract from them, but merely provide scope for further research

7.8 Recommendations for Future Research

The outcome of this study has a number of significant implications for future practice, and thus has identified areas for further research. The following areas of study are therefore recommended for further investigation.

7.8.1 Recommendations for Software Developers

- Evidence from this research has shown that most studies see Computer-Aided Design packages and Energy Simulation tools differently. An interoperable standard, such as the gbXML (Green Building eXtensible Mark-up Language) enables the movement of models between various types of software. This take up has been slow and incomplete, thus resulting in the loss of data. It is recommended that software developers refine these schemas to allow seamless integration between tools.

- Adding extra operating features and perhaps expanding the database using interactive web-based applications are examples of the later applications that would help to strengthen the functionalities of the MSDSS Model. This should provide transparent access to distributed geo-data, so that users are able to operate in a heterogeneous computing environment.

- In addition, the factors identified in this research may be confined to the time of the research, as subsequent researchers' perception of an ideal range of sustainability principle indicators (factors) may change. The model will thus require regular updates in all aspects of the database, which is not unexpected.

7.8.2 Recommendations for Industry and Practice

- Setting up a website with online information that can be updated is recommended to manage the large volume of data typically associated with LCGBMCs. It is thus recommended that designating trained industry personnels for the maintenance of applications and programs could enhance the operations and features of the prototype MSDSS model.

- Traditional materials (such as mud and red bricks) appear to be the most appropriate alternatives in terms of thermal performance, and energy reduction, yet some of these materials are not given the deserving recognition. Therefore, improving the quality and method of production of traditional materials in line with the housing industry could make such products more durable and improve the quality of their appearance hence, attain greater industry and social acceptance.

- The attitude of trying to economise fund beyond reasonable limits has resulted in the design of housing projects that have instead served as poor examples of LIGHDs. It is therefore recommended that a lot of diligence and ingenuity be put into practice to come up with sample prototypes that truly represent LIGHDs, and are able to convince the population from an aesthetic, technical and economic points of view, since the population (particularly of the LDCs) is not so familiar with the socio-economic and ecological significance of these building types.

7.8.3 Recommendations for Research Communities

- The participants for this survey were derived from random sampling of design and building professionals to form a composite sample. This sampling method does not include other stakeholders, who in a way influence material selection such as clients and policy makers. The sample size may need to be extended to include more stakeholders involved in material selection in order to further strengthen the quality and validity of the data.

- The study also measured the relative indices of the factors limiting the use of LCGBMCs in the housing industry, hence may not be exhaustive. Thus, it forms a reference for further identification of other factors inhibiting their wider use in mainstream housing. This could aid in the formulation of more advanced system models, strategies and policies for further expansion of LCGBMCs industries, to reinstitute its value in the socio-economic development of the housing sector.

- This research was based on residential building; hence the relative importance of the factors may vary according to the building type. Thus, applying the green building index approach to other building types can carry out further research. The nature, construction methods, specifications and impacts on the environment will be different from residential building and further research on studying the sustainability/green index may provide new insights. This is particularly important for capital projects which are usually large scale and more likely to cause more environmental degradation.

- This area of research can, of course, be expanded to investigate other countries besides Nigeria, with the opportunity to draw some interesting international comparisons, and to consolidate the robustness of the selection methodology.

- The validation exercise was undertaken on a single-case study project in Nigeria involving a particular building type, size, location, and geometry. What may thus be worth doing in future is to elaborate on the model to comment more generally on the performance and robustness of the proposed MSDSS decision model, by applying it to multiple case studies and comparing it with other countries.

- From other studies, it appears that some studies view LIGHD, as the interest of a minority of people hence, may currently be true that there are not a large number of people interested in LIGHD, although that does not mean that its scope is by any means marginal. There is little knowledge about the extent of interest in LIGHD, thus, would be worthwhile to conduct further research to foster interest in lower impact options.

- The consequences of the planning system on LCGBMCs and LIGHDs are not widely known or documented and yet, as has been discovered from this research, the impact of the planning system within the context of Nigeria is wide-ranging.

7.8.4 Recommendations for Policy Makers

- The cause for the failing market mechanism is the discrepancy between the private costs a person faces and the social costs society faces for emitting green house gases through the production and use of certain building products (Ofori, 1991). Governments can address this anomaly by either imposing taxes on conventional building products with higher rates of CO_2 emissions or regulating the emission of the gases using an emission trading system. Other actions that are likely to hasten moves towards sustainable use of LCGBMCs include:

    — Regulation of what buildings materials can be used in housing construction and how they are to be managed – typically, promulgated through building codes. This will require building owners to post energy or other environmental performance scores of potential materials through the use of an energy-monitoring model;

    — A common and general methodology for calculating the integrated energy performance of building materials for new and existing buildings; and,

    — Energy certificate for new and existing residential buildings. Certificates must be less than five years old and must comply with government's policy of 50% – 70% use of LCGBMCs (most of which would be indigenous and recycled building products).

- The government could assist in the development of the housing industry's activities by including matters pertaining to LCGBMCs as part of the blue print in national development plans. Using indicators to benchmark the performance of LCGBMCs could help to identify deficiencies in their performance, hence proffer remedial actions.

- The lack of a proper certification system makes quicker adoption of LCGBMCs difficult. Certification of such products can play a major role in their transition to a more efficient product in the housing sector.

- Current market mechanisms alone do not seem very likely to accomplish a sufficient degree of energy efficiency and resource savings over the coming years as they often ignore the negative externalities caused by CO_2 emissions. Politicians can therefore seek strategies to encourage greater energy efficiency and more use of LCGBMCs through political measures such as subsidies and tax cuts.

- Unfortunately, at present, in a majority of cities in Nigeria, sustainable housing planning and development practices seem to be divorced from any long-term city vision, and pressures from various stakeholders influence many major decisions. Thus, an open, transparent process that integrates various kinds of house build stakeholders has more chances to address entrenched problems of exclusion, proposing solutions that are appropriate both culturally and politically to cater to the needs of the vast majority of the disadvantaged population. In this sense, such inclusive development of a vision and planning will in turn enhance the potential for collective ownership, commitment that is made by city authorities (who are the leaders, custodians and promoters of the vision) and the other tiers of government and civil society (who are major stakeholders in the process), as the proposed action plan would have been endorsed by the broadest possible constituency.

- Mandating higher efficiency standards for new construction materials is likely to make “low-impact green energy” homes mandatory by 2050. Therefore, stricter government regulations are likely to be the main reason for LIGHDs to become the de-facto standard for new and renovated buildings in 20 years to come-particularly for the very disadvantaged population.

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Appendices

Appendix A: Definitions

For the purposes of this study and clarity, the following definitions have been adopted.

Architects by definition, according to the Architects Registration Council of Nigeria's (ARCON) standard are; "persons who will have completed a six-year course in the design, specification and erection of buildings, passed the professional practice examination which is the final stage of the training, and fully endorsed by the Architect's Council's Registration Board" (NIA, 2012).

Sustainability Principle is defined as a concept that integrates the fundamental indicators or factors of sustainable development such as environmental responsibility, socio-cultural awareness, technical performance, sensorial value, and economic profitability to society at large to address a design, material selection or construction problem.

Sustainable development is defined as: A continuous improvement process of any development that does not only exhibit a minimum of negative environmental impact but also touches on the social, economic, legal, technical, emotional, and cultural dimensions, to effectively address a range of issues specific to the population it intends to serve during its life-cycle".

Appendix B: Research Ethics Application Form

OFFICE USE: ____ / ____/ ______

University of Westminster
Research Ethics sub-Committee

Application for Research Ethics Consideration
COVER SHEET (To be completed by all applicants)

Section 1 – PROJECT AND APPLICANT DETAILS To be completed by all applicants

1.1 Project Title: Low-Cost Green Building Material Selection in the Design of Low-Impact Green Energy Housing Developments in Nigeria

1.1 Applicant Details	
Name: IBUCHIM BOBO OGUNKAH	Email Address: i.ogunkah@my.westminster.ac.uk
Contact Address: 16 WOOD COTE ROAD, WALLINGTON, SUTTON, SURREY, UK	Telephone Number: +44(0) 75 3880 0736
Please check the relevant box: ¨ Undergraduate ¨ Postgraduate ■ MPhil/PhD Student ¨ Staff	

1.3 Supervisor/Dean of School/ School Research Director details Please note that all applicants with a supervisor(s) must ensure that the supervisor signs the declaration at the bottom of this page if completing Part A only or in Section 10.3 if completing Part B All staff must ensure that their Dean of School, or School Research Director (or nominee), as appropriate, signs the declaration at the bottom of this page if completing Part A only or in Section 10.3 if completing Part B	
Name: Junli Yang (Phd/Director of Studies) Brian Jones (Second Supervisor)	Email Address: J.yang2@westminster.ac.uk
School/Centre/Unit:	Telephone Number:

2.5 Timescales

Start Date (DD/MM/YY): 01/10/2009

Estimated duration of work: 36 Months

Section 3
RISK OF HARM

		Yes	No	N/A
1	Is pain or more than mild discomfort likely to result from the study		■	
2	Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?		■	
3	Will the study involve prolonged or repetitive testing?		■	

4	Will the study involve raising sensitive topics (e.g. sexual activity, drug use, revelation of medical history and/or illegal activities)			
5	Does your work involve any material containing human cells (e.g. blood, urine, saliva, body tissues) from living or deceased persons? (Such work must take account of the Human Tissue Act).			
6	Will DNA samples be taken from human participants? (Such work must take account of the Human Tissue Act).			
7	Does your study raise any issues of personal safety for you or other researchers involved in the project? (Especially relevant if taking place outside working hours or off University premises)			
8	Does your study involve deliberately misleading the participants (e.g. deception, covert observation)			
9	Does your work involve administration of a non-food substance in abnormally large amounts or one that is known to cause allergic reaction(s) in some people?			
PARTICIPANTS				
Does your work involve any of the following:				
		Yes	No	N/A
10	Human participants in health settings (e.g. private patients in private clinics)			
11	Human participants in health settings (e.g. NHS patients in NHS clinics/hospitals)			
12	Human participants who are in the care of a social worker			
13	Expectant or new mothers			
14	Refugees			
15	Minors (under the age of 18 years old)			
16	Participants in custody (e.g. prisoners or arrestees)			
17	Participants with impaired mental capacity (e.g. severe mental illness, brain damaged, sectioned under Mental Health Act, lowered or reduced sense of consciousness)			
INFORMATION TO PARTICIPANTS				
		Yes	No	N/A
18	Will you provide participants with a Participant Information Sheet prior to obtaining consent which can be taken away by the participant?			
19	Will you describe the procedures to participants in advance, so that they are informed about what to expect?			
20	Will you obtain consent for participation? (normally written)			
21	Will you tell participants that they may withdraw from the research at any time and for any reason?			
22	With questionnaires, will you give participants the option of omitting questions they do not want to answer?			
23	Will you tell participants that their data will be treated with full confidentiality and that, if published, it will not be identifiable as theirs?			
24	Will you debrief participants at the end of their participation (e.g. give them a brief explanation of their study)?			

Appendix C: Results of the Preliminary Study

Introduction

In order to address the specific issues identified in the literature review, a preliminary survey was conducted with leading experts in the field to: 1) get additional information regarding their views on the current information sources available to them for selecting LCGBMCs; 2) find out what they thought about the impacts of decision support systems on decision making; and 3) identify which factors they considered as most important for selecting building materials. The full report emerging from the preliminary study is discussed as follows.

Choice of Research Methodology

For the preliminary research study, two different methods were first considered before settling on the final choice. The advantages and drawbacks of in-person interviews and questionnaires were considered to assess their suitability for the study. Given that the respondents were widely dispersed, the constraints of time, importance of wider coverage, and limited budget meant that interviews were finally discarded in favour of questionnaires conducted by email. It was thus, decided that a semi-structured questionnaire containing a mixture of open and closed-ended questions would be more appropriate. The inclusion of qualitative open-ended questions provided respondents a chance to express their views more freely.

The Questionnaire

For the questionnaire survey, respondents were informed of the purpose for data collection and how the information provided will be used. This was done through a duly signed covering letter that clearly stated the rights of the respondents. The questionnaire was designed so that each question was worded in a clear and straightforward manner to minimise the risk of ambiguity, and to further increase the response rate. The questionnaire was divided into 3-sections. It consisted of 15 closed and 5 open-ended questions based on the findings of the reviewed literature. For easy analysis, quicker response, and to determine the weight of each factor, respondents were asked to select from a list of answers the extent to which they agreed with the factors influencing material choice using a five point likert scale from 1 (strongly disagree) to 5 (strongly agree) along with the 'other' option which gave them the chance to express their views.

Characteristics of the Respondents

The questionnaires were deployed to representatives of relevant professional groups from throughout the construction value chain, particularly from those who influence material choice decisions, have experience in green building rating schemes, and possess enough industry and product knowledge on issues associated with LCGBMCs. The selection of participants for the evaluation exercise was based on proposed sampling methods in section 4.5.2.9 of chapter 4. The target groups of respondents were taken from a directory of building professionals provided by the UK, China, Canada and US Green Building Councils (GBCs). The choice of theses countries was based on the fact that they had green building rating schemes in place. The data from the preliminary survey was an opportunity to elicit information from expertise from other countries with different socio-economic issues. Moreover, it was used to check the consistency of the information obtained in terms of whether they share similar problems with the area understudy. To receive a reasonably sized sample, 175 surveys were sent out by email, over a two-month period of March and April 2011). Out of the 175 randomly selected practices, one hundred and twenty-five opted out, and 50 were delivered successfully to achieve a response rate of 28.6 per cent. The response rate is in line with similar surveys in the construction industry such as Takim et al. (2004) who achieved a response rate of 20 percent.

Presentation of Survey Results

The following presents some of the main questions and results of the study.
Question 5 – Do you consider the use of low-cost green building materials in your housing projects?

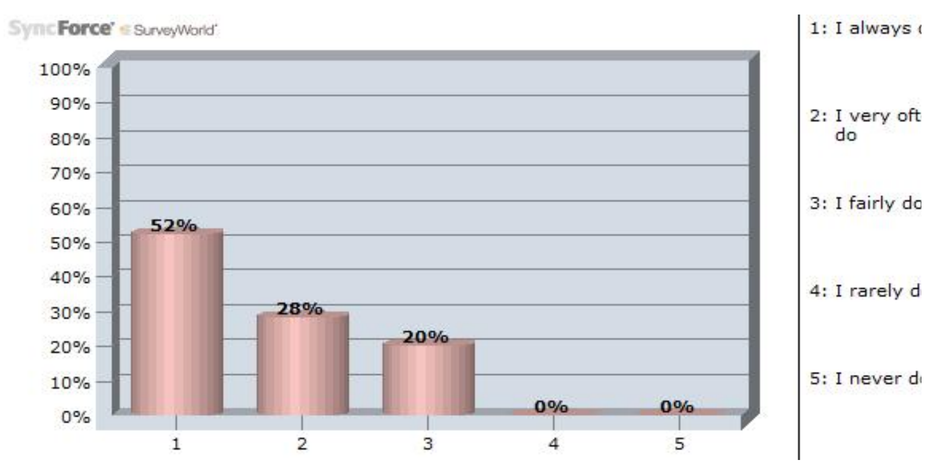


Figure 1. Graph showing percentage usage level of low-cost green materials

Question7 – Are you aware of any information source(s) used by building professionals for selecting low-cost green building materials/components for their projects? (Please specify any if known)

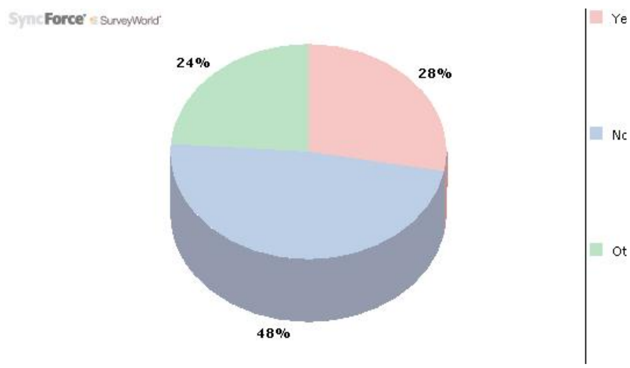


Figure 2. Chart showing the level of awareness of existing support systems for low-cost green materials

Question 14 – Which of the following factors do you consider being important for deciding the choice of low-cost green building materials/components? (Please select all that apply)

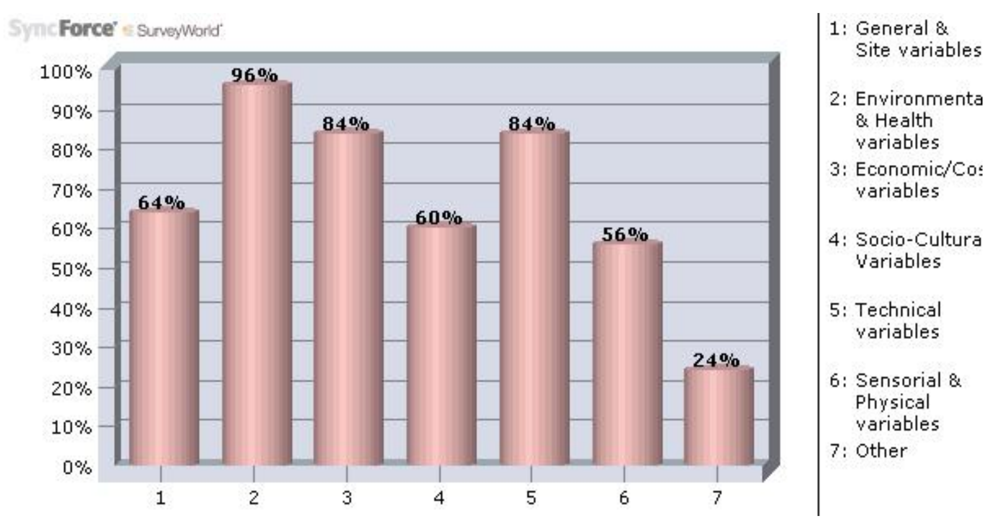


Figure3. Graph showing the relative importance of various groups of material-selection factors/variables

Discussion of Results

The analyses of the study revealed that over half of the respondents agreed to have used LCGBMCs in their designs (see fig. 1). These showed that the majority of the respondents are fairly knowledgeable about the topic, and so were able to offer some insightful views.

In respect of existing tools, the Green Guide to Specification from BREAAM was the most commonly used reference source. This result was not surprising, knowing that the Green Guide is the standard assessment method and information source particularly designed to address issues specific to the UK. It was however, noticeable when analysing the results that some respondents displayed skepticism regarding the usefulness and reliability of existing DSS, in terms of their impacts on LCGBMCs. One respondent stated, "Greenspec Guide is too limited with its product range, and not comprehensive enough or designed to determine the impact assessment of such materials".

In another question, a list of possible categories of sustainable principle indicators/ decision factors derived from the reviewed literature provided respondents the chance to rank each group in terms of their degree of importance as applicable to their views. The result showed that even though a large number of factors influence material choice in construction, environmental factors remain the overarching priority in developed regions.

In summary, none of the respondents made any comment that could imply they believed existing tools could be adopted, which further suggests that potential developers may have to consider a more localized system that can address the priorities of their respective markets. The aim to make the evaluation and selection process more systematic, formed the basis of their recommendations.

With only 50 responses, it was difficult to make any generalisations based on the results, which suggested that further studies be undertaken to fulfill the research aim and objectives.

Appendix D: Survey Questionnaire

SyncForce SurveyWorld

UNIVERSITY OF WESTMINSTER

School of Architecture and the Built Environment,
University of Westminster,
London, UK.
NW1 5LS
Email: i.ogunkah@my.westminster.ac.uk
Contact Phone Number: +44 (0) 208 7900 5000 ext. 3271

Dear (Participant's name),

Research on the Impacts of Low-Cost Green Building Materials on Sustainable Low-Impact Green Energy Housing

The University of Westminster, in conjunction with The Rivers State Sustainable Development Agency (RSSDA) are undertaking a research aimed at investigating "The impacts of LOW-COST GREEN MATERIALS on LOW-IMPACT GREEN HOUSING".

This study aims to; "Develop a Material-Selection Decision Support System (MSDSS), from which data/information appropriate to users' needs can be generated. The research goal is an attempt to ensure greater use of LCGBMCs-materials normally considered as agricultural, post-consumer, or post-industrial waste in mainstream housing. Such materials include; compressed earth blocks, earth or sand bags, bamboo, bales of hay, scrap metals, old blocks, tyres, jean insulation and recycled steel. To achieve this aim, this questionnaire is a survey to ask your views as a key stakeholder and/or an experienced building practitioner concerning the most essential factors or variables that influence the choice of materials at the design stage. You or your organization's participation is totally voluntary. You are guaranteed that responses in this survey will not be identified with you or your organisation, but shall be reported only in the overall analysis of this research.

Instruction: Please kindly indicate by ticking on the appropriate answer(s) or filling in the spaces provided in the questionnaire. Some of the questions require a simple YES/NO answer; some require RANKING/RATING and others are OPEN questions aimed at getting your views and suggestions. Kindly fill out these questions. It will only take a couple of minutes to complete this survey

Thank You!

SyncForce® SurveyWorld® The Research Centre-University of Westminster- UK: A Survey on Low-Cost Green Building Materials

A: GENERAL BACKGROUND

The following questions are about your general knowledge on low-cost green building materials and low-impact green energy housing

Question 1
How do you best describe your self?

○ An Architect
○ A Builder
○ An Engineer
○ A Quantity Surveyor
○ An Urban Designer
○ Other: ____________________________________

Question 2
Approximately, how many Low-Impact Green Energy Housing project(s) have you taken part in?

○ 0 (Not Experienced at all)
○ Less than 5 (Less Experienced)
○ 6-10 (Fairly Experienced)
○ 11-15 (Experienced-Some Experience)
○ More than 15 (Highly Experienced)
○ Other: ____________________________________

Question 3
What aspect of Low-Impact Green Energy Housing production do you play an active role?

○ Design
○ Construction
○ Materials Specification/Costing
○ All aspects
○ Other: ____________________________________
○ N/A

Question 4
As a practising professional in the housing industry, at what stage of building production do you consider the use of Low-Cost Green Building Materials?

○ Tendering/Planning/Decision-making
○ Design Development
○ Final Design
○ Construction
○ Operation
○ Maintenance
○ Other: ____________________________________
○ N/A

Comments-Please give reasons for your answer if any: ____________________________________

Question 5

How much (on a scale of 1-5) do you agree or disagree with the following factors, as obstacles that discourage you from using low-cost green materials in your housing projects? (where 1 = strongly disagree & 5 = strongly agree)

	Strongly Agree				Strongly Disagree
Limited availability of materials in the market	○	○	○	○	○
Maintenance concern	○	○	○	○	○
Lack of familiarity with their construction techniques	○	○	○	○	○
Lack of access to current and relevant information	○	○	○	○	○
Building code restriction	○	○	○	○	○
Perception that local materials are of low status	○	○	○	○	○
Aesthetically less pleasing	○	○	○	○	○
Unwillingness to change from conventional materials	○	○	○	○	○
Clients' preference	○	○	○	○	○
Limited availability & reliability of suppliers	○	○	○	○	○
Low flexibility for alternatives or substitutes	○	○	○	○	○
Uncertainty in the reliability of the project outcome	○	○	○	○	○
Nature of the design or building project	○	○	○	○	○
Contractual agreement	○	○	○	○	○

Comments: Please tell us what you think: ______________________________________

B:YOUR VIEWS ON EXISTING SYSTEMS FOR SELECTING LOW-COST GREEN MATERIALS

The following questions are about your general knowledge on existing green building assessment support systems that aid the informed selection on low-cost green building materials

Question 6

Are you aware of any existing or specific support system(s) available for building professionals that can aid informed decision-trade-offs at the design stage, when selecting low-cost green building materials & components for low-impact green energy housing projects?

- ○ Yes
- ○ No
- ○ Other: ____
- ○ N/A

Comments-Please tell us what you think: ____

If 'YES' to question 6 above, please answer to questions 7-10; if 'NO' to question 6 tick n/a all through and go over to question 11

Question 7

Please kindly identify the name of the support system available for building professionals, if your response was "Yes" to question 6

____

○ N/A

Question 8
For which particular building professional group, is the support system you have identified in question 7 designed for?

○ Architects and Designers
○ Builders
○ Engineers
○ Quantity Surveyors
○ Urban Designers
○ Other: ______________________________________
○ N/A

Comments-Please tell us what you think: ______________________________________

Question 9
How effective is the support system you have identified in question 7?

○ Highly Effective
○ Effective
○ Somewhat Effective
○ Rarely Effective
○ Not Effective At All
○ N/A

Question 10
Please kindly give reasons for your answer to question 9

____

○ N/A

C. YOUR VIEWS ON FACTORS THAT INFLUENCE MATERIAL-SELECTION

The following questions are about your general knowledge on factors that influence the informed selection on low-cost green building materials and components

Question 11
How often do you consider the most essential factors/variables when selecting Low-Cost Green Construction Materials for your design or housing projects?

○ I very often do consider all the essential factors when selecting materials
○ I often or occasionally do, but not very often do I consider all the factors, as previous experience from past projects tend to determine my choice of materials.
○ I less often do, although my method of selection still relies on subjective individual perceptions of values and priorities.
○ I rarely do, as considering the essential factors in my choice of materials may delay me from meeting set targets, knowing the increasingly stringent requirements of the design.
○ I never do, as my choice of materials depends on clients' preferences
○ None of the above applies to my case
○ Other: ____

Comments-Please tell us what you think: ____

Question 12

In the order of priorities, please rank the importance of each of the following groups of factors on a scale of 1 to 10, (where 1= Least Important & 10 = Most Important).

		1	2	3	4	5	6	7	8	9	10
General/Site factors/variables (i.e., relating to site conditions)	Score	○	○	○	○	○	○	○	○	○	○
	Importance	○	○	○	○	○	○	○	○	○	○
Environmental & Health factors/variables (relating to the well-being of the occupants and surrounding environment)	Score	○	○	○	○	○	○	○	○	○	○
	Importance	○	○	○	○	○	○	○	○	○	○
Economic factors/variables (relating to cost and expenses)	Score	○	○	○	○	○	○	○	○	○	○
	Importance	○	○	○	○	○	○	○	○	○	○
Socio-Cultural factors/variables (i.e., relating to the associated customs, knowledge, lifestyle and geographical characteristics of a region)	Score	○	○	○	○	○	○	○	○	○	○
	Importance	○	○	○	○	○	○	○	○	○	○
Technical factors/variables (relating to the performance attributes, conditions or functional requirements of the material)	Score	○	○	○	○	○	○	○	○	○	○
	Importance	○	○	○	○	○	○	○	○	○	○
Sensorial factors/variables (i.e., relating to human senses/emotions such as touch, feel, and smell)	Score	○	○	○	○	○	○	○	○	○	○
	Importance	○	○	○	○	○	○	○	○	○	○

Comments- Please kindly specify if "others'' and tell us what you think generally:

____

Please rate the importance of each of the following sub-factors on a scale of 1 to 5, (where 1 is Not Important at All, and 5 is Extremely Important)?

GENERAL AND SITE FACTORS/VARIABLES

Question 13

How important are the following SITE FACTORS in your choice of materials?

	Extremely Important				Not Important
GS1:Geographic Location of Building Site	○	○	○	○	○
GS2: Material Availability	○	○	○	○	○
GS3: Distance to Market/Material Production Site	○	○	○	○	○
GS4: Building Regulation and Certification for Use	○	○	○	○	○
GS5:Design Criteria and Concept	○	○	○	○	○
GS6:The Type(s) of Natural Disasters Common to the Site	○	○	○	○	○
GS7: The Type of Building Material(s)	○	○	○	○	○
GS8: Project Site Geometry/Setting/Condition	○	○	○	○	○
GS9: Knowledge Base in Construction	○	○	○	○	○
GS10: Building and Space Usage	○	○	○	○	○
GS11: Building Orientation and Spatial Structure	○	○	○	○	○
GS12: Spatial Scale:Building Size and Mass	○	○	○	○	○

Comments-Please list other important factors that ought to have been considered:

____

ENVIRONMENTAL AND HEALTH FACTORS/VARIABLES

Question 14

How important are the following ENVIRONMENTAL/HEALTH FACTORS in your choice of materials?

	Extremely Important				Not Important
EH1: Environmental Statutory Compliance	○	○	○	○	○
EH2: Level of Carbon Emissions/Toxicity	○	○	○	○	○
EH3: Safety and Health of End-users	○	○	○	○	○
EH4: Habitat Disruption:Ozone Depletion Potential	○	○	○	○	○
EH5: The Amount of Pesticide Treatment Required	○	○	○	○	○
EH6: The Climatic Condition of the Region	○	○	○	○	○
EH7: Material Environmental Impact	○	○	○	○	○

Comments-Please list other important factors that ought to have been considered: ______________

COST OR ECONOMIC FACTORS/VARIABLES

Question 15

How important are the following COST/ECONOMIC FACTORS in your choice of materials?

	Extremely Important				Not Important
C1:Life Cycle Cost:Overall Cost Used During the Building Life Span (i.e., Investment, Operation, Maintenance, Demolition and disposal Cost)	○	○	○	○	○
C2:Material Embodied Energy:Cost of Energy Spent in Manufacturing and Transporting Materials to Site	○	○	○	○	○
C3: Economic Status of the Client: The Client's Financial Budget	○	○	○	○	○
C4: Affordability Cost of the Material(s)	○	○	○	○	○
C5: Labour Cost for Installing Material(s)	○	○	○	○	○

Comments-Please list other important factors that ought to have been considered: __________________

SOCIO-CULTURAL FACTORS/VARIABLES

Question 16

How important are the following SOCIO-CULTURAL FACTOR in your choice of materials?

	Extremely Important				Not Important
SC1: Material Compatibility with Cultural Traditions	○	○	○	○	○
SC2: Material Compatibility with Regional Settings	○	○	○	○	○
SC3: Cultural Restriction(s) on Usury	○	○	○	○	○
SC4: Family Structure: Type & Size of Family Unit	○	○	○	○	○
SC5: Client's Preference of Material Type	○	○	○	○	○
SC6:Local Knowledge of the Custom & Lifestyle	○	○	○	○	○

Comments-Please list other important factors that ought to have been considered: __________________

TECHNICAL FACTORS/VARIABLES

Question 17
How important are the following TECHNICAL FACTORS in your choice of materials?

	Extremely Important				Not Important
T1: Recyclability and Reusability: Potential to Use Material After it's Useful Life	○	○	○	○	○
T2: De-mountability: Ease to Remove and Reaffix Materials	○	○	○	○	○
T3: Level of Maintenance Requirement	○	○	○	○	○
T4: Ability to Accommodate Movement/Vibration : Materials Ability to Tolerate Expansion and Contraction	○	○	○	○	○
T5: Availability of the Technical Skills	○	○	○	○	○
T6: Material Fixing: Ease and speed of Method fixing	○	○	○	○	○
T 7 : Resistance to Fire	○	○	○	○	○
T 8 : Resistance to Heat	○	○	○	○	○
T 9 : Resistance to Water/Moisture	○	○	○	○	○
T10: Resistance to Scratch	○	○	○	○	○
T11: Resistance to Weather	○	○	○	○	○
T12: Resistance to Chemicals	○	○	○	○	○
T13: Resistance to Decay	○	○	○	○	○
T14: Weight and Mass of the Material	○	○	○	○	○
T15: Life to Replacement: Durability & Strength	○	○	○	○	○

Comments-Please list other important factors that ought to have been considered:
____

SENSORIAL FACTOR/VARIABLE

Question 18
How important are the following SENSORIAL FACTORS in your choice of materials?

	Extremely Important				Not Important
SN1: Aesthetics, Appearance Or Visual Density	○	○	○	○	○
SN2: Texture of the Material	○	○	○	○	○
SN3: Colour of the Material	○	○	○	○	○
SN4: Temperature and Thermal Capacity	○	○	○	○	○
SN5: Acoustic Property of the Material	○	○	○	○	○
SN6: Odour and Level of off Gassing	○	○	○	○	○
SN7: Thinness and Thickness	○	○	○	○	○
SN8: Glossiness or Roughness of Material	○	○	○	○	○
SN9: Fineness Quality of the Material	○	○	○	○	○
SN10: Lighting Effect of the Material	○	○	○	○	○

Comments-Please list other important factors that ought to have been considered: ___________________

D. GENERAL COMMENTS ON LOW-COST GREEN MATERIALS AND HOUSING

The following questions are about your general knowledge on low-cost green materials, housing, and the proposed support system

Question 19

Most building practitioners have sought to explain the relatively low use of LCGBMCs by pointing out perceived obstacles. Please indicate on a scale of 1-10 (where 1 = Least Relevant & 10= Most Relevant), how relevant each of the following would be, in facilitating the wider-scale use of such materials in the housing industry?

		1	2	3	4	5	6	7	8	9	10
Provision of readily available information specific to the informed selection of low-cost green materials- that can assist decision makers to know whether or not a material is sustainable.	Score	○	○	○	○	○	○	○	○	○	○
	Relevance	○	○	○	○	○	○	○	○	○	○
Subsidising low-cost green building materials and components	Score	○	○	○	○	○	○	○	○	○	○
	Relevance	○	○	○	○	○	○	○	○	○	○
Using highly mechanized and capital-intensive production facilities	Score	○	○	○	○	○	○	○	○	○	○
	Relevance	○	○	○	○	○	○	○	○	○	○
Stringent building regulation (standard specifications, codes & ordinances) for use of Materials	Score	○	○	○	○	○	○	○	○	○	○
	Relevance	○	○	○	○	○	○	○	○	○	○
Setting up workshops to spread awareness to building professionals & clients of their potential economic, environmental and health benefits	Score	○	○	○	○	○	○	○	○	○	○
	Relevance	○	○	○	○	○	○	○	○	○	○
Strong mainstreaming initiatives, and effective implementation of policies that encourage their wider scale use	Score	○	○	○	○	○	○	○	○	○	○
	Relevance	○	○	○	○	○	○	○	○	○	○
Stringent measures and penalties for corruption in the construction industries	Score	○	○	○	○	○	○	○	○	○	○
	Relevance	○	○	○	○	○	○	○	○	○	○
Diversification and decentralization of production technologies	Score	○	○	○	○	○	○	○	○	○	○
	Relevance	○	○	○	○	○	○	○	○	○	○
Import restriction of imported or foreign materials	Score	○	○	○	○	○	○	○	○	○	○
	Relevance	○	○	○	○	○	○	○	○	○	○
Government's adequate funding of research to boost production and wide-scale use	Score	○	○	○	○	○	○	○	○	○	○
	Relevance	○	○	○	○	○	○	○	○	○	○

Comments: Please tell us what you think: ____

Question 20
Please rate the following conditions on a scale of 1-5 as they will likely affect your decision to use the proposed Material Selection Decision Support System. (1= least likely & 5 = most likely)

	Most Likely				Least Likely
Provided the proposed support system will lead me to making more informed choices	○	○	○	○	○
Provided the system will aid minimal uncertainties and errors during the evaluation and selection process	○	○	○	○	○
Provided the system will ensure more sustainable consideration of a larger number of materials alternatives	○	○	○	○	○
Provided the system will quicken the selection process, and NOT necessarily replace my professional judgment(s)	○	○	○	○	○
Provided the information in the system databases are as adequate as not to lead me to source for information elsewhere	○	○	○	○	○
Provided the system is simple, clear and easy to understand and use with little or no practical difficulties	○	○	○	○	○
Provided the system can be adjusted to suit the priorities, context, and needs of different regions	○	○	○	○	○
Provided the system will encourage greater industry acceptance of low-cost green building materials and components	○	○	○	○	○
Provided the proposed system is amenable to create room for improvement and modifications	○	○	○	○	○
Provided the system will keep up-to-date on new information	○	○	○	○	○
Provided the system meets all the above conditions	○	○	○	○	○

Comments- Please specify if "others'' and tell us what you think generally: ______________________

Thank you for helping out with this study!

Appendix E: Interview Questionnaire

Introduction-This interview is to investigate the views of building professionals who are strongly identified with use of low-cost green building materials in Nigeria.

Aim- This research is aimed at developing a MCDM (Multi-Criteria Decision Support Model) that will facilitate the progress of design decision-making in the selection of low-cost green building materials and components.

Purpose- The purpose of the prototype model is to enable designers analyse and understand the impacts of the materials at the design stage before they are used for construction. By evaluating multiple alternatives simultaneously designers are able to make informed decisions.

Section A: General Information

1. How do you best describe your self?

- ◌ An Architect
- ◌ A Builder
- ◌ An Engineer
- ◌ A Quantity Surveyor
- ◌ An Urban Designer
- ◌ Other:

2. How much of experience would you say you possess in terms of Low Impact Green Housing (LIGHD) design or projects?

a. Do you have any experience of Low Cost Green Housing (LCGHs) design using low-cost green materials?

b. If Yes, how many years?

3. Which stage of the design process would you say needs more focus in terms of decision support for the selection of LCGBMCs in housing design projects?

- ◌ Preparation Stage
- ◌ Concept Design Stage
- ◌ Design Development
- ◌ Technical Design Stage
- ◌ All Design Stages

Section B: Barriers and Measures

4. What do you think are the barriers to low-impact green housing design and delivery in Nigeria?

a. (Interviewees to list the barriers)
b. Some Common Barriers

5. What do you think would be the barriers that hinder greater use of low-cost green building materials in the housing industry?

a. (Interviewees to list the barriers)
b. Some Common Barriers

6. What do you think would be justifiable measures needed to promote greater use of LCGBM in mainstream housing?

a. (Architects to list the barriers)
b. Some Common Barriers

7. What decision support tools do you think designers would need for Low Impact Green Housing Design? (What have you been using for your design of LIGHDs?)

a. Design and building professionals to List the known Support /Tools
b. Some Proposed Support /Tools
c. What type of tools do you use at the moment for your design of LCGHs?

Section C: Design Information Requirements

8. What features of the DSS model would you say are essential to be included in the decision making process?

9. What type of information in the form of material selection information requirements should be incorporated in the Decision Support System (DSS) model?

a. What type / categories of material and component information should be included in the DSS?

10.How would you want the information on material and components to be presented?

Please provide further matters of importance that ought to have been considered in the development of the tool and suggest areas that need further improvement.

Appendix F: Results of Factor Analysis for Sub-Categories of Material Selection Factors

Correlation Matrix for General/Site (GS) Factors Using "Varimax/Orthogonal" Rotation

		GS1	GS2	GS3	GS4	GS5	GS6	GS7	GS8	GS9	GS10	GS11	GS12
Correlation	GS1	1.000	.622	.244	.292	.295	.372	.310	.409	.397	.372	.289	.321
	GS2	.622	1.000	.446	.486	.449	.497	.537	.464	.487	.465	.282	.389
	GS3	.244	.446	1.000	.523	.436	.325	.310	.399	.346	.299	.286	.312
	GS4	.292	.486	.523	1.000	.714	.559	.559	.494	.488	.393	.435	.458
	GS5	.295	.449	.436	.714	1.000	.578	.621	.608	.659	.420	.566	.527
	GS6	.372	.497	.325	.559	.578	1.000	.641	.531	.586	.480	.529	.561
	GS7	.310	.537	.310	.559	.621	.641	1.000	.549	.615	.581	.434	.529
	GS8	.409	.464	.399	.494	.608	.531	.549	1.000	.579	.443	.605	.577
	GS9	.397	.487	.346	.488	.659	.586	.615	.579	1.000	.604	.526	.535
	GS10	.372	.465	.299	.393	.420	.480	.581	.443	.604	1.000	.501	.470
	GS11	.289	.282	.286	.435	.566	.529	.434	.605	.526	.501	1.000	.786
	GS12	.321	.389	.312	.458	.527	.561	.529	.577	.535	.470	.786	1.000

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.883
Bartlett's Test of Sphericity	Approx. Chi-Square	1468.871
	df	66
	Sig.	.000

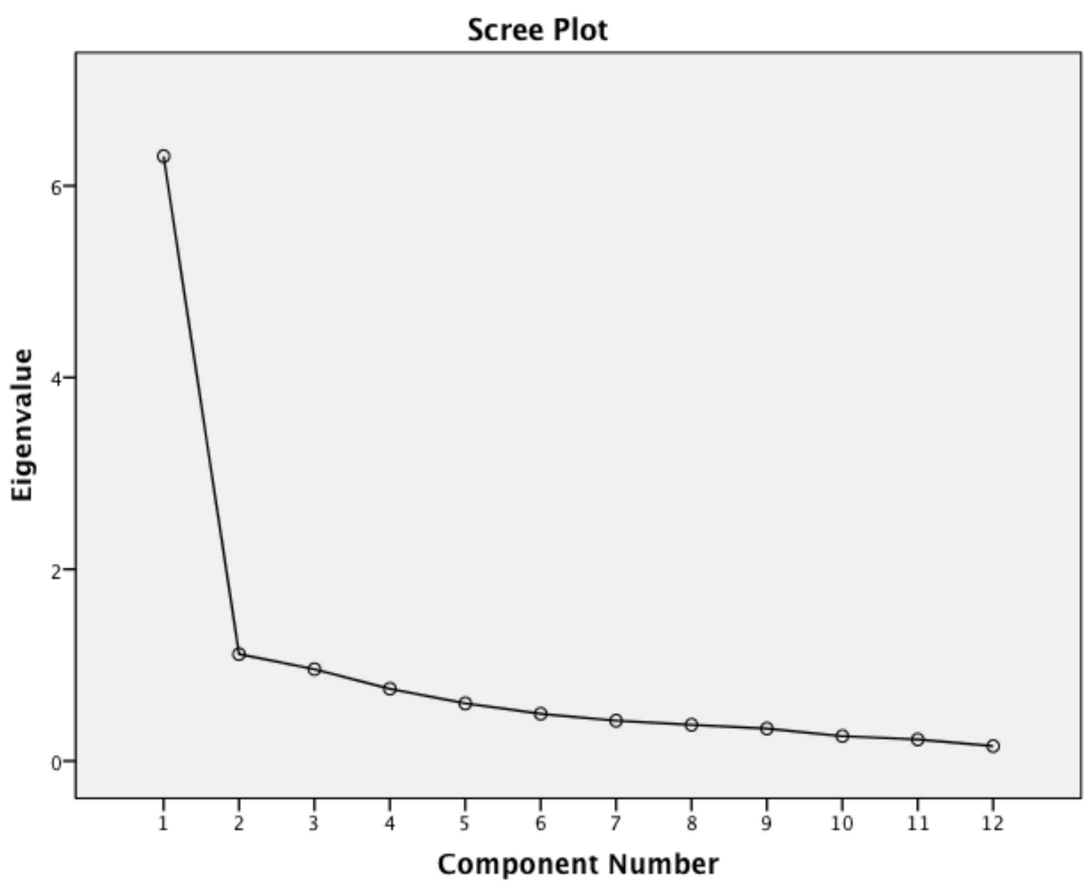
Component Transformation Matrix

Component	1	2
1	.812	.583
2	-.583	.812

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	Variance %	Cumulative %	Total	Variance %	Cumulative %	Total	% of Variance	Cumulative %
1	6.308	52.571	52.571	6.308	52.571	52.571	4.543	37.857	37.857
2	1.114	9.284	61.854	1.114	9.284	61.854	2.880	23.997	61.854
3	.957	7.974	69.829						
4	.753	6.274	76.103						
5	.601	5.005	81.108						
6	.492	4.104	85.212						
7	.420	3.500	88.713						
8	.378	3.147	91.860						
9	.338	2.819	94.679						
10	.259	2.159	96.838						
11	.224	1.869	98.707						
12	.155	1.293	100.000						



Component Matrix[a]

	Component	
	1	2
Design Concept	.805	
Knowledge Base in Construction	.796	
The Type of Building Material(s)	.783	
The Type(s) of Natural Disasters Common to the Site	.777	
Project Site Geometry/Setting/Condition	.773	
Spatial Scale: Building Size and Mass	.754	-.381
Building Regulation and Certification for Use	.741	
Building Orientation	.728	-.482
Building and Space Usage	.695	
Material Availability	.694	.562
Distance	.548	
Geographic Location of Building Site	.546	.545

Extraction Method: Principal Component Analysis.
a. 2 components extracted.

Rotated Component Matrix[a]

	Component	
	1	2
Building Orientation	.873	
Spatial Scale: Building Size and Mass	.835	
Design Concept	.724	.372
Project Site Geometry/Setting/Condition	.686	.371
Knowledge Base in Construction	.675	.426
The Type(s) of Natural Disasters Common to the Site	.666	.405
The Type of Building Material(s)	.644	.446
Building Regulation and Certification for Use	.562	.489
Building and Space Usage	.562	.410
Material Availability		.861
Geographic Location of Building Site		.761
Distance		.561

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 3 iterations.

Reproduced Correlations

		GS1	GS2	GS3	GS4	GS5	GS6	GS7	GS8	GS9	GS10	GS11	GS12
Reproduced Correlation	GS1	.595[a]	.685	.461	.442	.374	.392	.420	.368	.408	.382	.135	.203
	GS2	.685	.797[a]	.547	.553	.491	.506	.536	.481	.525	.485	.234	.308
	GS3	.461	.547	.389[a]	.427	.406	.409	.426	.395	.422	.383	.256	.300
	GS4	.442	.553	.427	.554[a]	.588	.572	.580	.567	.587	.516	.507	.532
	GS5	.374	.491	.406	.588	.662[a]	.633	.632	.634	.647	.559	.644	.652
	GS6	.392	.506	.409	.572	.633	.608[a]	.609	.607	.622	.540	.595	.608
	GS7	.420	.536	.426	.580	.632	.609	.613[a]	.607	.624	.544	.576	.595
	GS8	.368	.481	.395	.567	.634	.607	.607	.608[a]	.621	.537	.611	.621
	GS9	.408	.525	.422	.587	.647	.622	.624	.621	.636[a]	.553	.603	.618
	GS10	.382	.485	.383	.516	.559	.540	.544	.537	.553	.483[a]	.504	.522
	GS11	.135	.234	.256	.507	.644	.595	.576	.611	.603	.504	.763[a]	.733
	GS12	.203	.308	.300	.532	.652	.608	.595	.621	.618	.522	.733	.714[a]
Residual[b]	GS1		-.062	-.217	-.150	-.079	-.020	-.110	.041	-.011	-.010	.155	.118
	GS2	-.062		-.101	-.067	-.042	-.009	.001	-.017	-.038	-.020	.048	.081
	GS3	-.217	-.101		.096	.030	-.084	-.116	.004	-.077	-.084	.029	.012
	GS4	-.150	-.067	.096		.125	-.013	-.021	-.073	-.099	-.123	-.072	-.074
	GS5	-.079	-.042	.030	.125		-.054	-.011	-.027	.012	-.139	-.078	-.125
	GS6	-.020	-.009	-.084	-.013	-.054		.032	-.076	-.036	-.060	-.066	-.048
	GS7	-.110	.001	-.116	-.021	-.011	.032		-.058	-.009	.036	-.143	-.066
	GS8	.041	-.017	.004	-.073	-.027	-.076	-.058		-.042	-.094	-.006	-.044
	GS9	-.011	-.038	-.077	-.099	.012	-.036	-.009	-.042		.051	-.077	-.084
	GS10	-.010	-.020	-.084	-.123	-.139	-.060	.036	-.094	.051		-.003	-.052
	GS11	.155	.048	.029	-.072	-.078	-.066	-.143	-.006	-.077	-.003		.053
	GS12	.118	.081	.012	-.074	-.125	-.048	-.066	-.044	-.084	-.052	.053	

Extraction Method: Principal Component Analysis.
a. Reproduced communalities
b. Residuals are computed between observed and reproduced correlations. There are 37 (56.0%) non-redundant residuals with absolute values greater than 0.05.

Correlation Matrix for General/Site (GS) Factors Using "Direct Oblimin/Oblique" Rotation

		GS1	GS2	GS3	GS4	GS5	GS6	GS7	GS8	GS9	GS10	GS11	GS12
Correlation	GS1	1.000	.622	.244	.292	.295	.372	.310	.409	.397	.372	.289	.321
	GS2	.622	1.000	.446	.486	.449	.497	.537	.464	.487	.465	.282	.389
	GS3	.244	.446	1.000	.523	.436	.325	.310	.399	.346	.299	.286	.312
	GS4	.292	.486	.523	1.000	.714	.559	.559	.494	.488	.393	.435	.458
	GS5	.295	.449	.436	.714	1.000	.578	.621	.608	.659	.420	.566	.527
	GS6	.372	.497	.325	.559	.578	1.000	.641	.531	.586	.480	.529	.561
	GS7	.310	.537	.310	.559	.621	.641	1.000	.549	.615	.581	.434	.529
	GS8	.409	.464	.399	.494	.608	.531	.549	1.000	.579	.443	.605	.577
	GS9	.397	.487	.346	.488	.659	.586	.615	.579	1.000	.604	.526	.535
	GS10	.372	.465	.299	.393	.420	.480	.581	.443	.604	1.000	.501	.470
	GS11	.289	.282	.286	.435	.566	.529	.434	.605	.526	.501	1.000	.786
	GS12	.321	.389	.312	.458	.527	.561	.529	.577	.535	.470	.786	1.000

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.883
Bartlett's Test of Sphericity	Approx. Chi-Square	1468.871
	df	66
	Sig.	.000

Communalities[a]

	Initial	Extraction
Geographic Location of Building Site	.439	.261
Material Availability	.591	.514
Distance	.352	.270
Building Regulation and Certification for Use	.605	.533
Design Concept	.693	.629
The Type(s) of Natural Disasters Common to the Site	.552	.573
The Type of Building Material(s)	.629	.629
Project Site Geometry/Setting/Condition	.550	.557
Knowledge Base in Construction	.611	.599
Building and Space Usage	.508	.437
Building Orientation	.711	.999
Spatial Scale: Building Size and Mass	.677	.670

Extraction Method: Maximum Likelihood.

a. One or more communality estimates greater than 1 were encountered during iterations. The resulting solution should be interpreted with caution.

Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	6.308	52.571	52.571	3.766	31.379	31.379	3.716
2	1.114	9.284	61.854	2.904	24.203	55.582	5.602
3	.957	7.974	69.829				
4	.753	6.274	76.103				
5	.601	5.005	81.108				
6	.492	4.104	85.212				
7	.420	3.500	88.713				
8	.378	3.147	91.860				
9	.338	2.819	94.679				
10	.259	2.159	96.838				
11	.224	1.869	98.707				
12	.155	1.293	100.000				

Extraction Method: Maximum Likelihood.
a. When factors are correlated, sums of squared loadings cannot be added to obtain a total variance.

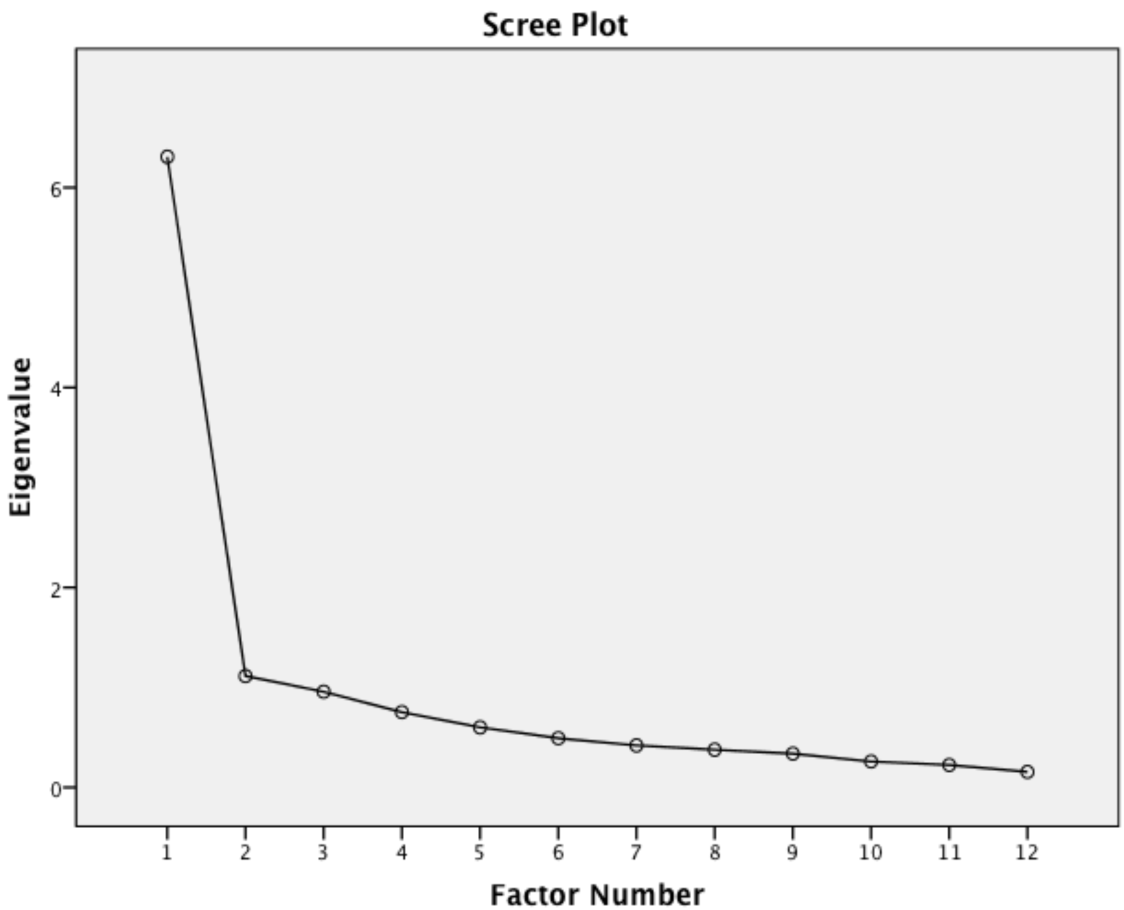
Factor Matrix[a]

	Factor	
	1	2
Building Orientation	.999	-.006
Spatial Scale: Building Size and Mass	.788	.222
Project Site Geometry/Setting/Condition	.608	.433
Design Concept	.570	.551
Building and Space Usage	.504	.428
The Type of Building Material(s)	.438	.662
Material Availability	.286	.657
Building Regulation and Certification for Use	.438	.584
Knowledge Base in Construction	.529	.565
The Type(s) of Natural Disasters Common to the Site	.532	.538
Distance	.288	.432
Geographic Location of Building Site	.292	.419

Extraction Method: Maximum Likelihood.
a. 2 factors extracted. 6 iterations required.

Goodness-of-fit Test

Chi-Square	df	Sig.
183.634	43	.000



Reproduced Correlations

		GS1	GS2	GS3	GS4	GS5	GS6	GS7	GS8	GS9	GS10	GS11	GS12
Reproduced Correlation	GS1	.261[a]	.359	.265	.373	.397	.381	.405	.359	.391	.326	.289	.323
	GS2	.359	.514[a]	.366	.509	.525	.506	.560	.459	.523	.425	.282	.371
	GS3	.265	.366	.270[a]	.378	.402	.386	.412	.362	.396	.330	.286	.323
	GS4	.373	.509	.378	.533[a]	.572	.547	.578	.519	.562	.471	.435	.475
	GS5	.397	.525	.402	.572	.629[a]	.600	.614	.585	.613	.523	.566	.571
	GS6	.381	.506	.386	.547	.600	.573[a]	.589	.557	.585	.498	.529	.538
	GS7	.405	.560	.412	.578	.614	.589	.629[a]	.553	.605	.504	.434	.492
	GS8	.359	.459	.362	.519	.585	.557	.553	.557[a]	.566	.492	.605	.575
	GS9	.391	.523	.396	.562	.613	.585	.605	.566	.599[a]	.508	.526	.542
	GS10	.326	.425	.330	.471	.523	.498	.504	.492	.508	.437[a]	.501	.492
	GS11	.289	.282	.286	.435	.566	.529	.434	.605	.526	.501	.999[a]	.786
	GS12	.323	.371	.323	.475	.571	.538	.492	.575	.542	.492	.786	.670[a]
Residual[b]	GS1		.263	-.021	-.080	-.103	-.009	-.095	.050	.006	.045	9.635E-005	-.002
	GS2	.263		.080	-.023	-.077	-.009	-.023	.006	-.036	.040	1.646E-006	.018
	GS3	-.021	.080		.144	.033	-.061	-.102	.037	-.050	-.031	4.138E-005	-.011
	GS4	-.080	-.023	.144		.142	.012	-.020	-.026	-.073	-.077	2.034E-005	-.017
	GS5	-.103	-.077	.033	.142		-.021	.007	.022	.046	-.103	6.279E-005	-.044
	GS6	-.009	-.009	-.061	.012	-.021		.052	-.025	.000	-.018	-9.272E-006	.022
	GS7	-.095	-.023	-.102	-.020	.007	.052		-.004	.010	.077	.000	.037
	GS8	.050	.006	.037	-.026	.022	-.025	-.004		.012	-.048	1.287E-005	.001
	GS9	.006	-.036	-.050	-.073	.046	.000	.010	.012		.096	-5.952E-005	-.008
	GS10	.045	.040	-.031	-.077	-.103	-.018	.077	-.048	.096		.000	-.021
	GS11	9.635E-005	1.646E-006	4.138E-005	2.034E-005	6.279E-005	-9.272E-006	.000	1.287E-005	-5.952E-005	.000		3.268E-005
	GS12	-.002	.018	-.011	-.017	-.044	.022	.037	.001	-.008	-.021	3.268E-005	

Extraction Method: Maximum Likelihood.
a. Reproduced communalities
b. Residuals are computed between observed and reproduced correlations. There are 17 (25.0%) non-redundant residuals with absolute values greater than 0.05.

Pattern Matrix[a]

	Factor	
	1	2
Building Orientation	.997	
Spatial Scale: Building Size and Mass	.623	
The Type of Building Material(s)		.816
Material Availability		.809
Building Regulation and Certification for Use		.721
Knowledge Base in Construction		.699
Design Concept		.683
The Type(s) of Natural Disasters Common to the Site		.666
Project Site Geometry/Setting/Condition		.538
Distance		.533
Building and Space Usage		.530
Geographic Location of Building Site		.518

Extraction Method: Maximum Likelihood.
Rotation Method: Oblimin with Kaiser Normalization.
a. Rotation converged in 6 iterations.

Factor Correlation Matrix

Factor	1	2
1	1.000	.579
2	.579	1.000

Extraction Method: Maximum Likelihood.
Rotation Method: Oblimin with Kaiser Normalization.

Goodness-of-fit Test

Chi-Square	df	Sig.
165.133	14	.000

Correlation Matrix for Environmental/Health Factors

		EH1	EH2	EH3	EH4	EH5	EH6	EH7
Correlation	EH1	1.000	.569	.538	.475	.336	.363	.370
	EH2	.569	1.000	.653	.767	.580	.545	.579
	EH3	.538	.653	1.000	.678	.550	.706	.701
	EH4	.475	.767	.678	1.000	.738	.603	.663
	EH5	.336	.580	.550	.738	1.000	.536	.611
	EH6	.363	.545	.706	.603	.536	1.000	.834
	EH7	.370	.579	.701	.663	.611	.834	1.000
Sig. (1-tailed)	EH1		.000	.000	.000	.000	.000	.000
	EH2	.000		.000	.000	.000	.000	.000
	EH3	.000	.000		.000	.000	.000	.000
	EH4	.000	.000	.000		.000	.000	.000
	EH5	.000	.000	.000	.000		.000	.000
	EH6	.000	.000	.000	.000	.000		.000
	EH7	.000	.000	.000	.000	.000	.000	

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.867
Bartlett's Test of Sphericity	Approx. Chi-Square	1027.062
	df	21
	Sig.	.000

Communalities

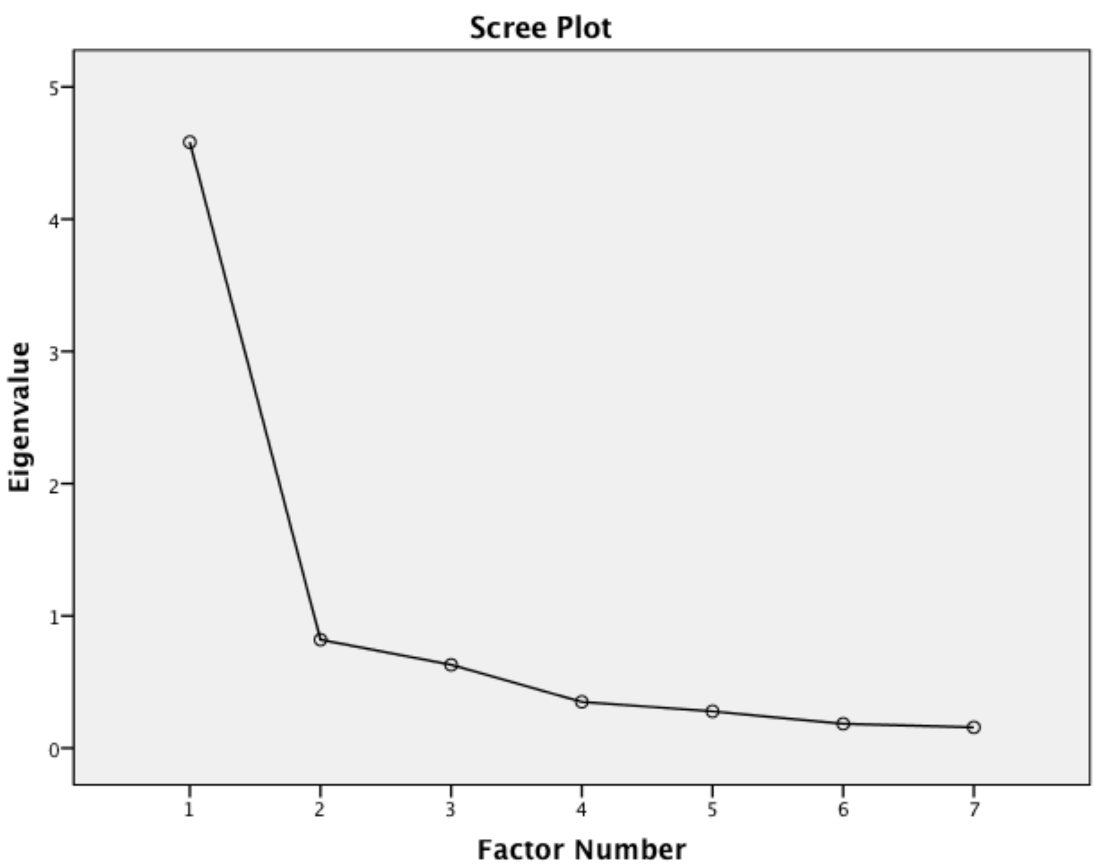
	Initial	Extraction
Environmental Statutory Compliance	.380	.301
Level of Carbon Emissions and Toxicity	.655	.620
Safety and Health of End-users	.656	.687
Habitat Disruption: Ozone Depletion Potential	.743	.725
The Amount of Pesticide Treatment Required	.572	.542
The Climatic Condition of the Region	.725	.642
Material Environmental Impact	.750	.699

Extraction Method: Maximum Likelihood.

Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.582	65.458	65.458	4.215	60.217	60.217
2	.820	11.710	77.168			
3	.630	8.995	86.163			
4	.350	4.993	91.157			
5	.278	3.970	95.126			
6	.184	2.626	97.752			
7	.157	2.248	100.000			

Extraction Method: Maximum Likelihood.



Factor Matrix[a]

	Factor
	1
Habitat Disruption: Ozone Depletion Potential	.851
Material Environmental Impact	.836
Safety and Health of End-users	.829
The Climatic Condition of the Region	.801
Level of Carbon Emissions and Toxicity	.787
The Amount of Pesticide Treatment Required	.736
Environmental Statutory Compliance	.549

Extraction Method: Maximum Likelihood.
a. 1 factors extracted. 4 iterations required.

Reproduced Correlations

		EH1	EH2	EH3	EH4	EH5	EH6	EH7
Reproduced Correlation	EH1	.301[a]	.432	.455	.467	.404	.440	.459
	EH2	.432	.620[a]	.652	.670	.580	.631	.658
	EH3	.455	.652	.687[a]	.706	.610	.664	.693
	EH4	.467	.670	.706	.725[a]	.627	.682	.712
	EH5	.404	.580	.610	.627	.542[a]	.590	.615
	EH6	.440	.631	.664	.682	.590	.642[a]	.670
	EH7	.459	.658	.693	.712	.615	.670	.699[a]
Residual[b]	EH1		.137	.083	.008	-.068	-.077	-.089
	EH2	.137		.001	.097	.001	-.085	-.079
	EH3	.083	.001		-.028	-.060	.042	.008
	EH4	.008	.097	-.028		.111	-.079	-.048
	EH5	-.068	.001	-.060	.111		-.054	-.005
	EH6	-.077	-.085	.042	-.079	-.054		.165
	EH7	-.089	-.079	.008	-.048	-.005	.165	

Extraction Method: Maximum Likelihood.
a. Reproduced communalities
b. Residuals are computed between observed and reproduced correlations. There are 13 (61.0%) non-redundant residuals with absolute values greater than 0.05.

Correlation Matrix for Economic/Cost Factors

		C1	C2	C3	C4	C5
Correlation	C1	1.000	.629	.586	.647	.597
	C2	.629	1.000	.381	.455	.523
	C3	.586	.381	1.000	.763	.639
	C4	.647	.455	.763	1.000	.817
	C5	.597	.523	.639	.817	1.000
Sig. (1-tailed)	C1		.000	.000	.000	.000
	C2	.000		.000	.000	.000
	C3	.000	.000		.000	.000
	C4	.000	.000	.000		.000
	C5	.000	.000	.000	.000	

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.794
Bartlett's Test of Sphericity	Approx. Chi-Square	648.915
	df	10
	Sig.	.000

Communalities

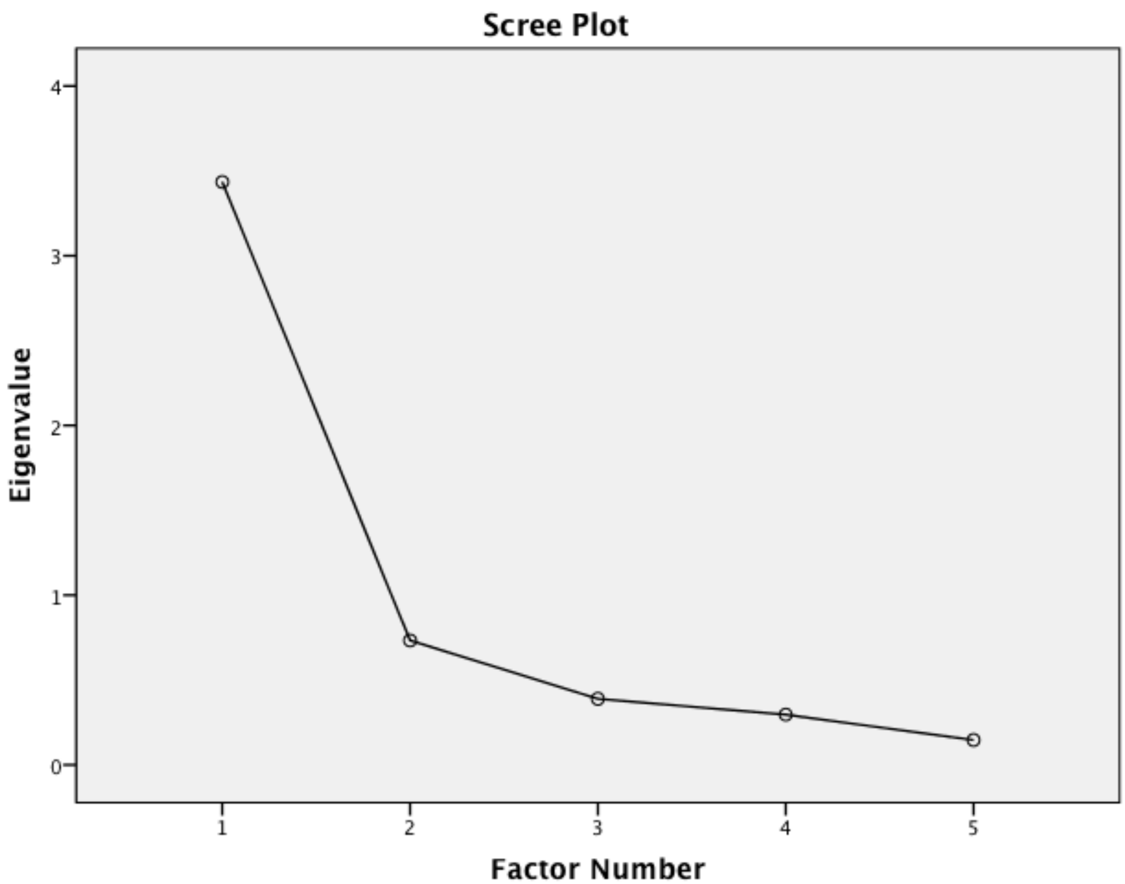
	Initial	Extraction
Life Cycle Cost	.575	.509
Material Embodied Energy Cost	.440	.295
Capital Cost (Economic Status of the Client)	.598	.628
Maintenance or Replacement Cost	.778	.879
Labour or Installation Cost	.697	.742

Extraction Method: Maximum Likelihood.

Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.435	68.700	68.700	3.054	61.078	61.078
2	.733	14.664	83.364			
3	.389	7.785	91.149			
4	.296	5.920	97.070			
5	.147	2.930	100.000			

Extraction Method: Maximum Likelihood.



Factor Matrix[a]

	Factor
	1
Maintenance or Replacement Cost	.938
Labour or Installation Cost	.861
Capital Cost (Economic Status of the Client)	.793
Life Cycle Cost	.714
Material Embodied Energy Cost	.544

Extraction Method: Maximum Likelihood.
a. 1 factors extracted. 5 iterations required.

Goodness-of-fit Test

Chi-Square	df	Sig.
61.126	5	.000

Reproduced Correlations

		C1	C2	C3	C4	C5
Reproduced Correlation	C1	.509[a]	.388	.566	.669	.615
	C2	.388	.295[a]	.431	.510	.468
	C3	.566	.431	.628[a]	.743	.683
	C4	.669	.510	.743	.879[a]	.808
	C5	.615	.468	.683	.808	.742[a]
Residual[b]	C1		.241	.021	-.022	-.017
	C2	.241		-.050	-.055	.055
	C3	.021	-.050		.020	-.044
	C4	-.022	-.055	.020		.010
	C5	-.017	.055	-.044	.010	

Extraction Method: Maximum Likelihood.

a. Reproduced communalities

b. Residuals are computed between observed and reproduced correlations. There are 3 (30.0%) non-redundant residuals with absolute values greater than 0.05.

Correlation Matrix for Socio-Cultural Factors

		SC1	SC2	SC3	SC4	SC5	SC6
Correlation	SC1	1.000	.780	.675	.225	.369	.544
	SC2	.780	1.000	.759	.286	.407	.632
	SC3	.675	.759	1.000	.402	.457	.560
	SC4	.225	.286	.402	1.000	.451	.360
	SC5	.369	.407	.457	.451	1.000	.506
	SC6	.544	.632	.560	.360	.506	1.000
Sig. (1-tailed)	SC1		.000	.000	.001	.000	.000
	SC2	.000		.000	.000	.000	.000
	SC3	.000	.000		.000	.000	.000
	SC4	.001	.000	.000		.000	.000
	SC5	.000	.000	.000	.000		.000
	SC6	.000	.000	.000	.000	.000	

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.831
Bartlett's Test of Sphericity	Approx. Chi-Square	626.700
	df	15
	Sig.	.000

Communalities

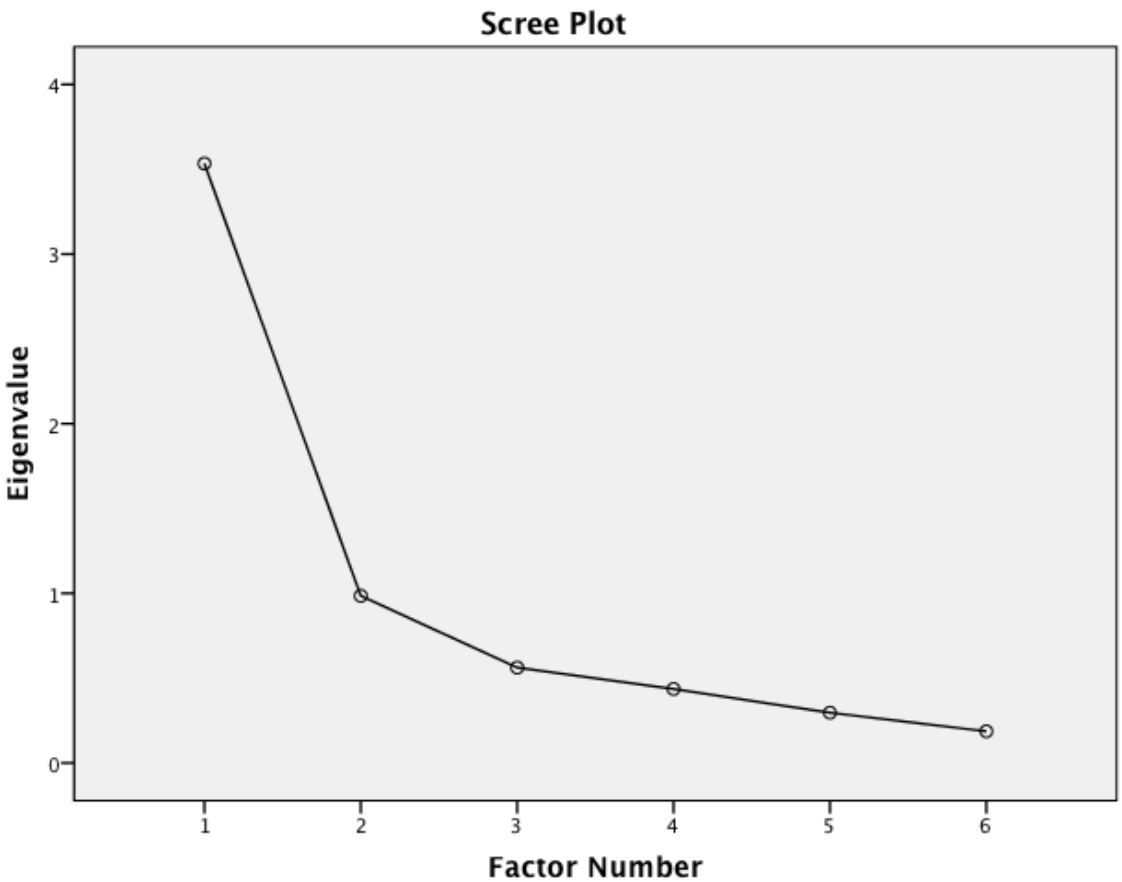
	Initial	Extraction
Material Compatibility with Cultural Traditions	.630	.682
Material Compatibility with Regional Settings	.734	.834
Cultural Restriction(s) on Usury	.638	.693
Family Structure: Type & Size of Family Unit	.270	.143
Local Knowledge of the Custom & Lifestyle	.360	.255
Material Compatibility with Cultural Traditions	.486	.484

Extraction Method: Maximum Likelihood.

Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.534	58.898	58.898	3.090	51.498	51.498
2	.985	16.421	75.320			
3	.562	9.368	84.688			
4	.436	7.266	91.954			
5	.296	4.938	96.892			
6	.186	3.108	100.000			

Extraction Method: Maximum Likelihood.



Factor Matrix[a]

	Factor
	1
Material Compatibility with Regional Settings	.913
Cultural Restriction(s) on Usury	.833
Material Compatibility with Cultural Traditions	.826
Material Compatibility with Cultural Traditions	.695
Local Knowledge of the Custom & Lifestyle	.505
Family Structure: Type & Size of Family Unit	.378

Extraction Method: Maximum Likelihood.
a. 1 factors extracted. 5 iterations required.

Goodness-of-fit Test

Chi-Square	df	Sig.
61.017	9	.000

Reproduced Correlations

		SC1	SC2	SC3	SC4	SC5	SC6
Reproduced Correlation	SC1	.682[a]	.754	.687	.312	.417	.574
	SC2	.754	.834[a]	.760	.345	.461	.635
	SC3	.687	.760	.693[a]	.315	.420	.579
	SC4	.312	.345	.315	.143[a]	.191	.263
	SC5	.417	.461	.420	.191	.255[a]	.351
	SC6	.574	.635	.579	.263	.351	.484[a]
Residual[b]	SC1		.027	-.013	-.087	-.048	-.030
	SC2	.027		-.001	-.059	-.054	-.003
	SC3	-.013	-.001		.088	.037	-.019
	SC4	-.087	-.059	.088		.260	.097
	SC5	-.048	-.054	.037	.260		.155
	SC6	-.030	-.003	-.019	.097	.155	

Extraction Method: Maximum Likelihood.
a. Reproduced communalities

b. Residuals are computed between observed and reproduced correlations. There are 7 (46.0%) non-redundant residuals with
absolute values greater than 0.05.

Correlation Matrix for Technical Factors

		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
Correlation	T1	1.000	.667	.475	.550	.343	.406	.470	.422	.413	.479	.482	.471	.416	.389	.062
	T2	.667	1.000	.631	.622	.554	.627	.440	.418	.487	.522	.454	.563	.488	.599	.148
	T3	.475	.631	1.000	.733	.760	.658	.631	.640	.779	.419	.746	.562	.629	.562	.174
	T4	.550	.622	.733	1.000	.668	.637	.627	.635	.632	.527	.661	.588	.640	.541	.175
	T5	.343	.554	.760	.668	1.000	.736	.631	.656	.746	.344	.683	.460	.586	.577	.183
	T6	.406	.627	.658	.637	.736	1.000	.542	.608	.649	.570	.623	.603	.695	.583	.189
	T7	.470	.440	.631	.627	.631	.542	1.000	.796	.830	.477	.790	.610	.597	.517	.110
	T8	.422	.418	.640	.635	.656	.608	.796	1.000	.816	.573	.798	.644	.586	.555	.204
	T9	.413	.487	.779	.632	.746	.649	.830	.816	1.000	.482	.859	.636	.731	.574	.208
	T10	.479	.522	.419	.527	.344	.570	.477	.573	.482	1.000	.553	.757	.591	.602	.164
	T11	.482	.454	.746	.661	.683	.623	.790	.798	.859	.553	1.000	.626	.684	.577	.217
	T12	.471	.563	.562	.588	.460	.603	.610	.644	.636	.757	.626	1.000	.780	.737	.194
	T13	.416	.488	.629	.640	.586	.695	.597	.586	.731	.591	.684	.780	1.000	.665	.199
	T14	.389	.599	.562	.541	.577	.583	.517	.555	.574	.602	.577	.737	.665	1.000	.193
	T15	.062	.148	.174	.175	.183	.189	.110	.204	.208	.164	.217	.194	.199	.193	1.000
Sig. (1-tailed)	T1		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.186
	T2	.000		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.016
	T3	.000	.000		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.006
	T4	.000	.000	.000		.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.006
	T5	.000	.000	.000	.000		.000	.000	.000	.000	.000	.000	.000	.000	.000	.004
	T6	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000	.000	.000	.000	.003
	T7	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000	.000	.000	.056
	T8	.000	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000	.000	.002
	T9	.000	.000	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000	.000	.001
	T10	.000	.000	.000	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000	.009
	T11	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000		.000	.000	.000	.001
	T12	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000		.000	.000	.002
	T13	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000		.000	.002
	T14	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000		.003
	T15	.186	.016	.006	.006	.004	.003	.056	.002	.001	.009	.001	.002	.002	.003	

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.902
Bartlett's Test of Sphericity	Approx. Chi-Square	2848.547
	df	105
	Sig.	.000

Communalities

	Initial	Extraction
Recyclability and Reusability	.570	.400
Ease to Remove and Reaffix	.729	.737
Level of Maintenance Requirement	.778	.779
Ability to Tolerate Expansion and Contraction	.698	.661
Availability of the Technical Skills	.773	.752
Ease and Speed of Method fixing	.722	.653
Resistance to Fire	.775	.752
Resistance to Heat	.793	.762
Resistance to Moisture	.887	.909
Resistance to Scratch	.672	.643
Resistance to Weather	.817	.822
Resistance to Chemicals	.808	.918
Resistance to Decay	.791	.705
Weight and Mass of the Material	.660	.631
Life Expectancy	.090	.052

Extraction Method: Maximum Likelihood.

Goodness-of-fit Test

Chi-Square	df	Sig.
295.235	63	.000

Total Variance Explained

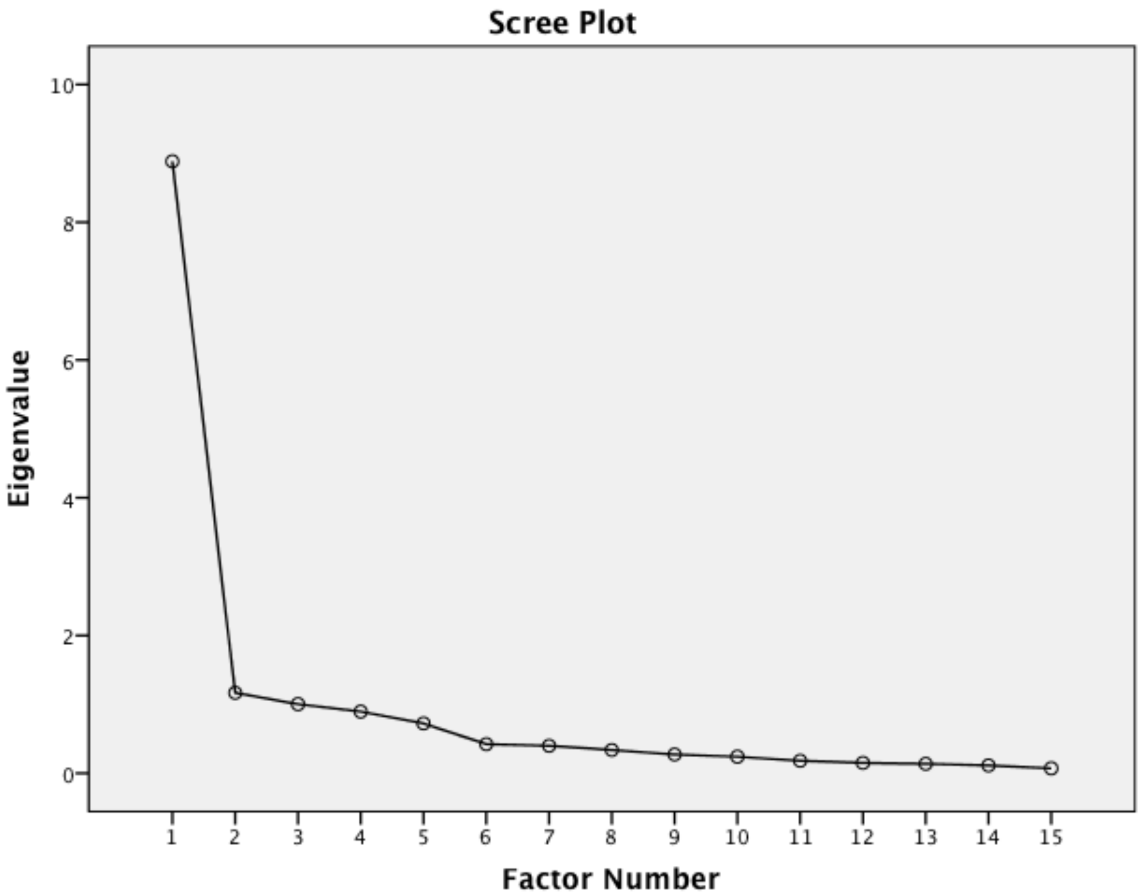
Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	8.884	59.227	59.227	8.561	57.073	57.073	7.528
2	1.168	7.786	67.013	.877	5.849	62.921	5.787
3	1.003	6.689	73.701	.737	4.916	67.837	5.471
4	.895	5.969	79.670				
5	.723	4.822	84.492				
6	.423	2.818	87.309				
7	.399	2.662	89.971				
8	.338	2.256	92.227				
9	.272	1.815	94.042				
10	.240	1.603	95.645				
11	.181	1.207	96.852				
12	.151	1.003	97.855				
13	.137	.912	98.767				
14	.114	.759	99.526				
15	.071	.474	100.000				

Extraction Method: Maximum Likelihood.
a. When factors are correlated, sums of squared loadings cannot be added to obtain a total variance.

Factor Matrix[a]

	Factor		
	1	2	3
Resistance to Moisture	.900	-.284	-.134
Resistance to Weather	.870	-.221	-.124
Resistance to Heat	.837	-.159	-.191
Resistance to Chemicals	.832	.460	-.119
Resistance to Decay	.823	.159	-.042
Resistance to Fire	.821	-.209	-.187
Level of Maintenance Requirement	.817	-.222	.248
Ability to Tolerate Expansion and Contraction	.770	-.039	.258
Ease and Speed of Method fixing	.767	.005	.254
Availability of the Technical Skills	.766	-.319	.252
Weight and Mass of the Material	.742	.265	.103
Resistance to Scratch	.684	.417	-.034
Ease to Remove and Reaffix	.658	.173	.523
Recyclability and Reusability	.556	.126	.274
Life Expectancy	.228	.013	.000

Extraction Method: Maximum Likelihood.
a. 3 factors extracted. 7 iterations required.


Scree Plot
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Factor Number

Reproduced Correlations

		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
Reproduced Correlation	T1	.400[a]	.531	.495	.494	.455	.497	.379	.393	.428	.424	.422	.488	.466	.474	.128
	T2	.531	.737[a]	.630	.635	.581	.638	.407	.424	.474	.505	.470	.566	.547	.588	.152
	T3	.495	.630	.779[a]	.702	.759	.689	.671	.672	.766	.458	.729	.549	.627	.573	.183
	T4	.494	.635	.702	.661[a]	.667	.656	.592	.601	.669	.502	.646	.593	.617	.588	.175
	T5	.455	.581	.759	.667	.752[a]	.650	.648	.643	.746	.383	.706	.461	.569	.510	.170
	T6	.497	.638	.689	.656	.650	.653[a]	.581	.593	.655	.518	.635	.611	.621	.597	.175
	T7	.379	.407	.671	.592	.648	.581	.752[a]	.756	.823	.481	.784	.609	.650	.534	.184
	T8	.393	.424	.672	.601	.643	.593	.756	.762[a]	.824	.513	.787	.646	.672	.559	.189
	T9	.428	.474	.766	.669	.746	.655	.823	.824	.909[a]	.502	.863	.634	.701	.579	.201
	T10	.424	.505	.458	.502	.383	.518	.481	.513	.502	.643[a]	.507	.765	.631	.614	.161
	T11	.422	.470	.729	.646	.706	.635	.784	.787	.863	.507	.822[a]	.637	.687	.574	.195
	T12	.488	.566	.549	.593	.461	.611	.609	.646	.634	.765	.637	.918[a]	.763	.727	.195
	T13	.466	.547	.627	.617	.569	.621	.650	.672	.701	.631	.687	.763	.705[a]	.648	.189
	T14	.474	.588	.573	.588	.510	.597	.534	.559	.579	.614	.574	.727	.648	.631[a]	.172
	T15	.128	.152	.183	.175	.170	.175	.184	.189	.201	.161	.195	.195	.189	.172	.052[a]
Residual[b]	T1		.135	-.020	.056	-.111	-.091	.091	.029	-.015	.055	.060	-.017	-.051	-.085	-.066
	T2	.135		.001	-.014	-.027	-.012	.033	-.006	.014	.017	-.016	-.002	-.059	.011	-.004
	T3	-.020	.001		.031	.001	-.031	-.039	-.031	.014	-.039	.017	.013	.001	-.011	-.010
	T4	.056	-.014	.031		.001	-.019	.035	.034	-.038	.025	.014	-.005	.023	-.047	9.894E-005
	T5	-.111	-.027	.001	.001		.086	-.017	.013	-5.532E-005	-.038	-.023	-.001	.016	.067	.013
	T6	-.091	-.012	-.031	-.019	.086		-.039	.015	-.006	.052	-.012	-.008	.073	-.013	.014
	T7	.091	.033	-.039	.035	-.017	-.039		.040	.007	-.003	.007	.001	-.053	-.018	-.074
	T8	.029	-.006	-.031	.034	.013	.015	.040		-.008	.060	.010	-.002	-.086	-.004	.015
	T9	-.015	.014	.014	-.038	-5.532E-005	-.006	.007	-.008		-.020	-.004	.002	.029	-.005	.006
	T10	.055	.017	-.039	.025	-.038	.052	-.003	.060	-.020		.045	-.009	-.040	-.012	.003
	T11	.060	-.016	.017	.014	-.023	-.012	.007	.010	-.004	.045		-.012	-.002	.003	.022
	T12	-.017	-.002	.013	-.005	-.001	-.008	.001	-.002	.002	-.009	-.012		.017	.010	-.001
	T13	-.051	-.059	.001	.023	.016	.073	-.053	-.086	.029	-.040	-.002	.017		.016	.010
	T14	-.085	.011	-.011	-.047	.067	-.013	-.018	-.004	-.005	-.012	.003	.010	.016		.021
	T15	-.066	-.004	-.010	9.894E-005	.013	.014	-.074	.015	.006	.003	.022	-.001	.010	.021	

Extraction Method: Maximum Likelihood.
a. Reproduced communalities.
b. Residuals are reproduced between observed and reproduced correlations. There are 19(18%) non-redundant residuals with absolute values greater than 0.05

Pattern Matrix[a]

	Factor		
	1	2	3
Resistance to Moisture	.946	.025	-.014
Resistance to Weather	.856	.086	-.006
Resistance to Fire	.851	.108	-.093
Resistance to Heat	.812	.174	-.095
Availability of the Technical Skills	.655	-.211	.446
Level of Maintenance Requirement	.589	-.077	.453
Life Expectancy	.530	.093	.041
Resistance to Chemicals	.119	.875	.012
Resistance to Scratch	.017	.741	.091
Weight and Mass of the Material	.125	.528	.270
Resistance to Decay	.379	.487	.099
Ease to Remove and Reaffix	-.095	.228	.779
Ability to Tolerate Expansion and Contraction	.362	.119	.462
Ease and Speed of Method fixing	.318	.171	.456
Recyclability and Reusability	.045	.234	.448

Extraction Method: Maximum Likelihood.
Rotation Method: Oblimin with Kaiser Normalization.

a. Rotation converged in 15 iterations.

Factor Correlation Matrix

Factor	1	2	3
1	1.000	.602	.584
2	.602	1.000	.507
3	.584	.507	1.000

Extraction Method: Maximum Likelihood.

Rotation Method: Oblimin with Kaiser Normalization.

Structure Matrix

	Factor		
	1	2	3
Resistance to Moisture	.953	.587	.552
Resistance to Weather	.904	.598	.538
Resistance to Fire	.862	.573	.459
Resistance to Heat	.861	.615	.468
Level of Maintenance Requirement	.807	.507	.758
Availability of the Technical Skills	.788	.410	.722
Life Expectancy	.210	.192	.164
Resistance to Chemicals	.653	.953	.526
Resistance to Scratch	.516	.797	.477
Resistance to Decay	.729	.765	.567
Weight and Mass of the Material	.601	.740	.611
Ease to Remove and Reaffix	.498	.567	.840
Ability to Tolerate Expansion and Contraction	.703	.571	.733
Ease and Speed of Method fixing	.687	.594	.729
Recyclability and Reusability	.448	.489	.593

Extraction Method: Maximum Likelihood.
Rotation Method: Oblimin with Kaiser Normalization.

Factor Score Covariance Matrix

Factor	1	2	3
1	3.605	3.386	4.325
2	3.386	3.251	3.973
3	4.325	3.973	4.750

Extraction Method: Maximum Likelihood.

Rotation Method: Oblimin with Kaiser Normalization.

Correlation Matrix for Sensorial Factors

		SN1	SN2	SN3	SN4	SN5	SN6	SN7	SN8	SN9	SN10
Correlation	SN1	1.000	.674	.653	.623	.570	.600	.595	.532	.582	.057
	SN2	.674	1.000	.791	.668	.683	.588	.610	.557	.527	.137
	SN3	.653	.791	1.000	.652	.670	.597	.624	.692	.628	.164
	SN4	.623	.668	.652	1.000	.875	.766	.593	.550	.561	.138
	SN5	.570	.683	.670	.875	1.000	.776	.538	.572	.520	.136
	SN6	.600	.588	.597	.766	.776	1.000	.577	.569	.546	.130
	SN7	.595	.610	.624	.593	.538	.577	1.000	.772	.781	.183
	SN8	.532	.557	.692	.550	.572	.569	.772	1.000	.830	.205
	SN9	.582	.527	.628	.561	.520	.546	.781	.830	1.000	.209
	SN10	.057	.137	.164	.138	.136	.130	.183	.205	.209	1.000
Sig. (1-tailed)	SN1		.000	.000	.000	.000	.000	.000	.000	.000	.208
	SN2	.000		.000	.000	.000	.000	.000	.000	.000	.024
	SN3	.000	.000		.000	.000	.000	.000	.000	.000	.009
	SN4	.000	.000	.000		.000	.000	.000	.000	.000	.023
	SN5	.000	.000	.000	.000		.000	.000	.000	.000	.024
	SN6	.000	.000	.000	.000	.000		.000	.000	.000	.030
	SN7	.000	.000	.000	.000	.000	.000		.000	.000	.004
	SN8	.000	.000	.000	.000	.000	.000	.000		.000	.001
	SN9	.000	.000	.000	.000	.000	.000	.000	.000		.001
	SN10	.208	.024	.009	.023	.024	.030	.004	.001	.001	

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.891
Bartlett's Test of Sphericity	Approx. Chi-Square	1705.393
	df	45
	Sig.	.000

Goodness-of-fit Test

Chi-Square	df	Sig.
134.916	26	.000

Communalities

	Initial	Extraction
Aesthetics or Visual density	.584	.518
Texture	.715	.597
Colour	.734	.649
Temperature	.810	.858
Acoustics	.820	.881
Odour	.668	.686
Thickness/Thinness	.711	.743
Glossiness/Fineness	.776	.815
Hardness	.755	.823
Lighting Effect	.062	.048

Extraction Method: Maximum Likelihood.

Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	6.143	61.429	61.429	5.834	58.336	58.336	5.241
2	1.056	10.558	71.987	.785	7.853	66.189	4.934
3	.870	8.703	80.690				
4	.583	5.828	86.518				
5	.409	4.087	90.605				
6	.274	2.738	93.343				
7	.246	2.456	95.798				
8	.164	1.644	97.443				
9	.154	1.545	98.987				
10	.101	1.013	100.000				

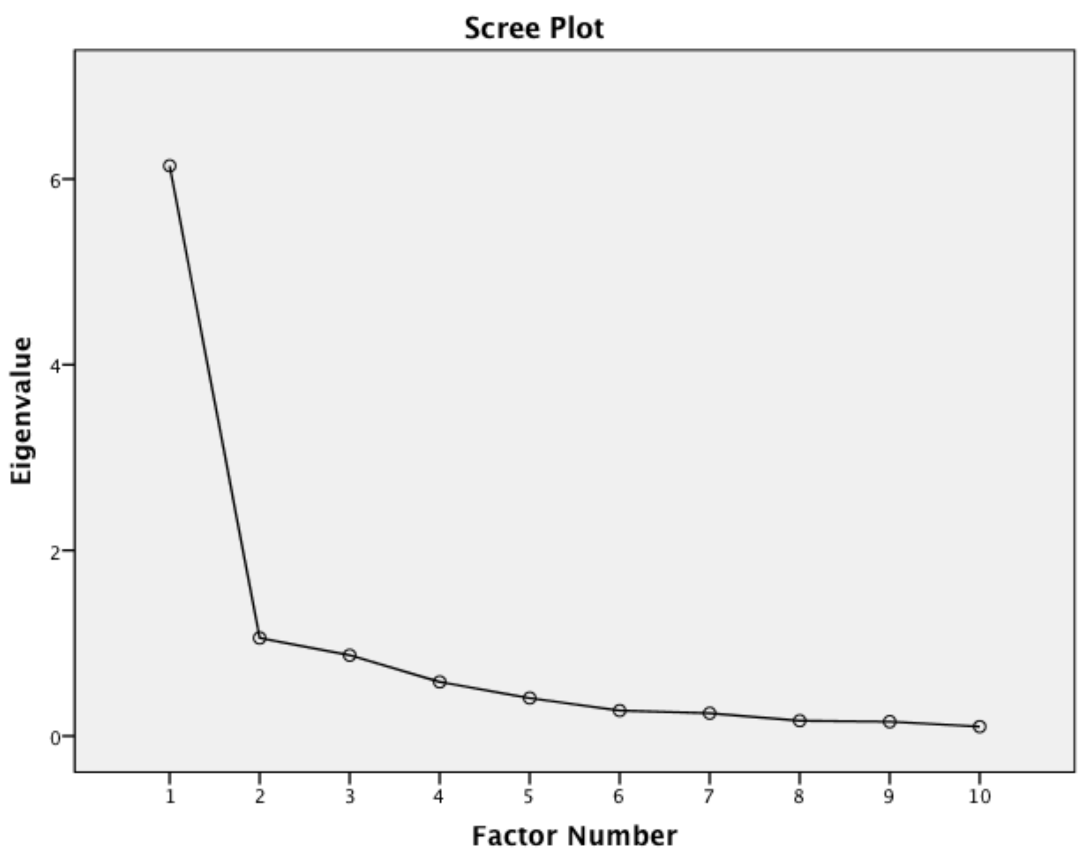
Extraction Method: Maximum Likelihood.

a. When factors are correlated, sums of squared loadings cannot be added to obtain a total variance.

Factor Matrix[a]

	Factor	
	1	2
Temperature	.872	-.311
Acoustics	.869	-.355
Odour	.806	-.193
Colour	.803	.065
Glossiness/Fineness	.802	.416
Thickness/Thinness	.786	.354
Hardness	.785	.454
Texture	.770	-.068
Aesthetics or Visual density	.719	.029
Lighting Effect	.192	.107

Extraction Method: Maximum Likelihood.
a. 2 factors extracted. 4 iterations required.



Reproduced Correlations

		SN1	SN2	SN3	SN4	SN5	SN6	SN7	SN8	SN9	SN10
Reproduced Correlation	SN1	.518[a]	.551	.579	.618	.614	.574	.575	.588	.578	.141
	SN2	.551	.597[a]	.614	.693	.693	.633	.581	.589	.573	.140
	SN3	.579	.614	.649[a]	.681	.675	.635	.654	.671	.660	.161
	SN4	.618	.693	.681	.858[a]	.868	.763	.576	.570	.544	.134
	SN5	.614	.693	.675	.868	.881[a]	.769	.558	.549	.521	.129
	SN6	.574	.633	.635	.763	.769	.686[a]	.565	.565	.545	.134
	SN7	.575	.581	.654	.576	.558	.565	.743[a]	.777	.778	.189
	SN8	.588	.589	.671	.570	.549	.565	.777	.815[a]	.818	.198
	SN9	.578	.573	.660	.544	.521	.545	.778	.818	.823[a]	.199
	SN10	.141	.140	.161	.134	.129	.134	.189	.198	.199	.048[a]
Residual[b]	SN1		.123	.073	.005	-.044	.026	.020	-.056	.005	-.084
	SN2	.123		.178	-.024	-.010	-.045	.029	-.031	-.047	-.003
	SN3	.073	.178		-.028	-.005	-.037	-.031	.022	-.032	.003
	SN4	.005	-.024	-.028		.007	.003	.017	-.020	.017	.004
	SN5	-.044	-.010	-.005	.007		.007	-.019	.023	-.002	.008
	SN6	.026	-.045	-.037	.003	.007		.012	.004	.001	-.004
	SN7	.020	.029	-.031	.017	-.019	.012		-.005	.003	-.005
	SN8	-.056	-.031	.022	-.020	.023	.004	-.005		.011	.007
	SN9	.005	-.047	-.032	.017	-.002	.001	.003	.011		.010
	SN10	-.084	-.003	.003	.004	.008	-.004	-.005	.007	.010	

Extraction Method: Maximum Likelihood.

a. Reproduced communalities

b. Residuals are computed between observed and reproduced correlations. There are 5 (11.0%) non-redundant residuals with absolute values greater than 0.05.

Pattern Matrix[a]

	Factor	
	1	2
Acoustics	1.000	-.117
Temperature	.965	-.056
Odour	.775	.074
Texture	.596	.227
Colour	.453	.420
Aesthetics or Visual density	.442	.336
Hardness	-.041	.935
Glossiness/Fineness	.017	.891
Thickness/Thinness	.084	.801
Lighting Effect	-.005	.223

Extraction Method: Maximum Likelihood.
Rotation Method: Oblimin with Kaiser Normalization.

a. Rotation converged in 9 iterations.

Structure Matrix

	Factor	
	1	2
Acoustics	.935	.598
Temperature	.925	.622
Odour	.827	.619
Texture	.755	.646
Colour	.748	.739
Aesthetics or Visual density	.678	.647
Hardness	.617	.907
Glossiness/Fineness	.644	.903
Thickness/Thinness	.647	.860
Lighting Effect	.152	.220

Extraction Method: Maximum Likelihood.
Rotation Method: Oblimin with Kaiser Normalization.

Appendix G: Data Analysis of Main Study

Introduction

This research set out to understand how designers could be better enabled to incorporate sustainability principles when formulating decisions to select LCGBMCs at the early stages of the design, for their use in a wider industry context. As the research progressed, it became evident that extending the research beyond the literature and preliminary studies and including a wide-range of professionals involved in the material selection process was required for a broader understanding of the study.

This chapter outlines the findings from both the surveyed questionnaire and interviews of participants who are actively engaged with sustainable material selection. A general description of the results and the demographic study is given in this section. As far as possible, data were tabulated and displayed through tables, charts, and graphs, with the aim of identifying and discerning any patterns that provided the best interpretation of the results of the study. The size of the response across available response categories is indicated in both percentage (%) and raw numeric terms. Presented also within this chapter are the conclusions of the analysis.

General Analysis of the Demographic Study

Relevant data relating to the informed selection of LCGBMCs were obtained from leading experts in the field of housing construction in Nigeria, following the closure of the main survey launched between November 2012 and January 2013. Participants' responses and results summaries of the survey were automatically generated by the survey tool and stored in SPSS v.20. To provide insights to responsible material selection decision-making process, a combined research approach consisting of qualitative personal interviews supported by a quantitative online survey was adopted. Interviews were conducted with senior decision-makers across 10 organisations with a further 210 individuals participating in the online survey.

The surveyed questionnaire attracted 480 interested participants with 210 eligible respondents representing various fields in housing, and who had relevant knowledge on issues specific to the use of LCGBMCs. The choice of respondents for the survey followed the sampling methods adopted in section 4.5.2.7 in chapter 4. The sampling methods adopted ensured sampling equivalence amongst various building professionals both in higher institutions and practicing building design and construction firms.

The reason for sampling equivalence was to ensure a sample size that would be statistically adequate to eliminate bias and obtain valid data (Hair et al., 2003). These activities were undertaken across the five areas of geographic interest due to different geographies, and variations in the technical nature of participants' roles. This means the project evidence base was informed by feedback from over 200 individual participants leading to views of separate data items on various issues of interest. The survey was interested in how informed-decision making changes between conventional building material and LCGBMCs choices, and how designers' choices influence life-cycle cost, energy use and performance of housing projects. The results of the survey are summarized below.

Designation of Respondents

The question as to how best you describe your self, revealed the participants' respective job affiliations. In order to detect disciplinary differences and conduct the inter-group comparison among professionals, all categories were binned into five main groups. Participants that did not fall into any of the 5 categories were grouped under the 'other' option.

Remarkably, under the "Other" option, a number (7%) of other professionals within the housing sector also provided complete responses. The 'Other' category included sustainability consultants, academics, research consultants, program/software developers and other specialist consultants. The summary report showed that 20% of the sampled population were architects and accredited members of the Nigerian Institute of Architects (NIA) with surprisingly, almost the same proportion as the members of the Nigerian Institute of Builders (NIB) who had slightly more (22%) than expected. On the other hand, more than a quarter of engineers (16%) were Professional Engineers (PE) of the Nigerian Institute of Civil Engineers, with a higher representation from the Society of Construction Industry Arbitrators of Nigeria. 22% of the respondents were accredited professionals of the Nigerian Institute of Quantity Surveyors, and (13%) of the Nigerian Institute of Urban Designers.

The encouraging finding here is that on average the size of each group was nearly as balanced as the others, and so allowed the study to reasonably compare views of respective professionals. **Table 1** and **Figure 1** show the number of respondents grouped under each professional category.

Table 1: Job Affiliation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Architect	43	20.0	20.0	20.0
	Builder	47	22.0	22.0	42.0
	Engineer	33	16.0	16.0	58.0
	Quantity Surveyor	46	22.0	22.0	80.0
	Urban Designer	27	13.0	13.0	93.0
	Other	14	7.0	7.0	100.0
	Total	210	100.0	100.0	

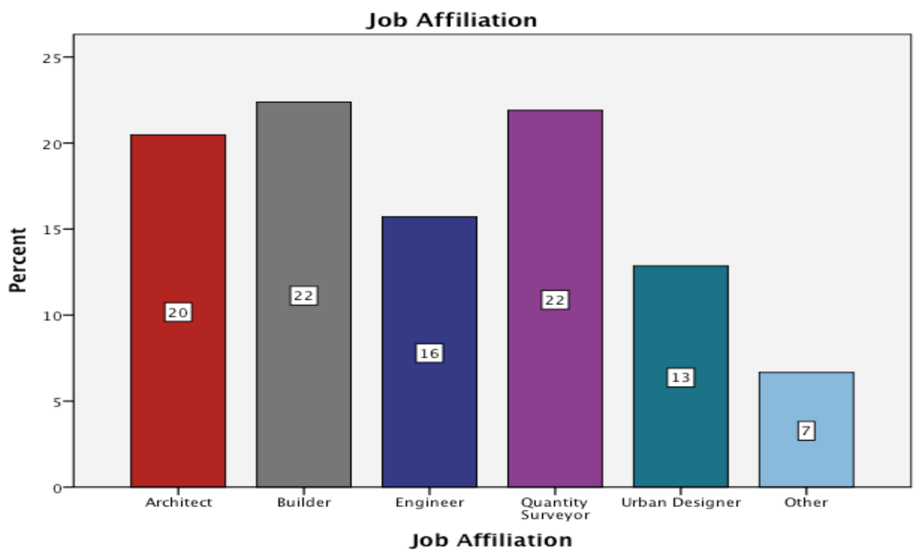


Figure 1: Illustration of the percentage of respondents' designations, affiliations and certifications.

Source: Analysis of surveyed data, 2013

Experience of Respondents

The second question revealed the participants' level of experience in the field of low-impact green housing construction. Zhou et al. (2008) and Ofori (1991) have argued that the knowledge and experience of building and design professionals is indispensable in the successful implementation of sustainable development principles in housing design and construction. From the survey results, 95% of the respondents had sufficient to excellent knowledge in low-impact green development concepts. The analysis of the study indicated that 15% of the respondents who participated in the study had between 1 and 5 years of experience, 26% had industry experience ranging between 6 and 10 years, 36% had at least 11-15 years of experience, while 18% had over 20 years experience working on low-impact green housing projects.

4% reported an insufficient knowledge and 1% undecided. An explanation for the 1% and 4% suggests that there is a possibility that the respondents who fell under those categories may not have handled housing projects in which sustainable development concepts were part of the project criteria.

The encouraging finding is that in spite of their academic qualifications, the majority of respondents who participated in the survey also had reasonable experience in low-impact green housing construction, which further showed that more than half of the respondents were sufficiently experienced to provide data that were reliable and credible. Knowledge on materials sustainability was however, found to vary significantly between participants due to different geographies, areas of interest and variations in the technical nature of participant's roles. The results of the survey on their knowledge and experience are shown below in **Table 2** and **Figure 2**.

Table 2: Summary of respondents experience in green building projects

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0 [No Experience]	10	4.0	4.0	4.0
	1-5 [Less Experienced]	32	15.0	15.0	19.0
	6-10 [Fairly Experienced]	54	26.0	26.0	45.0
	11-15 [Very Experienced]	75	36.0	36.0	81.0
	15 and Above [Highly Experienced]	38	18.0	18.0	99.0
	Other	1	1.0	1.0	100.0
	Total	210	100.0	100.0	

Figure 2.Summary of respondent's level of experience in low-cost green developments
Source: Analysis of surveyed data, 2013

Areas of Project Interest

The question about their area of interest reported a higher rate of respondents concerned with the design aspects of low-impact green housing projects. Within the combined valid response (from **Table 3** and **Figure 4**), "all aspects of housing design" (36%) was the leading area of specialty reported by respondents, with "design and build" (23%) making a significant proportion of the responses. 21% of the respondents agreed that the "material specification" aspects of the building project was their most important area of interest, 14% considered construction aspect of the building project as the most crucial aspect of the project, while 6% came in the "other" category of specialisation. The larger numbers of residential design respondents further reflect the intended focus of the research, which is on all aspects of housing design.

Table 3: Participants' area of interest, shown by the frequency they influence material choice

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Design	48	23.0	23.0	23.0
	Construction	30	14.0	14.0	37.0
	Material Specification	44	21.0	21.0	58.0
	All Aspects	76	36.0	36.0	94.0
	Other	12	6.0	6.0	100.0
	Total	210	100.0	100.0	

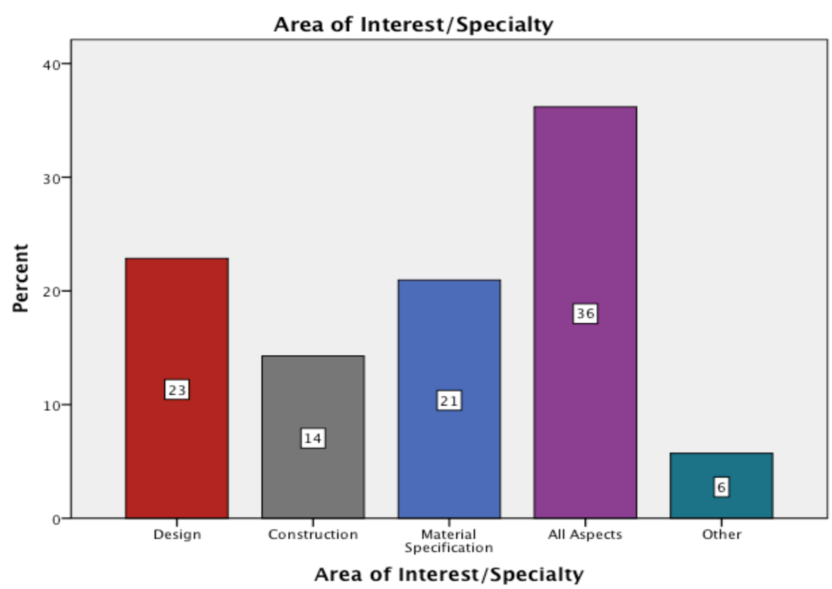


Figure 3. Illustration of the percentage of interest in the area of low-cost green housing construction

Source: Analysis of surveyed data, 2012

Views on Decisions Regarding the Phase of Material Choice

In the follow up question, respondents were asked to indicate the phase for which they thought best to make decisions in the choice of materials for housing projects. Analysis of the returned questionnaire (refer to **Table 4** and **Figure 4**) showed that planning and decision-making requirements were found to be significant, as 60% of respondents considered the choice of materials at these phases. Of the other lots, 23% noted the design development phase, 11% of them went for construction, while as little as 1% and 3% went for operation and final design stages. 2% made up the "other" option. The views obtained from this survey tend to be more representative of respondents who are more particular about the cost, social and environmental implications of materials at the decision-making, planning and preliminary design stages of the project; as changes to the overall building performance, visual appearance or energy cost can be difficult after this point.

Table 4: Phase of Material Selection

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Decision-Making	125	60.0	60.0	60.0
	Design Development	49	23.0	23.0	83.0
	Final Design	7	3.0	3.0	86.0
	Construction	23	11.0	11.0	97.0
	Operation	1	1.0	1.0	98.0
	Other	5	2.0	2.0	100.0
	Total	210	100.0	100.0	

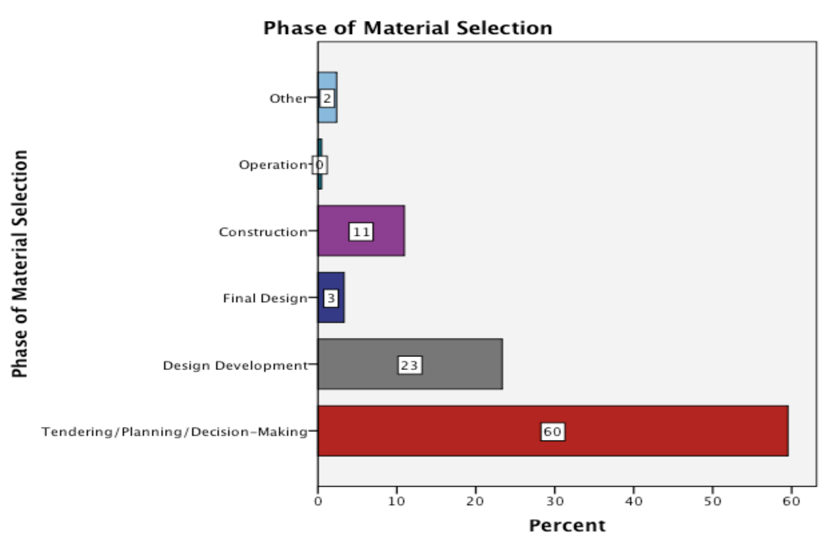


Figure 4. Illustration of the percentage of the phase of material selection
Source: Analysis of surveyed data, 2013

Obstacles in the Use of Low-Cost Green Building Materials

An attempt was made to identify obstacles perceived by design and building professionals as they sought to use LCGBMCs in their design and building projects. Using the 5-point likert scale from "strongly disagree" (=1) to "strongly agree" (=5), respondents were asked to rank the extent to which they agreed on the following factors as obstacles that significantly deter them from using LCGBMCs in housing design projects.

The Kendall's W was adopted for this study since it makes no assumptions regarding the nature of the probability distribution and can also handle as many numbers of distinct outcomes as possible (Kline, 2002). Kendall's procedure states that if the test statistic W is 1, then all the survey respondents have been unanimous, and each respondent has assigned the same order to the list of concerns. If W is 0, then there is no overall trend of agreement among the respondents, and their responses may be regarded as essentially random. To check whether or not intermediate values obtained for W indicated a greater or lesser degree of unanimity among the various professional groups, and to verify that the degree of agreement or disagreement did not occur by chance, the significance of W was tested, resulting in the null hypothesis being in relatively perfect disagreement. The Kendall's coefficient of concordance (W) value obtained was 0.226, which was significant at 95% confidence level. The analysis implied that the W was significant with Asymp.Significant value of 0.00 and as such the null hypothesis was not supported and thus, rejected.

Test statistics was further applied to the rankings in order to test the significance of the findings (as shown in **Table 5a**). The result of the analysis showed a greater degree of agreement in opinions among the various responses, so that there was no relatively significant difference in agreement between the number of 'k' dependent variables and the population from which these samples were drawn. The analysis was interpreted to indicate a significant degree of agreement among various design and building professionals as to the ranking of the perceived obstacles.

Table 5a: Test statistics for perceived obstacles affecting the patronage of LCGBM

Kendall's W[a]	0.226
Chi-Square	396.655
Difference of freedom (df)	13
Asymp. Sig.	0.000

a. Kendall's Coefficient of Concordance

The biggest concern of the ten potential obstacles listed in **Table 5b** and as illustrated in **Figure 5**, was client's preference, with a relative index of (RI =0.795). This was closely followed by the contractual agreement with (RI = 0.775); lack of access to adequate and sustainable material information to compare material alternatives (RI= 0.772); nature of the building project (RI =0.699); Unwillingness to change from conventional materials (RI = 0.683); with limited availability of materials (RI=0.479) and maintenance concern (0.480) trailing in the last positions.

The ranking of client's preference as the most recognised obstacle is not surprising as clients greatest financial obligation for selecting ideal and cost effective building products is frequently their central concern, since costs must be monitored and controlled, whether from the point of view of the owner, or the designer.

Remarkably, within the "Architects category", "Aesthetically less pleasing" was clearly identified as the most critical factor inhibiting greater industry acceptance of LCGBMCs, which corroborates with Jiboye's (2009) observation about their reluctance in using such materials in their design projects.

Summary discussions of the top three obstacles are presented in the following sections.

Table 5b: Ranking indices of perceived obstacles inhibiting the wide-scale use of low-cost green materials in the housing industry

Obstacles	Architect [1]		Builder [2]		Engineer [3]		Quantity Surveyor [4]		Urban Designer [5]		Other [6]		Overall	
	RI	Rank	RI	Rank	RI	Rank	RI	Rank	RI	Rank	RI	Rank	RI	Rank
Clients' Preference	0.600	9	0.786	2	0.986	1	0.852	1	0.956	1	0.943	1	0.795	1
Contractual Agreement	0.815	2	0.800	1	0.725	5	0.719	3	0.733	2	0.800	2	0.775	2
Limited Accessibility to Relevant Information	0.755	3	0.779	3	0.863	2	0.778	2	0.689	3	0.743	3	0.772	3
Nature of the Project Design	0.730	4	0.676	5	0.625	7	0.711	4	0.733	2	0.700	4	0.699	4
Unwillingness to Change	0.680	6	0.683	4	0.825	3	0.644	6	0.533	8	0.700	4	0.683	5
Lack of Familiarity with Techniques	0.700	5	0.593	7	0.788	4	0.659	5	0.622	5	0.514	9	0.655	6
Unreliability of Suppliers	0.605	8	0.634	6	0.700	6	0.615	7	0.444	10	0.743	3	0.628	7
Aesthetically Less Pleasing	0.950	1	0.538	12	0.525	11	0.437	13	0.378	11	0.486	10	0.622	8
Low Flexibility for Substitutes	0.595	10	0.572	8	0.588	9	0.600	8	0.511	9	0.614	6	0.587	9
Uncertainty in the Project Outcome	0.565	13	0.517	11	0.613	8	0.578	10	0.556	6	0.671	5	0.572	10
Building Code Restriction	0.580	11	0.531	10	0.563	10	0.593	9	0.555	7	0.586	8	0.569	11
Perception that Materials are of Low Status	0.635	7	0.517	11	0.513	12	0.526	11	0.533	8	0.600	7	0.563	12
Limited Availability of Materials	0.575	12	0.545	9	0.338	13	0.593	9	0.667	4	0.371	11	0.529	13
Maintenance Concern	0.560	14	0.386	13	0.525	11	0.504	12	0.511	9	0.329	12	0.480	14

Source: Analysis of surveyed data, 2013

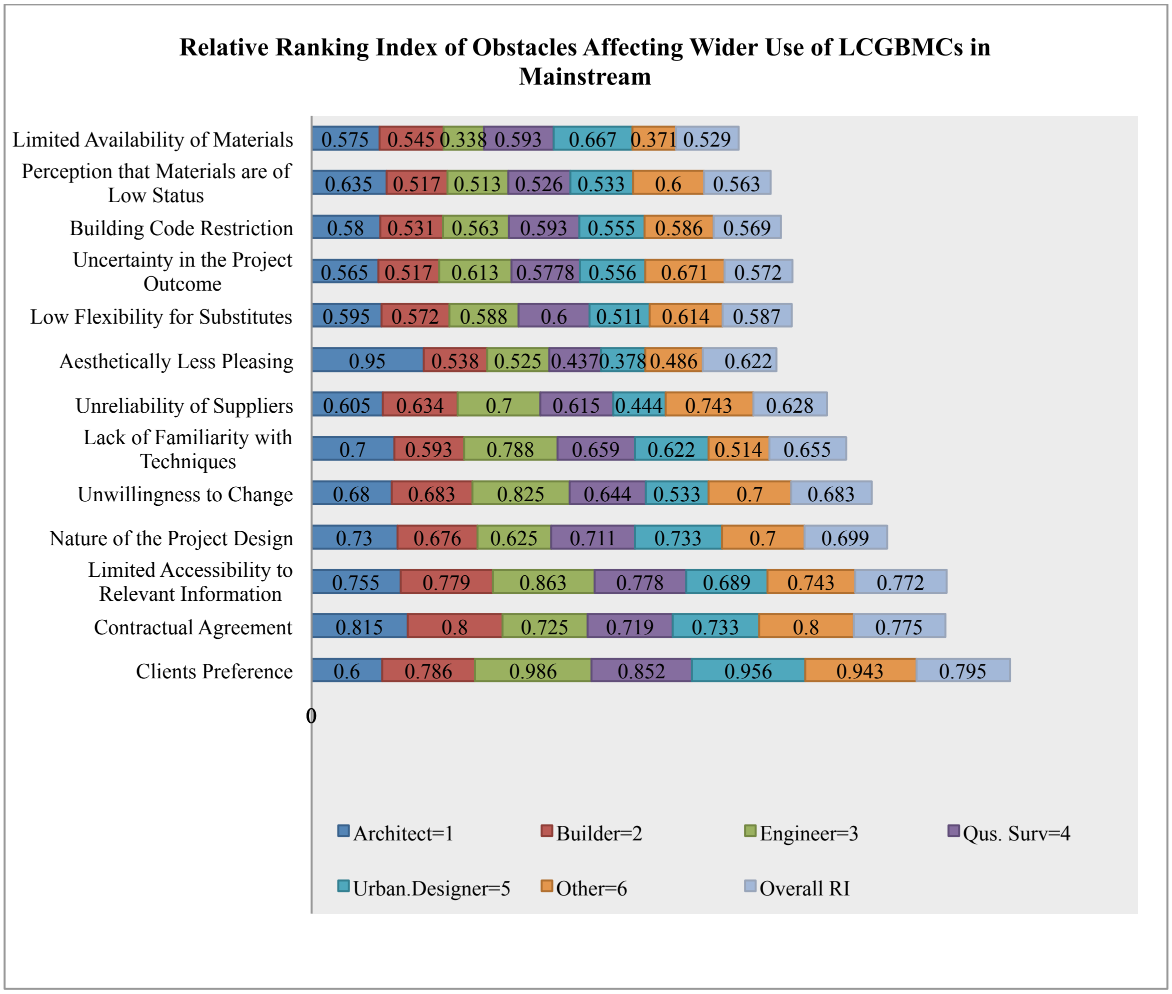


Figure 5. Graph illustrating the "relative mean rank" of the perceived obstacles limiting greater use of low-cost green materials

Client's preference

In an attempt to identify the potential factors barring the use of LCGBMCs in housing projects, the feedbacks demonstrated that 'client's preference' had the most significant influence on the decision of which materials to use, since clients and investors regularly have significant influence on material choices due to the terms they impose on a project through budget and brief. This is not entirely surprising as clients, who normally are anxious to minimise the running costs associated with housing solicit for cost effective products (Chan et al, 2009). Some participants noted that the degree to which they use building materials largely depends on clients' perception, as they are led to believe that buildings designed with locally-sourced/traditional building products are not permanent and has to be re-worked, maintained or out rightly re-built more often than it is with buildings constructed with conventional building materials. The significance of this factor was well phrased by one respondent;

"The choice of building materials is governed by the economic power of the client, hence his preference of choice".

He suggests that scientific research into best practices is likely to enhance their durability in construction, and thus greater use. He added that clients' influence is understandable as they are legally responsible for the project, and carry the initial risks for the costs of the project.

Contractual agreement

Contractual agreement was rated as the second most significant factor that affects the effective use of LCGBMCs in housing projects. The issue of the impacts of the contractual agreement on the choice of materials has been repeatedly highlighted in various literatures (Ofori, 1999; Augenbroe 2002). Ofori (1999) argues that despite the many strong advantages of standard form construction contracts, they are not flexible to fit all projects, material types and circumstances. He notes that the materials specified in the contract agreement are usually defined by codes and standards.

Perhaps the reason why most local building products are left out during the tendering stage of the contract is because nearly all of such products do not have ideal codes and standard of use, and so may be impossible to include them in the contract document, since contractors are less likely to determine the potential risks or benefits in using them.

Lack of access to adequate and up-to-date material information

The identification of information scarcity was noted as the third biggest obstacle to specifying LCGBMCs in light of the current proliferation of documentary resources relating to the informed selection of such materials. The issue of accessing up-to-date information through different steps of the housing construction process, what the sources are and how they are obtained is one of the most discussed topics in the field of construction (Seyfang, 2009a). The respondents reported that many sustainability principles in the choice of materials and low-impact green housing development goals have fallen by the wayside due to the absence of readily available information.

Building Assessment Tools for Low-Cost Green Materials

This part of the survey included questions that explored the sources of information and assessment tools design and building professionals use when assessing LCGBMCs for low-impact green housing projects. Van Kesteren (2008) noted that selecting materials could be a problem-solving activity, given the high influx of new products of different qualities entering into the market. He added that this increases the workload and responsibilities of the specifiers who have to evaluate and select the building materials needed, as this demands a large and constant flow of adequate information.

Participants were asked to indicate their familiarity with any source of information or tools for LCGBMCs. As shown in **Table 6**, approximately 6% of the respondents confirmed knowledge of likely information sources. A large proportion (93%) of the respondents noted otherwise since they had no knowledge of any existing tool. The decision-making approaches currently taken by the participatory house builders were identified within the context of build system for LCGBMCs. All of them relied upon heuristic decision-making, drawing on individual experience and intuition, and informal group discussion.

Two companies (1%) of the sample had used some simple tools like best practice templates and estimate workbook. None had used any formal decision-making software. No company had applied any sophisticated decision theories such as: AHP, utility theory, linear programming, fuzzy sets or Bayesian analysis. However, all of the companies used, to a varied degree, external management consultants for decision support.

One of the respondents noted that data on LCGBMCs exists generally in paper form (e.g. brochures and catalogues). He added that paper-based information becomes quickly obsolete, as their updates do not keep pace with the speed with which new building materials appear on the market. The result of this question however, suggested the need for a system capable of evaluating decision trade-offs when selecting LCGBMCs. A summary of the result is presented in **Figure 6** and **Table 6**

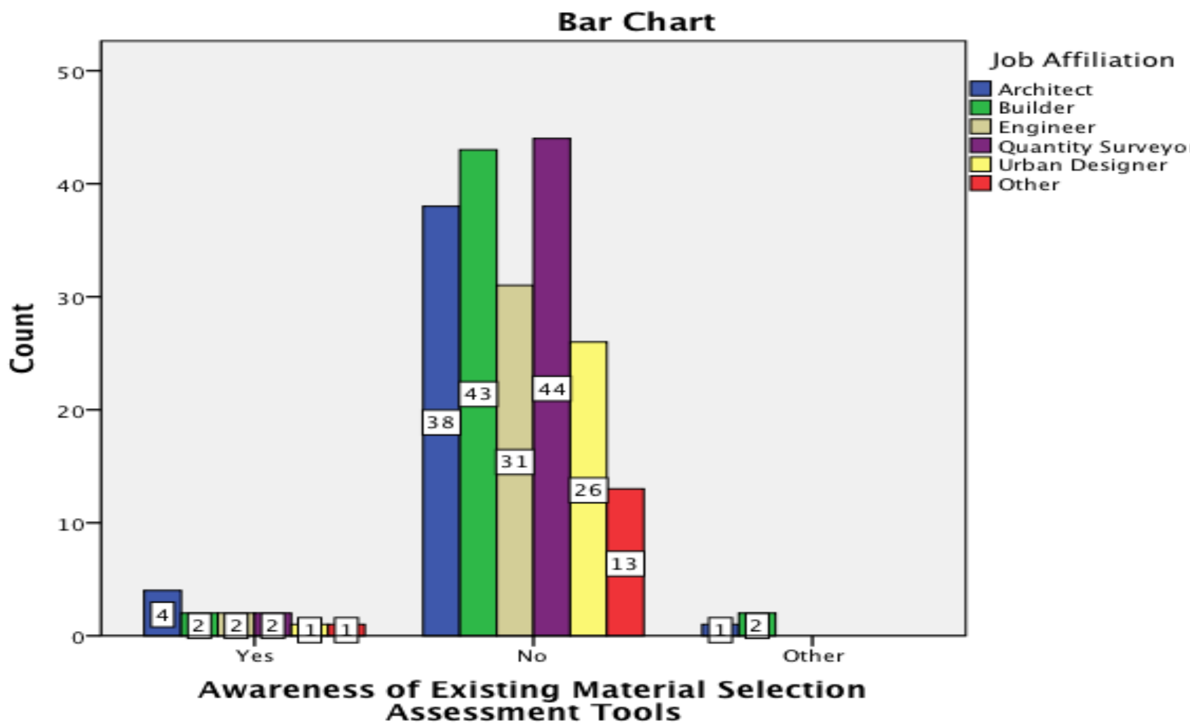


Figure 6. Illustration of the report on the available tools for evaluating low-cost green materials

Source: Analysis of surveyed data, 2013

Table 6: Awareness of Existing Material Selection Assessment Tools * Job Affiliation Cross tabulation

			Job Affiliation						Total
			Architect	Builder	Engineer	Quantity Surveyor	Urban Designer	Other	
Awareness of Existing Material Selection Assessment Tools	Other	Count	1_a	2_a	0_a	0_a	0_a	0_a	3
		Expected Count	.6	.7	.5	.7	.4	.2	3.0
		% within Awareness of Existing Material Selection Assessment Tools	33.3%	66.7%	0.0%	0.0%	0.0%	0.0%	100.0%
		% within Job Affiliation	2.3%	4.3%	0.0%	0.0%	0.0%	0.0%	1.4%
		% of Total	0.5%	1.0%	0.0%	0.0%	0.0%	0.0%	1.4%
		Std. Residual	.5	1.6	-.7	-.8	-.6	-.4	
	No	Count	38_a	43_a	31_a	44_a	26_a	13_a	195
		Expected Count	39.9	43.6	30.6	42.7	25.1	13.0	195.0
		% within Awareness of Existing Material Selection Assessment Tools	19.5%	22.1%	15.9%	22.6%	13.3%	6.7%	100.0%
		% within Job Affiliation	88.4%	91.5%	93.9%	95.7%	96.3%	92.9 %	92.9%
		% of Total	18.1%	20.5%	14.8%	21.0%	12.4%	6.2%	92.9%
		Std. Residual	-.3	-.1	.1	.2	.2	.0	
	Yes	Count	4_a	2_a	2_a	2_a	1_a	1_a	12
		Expected Count	2.5	2.7	1.9	2.6	1.5	.8	12.0

		% within Awareness of Existing Material Selection Assessment Tools	33.3%	16.7%	16.7%	16.7%	8.3%	8.3%	100.0%
		% within Job Affiliation	9.3%	4.3%	6.1%	4.3%	3.7%	7.1%	5.7%
		% of Total	1.9%	1.0%	1.0%	1.0%	0.5%	0.5%	5.7%
		Std. Residual	1.0	-.4	.1	-.4	-.4	.2	
Total		Count	43	47	33	46	27	14	210
		Expected Count	43.0	47.0	33.0	46.0	27.0	14.0	210.0
		% within Awareness of Existing Material Selection Assessment Tools	20.5%	22.4%	15.7%	21.9%	12.9%	6.7%	100.0%
		% within Job Affiliation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0 %	100.0%
		% of Total	20.5%	22.4%	15.7%	21.9%	12.9%	6.7%	100.0%

Each subscript letter denotes a subset of Job Affiliation categories whose column proportions do not differ significantly from each other at the .05 level.

Source: Analysis of surveyed data, 2013

Decision Factors for Selecting Low-Cost Green Materials

One of the key objectives of this research was to identify and define the key decision selection factors that will influence design team members in the selection of LCGBMCs at the early design stages of LIGHDs. A wide scope literature review in chapters 2 and 3 including findings from the preliminary survey revealed that there was lack of a comprehensive list of assessment factors developed specifically for assessing LCGBMCs. Consequently, a further study consisting of a list of material-selection factors - (gleaned from the results of both the preliminary study and in-depth literature review in chapter 2) was undertaken to identify the key decision factors that would influence designers decisions in their choice of materials. Overall a total of 60 factors were identified and selected for LCGBMCs assessment, with 6 variables in socio-cultural criteria category, 18 variables in technical category, 10 variables in environmental category, 5 variables in economic/cost category, 12 variables in general/site category, and 12 variables in sensorial category (as shown in **Table 7**). Foxon et al. (2002) argue that the validity of a given list of decision factors or variables depends on how well it satisfies the following requirements:

(1) Comprehensiveness: In order to ensure that the choice of materials meets the SD objectives, Foxon et al. (2002) suggest that each factor must fall within a category to eliminate uncertainties during the selection process.

(2) Applicability: Another point noted is that the identified factors or variables chosen should be applicable across the range of options under consideration.

(3) Transparency: Thirdly, the factors should be chosen in a transparent way, to understand the criteria used, and be able to propose any other criterion for consideration.

(4) Practicability: Finally, the set of factors chosen must form a practicable set for the purposes of the decision to be assessed.

To ensure a better understanding of the list of factors and variables gleaned from the reviewed literature and preliminary study in chapter 2, the following requirements were applied before deploying the survey questionnaire. The definition of each factor or variable under their respective categories encouraged respondents to provide accurate, unbiased and complete information. The following section presents the results analysis of the surveyed factors.

Table 7: Pre-Analysed decision factors for evaluating trade-offs between low-cost green building material s

(GS) General /Site Factor	(EH) Environmental /Health Factor	(C) Economic/Cost Factor	(SC) Socio-Cultural Factor	(T) Technical Factor	(SN) Sensorial Factor
GS1-Location GS2-Availability GS3-Distance GS4-Certification GS5-Disaster Prone GS6-Site Geometry GS7-Design Geometry GS8-Spatial Structure GS9-Spatial Activities GS10-Material Scale GS11-Bldg Orientation GS12-Spatial Scale	EH1- Env. Compliance EH2-CO2 Emissions EH3-Users' Safety EH4-Ozone Depletion EH5-Pesticide Treatment EH6-Climate EH7-Env-Toxicity EH8-Fossil Depletion EH9-Nuclear Waste EH10-Waste Disposal	C1-Life-Ccycle Cost C2-Embodied Energy Cost C3-Capital Cost C4-Labour Cost C5-Maintenance Cost	SC1-Compatibility (Tradition) SC2-Compatibility (Region) SC3-Resistriction on Usury SC4-Clients' Preference SC5-Custom Knowledge	T1-Recyclability T2-Ease to remove T3-maintenance Level T4-Contraction Tolerance T5-Skills Availability T6-Speed of Fixing T7-Fire Resistance T8-Thermal Resistance T9-Moisture Resistance T10-Scratch Resistance T11-Weather Resistance T12-Chemical Resistance T13-Resistance to Decay T14-Weight/Mass T15-Life Expectancy T16-Renewable T17-UV Resistance T18-Compatibility with other Materials	SN1-Aesthetics SN2-Texture SN3-Colour SN4-Temperature SN5-Acoustics SN6-Odour SN7-Thick/Thin SN8-Glosiness SN9-Hardness SN10-Lighting Effect SN11-Translucence SN12-Structure

Development of the Key Material Selection Factors or Variables

To identify the key influential factors needed for the MSDSS model, respondents were asked to rate the validity of a range of sub-factors under each category of the parent groups on the frequency for which they were relevant in the selection of LCGBMCs using a 5- point Likert scale (where "1= least important" to "5 =extremely important") as shown in **Appendix D**. They were also asked to add and rate the relative importance of any other relevant factors not included in the list. The study results (in table 10) showed that a large number of factors influence the selection of LCGBMCs, with cost, technical and socio-cultural factors/variables remaining the overarching priorities.

The analysis in **Table 8** indicated that "Economic/Cost (RI=0.918)" and "Technical (RI=0.916)" factors were found to have the strongest influence on material choice(s). These were followed by "Socio-Cultural (RI=0.912)", "Environmental (RI=0.890)", "General/Site (RI=0.838)" and "Sensorial (RI=0.830)". Within the "Economic/Cost" category, key factors such as maintenance cost (with RI=0.912) and "Labour/Installation cost" with (RI=0.898) were commonly found to have more influence in the project's budget. Surprisingly, result analysis based on the views from the participants indicated that factors such as "Capital cost (RI=0.891)" and "Material embodied energy cost (RI=0.876)" were found to have the least impact on material choices.

Factors Importance Rating

To ensure that the rating scale (1–5) for measuring the factors yielded the same results, a reliability analysis test was first conducted. Cronbach's alpha was calculated to test the internal consistency reliability of the generated scale examined (see **Table 9**). The Cronbach's rule states that the closer alpha value for each factor is to 1, the greater the internal consistency reliability of the factor in the scale. Cronbach's formula is given as:

$$\alpha = \frac{N \cdot \bar{c}}{\bar{v} + (N-1) \cdot \bar{c}}$$

Here N is equal to the number of items, c-bar is the average inter-item covariance among the items and v-bar equals the average variance. (Note that a reliability coefficient of 0.70 or higher is considered "acceptable" in most social science research situations.)

Table 8: Item Statistics

	Relative Index (RI)	Rank	Std. Deviation	N
F3: Economic or Cost Factors (C)	0.918	1	1.340	210
F5: Technical Factors (T)	0.916	2	1.429	210
F4: Socio-Cultural Factors (SC)	0.912	3	1.385	210
F2: Environmental and Health Factors (EH)	0.890	4	1.331	210
F1: General and Site Factors (GS)	0.838	5	1.518	210
F6: Sensorial Factors (SN)	0.830	6	2.146	210

Table 9: Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.781	0.789	6

The value for Cronbach's alpha was estimated at 0.781, which was well above Cronbach's specification of 0.7, and thus, provided evidence for composite reliability. Therefore, the results shown in **Tables 8** and **9** proved that all the six group of factors presented adequate reliability scores. This indicates that the six group of factors (i.e. GS-Site variables; EH-Environmental; EC-Economic; SC-Socio-Cultural; T-Technical; and SN-Sensorial) extracted from the factor analysis could be used as a multidimensional measure for internal and external forces affecting designers' decisions relating to material-selection practices. Cronbach's alpha values for sensorial, site, environmental, technical, economic, and socio-cultural criteria came up as 0.830, 0.838, 0.890, 0.916, 0.918, and 0.912, respectively. Given that the resultant alpha values for each factor category was greater than 0.7, there was strong evidence to show that all coefficients of all the factors were acceptable, and internally consistent.

In order to identify the relative importance of the sub-categorical factors based on the surveyed data, ranking analysis was performed. The Relative index analysis was used to rank the sub-factors according to their relative importance as shown in table 10. Five important levels were transformed from Relative Index values: Highly Significant Level (H) ($0.8 \leq RI \leq 1$), High–Medium Level (H–M) ($0.6 \leq RI < 0.8$), Medium Level (M) ($0.4 \leq RI < 0.6$), Medium–Low Level (M–L) ($0.2 \leq RI < 0.4$), and Low Level (L) ($0 \leq RI < 0.2$).

Considering that the nature of the factors to be extracted was unknown, an exploratory factor analysis- was undertaken using the maximum likelihood approach as the factor analysis extraction method. Exploratory factor analysis is an effective statistical method used to describe variability among observed variables in terms of fewer unobserved variables (Hair et al., 1995).

In other words, it reduces variables with similar characteristics together into a smaller set of correlated or uncorrelated dimensional factors, which are capable of explaining the observed variance in the larger number of variables (Kline, 2002). Kaiser–Meyer–Olkin (KMO) measure and Bartlett's Test of Sphericity were conducted to examine the sampling adequacy, ensuring that factor analysis was going to be appropriate. Afterwards, the maximum likelihood factor analysis method was also used to derive the minimum number of factors, which helped to explain the maximum portion of variance in the original variable. It was chosen to extract the unobserved variables based on the criterion that the associated eigenvalue should be greater than 1(Hair et al., 1995).

However, Kline (2002) argued that with a sample size of at least 100 participants or above, loadings of 0.30 or higher could be considered significant (see discussion in Kline, 2002, pp. 52-53). This meant that variables with factor loadings of 0.30 or higher were considered highly significant, while variables that loaded near zero (0) were clearly considered as highly insignificant. However, given that a broad consensus of recent studies in the literature (Velicer & Jackson, 1990) confirmed that the Eigen value of 1 was among the least accurate methods for selecting the number of factors to retain, + 0.30 was classified as the minimum consideration level and statistically significant factor loading for the selected factors in this study, since attaining a value of 0.8 or greater was unlikely to occur in real data (Costello & Osborne, 2005). To interpret the relationship between the observed variables and to identify the unobserved variables more easily- given the sample size of 210, the most ideal and more robust rotation method, "direct oblimin rotation" was selected since oblique rotation produces results nearly identical to the orthogonal rotation when using the same extraction method, as evident in **Appendix F** (Tabachnick & Fidell, 2007). To ascertain whether or not "direct oblimin" was the ideal rotation method, or a more accurate, and perhaps more reproducible solution for simplifying and clarifying the data structure, factor analyses- using both "varimax" and "oblique" rotation methods were conducted (as shown in **Appendix F**). This also helped to check whether or not the correlation matrix produced results of values that were truly uncorrelated ($+0.1 \leq X < +0.3$) or significantly correlated ($+0.3 \leq X \leq 1$).

Kline (2002, p. 65) argued that the choice of rotation (whether orthogonal or oblique) could make much difference, particularly where the factors are markedly correlated (as demonstrated in **Appendix F**).

The results of the analysis (shown in **Appendix F**) indicated that the correlations for both varimax and oblique rotations exceeded +0.32, showing a 10% overlap in variance among factors, which was enough to warrant oblique rotation. Therefore, based on the result of the analysis, and given that oblique rotation will easily reproduce an orthogonal solution but not vice versa (Costello & Osborne, 2005), the oblique rotation was recommend as ideal for this research (Detailed results of the analysis is displayed in **Appendix F**).

Table 10 shows the ranking results for each sub-factor under each factor category derived using the relative index analysis equation in chapter 4. The value of KMO is 0.862, which is well above Kaiser's (1974) specification of 0.5. Therefore, the results shown in **Table 10** proved that fifty-five (55) out of sixty factors were adequate to undertake any material selection problem. From the results of the analysis shown in table 10, forty factors were identified under the "Highly significant" level for evaluating LCGBMCs with an RI value ranging from 0.952 to 0.806, with "life expectancy (T15)" topping the list of this group and "Thickness of material" (SN7) occupying the least position. Fifteen factors where grouped under the "High-Medium" level.

"Life Expectancy" was ranked as the first priority in the technical category with an RI value of 0.952, and it was also the highest among all factors and was highlighted at "High" importance level. "Resistance to fire" was also rated second in importance among the selection factors. "Maintenance Cost" was ranked third in importance. It was clear from this research that there is a perception of ambiguity surrounding the long-term maintenance of LCGBMCs. This is not entirely surprising given that maintenance free buildings are increasingly sought after by clients, anxious to minimise the running costs associated with buildings. "Life-cycle cost" has been, and continues to be major concerns for building designers. Among the top 20 ranking factors, it was observed that only one factor from the environmental category out of the list was ranked high among the selection factors. This again suggests that environmental issues within the context of the developing countries are not strongly considered despite the high environmental awareness exhibited by design and building professionals in developed regions. This finding also corroborates the initial observations of various studies (Ellis, 2009; Seyfang, 2009a; Malanca, 2010) repeatedly highlighted in the background and literature studies in chapters 1 and 2.

Table 10: Ranked decision factors for low-cost green building material selection

Material selection factors/variables	Valid percentage of score (%)					Relative Index Scores	Ranking by Category	Overall Ranking	Importance Level
	1	2	3	4	5				
GENERAL/SITE FACTORS									
GS2-Material Availability	1.6	2.9	17.9	50.5	27.0	0.795	1	35	H-M
GS1-Geographic Location of Building Site	2.1	2.6	19.3	51.2	24.3	0.773	2	38	H-M
GS10-Building and Space Usage	0.8	5.5	21.4	52.2	20.1	0.764	3	39	H-M
GS9-Knowledge Base in Construction	1.1	7.4	33.2	42.1	16.3	0.731	4	41	H-M
GS6- Natural Disasters Common to the Site	1.4	11.3	27.7	39.5	20.1	0.726	5	42	H-M
GS7-The Type of Building Material(s)	1.8	8.2	36.3	37.0	16.7	0.712	6	43	H-M
GS4-Building Regulation and Certification for Use	2.7	10.8	33.5	36.1	16.9	0.709	7	44	H-M
GS5-Design Concept	0.8	15.2	35.5	13.1	15.4	0.702	8	45	H-M
GS12-Spatial Scale: Building Size and Mass	4.5	17.8	30.3	28.4	19.0	0.675	9	47	H-M
GS8-Project Site Geometry/Setting/Condition	1.4	17.5	38.1	33.3	9.7	0.663	10	46	H-M
GS3-Distance	5.6	17.9	32.1	31.3	13.1	0.653	11	47	H-M
GS11-Building Orientation	4.6	21.9	29.5	28.4	15.6	0.652	12	48	H-M
ENVIRONMENTAL/HEALTH FACTORS									
EH3-Safety and Health of End-users	0.5	2.5	3.1	46.2	47.1	0.876	1	17	H
EH6-The Climatic Condition of the Region	0.3	2.0	5.3	49.2	42.6	0.860	2	23	H
EH7-Material Environmental Impact	0.7	2.6	6.0	49.0	41.1	0.850	3	27	H
EH2-Level of Carbon Emissions and Toxicity	0.3	4.9	5.6	49.2	39.5	0.849	4	28	H
EH4-Habitat Disruption: Ozone Depletion Potential	1.6	1.8	9.6	52.0	34.4	0.830	5	30	H
EH1-Environmental Statutory Compliance	2.1	6.3	9.7	42.7	38.7	0.820	6	32	H
EH5-The Amount of Pesticide Treatment Required	3.0	2.9	8.2	52.5	32.9	0.813	7	33	H
ECONOMIC/COST FACTORS									
C4-Maintenance or Replacement Cost	0.5	1.8	5.9	20.2	71.6	0.912	1	3	H
C5-Labour or Installation Cost	0.5	2.0	5.2	27.3	64.9	0.898	2	8	H
C1-Life Cycle Cost	4.5	3.0	26.1	66.4	99.6	0.897	3	9	H
C3-Capital Cost (Economic Status of the Client)	0.8	3.6	7.1	22.0	66.5	0.891	4	10	H
C2-Material Embodied Energy Cost	0.5	5.6	4.0	25.4	64.5	0.876	5	17	H

SOCIO-CULTURAL FACTORS								
SC5-Local Knowledge of the Custom	0.5	3.7	5.5	32.0	57.8	0.884	1	13	H
SC1-Material Compatibility with Cultural Traditions	1.0	4.5	2.7	33.9	57.4	0.879	2	16	H
SC6-Material Compatibility with Cultural Traditions	0.4	2.9	3.7	36.2	56.2	0.876	3	17	H
SC2-Material Compatibility with Regional Settings	0.5	2.5	6.4	32.7	57.4	0.875	4	18	H
SC3-Cultural Restriction(s) on Usury	1.0	3.3	10.8	31.1	53.3	0.851	5	26	H
SC4-Family Structure: Type & Size of Family Unit	3.0	21.0	15.7	19.8	39.9	0.737	6	40	H-M
TECHNICAL FACTORS									
T15-Life Expectancy	1.1	0.3	4.2	26.9	66.8	0.952	1	1	H
T7-Resistance to Fire	0.3	1.2	4.8	28.8	64.9	0.919	2	2	H
T9-Resistance to Moisture	0.5	1.5	3.6	24.7	69.7	0.911	3	4	H
T11-Resistance to Weather	0.3	1.0	4.8	25.0	69.0	0.911	3	4	H
T5-Availability of the Technical Skills	0.5	1.5	4.5	28.4	65.0	0.905	4	5	H
T8-Resistance to Heat	0.3	1.2	4.8	28.8	64.9	0.904	5	6	H
T13-Resistance to Decay	0.3	1.5	5.7	25.7	66.8	0.902	6	7	H
T3-Level of Maintenance Requirement	0.5	1.8	4.2	30.6	62.8	0.897	7	9	H
T6-Ease and Speed of Method fixing	0.5	2.2	7.5	29.4	60.4	0.883	8	14	H
T4-Ability to Tolerate Expansion and Contraction	8.3	2.0	6.7	32.9	50.0	0.882	9	15	H
T1-Recyclability and Reusability	2.2	2.2	5.2	31.4	59.0	0.868	10	20	H
T12-Resistance to Chemicals	0.1	1.9	13.1	27.9	57.0	0.865	11	21	H
T2-Ease to Remove and Reaffix	0.7	2.2	6.8	36.5	53.8	0.864	12	22	H
T14-Weight and Mass of the Material	0.3	2.6	12.4	29.2	55.5	0.856	13	24	H
T10-Resistance to Scratch	1.1	3.1	11.6	27.0	57.1	0.852	14	25	H
SENSORIAL FACTORS									
SN4-Temperature	0.4	0.4	3.1	44.8	51.0	0.887	1	11	H
SN6-Odour	0.4	1.2	5.6	37.7	54.8	0.886	2	12	H
SN10-Lighting Effect	1.4	8.9	17.5	33.5	37.8	0.886	2	12	H
SN5-Acoustics	0.7	0.5	5.6	42.2	50.7	0.876	3	17	H
SN1-Aesthetics or Visual density	0.3	1.4	6.0	46.0	46.0	0.870	4	19	H
SN2-Texture	3.1	10.0	45.2	41.4	0.3	0.839	5	29	H
SN3-Colour	0.3	3.0	12.2	46.0	38.2	0.823	6	31	H

SN7-Thickness/Thinness	1.5	8.9	13.3	35.5	40.6	0.806	7	34	H
SN9-Hardness	1.5	8.9	18.9	30.6	39.9	0.790	8	36	H-M
SN8-Glossiness/Fineness	2.6	9.2	18.7	33.1	36.2	0.774	9	37	H-M

Source: Analysis of surveyed data, 2013

Table 11: Kaiser-Meyer-Olkin and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.862
Bartlett's Test of Sphericity	Approx. Chi-Square	42121.213
	df	1485
	Sig.	0.000

Source: Analysis of surveyed data, 2013

From **Table 10**, a total of 15 factors, consisting of 12 site factors, 1 socio-cultural factor, and 2 sensorial factors, were recorded to have "High–Medium" importance levels. Although these 15 variables were in the same importance level category, the "building orientation" factor within the "general/site category" (average RI=0.652) was considered to be the least important variable compared to the factor "Glossiness" under the "sensorial category" (with an average RI=0.774), and "material availability" still under the "general/site category" (with an average RI=0.795). However, it should be noted that site factor account for 75% in the "High-Medium" importance level. The result is an example of evidence pointing to the trend that environmental and perhaps site issues are no longer considered as the most important factors in the choice of materials for housing projects, especially within the context of the emerging economies.

Some factors in the three categories were ranked relatively higher in the "High– Medium" level. For example, "material availability (GS1)" was rated as first in the general/site subcategory, but ranked thirty-fifth in the overall ranking with an RI value of 0.795. An interesting observation from the results shown in **Table 10** is that none of the criteria fell under the medium and other lower importance level. This clearly shows how important the factors are to building designers in evaluating LCGBMCs. All factors were rated with "High" or "High– Medium" importance levels. The findings of the analysis suggest that the criteria with low RI do not mean they are not important for selecting materials, but rather created an opportunity to highlight the relative importance of criteria from their vantage point.

Factor analysis for Sub-Categorical Factors

Given that the reliability test proved to be consistent in the measuring instrument as proven by the Cronbach's alpha score of 0.781 (following the results in **Table 9**), a factor analysis was performed using SPSS v.20 to determine the optimal number of the factors that were retainable, and identify the unobserved variables within each category.

According to Hutcheson & Sofroniou (1999, p.224-225), a KMO value is regarded as ideal if it falls within the range of 0.7 and above. They argued that values closer to 1 indicate that patterns of correlation are relatively compact and therefore, should yield reliable factors that are able to assess decisions in the selection of LCGBMCs.

They note that values between 0.5-0.7 are mediocre, values between 0.7-0.8 are good, values between 0.8- 0.9 are excellent and values above 0.9 are superb. They further argued that for factor analysis to produce efficient results there must be strong and close relationships between variables, and the test analysis must exhibit a significant value of $p<0.05$. The following sections present the results of the factor analysis for the various categories of the material-selection factors.

General/Site Category

For the "General/Site" category, the analysis results showed a Kaiser–Meyer–Olkin's (KMO) measure of sampling adequacy score of 0.883 falling within the range of 0.8-0.9. Therefore, the value of 0.883 suggests that the sample was excellent for factor analysis, as recommended by Hutcheson & Sofroniou (1999, p.224-225). The Bartlett Test of Sphericity was 1468.871 and the associated significance level of 0.000 ($p<0.001$), indicated that the test was highly significant and that the population correlation matrix was not an identity matrix. Both tests showed that the obtained data in the general/site category supported the use of factor analysis, which was grouped into smaller sets of underlying factors. Using maximum likelihood analysis, the factor analysis extracted two latent factors under general/site category, namely Factor GS11: building orientation; and Factor GS12: Spatial scale. The two variables accounted for 55.6% of the total variance. The rotated factor-loading matrix results based on the direct oblimin rotation for the two latent factors are shown in **Table 12**, and **Appendix F**.

Table 12: Factor loadings for general-site factors after direct oblimin rotation

Observed general/site variable	Latent general/site factors	
	1	2
GS11: Building Orientation	0.997	
GS12 Spatial Scale: Building Size and Mass	0.623	
GS7: The Type of Building Material(s)		0.816
GS2: Material Availability		0.809
GS4: Building Regulation and Certification for Use		0.721
GS9: Knowledge Base in Construction		0.699
GS5: Design Concept		0.683
GS6: The Type(s) of Natural Disasters Common to the Site		0.666
GS8: Project Site Geometry/Setting/Condition		0.538
GS3: Distance		0.533
GS10: Building and Space Usage		0.530
GS1: Geographic Location of Building Site		0.518
Eigenvalues	3.766	2.904
Percentage of variance (%)	31.379	24.203
Cumulative of variance (%)	31.379	55.582

The pattern matrix shown in table 12 identifies the relationship between the observed variables and the latent factors. The higher the absolute value of the loading, the more the latent factor contributes to the observed variable. Small factor loadings with absolute values less than 0.3 were suppressed to help simplify **Table 12**. Further interpretation(s) thus conceptualised the two latent factors under the general/site category as: 1= "building spatial analysis" and 2= "site suitability" since they both, relate to the site dimension.

Environmental/Health Category

The analysis performed on the Environmental/Health category produced a KMO measure of sampling adequacy test score of (0.867) and Bartlett's Sphericity of (1027.062), with an associated significant score of (p=0.000). The results indicated that factor analysis was also appropriate for this category. However, only one factor under environmental/health category was extracted from the factor analysis using both the scree plot diagram and the total variance table in **Appendix F**. The percentage of variance attributable to each factor and the cumulative variance values are shown in **Table 13** and Appendix F. From **Table 13**, it can be seen that only one factor -EH4 accounted for 60.2% of the total variance of the seven environmental criteria.

Table 13: Factor loadings for environmental/health factors after direct oblimin rotation

Observed environmental/health variable	Latent environmental/health factors	
	1	2
EH4: Habitat Disruption: Ozone Depletion Potential	0.851	
EH7: Material Environmental Impact	0.836	
EH3: Safety and Health of End-users	0.829	
EH6: The Climatic Condition of the Region	0.801	
EH2: Level of Carbon Emissions and Toxicity	0.787	
EH5: The Amount of Pesticide Treatment Required	0.736	
EH1: Environmental Statutory Compliance	0.549	
Eigenvalues	4.215	-
Percentage of variance (%)	60.217	-
Cumulative of variance (%)	60.217	-

Source: Analysis of surveyed data, 2013

Economic/Cost Category

In the economic/cost category, the results for the factor analysis showed that the KMO measure was 0.794 and the Bartlett's test (p=0.000), indicating that the factor analysis was also appropriate in identifying the underlying structure of the economic category.

This means that the test is highly significant and that the population correlation matrix was not an identity matrix. The results of the analysis are presented in **Table 14**. Just one factor named Factor C4: Maintenance and replacement cost was extracted, explaining 61.1% of the total variance.

Table 14: Factor loadings for economic/cost factors after direct oblimin rotation

Observed economic/cost variable	Latent economic/cost factors	
	1	2
C4: Maintenance or Replacement Cost	0.938	
C5: Labour or Installation Cost	0.861	
C3: Capital Cost	0.793	
C1: Life Cycle Cost	0.714	
C2: Material Embodied Energy Cost	0.544	
Eigenvalues	3.054	-
Percentage of variance (%)	61.078	-
Cumulative of variance	61.078	-

Source: Analysis of surveyed data, 2013

Socio-Cultural Category

Similarly, the results for the exploratory or common factor analysis in the social category produced a KMO measure of 0.831 and a Bartlett's test of Sphericity value of 626.700, indicating that the test is highly significant and that the population correlation matrix was not an identity matrix. A significant value of (p=0.000) indicated that factor analysis was also suitable in identifying the underlying structure of the factors within the socio-cultural category. However, both the scree plot diagram and the total variance table in **Appendix F**, only one factor (factor SC2: material compatibility with regional settings) was extracted, explaining 51.5% of the total variance of the six socio-cultural criteria The results of the analysis are presented in **Table 15** and an extension in **Appendix F**.

Table 15: Factor loadings for socio-cultural factors after direct oblimin rotation

Observed socio-cultural variable	Latent socio-cultural factor
	1
SC2: Material Compatibility with Regional Settings	0.913
SC3: Cultural Restriction(s) on Usury	0.833
SC1: Material Compatibility with Cultural Traditions	0.826
SC6: Material Compatibility with Cultural Traditions	0.695
SC5: Local Knowledge of the Custom & Lifestyle	0.505
SC4: Family Structure: Type & Size of Family Unit	0.378
Eigenvalues	3.090
Percentage of variance (%)	51.498
Cumulative of variance (%)	51.498

Source: Analysis of surveyed data, 2013

Technical Category

For the technical category, the results for the factor analysis showed a KMO measure of 0.902 and the Bartlett's test of Sphericity value of 2848.547, with significant p value=0.000, indicating that the test was highly significant and that the population correlation matrix was not an identity matrix. This indicated that the factor analysis was also appropriate in identifying the underlying structure of the technical category. Three factors under technical category, namely Factor T9: Resistance to moisture; Factor T11: Resistance to weather; and Factor T7: Resistance to fire were extracted from the factor analysis, explaining 67.8% of the total variance after rotation. The three groups of factors 1, 2 and 3 were conceptualised as "Performance", "Efficiency", and "Specialty" respectively. The results of the analysis are presented in **Table 16**, and in **Appendix F**.

Table 16: Factor loadings for technical factors after direct oblimin rotation

Observed technical variable	Latent technical factor		
	1	2	3
T9: Resistance to Moisture	0.946		
T11: Resistance to Weather	0.856		
T7: Resistance to Fire	0.851		
T8: Resistance to Heat	0.812		
T5: Availability of the Technical Skills	0.655		
T3: Level of Maintenance Requirement	0.589		
T15: Life Expectancy	0.530		.
T12: Resistance to Chemicals		0.875	
T10: Resistance to Scratch		0.741	
T14: Weight and Mass of the Material		0.528	
T13: Resistance to Decay		0.487	
T2: Ease to Remove and Reaffix			0.779
T4: Ability to Tolerate Expansion and Contraction			0.462
T6: Ease and Speed of Method fixing			0.456
T1: Recyclability and Reusability			0.448
Eigenvalues	8.561	0.877	0.737
Percentage of variance (%)	57.073	5.849	4.916
Cumulative of variance (%)	57.073	62.921	67.837

Source: Analysis of surveyed data, 2013

Sensorial Category

In the sensorial category, the results for the exploratory factor analysis showed a KMO measure of 0.891 and Bartlett's test of Sphericity score of 1705.393, with a significant value of (p=0.000), which revealed that the factors were appropriate. Two factors- Factor SN5: Acoustics and Factor SN4: Temperature were extracted, both accounting for 66.19% of the total variance. SN5, SN4, SN6, SN2, SN3, and SN1, constituted the first factor group. The study conceptualised this factor group as "Receptive/Emotive" and SN9, SN8, SN7, and SN10 constituted the second factor and this was conceptualized as "Intrinsic/Sensitivity qualities of a product". Along with rotated factor-loading matrix, the percentage of variance attributable to each factor and the cumulative variance values are shown in **Table 17**, with an extended version in **Appendix F**.

Table 17: Factor loadings for sensorial factors after direct oblimin rotation

Observed sensorial variable	Latent sensorial factor	
	1	2
SN5: Acoustics	1.000	
SN4: Temperature	0.965	
SN6: Odour	0.775	
SN2: Texture	0.596	
SN3: Colour	0.453	
SN1: Aesthetics or Visual density	0.442	
SN9: Hardness		0.935
SN8: Glossiness/Fineness		0.891
SN7: Thickness/Thinness		0.801
SN10: Lighting Effect		0.223
Eigenvalues	5.834	0.785
Percentage of variance (%)	58.336	7.853
Cumulative of variance (%)	58.336	66.189

Source: Analysis of surveyed data, 2013

In summary, a total of ten latent factors resulting from the overall analysis were extracted to present the underlying structure of the variables used for selecting LCGBMCs for building projects, at the design stage. Two factors were identified under the general/site category; one factor under the environmental/health category; one factor each for both the economic and socio-cultural categories; three factors for the Technical dimension, and two factors for the sensorial group. However, as Kline (2002) argued, factors with loadings of 0.30 or higher were considered significant, or at least salient in this study, so that the model constituted of all those variables that had factor loadings greater than or equal to 0.3 after rotation.

Although the factor "Lighting Effect" was included as part of the decision selection factors, the value 0.223 showed that its impact on the material selection decision-making process is not as effective or salient as the other factors. The results of the analysis showed that the identified decision criteria,, and the sub-criteria could be used ideally as a checklist by house building organisations for the selection of LCGBMCs.

General View on Low-Cost Green Building Materials

The final set of questions bordered on issues associated with the integration of the proposed material selection decision support tool in design practice, aiming to give participants the opportunity to share or clarify their views regarding the proposed MSDSS model. The following sections present full analyses of respondents' view(s) of the final set of questions.

Measures to Facilitate Mass use of LCGBMCs in Housing

The literature review conducted in chapter 2 identified some potential measures that could be undertaken to encourage greater industry acceptance of LCGBMCs. Respondents were asked to rank on a 10-point scale from (1) "least relevant" to (10) "extremely relevant", the level of relevance of each measure as it will influence or facilitate greater use of LCGBMCs in mainstream housing.

The importance accorded to "Provision of readily available information relating to LCGBMCs" was rated highest with a relative index of (RI=0.929). "Subsidising LCGBMCs" followed with a relative index score of (RI=0.888). "Government's adequate funding of research to boost production and wide-scale use" ranked third with a relative index of (RI=0.874). "Setting up workshops to spread awareness to building professionals & clients of their potential economic, environmental and health benefits" placed fourth on the list (RI=0.857), while "Strong mainstreaming initiatives, and effective implementation of policies that encourage their wider scale use" trailing the fifth position with a relative index of (RI=0.839)- all making the top five of the potential measures as shown in **Table 18**. **Figures 7** compares the different preferences of all measures. Summary of the top three potential measures are discussed in their order of importance in the following sections.

Table 18: Potential measures that could influence the wider-scale use of low-cost green materials

Measures	Relative Index (RI)	Rank
M1: Provision of Adequate Information on Low-Cost Green Materials	0.929	1
M10: Adequate Research Funding	0.888	2
M2: Subsidising Low-Cost Green Building Materials	0.874	3
M5: Setting up Workshops to Sensitise Building Professionals & Clients	0.857	4
M6: Effective Implementation of Policies	0.839	5
M7: Stringent Measures for Corruption in the Construction Industry	0.787	6
M9: Import Restriction of Foreign Building Materials	0.751	7
M4: Stringent Building Regulation Standards	0.741	8
M8: Diversification of Production Technology	0.591	9
M3: Use of Highly Mechanised Production System	0.515	10

Source: Analysis of surveyed data, 2013

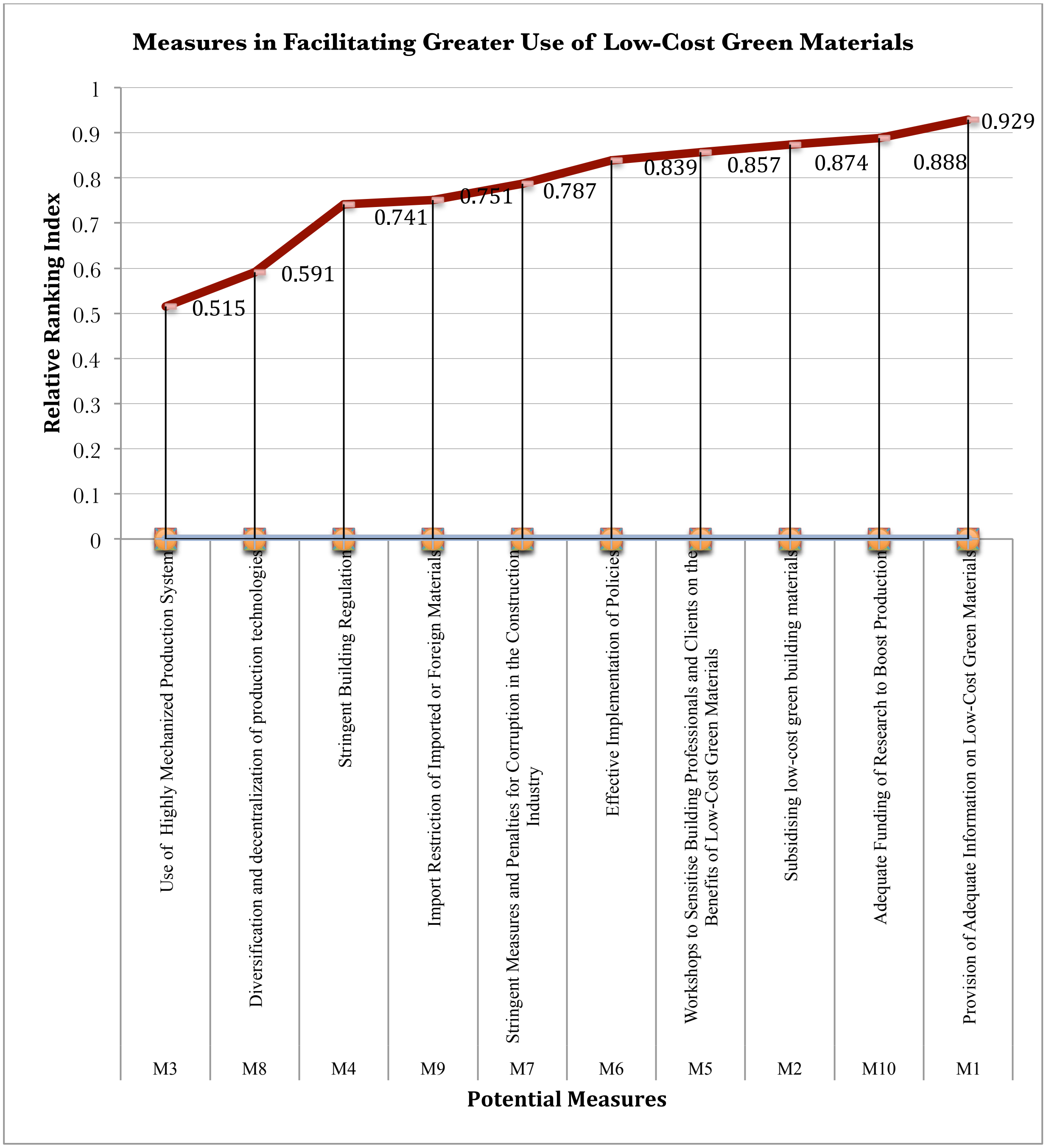


Figure 7. Potential measures that influence the wider-scale use of low-cost green materials

Provision of well-informed information on low-cost green materials

In the question about the suggestive measures that could be undertaken to encourage greater use of LCGBMCs, a consensus of the respondents agreed that provision of readily available information was the most critical of the ten factors listed with a relative index of 0.929 (see **Table 18**). The survey revealed that the documentation and dissemination of information have high influence on the availability of information, hence, the adequacy of professional knowledge on best practices relating to their social, economic and environmental impacts. The results obtained from this analysis are consistent with previous empirical findings by Nwokoro and Onukwube (2011), who stated that regulatory pressures on the use of such materials are associated with both the availability of sustainable information, and firms' decisions to implement sustainability principles.

Government's adequate funding of research to encourage wider-scale use

The results of the analysis reported that the limited availability of reliable information was strongly influenced by the lack of investment in research and development (R&D), which ranked second with a relative index of 0.888. About half the respondents acknowledged the contribution of R&D to the transference of new information and technologies, as plenty of proven choice of alternative and massively abundant LCGBMCs are yet to be tapped.

The majority of respondents note that currently the Nigerian housing sector does not have a physical development plan that supports longitudinal research on LCGBMCs. They suggest that appropriate building material and technology programmes mandated to enforce research schemes might help to educate the government on the viability and effectiveness of funding research on alternative cost and energy-efficient materials. They recommend that the Ministry of Housing could potentially explore a variety of LCGBMCs options that are yet to be tapped through this means.

The findings of the survey supports Oluwakiyesi's (2011) view, which acknowledged that the long delays in implementing research schemes have significantly affected housing developers looking to introduce new and cost effective building materials and technology. He noted that the research incentives introduced in by the government in 2007 to encourage their production capacity are still the only means by which the government could encourage progressive research on such products.

Subsidising low-cost green building materials and components

While the adequacy of informed data (0.929) and funding of research and development programmes (0.888) topped the list, quite a number of the respondents also emphasised the benefits of subsidising LCGBMCs, which ranked third with an RI of 0.874. The survey results indicate that social acceptability of alternative LCGBMCs particularly centres on the rate at which they are subsidised.

Respondents suggested that full subsidies and credit guarantee programmes and the promotion of alternative construction materials could deliver cheaper housing. They stressed that subsidising LCGBMCs to private developers could be one of the government's ways of facilitating the provision of affordable housing, considering that the provision of housing is mostly undertaken by private sectors. They advise that government should grant subsidy to the industries manufacturing such local building materials until the society develops enough taste for such product to stimulate substantial demand. One respondent notes;

"Subsidizing LCGBMCs would take into account the adequacy of household income, as low-income earners are able to pay for affordable materials".

Along with the agreement of respondents on the role of subsidies in LCGBMCs development, Nwafor (2006) also observed that clients and developers around the fast growing urban areas in Nigeria face a number of barriers that prevent them from being able to deliver affordable housing, some of which were the relatively high cost of building materials, and restrictive regulations that limit the use of alternative cheaper cost and energy efficient building materials.

In their study, "Acquisition of Technological Capability in Africa", Oruwari et al. (2002) suggest that subsidizing LCGBMCs could create an enabling environment, particularly for the low-income groups, through partnerships and participation by all key actors. They add that this initiative has been known to be responsible for reducing housing cost in other developing regions like South Africa (Aluko, 2002; Akinlusi, 2007).

Views on the Proposed MSDSS Model

The last question consisted of both closed and open-ended questions aimed at giving participants the opportunity to share their general views regarding the proposed MSDSS model. The final question which suggests for further improvement of the proposed system, showed contradictory priorities for each group of design and building professionals. Scoring a record high of 30% as respondents' first preference is the confidence to create real low-impact green design that considers the social, economic and environmental implications of the various material alternatives with the information provided in the system. This choice is in line with Holms and Donn's study in which they confirm that many design and building professionals doubt the ability of decision support systems to create real green designs based on the information in the database (Donn, 2001; p.128).

The second priority (with a percentage score of 25%) was the ability of the system to provide accurate and reality like results followed by (15%) the ability to provide validated performance measures. The ability to calibrate the uncertainty (10%) and the high resolution of decision support model (5%) were the least important criteria.

Another important criterion (15%) was the ability to provide validated performance measures to support effective design decision trade-offs in the choice of such materials at the early stages. In this context, accuracy of material assessment results was not as important to some respondents as much as understanding the relative effect on material performance due to changes in design decision of material alternatives. This finding also suggested that the accuracy of the decision support model should be adaptive and adjustable to the user type and design phases, to correspond to the different needs of the designer as well as other potential users.

Other participants concentrated more on the operability of the system, some of which include:

- Allowing debugging;
- Error-checking to ensure models are correct;
- User friendliness;
- Easy searchable material selection inputs database;
- Ability to add/remove material selection features with ease;

- Ability to make custom reports;
- Ability to easily navigate all components with ease;
- Assisting decision making process through guidance
- Comprehensive "HELP or USER INSTRUCTIONS" menu explaining what the tool is doing;
- Being able to understand the material selection process through the lens of non experts;
- Must be built on an underlying database to aid in benchmarking;
- Ability to perform trade-off analysis to compare different material options;
- Clarity on the algorithms used to perform the simulations and the limitations of those algorithms; and,
- Having a huge amount of customizability in terms of output.

This question also revealed another important finding, showing contradictory priorities for each group. Architects, designers, and Specifiers first preference was the confidence to create real low-cost green/sustainable design. They suggest developing software that corresponds to all design stages.

There was on the other hand an agreement between engineers and software programmers. Engineers ranked the accuracy of tools and ability to simulate complex design elements in the first place. The second most important criterion was the friendliness of interface mainly on issues relating to usability and information management followed by the ability of the tool to integrate intelligent design knowledge-base to assist designers in decision making.

There is no doubt that engineers and programmers require adaptive and friendly interfaces and are looking for tools that can assist the decision, taking whether for code compliance or optimization issues. They clearly identified the quality control of simulation input as another important feature. This is not surprising since the issue of attaining quality assurance of simulation input has been repeatedly highlighted in various literatures (such as Donn 2001; Augenbroe 2002 and Reinhart 2009).

Analysis of the Interviews

The purpose of the one-on-one interview was to achieve the qualitative part of objectives 1, 2 and 3 as listed in chapter one of the study. Ten interviews were conducted with construction sector policy makers who influence material choice decisions in the Nigerian housing construction industry from the period May 2013 to August 2013. The interviewees were drawn from a range of design firms, institutions and construction sector. The cross sectional convenience sampling method was adopted as the sampling technique, since this study did not have the resources and time to interview larger groups (see section 4.5.2.12 in chapter 4). The following sections summarise the scope of the interview findings.

Interview Procedures

The interviews were typically between one and two hours in length. Whenever possible the interviewees were recorded and fully transcribed to allow for subsequent analysis and the coding of emergent themes. The face-to-face interviews were recorded using a digital Dictaphone to ensure accuracy and no loss of understanding whilst the telephone interviews were carried out using Skype Voip software (Microsoft, 2013b), However, 8 of the 10 interviewees were uncomfortable with being recorded and in these cases the subsequent analysis relied on handwritten notes. The credibility of the summary analysis presented below has subsequently been validated by a series of focus groups involving industry practitioners.

Transcription Techniques

Ten interviews were conducted with construction sector policy makers who influence material choice decisions in the Nigerian housing construction industry from the period May 2013 to August 2013. The interviewees were drawn from a range of design firms, institutions and construction sector. Full transcriptions were created for both the interview scoping study and the company studies. It is important to ensure that the data is collected in a reliable manner, for example, when transcribing interviews the placement of grammar according to pauses can mean something different as sentences can have different interpretations. For easy identification and evaluation, the transcriptions were put into the Nvivo software (QSR International, 2012) as individual sources. The use of Nvivo enabled flexibility to amend the structure and clustering of codes whilst also allowing for fast retrieval of statements relating to codes. The researcher created a rule set for transcribing based on a similar list given by (Macnaghten and Myers, 2010):

-Repeated words were ignored
-Pauses were indicated with
-Emotional expressions were placed in brackets, e.g. (laughing)
- Ensure transcriptions are readable

Scope of the Interviews

The essence of conducting interviews was to:

- Investigate the extant of the problems associated with the limited use of LCGBMCs in the Nigerian housing industry;

- Identify proactive measures that could be undertaken to encourage greater industry acceptance of such materials in mainstream housing;

- Examine knowledge of the current trend in the use of design and decision support tools; and

- Identify sustainable material selection information requirements of the practitioners towards the development of the proposed model that will suit their decision- making process.

The in-depth interviews were of the format recommended by Mason (2002), where questions were simplified into semi-formal questions (see **Appendix E**). There were a total of ten semi-formal questions towards achieving the goals listed above as well as to qualitatively address objectives 1, 2, and 3 of chapter one.

Profile of Interviewees

The interview sessions, which were held on different occasions, consisted of ten (10) interested building professionals in academia and practitioners with diverse qualifications and years of experience. The criterion for their selection was based on whether they had designed or supervised the development of sustainable low-impact housing projects using LCGBMCs in Nigeria. Details of their profiles and years of experience as derived from the interview questions are detailed as follows:

- Interviewee ‘**A’** is a registered design and build project architect in practice with fifteen years of experience and a wide knowledge of different aspects associated with low-cost housing.

- Interviewee **‘B’** is a designer in practice with twenty years of experience and a wide knowledge of different areas of low-cost housing issues in Nigeria.

- Interviewee ‘**C’** is a registered urban designer in academia with ten years of experience and vast knowledge in reduced cost housing projects.

- Interviewee **‘D’** is a quantity surveyor eight years of experience in academia now in practice.

- Interviewee **‘E’** is an accredited building engineer with over thirty years of experience in practice using low-cost green materials in housing construction.

- Interviewee ‘**F’** is a registered practicing architect with twenty- five years of experience in sustainable housing design.

- Interviewee **‘G’** is an enthusiast in design and construction with strong ideas and innovation and information technology in housing construction that has five years of experience.

- Interviewee **‘H’** is a builder with a record of past sustainable housing projects that has twelve years of experience.

- Interviewee **‘I’** is a material analyst of ten years experience working on residential building projects.

- Interviewee **‘J’** is a practicing developer and project consultant of fifteen years experience that have handled several residential housing projects.

Factors limiting the wider-use of low-cost green building materials

The question in relation to the theme above was directed to all the interviewees. Analysis was undertaken to identify the problems that significantly hinder the wider use of LCGBMCs in the housing industry.

Lack of an informed system to assess current information associated with LCGBMCs; codes, and standards not supporting the appropriate use of LCGBMCs and Social perception and preference of clients and users, were all recognised by interviewees 'A', 'B', 'C', 'E' 'F', 'G', 'H', 'I' and 'J' as the three most critical factors that limit the use of LCGBMCs in the housing construction industry.

Interviewee 'A' noted; "Primary data remain the only possible way for investigating the problems of wider use of LCGBMCs in the Nigerian housing sector". I think the best option would be to develop a system that will help provide designers material information associated with LCGBMCs, to enable them analyse and understand the impacts and performance standard of the materials at the design stage before they are used for construction".

Interviewee 'E' 'F' and 'G' all agreed that lack of standard, codes, performance measures and development indicators for such products; clients' notion about the commercial viability of the project outcome; and low technological development dominated the list of the problems related to the use of LCGBMCs in housing construction. Interviewee 'E' added; "one of the key barriers is perhaps understanding the data associated with their impacts".

This was followed by interviewees 'C', 'H', 'I', and 'J' who identified other factors including: domination of foreign or imported conventional building materials in the market; nature of the contractual documents; inadequate capacity and inefficiency in the Building Material Industry (BMI); Corruption; Bureaucracy and administrative red tape; Rigid adherence to inappropriate management techniques and practices; Absence, underdevelopment, and weakness of institutions (legal, administrative, planning, financial, and professional institutions); Scarcity and shortage in the supply of BMs; and Shortage of plants, machinery, equipment, and spares.

Interviewee 'C' suggested; "'More money should be spent on making the prototype housing models more appealing and technically sound, so that if clients are willing to pay for houses made from LCGBMCs, then it would be very easy to convince them'.

He identified availability of skills to install such materials; confidence and competence of the artisans; designers' orientation, and unwillingness to change, as some of the factors he thinks are key obstacles to their wider use.

Interviewee 'H' also pointed out that Advocacy, planning Education, and public participation, all at inception give opportunity for active participation and to carry along all involved. He states; "It is mainly the issue of development, lack of awareness of the comparative advantage and the unwillingness on the part of government to provide policy on low-cost green technology".

Interviewee 'J' who has been a property developer for over fifteen (15) years had a different view to this question. He noted; "Developers, owners and users are reluctant to expose themselves to the risk of applying new materials and technologies due to the poor sample models of existing prototypes". He added; "Clients have veto power. The degree to which they use or accept to use such products largely depends on the factors I earlier mentioned and principally on clients self-perception".

Interviewees 'A', 'B', 'C', 'D' 'G', 'H', and 'J' admitted that most clients and even designers believe that local materials are associated with poverty and low socio-cultural status. One of the interviewees noted; "The problems of using LBMs are not attributed to the durability of those materials. They are, in the first place, attributed to other factors such as status, which impede the use of appropriate materials and technologies".

Interviewee 'I', who has once been a project manager, admitted that he has always been discouraged by the low quality of the local BMs and products in the market. He emphasised, "In the case of Nigeria and perhaps in some other African countries, the introduction of low-cost green building technologies has to come in as a substitute of the conventional materials, as the population is not very prepared to dare into the unknown. With the conventional systems, which are concrete based, the actual quality of the materials is much lower than the conventional products as per the norms, but the buildings somehow stand on their feet. With the earth brick technologies for example, diverting as much as 10-15% from the norms yields very poor results". He added; "We need to change our attitude to this especially in Nigeria and Africa as a whole".

All these obstacles agree favorably with the results of the surveyed questionnaire.

Measures to promote greater industry acceptance in mainstream housing

In a follow up question, interviewees were asked to identify proactive measures that would be most crucial in facilitating greater demand for LCGBMCs in the housing construction.

All groups of interviewees identified "the provision of readily available information" as the most crucial of all initiatives needed to facilitate the sustainable use of LCGBMCs. A common knowledge that all groups considered "the provision of readily available data" as the most important issue perhaps indicates a huge gap between the production and implementation of such products, since designers do not posses sufficient knowledge to make informed choices during the design process.

Interviewee 'B' noted; "A better understanding of the impacts of these materials and their innate characteristics, will help designers to fully overcome their shortcomings and perhaps identify ways to use them with confidence. I think this could be achieved, by applying new knowledge and techniques". An explanation to this might be that building practitioners are more involved with understanding the impacts of these materials and the ability to access quick energy analysis data of such products to support the decision-making process than the machineries needed for their production. This may be because design and building professionals are more particular about the early design phases and therefore, need guidance to answer "what if" scenarios that can assist them in the material selection and design optimisation processes.

The next priority was "Government's adequate funding of research to boost production capacity". Most of the interviewees agreed that the underdevelopment of the research sectors within the socio-economic context in Nigeria is an important contributory factor to the problems of low patronage. They added that investment in training, education and research is crucial to the development of the LCGBMCs industry. Interviewees 'A', 'B', 'H', 'I' and 'J' suggested that research studies should be undertaken to assess the possibility of introducing innovative materials, improving conventional ones and substituting some of expensive and imported materials by available low cost indigenous materials. They added that formidable research and development (R&D) facilities and programs could encourage innovation and create knowledge dissemination channels in the Nigerian housing industry.

Interviewee 'J' note: "there is hardly any known scientific research into these materials to enhance durability, quality, and use hence, making them 'OBSOLETE'". He notes that most clients want typical designs and products of the developed world replicated, stressing high level of ignorance as the root cause. Interviewees 'C' commented; "Most importantly, government agencies must be seen as encouraging research in their institutes through regular, adequate and prompt release of research grants". Interviewees 'A', 'B', 'C', 'D', 'E' 'F', 'G', and 'H', emphasised the need for integrated and/or collaborative research between different universities, institutions and organizations to improve the dissemination of the results of researches on such materials no matter how good and valid or poor the results may be. They suggest that government need to have independent and profit-oriented research and production technology organizations that are solely responsible for producing proto-type simple spare parts from local raw materials for industrial use.

Followed closely was "setting up workshops to spread awareness to building professionals and clients of their potential economic, environmental and health benefits". Interviewees all suggest that organising workshops and initiation of training programs could help both designers and clients to share knowledge about successful and appropriate technologies for the development of LCGBMCs, and popularize their use. Interviewees 'A', 'B', 'C', all agreed with interviewee 'F' that improving the efficiency of industry-wide quality assurance systems and/or thorough review of laws, legislations and regulatory instruments governing corrupt practices in the housing industry could help to eliminate such intentions.

Among all measures listed to facilitate the wider use of LCGBMCs in housing development, the strongest positive correlation was observed between the lack of accurate informed data associated with the use of LCGBMCs and poor linkage between research and practice. The application of inappropriate conventional building materials and technologies was attributed to limited variety of local materials and inappropriateness and rigidity of regulations, codes, and standards. Lack of development and poor quality of locally produced materials was associated with lack of government strategies. Lack of government's fund and policies was linked to lack of awareness, lack of technological infrastructure, lack of professional bodies for screening and diffusion of technologies, and incapability to innovate and benefit from IT. The ineffectiveness of technology diffusion networks was attributed to investment in training, education and research, and poor linkage between research and application/development.

Existing material selection methods

In the questions related to the sources of information, most interviewees identified non-availability of readily sourced, reliable and accurate information as a potential cause of the low use in mainstream.

Interviewee 'G' noted; "The available material selection methods in Nigeria is only erratic, and unsystematic and therefore a more competent and reliable system is required. An informed support system that is capable of checking for current and emerging information will be an advantage. By evaluating multiple alternatives simultaneously designers would be able to make informed and sustainable decisions".

Interviewee 'C', remarked; "I think a more realistic methodology is needed. Evolving such method would help ease the decision-making process. Such system could be made in form of either a check or decision matrix". She further notes; "Choice of technology should follow pre-specified criteria to help determine the most appropriate system to transfer, adopt and apply".

Interviewee 'B' stated; "Most of the known or available systems are case based support systems, not really a full software. Designers tend to use information available through material manufacturers manual as guide at the design stage. I think that for some professionals and lay people developing such a kit could help them sort through various options of LCGBMCs and make better design choices".

Interviewee 'F' shared similar view noting; "To the best of my knowledge there are no assessment systems or guidelines in Nigeria and this is a major limiting factor to the selection of such materials. The idea to apply such materials is useful but there is not enough data to produce reliable prediction of materials. There is the need for in depth catalogue of these materials to be properly documented to serve as reference to material selection, so that designers are able to analyse and understand the impacts and performance standard of the materials at the design stage before they are tendered in the contract document".

The views of the interviewees were consistent with that of the respondents in the surveyed questionnaire.

Sustainable material selection data requirements for the proposed model

In the question to suggest their views about the information needed in the MSDSS model to aid sustainable material selection, the following were acknowledged as matters of importance that ought to be considered:

- Minimal details to avoid complications in the evaluation process
- Approximation and flexibility;
- Low input to avoid hampering creativity and design thinking;
- Quick output in a language understood by designers.
- Precision in specification;
- Higher level of accuracy of the output data;
- Higher level of detail input required;
- Ability to produce 'Realistic' outputs.

Interviewee 'A' 'C', 'E', 'G', 'H', 'I' and 'J' all stated that such tools should enable the designers using it to understand it much better, so that designers are able to understand the impacts of each material alternative. Interviewee 'B' stated; "Tools for decision support should be easily accessible to a variety of users and less complex". Interviewee E noted; " It will be good to have a tool that enables designers make more informed decisions about the performance requirements of commercially available LCGBMCs starting from when the client writes a brief to the management level, and then to the development stage". The discussion with the interviewees suggested that the criteria model could help house building organisations mainly in the following aspects:

- Structure the thinking of selecting appropriate building product for specific projects.
- Clarify the value management importance of each product.
- Provide a checklist of collecting „what‟ information from „where‟ and by „whom‟.
- Present a framework for measuring the performance of offsite technologies.

The interviewees also provided some extra factors for consideration and/or amendments to the hierarchy according to the practices of their companies. This enriches the practicality of the criteria model and expands further the coverage of the decision-making factors. Some of the extra factors provided are actually covered by other existing criteria in the model, but some supplement the original thinking and, thus, were taken on board for refining the model

Summary

This section of the study has evaluated the data collected on a wider scale to fulfill the quantitative and qualitative parts of objectives 1 and 2 as well as 3 and 4 in chapter 1. The questionnaire was aimed at eliciting information on current practices in low-impact green energy design and housing construction in the Nigerian housing industry, particularly as it relates to the informed selection of LCGBMCs. The interview sessions were used to deepen understanding in the areas where both the literature review and scoping studies were unable to establish a clear understanding.

The survey questionnaires were distributed to 480 building and design professionals across Nigeria, receiving an overall response rate of 44%, quite beyond the ideal response rate of 20 – 30%, which is believed to be the norm in construction surveys (Takim et al., 2004), due to the poor and conservative response rate common with housing construction industries. The interviews on the other hand, consisted of ten (10) interested building professionals in academia and practice. Almost 75 per cent of the subjects who represented the architectural practices have over 10 years of experience, with 18 percent having over 20 years. Thus, it is assumed that the wealth of architectural experience held by individuals in this study is such that the data they have provided can be recognised as credible. The analyses of both the surveyed questionnaire and interviews highlighted drivers and obstacles that limit the use of LCGBMCs in the Nigerian housing sector. It identified principal sustainability principle indicators (decision factors) for modeling the decision-making process.

The results of the analyzed data revealed that the limited use of LCGBMCs is encapsulated in issues of availability, and appropriateness of a reliable information storehouse. It also revealed that current material assessment tools are undermined by usage issues such as lack of familiarity, absence of appropriate informed information relating to the use of LCGBMCs, incompatibility, context specificity, and lack of clear and simple assessment procedures.

The results of statistical analysis suggested a favourable condition to develop a material selection decision support system aimed at improving the sharing of informed knowledge associated with the use of LCGBMCs (as shown in chapter 5), in order to assist design and building professionals during material selection at the various stages of the design process.

Appendix H: Proposed Analytical Technique for the MSDSS

The computational assessment procedure used in this study follows that of the AHP technique as mentioned in section 5.5 of chapter 5. Evaluating different material alternatives using the AHP numerical analysis involves three main steps. The process steps include:

(i) Determining the relevant applicable criteria and alternative material options in the form of a hierarchy of objectives. The hierarchy is structured on different levels: from the top (i.e. the goal) through intermediate levels (criteria and sub-criteria on which subsequent levels depend) to the lowest level (i.e. the alternatives);

(ii) Assigning numerical values (i.e., weights) to measure the relative importance of these criteria for a given material alternative. For this purpose, AHP uses simple pairwise comparisons to determine weights and ratings so that the analyst can concentrate on just two factors at one time and

(iii) Processing the numerical values (i.e., computational analysis) to determine the ranking of material alternative options along the various main sustainability criteria.

The following section describes the mathematical/decision model for sustainable material assessment and selection.

Mathematical Model Formulation

This section formulates the mathematical model for computing the Green Housing Utility Index (GHUI or GUI) using the Analytical hierarchical process. The GHUI is defined as a crisp value that is an aggregated measure of material alternative along various dimensions (of socio-economic, environmental, technical variables). The GHUI utilises the multi-criteria evaluation methods based on discrete problems to investigate a number of choice possibilities in the light of conflicting priorities (Nijkamp et al., 1990). Detailed description of the main steps contained in the model formulation is described as follows.

Step 1: Establishment of a structural hierarchy

Constructing the hierarchical structure is the first and most important step in AHP, Saaty (2008) comments that the structure of the hierarchy depends upon the nature or type of design decision. In a typical hierarchy, the alternatives are at the bottom; the next higher level would consist of the factors for judging the material alternatives. The first step sets the problem as a hierarchy, where the top most nodes is the overall objective of the decision, while subsequent nodes at lower levels consists of the factors used in arriving at this decision. The AHP hierarchy for this study is composed of four levels, as illustrated in **Figures 1** and **2**.

- Level 1 reveals the strategic objective for selecting the most suitable LCGBMCs.
- Level 2 consists of the main factors for which the most appropriate material selected depends on.
- Level 3 contains the associated sub-factors that are used to measure various material decision choices
- Level 4 or the bottom level consists of the alternative LCGBMCs.

Table 1: Legend of the sub-factor

(GS) General /Site Factor	(EH) Environmental /Health Factor	(C) Economic/Cost Factor	(SC) Socio-Cultural Factor	(T) Technical Factor	(SN) Sensorial Factor
GS2-Availability GS1-Location GS10-Material Scale GS9-Knowledge Base GS6-Site Geometry GS7-Design Geometry GS4-Certification GS5-Disaster Prone GS12-Spatial Scale GS8-Site Structure GS3-Distance GS11-Building Orientation	EH3-Users' Safety EH6-Climate EH7-Env-Toxicity EH2-CO2 Emissions EH4-Ozone Depletion EH1- Env. Compliance EH5-Pesticide Treatment EH8-Fossil Depletion EH10-Waste Disposal EH9-Nuclear Waste	C4-Maintenance/ Replacement Cost C5- Labour Cost C1-Life-Ccycle Cost C3-Capital Cost C2-Embodied Energy Cost	SC5-Custom Knowledge SC1-Compatibility (Tradition) SC6-Clients' Preference Compatibility SC2-Compatibility (Region) SC3-Resistriction on Usury SC4- Family Structure	T15-Life Expectancy T7-Fire Resistance T9-Moisture Resistance T11-Weather Resistance T5-Skills Availability T8-Thermal Resistance T13-Resistance to Decay T3-maintenance Level T6-Speed of Fixing T4-Contraction Tolerance T1-Recyclability T12-Chemical Resistance T2-Ease to remove T14-Weight/Mass T10-Scratch Resistance T16-Renewable T17-UV Resistance T18-Compatibility with other Materials	SN4-Temperature SN6-Odour SN10-Lighting SN5-Acoustics SN1-Aesthetics SN2-Texture SN3-Colour SN7-Thick/Thin SN9-Hardness SN8-Gloss Effect SN11-Structure SN12-Translucence

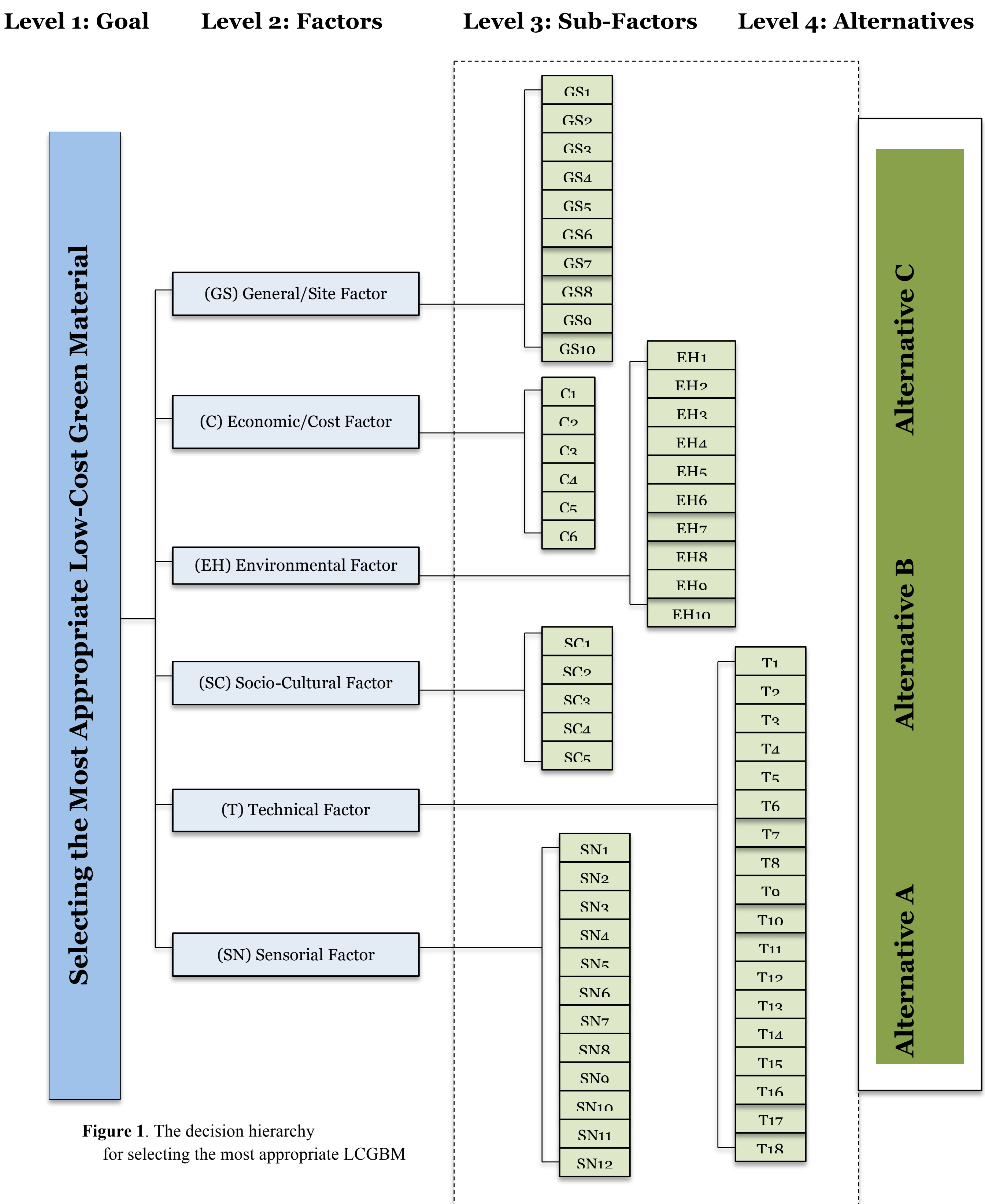


Figure 1. The decision hierarchy
for selecting the most appropriate LCGBM

Step 2A: Pairwise comparisons and computation of the criteria weights

The second step requires pair-wise comparisons to be made between each pair of criteria (of the given level of the hierarchy). After arranging the problem in hierarchical terms, the next step is to determine the relative importance of each criteria and sub-criteria, using a pairwise comparison technique as suggested by Saaty (1986). Comparisons are performed between pairs of elements within each branch of each level of the hierarchy to determine the relative worth of one element as compared with another in relation to the element directly above, using the preference scale shown in **Table 2**.

Table 2: Comparison scale adapted from (Saaty, 1980)

Degree of importance	Definition
1	Equal importance of elements
3	Importance of one element over another
5	Strong importance of one element over another
7	Demonstrated or very strong importance of one element over another
9	Absolute importance of one element over another
2,4,6,8	Intermediate values between two adhacent degrees of importance

The pairwise comparisons from each branch at each level of the hierarchy are entered into a matrix and used to determine a vector of priority weights. Only those elements that pertain to a common objective are compared against one another.

The following notation applies:

wi = weight for attribute *i*, *i*=1,..,*n* where *n* = number of attributes *aij* = *wi* / *wj* = the result of a pairwise comparison between attribute *i* as compared to attribute. A = matrix of pairwise comparison values, *aij* A set of pairwise comparisons can therefore be represented as:

	w_1/w_1	w_1/w_2	w_1/w_n
	w_2/w_1	w_2/w_2	w_2/w_n
$A=$	.	.	.
	.	.	.
	w_n/w_1	w_n/w_2	w_n/w_n

………………………………………………...1.1

where *w1/w2* is the importance of attribute *1* as compared to attribute *2*. Since the direct result of a pairwise comparison is *aij*, where *a12* is equal to *w1/w2*, matrix A becomes:

$$A=\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad \text{...1.2}$$

The goal of AHP is to uncover the underlying scale of priority values w_i. In other words, given a_{ij}, find the "true" values of w_i and w_j. This A matrix has some special properties. First, A is of rank one. If we look at each column of A, we have:

$$A= w_1^{-1}\begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}, w_2^{-1}\begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}, \dots, w_n^{-1}\begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \quad \text{..................................1.3}$$

Each column of A differs only by a multiplicative constant, w_i-1. If the A matrix is consistent only one column is required to determine the underlying scale ($w_1,\dots,w_n$). The same evaluation could be undertaken in a row-wise fashion with the same result. Second, if B is x times more important than C, then it follows that C is 1/x times as important as B. In other words, a_{ji} is the reciprocal of a_{ij} such that $a_{ij} = 1/a_{ji}$. This assumes the decision maker is consistent with respect to individual pairwise comparisons and is a fundamental assumption made by the AHP. With this assumption, matrix A is be reduced to:

$$A=\begin{bmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & \dots & a_{2n} \\ 1/a_{13} & 1/a_{23} & 1 & \dots & a_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & 1/a_{3n} & \dots & 1 \end{bmatrix} \quad \text{...1.4}$$

As seen in **Equation 1.4**, when a criterion is compared with itself each criterion has equal weight. This makes the diagonals equal to unity (i.e. $w_1/w_1 = 1$). The entries below the diagonal are reciprocal of those entries above the diagonal. The above reduction means that only $n(n-1)/2$ pairwise comparisons need to be solicited from decision makers as compared with n^2 total entries in the completed A matrix. If the assumption that the decision maker is consistent with respect to individual pairwise comparisons does not hold, in other words if $a_{ij} \neq 1/a_{ji}$, then; $(n^2 - n)$ pairwise comparisons would be required.

Step 2B: Deriving Weights

Once pairwise comparisons have been obtained from the decision maker, the next step is to use the matrix system to estimate the underlying scale of preferences. Weightings are included because no laws currently exist to enforce low-impact green housing designs, and thus any designer who wishes to have his designs implemented must first ensure that they are acceptable to the owner. Therefore, given the "random" error inherent in human judgment, it cannot be expected that the true values of *wi* and *wj* can be found. While several methods have been proposed to estimate weights from matrices of pairwise comparisons, the two most commonly used methods of deriving attribute weights are the eigenvector and the logarithmic least squares methods. Using the former attributes, weights are obtained by finding the eigenvector corresponding to the largest eigenvalue of the 'A' matrix.

For instance **Equation 1.4** showed a consistent matrix of pairwise comparisons, meaning that only one column or one row is necessary to derive the underling scale, *wi*, of weights. When inconsistency is introduced into pairwise comparisons, more than one row or column of 'A' is desired in order to derive a good estimate of the underlying scale of weights. The largest eigenvalue of 'A' max is used in consistency calculations (discussed below in Consistency) and its corresponding eigenvector, normalized such that its components sum to one represents the vector of attribute weights.

For example in a hierarchy of two branches with two and six sub-objectives, if the vector of weights were normalized such that the largest element is equal to one, the branch with six sub- objectives would be given more weight in total than the branch with only two sub- objectives. Likewise, a branch where there is little preference for one element over another would be given a higher total weight over a branch with the same number of elements but with larger differences in preferences between the individual elements.

Following the definition of $aij=wi/wj$ and $aij=1/aji$

$$a_{ij}a_{ji} = a_{ij}\frac{1}{aij} = a_{ij}\frac{1}{\frac{w_i}{w_j}} = a_{ij}\frac{w_j}{w_i} = 1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.5$$

If follows that in the consistent case:

$$\sum_{j=1}^{n} a_{ij} \frac{w_j}{w_i} = n \qquad i=1 \text{ to } n$$

……………………………………………………1.6

Or, stated another way, multiplying equation 6.11 through by *wi:*

$$\sum_{j=1}^{n} a_{ij} w_j = n w_i \qquad i=1 \text{ to } n$$

……………………………………………………1.7

These statements are equivalent to the matrix notation Aw = nw. If the goal is, given a positive reciprocal matrix A, to find w, the problem becomes (A - nI) w = 0.

Step 2C: Measurement of consistency

Deviations from both ordinal and cardinal consistency are considered, and to a certain extent allowed, within AHP. Ordinal consistency requires that if x is greater than y and y is greater than z, then x should be greater than z. Cardinal consistency is a stronger requirement stipulating that if x is 2 times more important than y and y is 3 times more important than z, then x must be 6 times more important than z. If A is cardinally consistent, then *aijajk* = *aik*. Using the previous definition of *aij* we can see that this is true:

$$a_{ij} a_{jk} = \frac{w_i}{w_j} \frac{w_j}{w_k} = \frac{w_i}{w_k}$$

………………………………………………………………………1.8

If the relationship *aijajk* = *aik* does not hold then A is said to be cardinally inconsistent. AHP has been designed to deal with inconsistent matrices (both cardinal and ordinal inconsistency), thus the problem becomes:

$$\frac{w_i}{w_j} \varepsilon_{ij} \bullet \frac{w_j}{w_k} \varepsilon_{jk} = \frac{w_i}{w_k} \varepsilon_{ik}$$

…………………………………………………………………………1.9

where ␣ij > 0 and represents some perturbation causing A to be inconsistent, producing an A matrix that looks like the following:

$$A = \begin{matrix} 1 & \varepsilon_{12}a_{12} & \varepsilon_{13}a_{13} & \dots & \varepsilon_{1n}a_{1n} \\ {}^{1}/\varepsilon_{12}a_{12} & 1 & \varepsilon_{23}a_{23} & \dots & \varepsilon_{2n}a_{2n} \\ {}^{1}/\varepsilon_{13}a_{13} & {}^{1}/\varepsilon_{23}a_{23} & 1 & \dots & \varepsilon_{3n}a_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ {}^{1}/\varepsilon_{1n}a_{1n} & {}^{1}/\varepsilon_{2n}a_{2n} & {}^{1}/\varepsilon_{3n}a_{3n} & \dots & 1 \end{matrix} \quad \text{..........................1.10}$$

Various methods have been devised to deal with inconsistency. Saaty (1980) suggests using the following consistency index (CI):

$$CI = \frac{(\lambda \max - n)}{(n-1)}$$

……………………....…………………………………………………1.11

where λmax is the largest eigenvalue of A and n is the number of elements within a branch being compared. If A is perfectly consistent (cardinally) than λmax will be at a minimum and equal to n, producing a CI equal to zero. As inconsistency increases λmax will become increasingly large, producing a larger value of CI. This consistency index can also be expressed as a consistency ratio:

$$CR = \frac{CI}{RI}$$

……………………………………………………...………………………1.12

where RI is a known random consistency index obtained from a large number of simulation runs and varies depending upon the order of matrix. **Tables 3** shows the value of the random consistency index (RI) for matrices of order 1 to 15 obtained by approximating random indices using a sample size of 500 (Saaty, 2000). However, various authors (Golden & Wang, 1990; Alonso & Lamata, 2006) have computed and obtained different RIs depending on the simulation method and the number of generated matrices involved in the process. These values were added to the corresponding matrix size of 15 making up a total of n=40 for the prototype model.

Table 3: Average random index for corresponding matrix size (Alonso & Lamata, 2006)

n	16	17	18	19	20	21	22	23
λ_{max}	39.9676	42.7375	45.5074	48.2774	51.0473	53.8172	56.5872	59.3571
RI	1.5978	1.6086	1.6181	1.6265	1.6341	1.6409	1.6470	1.6526
	24	**25**	**26**	**27**	**28**	**29**	**30**	**31**
	62.1270	64.8969	67.6669	70.4368	73.2067	75.9767	78.7466	81.5165
	1.6577	1.6624	1.6667	1.6706	1.6743	1.6777	1.6809	1.6839
	32	**33**	**34**	**35**	**36**	**37**	**38**	**39**
	84.2864	87.0564	89.8263	92.5962	95.3662	98.1361	100.9060	103.6759
	1.6867	1.6893	1.6917	1.6940	1.6962	1.6982	1.7002	1.7020

The acceptable CR range varies according to the size of matrix i.e. 0.05 for a 3 by 3 matrix, 0.08 for a 4 by 4 matrix and 0.1 for all larger matrices, n>= 5 (Saaty, 2000, Cheng and Li, 2001). If the value of CR is equal to, or less than that value, it implies that the evaluation within the matrix is acceptable or indicates a good level of consistency in the comparative judgments represented in that matrix. In contrast, if CR is more than the acceptable value, inconsistency of judgments within that matrix has occurred and the evaluation process should therefore be reviewed, reconsidered and improved. An acceptable consistency property helps to ensure decision-maker reliability in determining the priorities of a set of criteria.

Step 3: Scaling Attributes

After pairwise comparisons have been made and priority weights calculated for each element within the hierarchy, the input data for each alternative must be transformed to a usable value before alternatives can be compared. A major strength of AHP is its ability to incorporate attributes that are measured on a number of different scales, at different intensities, and can include both numeric, descriptive, and categorical data. This is achieved by converting all values to relative data. Relative values could be created by either comparing attribute values to other alternatives being compared or by comparing attributes to an “ideal” alternative. The choice of treatments will be dependent on the type of problem and available data.

Several studies have however, criticised relative scaling for its inappropriateness for the sustainable index development or any other problem where more than a small number of alternatives are considered.

Therefore an alterative method proposed to deal with alternatives is the absolute, or ideal, mode of AHP (Saaty, 1980). In the absolute mode, for a given factor or variable, each material alternative is compared with an "ideal" alternative to determine its weight, termed "scoring". The score for each factor or variable of each material alternative ranges between zero and one.

A common scoring technique involves dividing each factor or variable value by the maximum value for which that factor present among the alternatives. This assumes the decision maker's preference for that attribute is linear. Non-linear preferences can also be accommodated within AHP. These functions may be the result of scientific study, expert judgment, or pairwise comparisons between categorical variables.

Step 4: Synthesizing Priorities – calculating the green development index scores

Once relative values have been calculated for each factor of each material alternative, these factor scores are combined with the factor weights from pairwise comparisons to determine the overall ranking of each material alternative. The normalized local priority weights of dimensions of green development indices are obtained and are combined together in order to obtain the global or final composite priority weights, termed the green index of all sustainability factors used in the third level of the AHP model. This is accomplished using a simple additive function. The products of each factor score and its associated factor weight are summed across each branch of the hierarchy. This sum becomes the factor value for the node directly above and the process is repeated at the next level of the hierarchy.

Figure 2 shows the flowchart of the material computational analysis technique based on the concept of the Analytical Hierarchy Process model (Saaty, 1980)

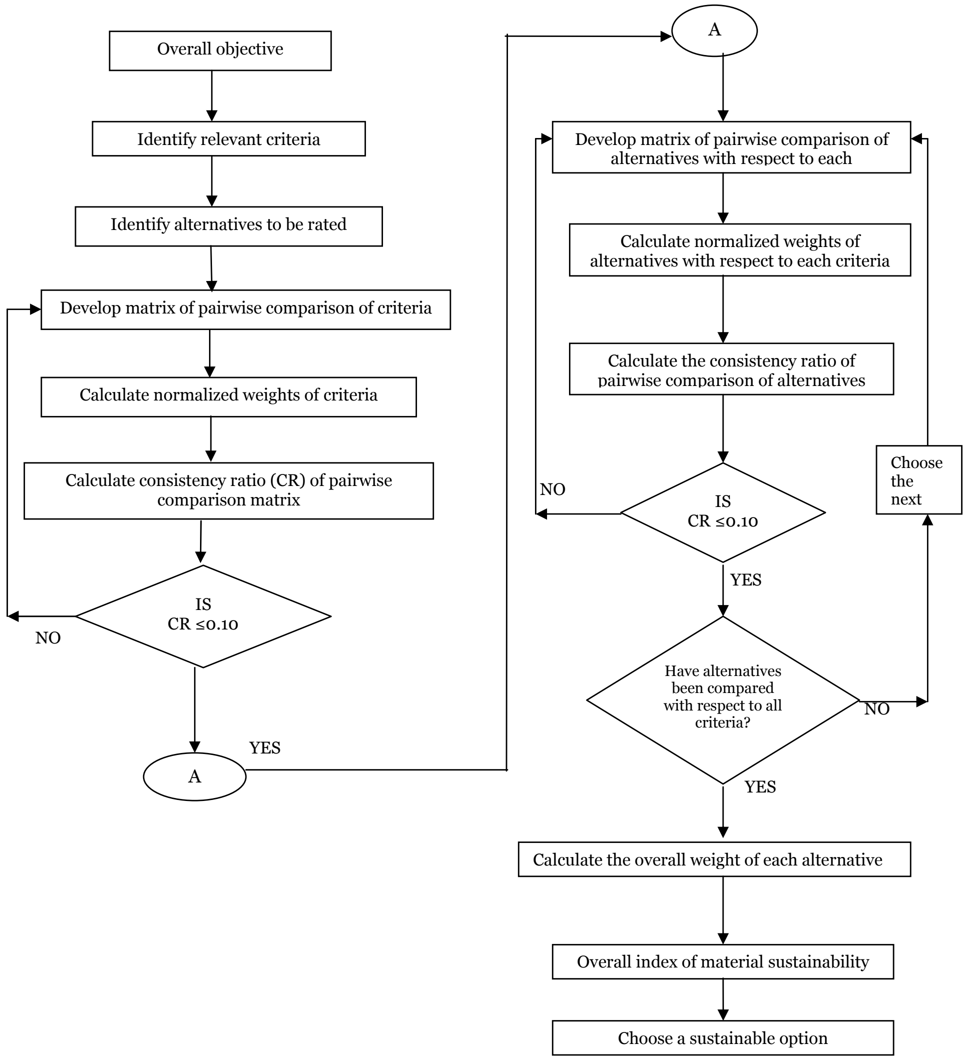


Figure 2. Flow chart based on the AHP concept of decision-making

The Composite Green Housing Utility Index

Ding (2005) notes that the overall score for a given material alternative is irrelevant, except when compared with the overall scores for other alternatives does the score become meaningful. He adds that alternatives could be ranked by their importance in contributing to the goal of the analysis by simply sorting material alternatives based on their overall green utility index score. This overall green index score is termed the composite green index value of material alternatives. Those alternatives with the higher score would receive a higher overall ranking. The green utility index (GHUI) model of alternative *i* can based on the derived weight be calculated using the following formula adapted from the works of Ding (2005):

GI= $\sum_{j=1}^{J} e_{ji} W_j$ (i=1,……..…..I) ……………………………………………1.13

eji =
f(GS,EH,EC,SC,T,SN)……………………………………………….1.14

The symbol GHUIi denotes the green housing utility index for an alternative I; Wj represents the weight of criterion j; and eji indicates value of alternative i for criterion j. The result will indicate that higher values for eji and Wj imply a better score, and that alternative i will be judged as better than alternative i' if the score of GHIi is greater than the score of GHIi'. The following is the generated formula for calculating the GHI for each factor. The GS is general site impact, EH denotes environmental/health impact, EC economic/cost efficiency, SC socio-cultural impact, SN sensorial and T technical performance capacity. The factors are obtained from the following formulae:

$GS=\sum S_{ji} W_j$ …………………………………………………………..1.15
Where: GS= General site impact
i =alternatives
j= sub-factor
S=site impact

$EH= \sum EI_{ji} W_j$…………………………………………………………..1.16
Where: EH= Environmental/Health impact
i =alternatives
j= sub-factor
EI=environmental impact

$EC= \sum C_{ji} W_j$…………………………………………………………..1.17
Where: EC= Economic/Cost
i =alternatives
j= sub-factor
C=Cost efficiency

$SC = \sum S_{ji} W_j$……………………………………………………………..1.18

Where: SC= Socio-Cultural

i =alternatives

j= sub-factor

S=Social benefits

$T = \sum T_{ji} W_j$……..………………………………………………………..1.19

Where: T= Technical

i =alternatives

j= sub-factor

T=Technical performance

$SN = \sum S_{ji} W_j$………………………………………………………………..1.20

Where: SN= Sensorial

i =alternatives

j= sub-factor

S=Sensorial Impacts

The sustainability/green index is calculated for each alternative by first multiplying each value by its appropriate weight followed by totaling the weighted scores for all factors. In the context of maximizing the appropriateness of a material alternative, the preferred material option would be the alternative that gives the highest corresponding value of the Green Housing Utility Index (GHUI). The amalgamation method yields a single index of alternative worth, which allows the options to be ranked. The higher the green index, the better the chosen alternative.

The Benefits of Green Index in Low-Impact Green Material Selection

The green utility index is a comprehensive methodology that includes the quantification of both objective and subjective measures that give a full life-cycle or performance analysis of low-cost green material alternatives, which will allow the impacts created by the buildings during their life cycle to be compared. The following exemplifies the benefits of the green utility index.

- The green housing utility index assists in decision-making for material selection from as early as the feasibility stage, which ensures the best material option that maximises cost and minimises detrimental effects to the environment.

- The index helps to distinguish material with reduced economic, social, and environmental impacts, and to induce the designer to incorporate holistic socio-economic, technical and environmental performance requirements.

- It can facilitate the designer's iterative approach, where initial understanding of the problems and means of addressing it are allowed to evolve even before the building project arrives at the design stage.

- Cooper (1999), Cole (1999) and Todd et al. (2001), observed that existing material assessment methods such as BREEAM and BEPAC are inadequate for addressing wider green development issues. With the green index concept designers are able to embrace economic, sensorial, technical and socio-cultural concerns as well as environmental aspects of green development goals

- It enhances the principle of futurity and equity in material assessment.

Section 5.6 of chapter 5 describes how the MSDSS analytical system for LCGBMCs selection is developed and how the internal storage structure and file organisation are specified using the proposed material selection mathematical computational method.

Appendix I: Questionnaire for Pairwise Comparison

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Dear (Participant's name),

RESEARCH ON THE IMPACTS OF LOW-COST GREEN BUILDING MATERIALS IN HOUSING CONSTRUCTION

This questionnaire is informed by the result analysis of the first questionnaire that identified sustainable material selection factors for low-cost green building materials. You are herby again asked to kindly evaluate the identified factors or variables by assigning weights to them through pairwise comparison. This is required in order to validate the decision support model developed to aid building designers in selecting low-cost green building products that are environmentally, socio-culturally, technically and economically balanced using the prototype Material Selection Decision Support [MSDSS] model. Detail description of the case project is described below.

The research is to help toward improving sustainable material evaluation and selection process, which would be of benefit to the housing construction industry. All of data collected from you will be used only for academic purpose. Thank You!

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The Sample Case: A Hypothetical Study Case

The case used intends to provide an indication and practical application of the MSDSS model to material selection problems, following the AHP multi-criteria decision-making technique. The proposed scenario taken as study case is a design of a 5-bedroom single-family home located in a sub-urban residential area of Port Harcourt in Rivers State, Nigeria.

An architect is selecting a set of LCGBMCs for a proposed 5-bedroom housing project. The client tells the architect that he wants a building made from materials that are environmentally friendly and cost effective, but does not want the building's functions to be compromised by the choice of materials. He has three material options (in this case floor materials) from which to decide. The architect is expected to weigh the selected factors and rank the selected material IDs using the MSDSS model, to decide the option that best suits the client's needs. The table below summarizes the details for the three options of flooring materials for the proposed project. From the table, the description of the three options was based on the standard practices and construction details commonly used in Nigeria.

Summary of flooring options for the proposed residential building project

Description	Material A	Material B	Material C
Design Element type	Panelled Flooring	Laminated Flooring	Concrete Flooring
Building type	Residential	Residential	Residential
Material Type	Bamboo XL laminated Split Panelled Flooring	Reclaimed/Recycled laminated Wood Flooring and Panelling	Fly Ash Cement concrete Floor slab
Size of materials	230mm x 150mm	50mm x 6000mm	900mm x 900mm

Instructions for filling and establishing relative importance

- Each criterion will be rated according to its degree of relative importance to another criterion within the group in the bases of pair wise comparison.
- Check for consistency of replies will be tested
- If you do not achieve acceptable level of consistency kindly refill the questionnaire until you reach an acceptable level of consistency.
- Use the scale below to find pair wise relative importance

The relative ratio scales are described as follows:

Ratio Scale

Importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favour one element over another
5	Strong importance of one element over another	An element is strongly favoured
7	Very strong importance of one element over another	An element is very strongly dominant
9	Extreme importance of one element over another	An element is favoured by at least an order of magnitude
2, 4, 6, 8	Intermediate values	Used to compromise between two judgments

Decision makers can determine the scale of any factor from 1 to 9 if they are equally or more important. If the factors are less important to the decision maker it takes the inverse of the scale. In the above table the score (1) is used to denote factors that have equal importance. This usually happens when the factor is compared to itself. When a factor falls within the "equally" to "moderately" important it takes the score (2) and the same applies to the other values as the users scale of preference changes.

In the table, environmental/health impact is strongly favoured to waste minimization while the cost efficiency is extremely favoured over technical performance. This means that when technical performance is compared with cost efficiency then waste minimization is preferred by 1/9 of resource efficiency.

Main/Parent Factor	Environmental/Health Impact	Economic/Cost Effect	Technical Performance
Environmental/Health Impact	1	1/2	5
Economic/Cost Effect	2	1	9
Technical Performance	1/5	1/9	1

Part I: Relative preference of criteria for roof covering selection

Instruction 1.1: Select the degree of relative importance/preference of each main criterion compared to each other in the selection of floor covering material option using the ratio scale stated above.

Pairwise Matrix and Priorities for Parent/Main Factors

Main/Parent Factor	GS	EH	EC	SC	T	SN
Site Impact	1					
Env. Effect		1				
Cost Efficiency			1			
Socio-Cultural Impact				1		
Technical Performance					1	
Sensorial Impact						1

Instruction 1.2: Select the degree of relative importance/preference of each sub factor for Environmental impact compared to each other

Pair-wise matrix & priorities for General/Site Suitability

Sub- Factor	GS1	GS2	GS3	GS4	GS5	GS6	GS7	GS8	GS9	GS10	GS11	GS12
GS1- Location	1											
GS2-Availability		1										
GS3-Distance			1									
GS4-Cert-Code				1								
GS5-Disaster					1							
GS6-Site Form						1						
GS7-Design-Form							1					
GS8-S-Structure								1				
GS9-S-Activities									1			
GS10-Mat-Scale										1		
GS11Orientation											1	
GS12-Spat-Scale												1

Pair-wise matrix & priorities for Environmental/Health impact

Sub Factor	EH1	EH2	EH3	EH4	EH5	EH6	EH7	EH8	EH9	EH10
EH1- Environment Compliance	1									
EH2-CO2 Emissions		1								
EH3-Users' Safety			1							
EH4-Ozone Depletion				1						
EH5-Pesticide Treatment					1					
EH6-Climate						1				
EH7-Level of Environmental Toxicity							1			
EH8-Fossil Fuel Depletion								1		
EH9-Nuclear Waste									1	
EH10-Waste Disposal										1

Pair-wise matrix & priorities for Economic/Cost efficiency

Sub Factor	C1	C2	C3	C4	C5
C1- Life-Cycle Cost	1				
C2-Embodied Energy Cost		1			
C3-Capital Cost			1		
C4-Labour Cost				1	
C5-Maintenance Cost					1

Pair-wise matrix & priorities for Socio-Cultural impact

Sub Factor	SC1	SC2	SC3	SC4	SC5
SC1- Compatibility with Tradition	1				
SC2-Compatibility with Region		1			
SC3-Restriction on Usury			1		
SC4- Clients' Preference				1	
SC5-Custom Knowledge					1

Pair-wise matrix & priorities for Technical performance

Sub Factor	T1	T2	T3	T4	T5	T6	T7	T8	T9	T 10	T 11	T 12	T 13	T 14	T 15	T 16	T 17	T1 8
T1- Recyclability	1																	
T2-Ease to Remove		1																
T3-Maintenance			1															
T4-Stree Tolerance				1														
T5-Skills Availability					1													
T6-Speed of Fixing						1												
T7-Fire Resistance							1											
T8-S-Thermal Resistance								1										
T9-S-Mosisture Resistance									1									
T10-Scratch Resistance										1								
T11-Weather Resistance											1							
T12-Chemical Resistance												1						
T13-Resistance to Decay													1					
T14- Weight/Mass														1				
T15-Life Expectancy															1			
T16-Renewable																1		
T17-UV Resistance																	1	
T18- Compatibility																		1

Pair-wise matrix & priorities for Sensorial impact

Sub Factor	SN1	SN2	SN3	SN4	SN5	SN6	SN7	SN8	SN9	SN10	SN11	SN12	SN13
SN1- Aesthetics	1												
SN2-Texture		1											
SN3-Colour			1										
SN4-Temperature				1									
SN5-Acoustics					1								
SN6-Odour						1							
SN7-Thickness							1						
SN8-Glossiness								1					
SN9-Hardness									1				
SN10-Light Effect										1			
SN11-Transluscence											1		
SN12-Structure												1	
SN13- Thermal Cond.													1

Part II: Relative preference of floor covering alternatives for selection

Instruction 1.3: Select the degree of relative preference of each floor alternative with respect to each sub-criterion

Pair-wise matrix & priorities for each floor alternative with respect to each selected sub factor

Location

	A	B	C
A	1		
B		1	
C			1

Material Availability

	A	B	C
A	1		
B		1	
C			1

Distance

	A	B	C
A	1		
B		1	
C			1

Certification Code

	A	B	C
A	1		
B		1	
C			1

Env. Compliance

	A	B	C
A	1		
B		1	
C			1

CO2 Emissions

	A	B	C
A	1		
B		1	
C			1

Users' Safety

	A	B	C
A	1		
B		1	
C			1

Ozone Depletion

	A	B	C
A	1		
B		1	
C			1

Life Cycle Cost

	A	B	C
A			
B			
C			

Energy Cost

	A	B	C
A			
B			
C			

Capital Cost

	A	B	C
A			
B			
C			

Labour Cost

	A	B	C
A			
B			
C			

Compatibility (Tradition)

	A	B	C
A			
B			
C			

Compatibility (Region)

	A	B	C
A			
B			
C			

Restriction on Usury

	A	B	C
A			
B			
C			

Clients' Preference

	A	B	C
A			
B			
C			

Recyclability

	A	B	C
A			
B			
C			

Ease to Remove

	A	B	C
A			
B			
C			

Maintenance Level

	A	B	C
A			
B			
C			

Stress tolerance

	A	B	C
A			
B			
C			

Aesthetics

	A	B	C
A			
B			
C			

Texture

	A	B	C
A			
B			
C			

Colour

	A	B	C
A			
B			
C			

Temperature

	A	B	C
A			
B			
C			

Thank you very much for your time. NB: Confidentiality and anonymity are guaranteed.

Appendix J: Evaluation Questionnaire Survey

UNIVERSITY OF WESTMINSTER

School of Architecture and The Built Environment,
University of Westminster,
London, UK.
NW1 5LS
Email: i.ogunkah@my.westminster.ac.uk
Contact Phone Number: +44 (0) 208 7900 5000 ext. 3721

Dear Sir or Madam,

EXPERT EVALUATION OF THE MSDSS MODEL

Given your expertise in green housing design and sustainable construction, the Research Centre of the University of Westminster, is writing to seek your consent as to whether you may be interested in evaluating a prototype MSDSS model developed for evaluating sustainable low-cost green building materials. **Please kindly indicate your interest by replying to this email**: cyrilguchi@ymail.com

Aim/Objective:

The aim of this questionnaire survey is to gather feedbacks and assess experts' views as to the significance of the model: workability in practice and adequacy in addressing the decision problem confronting design and building professionals on Sustainable Building Material selection. This is meant for validating and further improving the proposed decision support model.

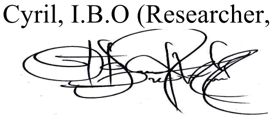
The Questionnaire:

The questionnaire, which contains just 12 key questions, is in three (3) parts. Section A seeks to collect information on your background; Sections B and C ask for your opinions or comments on specific and general aspects of the model, respectively. There are no correct or incorrect responses; only your much- needed views.

Conditions for participating in the survey

The MSDSS system has been designed to run under windows and Macintosh with MS Excel, based on the Analytical Hierarchy Process (AHP) model of decision-making. All of data collected from you will be used only for academic purpose. Thank you in advance for your valued and kind consideration.

Cyril, I.B.O (Researcher, University of Westminster Research Centre, UK)



SECTION A: BACKGROUND OF RESPONDENT (S)

Question 1
Please provide the name of your company/Organisation

____

Question 2
Which of these best describes your current job designation?
- ○ Material Specification Analyst
- ○ Building Energy Expert
- ○ Green Building/Sustainability Consultant
- ○ Program/Software Designer
- ○ Research Consultant (Please specify area of interest)
- ○ Other: ______________________________

Question 3
Please indicate your years of experience in the building construction industry

________ (Min. 0 - Max. 500)

SECTION B: GENERAL VIEW (S) ON THE MSDSS MODEL

Question 4
How significant is the MSDSS model in addressing the problems associated with sustainable material evaluation and selection of low-cost green materials?
- ○ Highly significant
- ○ Significant
- ○ Not so significant, as it would make no difference
- ○ Not significant at all, as I am not sure of its impact in housing construction

Comments (if any): ______________________________

Question 5
How capable is the MSDSS model in aiding sustainable and well informed choice(s) of materials for low-impact green housing projects?
- ○ Highly capable
- ○ Capable
- ○ Not so capable
- ○ Not sure of its capabilities

Comments (if any): ______________________________

Question 6
What would be your view on the resources to be used if the model is to be applied in real life evaluation and selection exercise?
- ○ The significant benefits derived from using the proposed model justifies any resource requirements
- ○ Would not be too costly to operate at current resource levels
- ○ Not so sure of its potential benefits when applied in real life material evaluation and selection exercise(s)
- ○ Would be too costly to operate at current resource levels

Comments-Please give reasons for your answer: ______________________________

Question 7
What would be your view on the overall interface layout of the MSDSS model?
○ Comprehensive
○ Adequate
○ Inadequate
○ Poor

Please specify in your view, further matters of importance or features that ought to have been disregarded or considered in the development of the model: _______________________._______

SECTION C: VIEWS ON THE MODEL'S INTEROPERABILITY ATTRIBUTES

Question 8
Is the proposed model simple, user friendly, flexible, clear, easy to understand and use in conducting material database queries?
○ Yes, very simple, clear and easy to understand with no practical difficulties
○ Yes, quite simple, clear and easy to understand but with very little/minor difficulties
○ No, not as quite as simple, clear and easy to understand as expected
○ No, not sure of its simplicity, clarity and capability

Question 9
Given your response to Q8, please comment on the specific aspects of the model that is in your view, likely to cause minor/major difficulties to its use.

____

Question 10
How efficient is Saaty's AHP concept and the "1-9" evaluation scale adopted for evaluating and ranking low-cost green building materials?
○ Highly Efficient
○ Efficient
○ Not sure of its efficiency
○ Not Efficient at all

Please identify any other likely MCDM approach and give reasons as to why it would have been preferred to consider in rating the materials against selected factors: _________________________

Question 11
What is your view on the set of factors used for evaluating and rating low-cost green materials?
○ Highly Adequate
○ Adequate
○ Not adequate
○ Not sure of their adequacy

Please list other factors/criteria that ought to have been considered: __________________________

Question 12
In what way(s) do you think the MSDSS model can be improved? Please provide any other general comments that you have on the model or suggestions for further improvement.

____

Appendix K: Application and Evaluation of the MSDSS Model

The research objectives posed in chapter one includes developing and testing a sustainable material selection and assessment model for aggregating the key influential factors needed for evaluating the selection of LCGBMCs. This was covered in detail in Chapter five. Therefore, the objectives of this section are to demonstrate this in practical application to material selection problem, and evaluate the performance of the MSDSS model through the lens of the experienced professionals.

Since it was anticipated that the initial participants would be willing to provide evidence on how successful the implemented system had achieved the key attributes specified in previous interviews and surveys, an evaluation exercise was carried out at the completion of the model. Consideration of the various evaluation techniques suggests face validity or expert opinion as the only appropriate techniques for evaluating the developed material selection model, since this study aims to validate the model for industry-wide application. Gass (1983) gives an extensive analysis of the various evaluation techniques.

The objectives of expert opinion validation are to assess the feasibility of the model in terms of its adequacy and clarity, and to ensure that the model is reasonably robust and will be acceptable to users, much in the same spirit as member checking in qualitative research in real life material selection problems. Questionnaires sent and returned by emails were used to conduct the feedback sessions as specified in section 4.5.2.1 of chapter 4.

The key objectives of the expert evaluation sessions were to:

- Allow industry practitioners (including design, building and construction stakeholders) to give expert feedback on the potential benefits and overall value (usability, workability, applicability and limitations) of the system for analysis of LCGBMCs information during the design process;

- Know whether or not the intended users would analyse data such as that which would be encountered in practice and real-life exercise; and,

- Identify areas of weaknesses in the operations provided and in the style of the interactions supported in the system so as to make necessary changes where applicable.

During the evaluation process, the following views of the evaluators were requested on:

1. The ease of accessibility to the system;

2. The ease of navigation within the system;

3. The underlying material selection information analytical procedures based on the Analytical Hierarchy Procedure (AHP) concept;

4.Other concepts implemented within the system and

5. Determining the overall value of the software system, including its usability and limitations.

The following section describes the sample procedure of the practical application used by the decision model following the AHP decision-making technique.

System Application of the MSDSS Model: The AHP Survey

The worked example for explaining the application and implementation of the MSDSS model in practice involves the application of the model to a realistic but hypothetical scenario of a building material selection problem. The scenario assumed for the worked example is defined as follows:

A hypothetical study case

The case used intends to provide an indication and practical application of the MSDSS model to material selection problems, following the AHP multi-criteria decision-making technique. The proposed scenario taken as study case is a design of a 5-bedroom single-family home located in a sub-urban residential area of Port Harcourt in Rivers State, Nigeria.

An architect is selecting a set of LCGBMCs for a proposed 5-bedroom housing project. The client tells the architect that he wants a building made from materials that are environmentally friendly and cost effective, but does not want the building's functions to be compromised by the choice of materials. He has three material options (in this case floor materials) from which to decide. The architect is expected to weigh the selected factors and rank the selected material IDs using the MSDSS model, to decide the option that best suits the client's needs.

Table 1 summarizes the details for the three options of flooring materials for the proposed project. From the table, the description of the three options was based on the standard practices and construction details commonly used in Nigeria.

Table 1: Summary of flooring options for the proposed residential building project

Description	**Material A**	**Material B**	**Material C**
Design Element type	Paneled Flooring	Laminated Flooring	Concrete Flooring
Building type	Residential	Residential	Residential
Material Type	Bamboo XL laminated Split Paneled Flooring	Reclaimed/Recycled laminated Wood Flooring and Paneling	Fly Ash Cement concrete Floor slab
Size of materials/piece	230mm x 150mm	50mm x 6000mm	900mm x 900mm

To achieve this goal, the model was sent to some experienced evaluators who possessed the following qualities:

- Had considerable amount of knowledge in material analysis based on the AHP concept,
- Had used a wide range of green building assessment tools for material selection, and
- Had taken part in the previous survey.

The aim of this exercise was to compare their views of the prototype model with existing models in terms of its usability, flexibility, and interoperability attributes.

Expert Knowledge Testing

The evaluation exercise was based on a combination of both the questionnaire and online discussions during and after the evaluation sessions. The analyses of the evaluation process are presented in the next sections.

General Characteristics of Evaluators and Selection Procedure

Hair et al. (1995) have emphasised the importance of considering not only the statistical significance of a sample population during sampling, but also the quality and practical significance of the results. They note that uneven sample sizes amongst different professional groups may induce bias, hence affect the validity of the results. In order to gather valid and reliable data from potential evaluators, the study invited eligible participants following the proposed sampling methods in section 4.5.2.9 of chapter 4, hence, giving each member of the various housing units a fair chance of being included in the survey.

A consent letter-describing the supposed task was sent to ten (10) willing building professionals of the initial survey exercise, requesting their views about the model's applicability and validity performance in material selection problems. Of the 10 experienced building practitioners contacted, 5 professionals who had considerable knowledge in the application of AHP and represent different fields within the construction sector expressed interest, and were willing to give their views in the AHP survey exercise.

The rate of response was an indication that only 5 out of the 10 selected respondents were familiar with the application of the AHP technique to material selection problems. The use of the previous survey respondent's list as a sample frame had two main advantages:

- Firstly, most of the practitioners in this list were individuals in senior positions from building construction firms with relevant expertise and experience in material assessment and selection; and,

- Secondly, their prior participation in the earlier survey makes them familiar with this research, which ensured valid response(s).

A list of the experts and their positions in the corresponding companies is summarized in **Table 2.** The names of the participants and companies were undisclosed to respect their anonymity.

Table 2: List of experts for the AHP survey

Position	Years of experience	No. of housing projects undertaken
1. Building Sustainability Consultant	25	> 30
2. Senior Architect and Urban Designer	30	> 40
3. Material Specifier	15	25
4. Project Architect	12	10
5. Senior Associate in design and building	22	> 35

The Structure of the Questionnaire

The first research instrument used to get valid feedback from the respondents was a questionnaire that captured data about the pair- wise comparison for each of the hierarchy level of the AHP model (questionnaire can be found in **Appendix I**). Five eligible respondents were made to fill the pair-wise comparison matrices using the verbal scale proposed by Saaty (1980), and calculate the consistency ratio.

The second questionnaire (see **Appendix J**) was designed to facilitate systematic data collection after the model evaluation exercise. The first section of the second questionnaire sought to obtain general information about the extent of evaluator's knowledge of the underlying software packages, whether the evaluator conducted any form of material selection information analysis in their current work, and how often these analyses were conducted. The second part was synthesised with reference to an AHP matrix proposed by Saaty (2000), while the final part focused on areas that needed further improvements.

According to Reza et al. (2010), AHP is a subjective MCDM method that does not necessarily involve a large sample. Wong & Li (2008) suggest that AHP surveys are useful for research focusing on a specific issue where large samples are not mandatory. Cheng and Li (2002) pointed out that AHP method might be impractical for a survey with a large sample size, as respondents may have tendencies to provide arbitrary and inconsistent answers. Previous studies have conducted AHP survey using a small sample size. For example, Cheng & Li (2002) invited 9 construction experts to undertake a survey to test comparability of critical success factors for construction partnering. Lam & Zhao (1998) also invited 8 experts for a quality-of-teaching survey. Both studies confirmed the usefulness of small sampling in AHP survey.

Since the assignment of weights in this research required logical and analytical thinking, and that larger samples may affect the viability of the data, only a small sample of the relevant building experts who were capable of providing deeper insights were highly valuable to this empirical inquiry. This ensured the validity and quality of the data as 5 out of 10 participants who had prior knowledge of the AHP expressed willingness. The package included the model, evaluation questionnaire and a cover letter stating the purpose of the research, the evaluation process and what was expected of them. To achieve this objective, this research adopted Chua's et al. (1999) approach based on a number of procedures followed during the exercise. The following procedures were undertaken:

- Issued out documents that explained the overall aim and objectives of the study;

- Deployed a sample demo illustrating a practical exercise of the AHP method of analysis (as shown in **Figure 1**).

- Administered the questionnaire for filling in weightings with which to conduct pairwise analysis (see **Appendix I**); The questionnaire emphasised the relevance of observing consistency in their answers;

- Issued out the actual prototype MSDSS model after completion of the AHP questionnaire. The introduction of an in-built demo in the model enabled the evaluators to see the controls and get a general overview of the MSDSS interface.

- Administered a reflective/post-user questionnaire used to obtain feedback (see questionnaire in **Appendix J**). This gave respondents the chance to comment on their experience(s) and provide feedback on the feel and overall performance of the MSDSS model;

- Modified problems uncovered by respondents and areas that proved difficult during the evaluation exercise, to avoid such problems arising in subsequent sessions;
  The first questionnaire (**Appendix I**) was used to assess the respondents' judgments about each floor material with respect to the factors introduced previously in figure 5.5 of chapter 5. Prior to the design of the pair-wise comparison matrices for the survey, the decision hierarchies were established (see **Figure** 1 of **Appendix H**).

  The chain of decision hierarchy established was based on the identification of decision factors framework in **Figure 5.5** of chapter 5. By evaluating the consistency level of the collected questionnaires, 5 questionnaires received had acceptable consistency and were entered into the analysis.

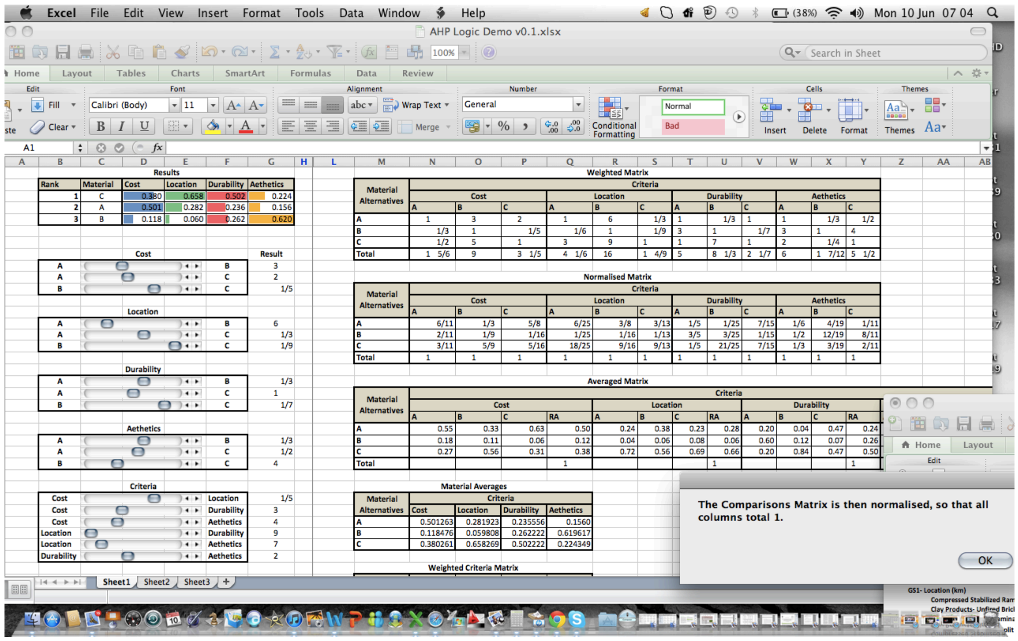


Figure 1. A sample AHP demo used for the illustrative analysis prior to the main survey exercise

The Application of the AHP Model to the Problem

To better illustrate the procedure of AHP, a complete example of applying AHP to the problem of material selection is provided here based on evaluators' results. The goal is placed at the top of the hierarchy (as shown in **Figure 2**). The hierarchy descends from the more general factors in the second level to sub- factors in the third level to the alternatives at the bottom or fourth level.

The general factors level involved six major criteria: cost efficiency, environmental impact, sensorial value, technical performance, site suitability, and socio-cultural benefit. The decision-making team considered three floor materials for the decision alternatives, and located them on the bottom level of the hierarchy. The following sections exemplify the process.

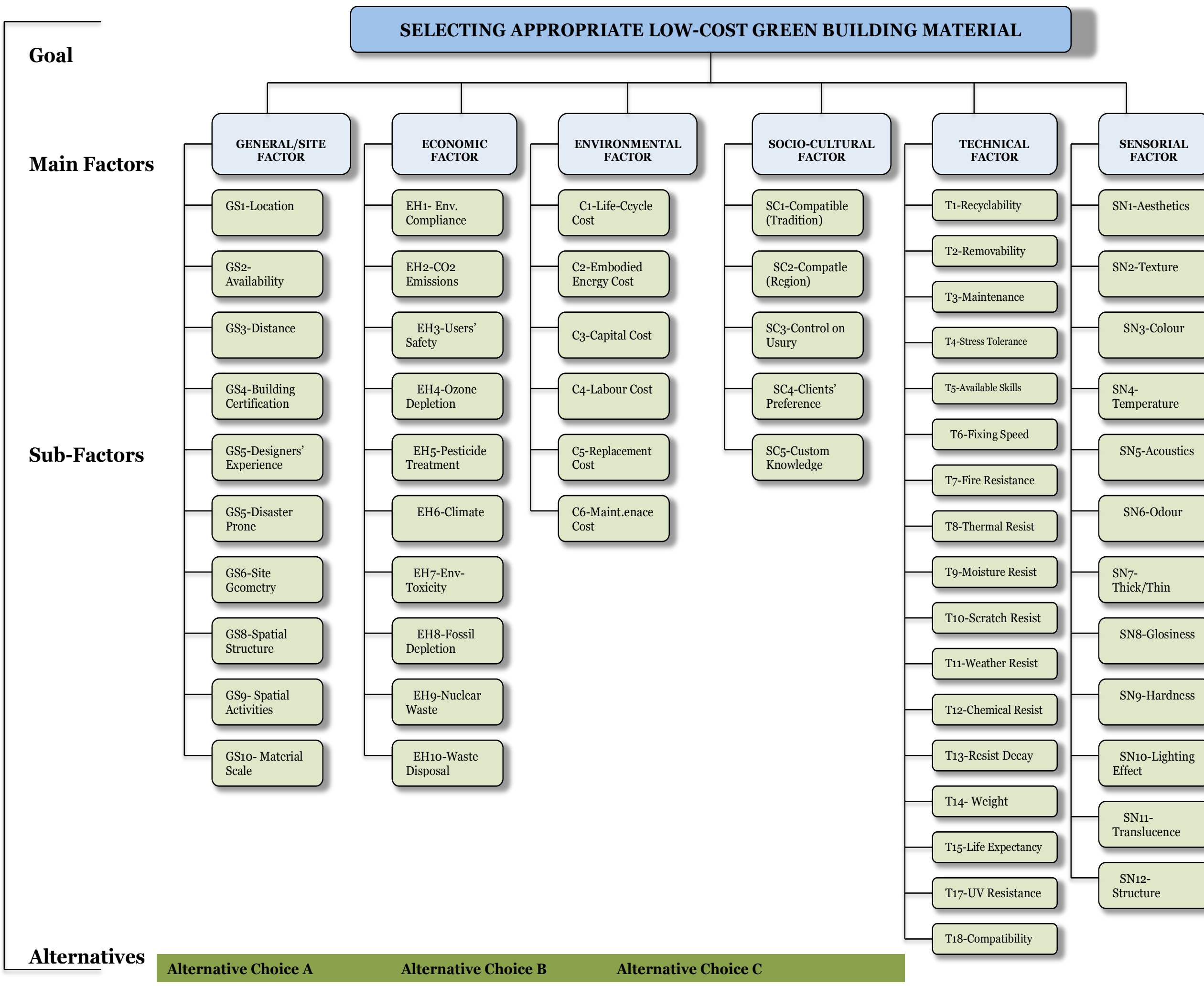


Figure 2. Shows the hierarchical representation of the floor material selection model

Step 1: Decomposition of the Decision Problem

This stage of the evaluation process offered users the opportunity to define the problem (i.e., the selection of a suitable floor material).

Define the Main Goal and Identify Feasible Material Alternatives

- The first step of the methodology was to define the main goal of the intended task, by identifying the design element needed for the analysis, and entering the relevant dimensional scales for the suggested design element (**Figure 3**).

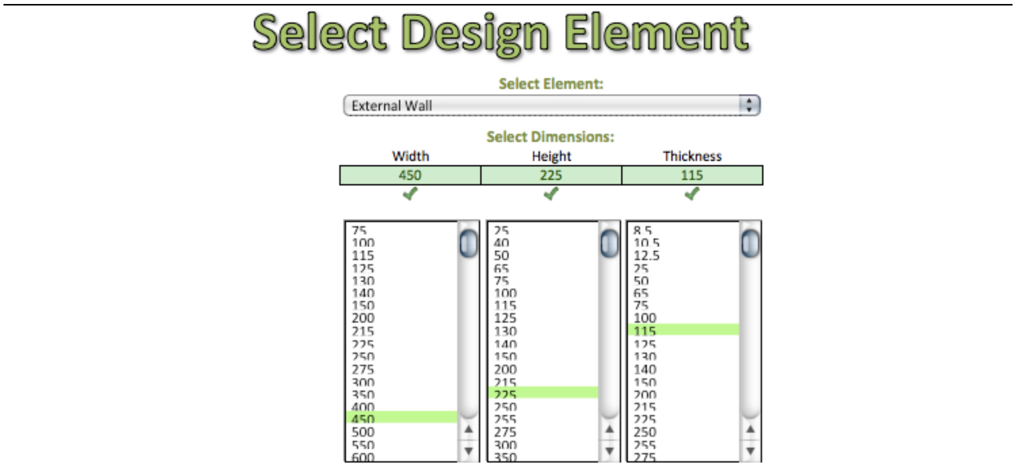


Figure 3. An illustrative example of the dimensional scale for the elected design element

- Next was to generate the set of all possible alternatives that were available for the intended task. The system prompts the user to identify a set of feasible floor material alternatives based on a range of material selection heuristics/rules as shown in **Figure 4**.

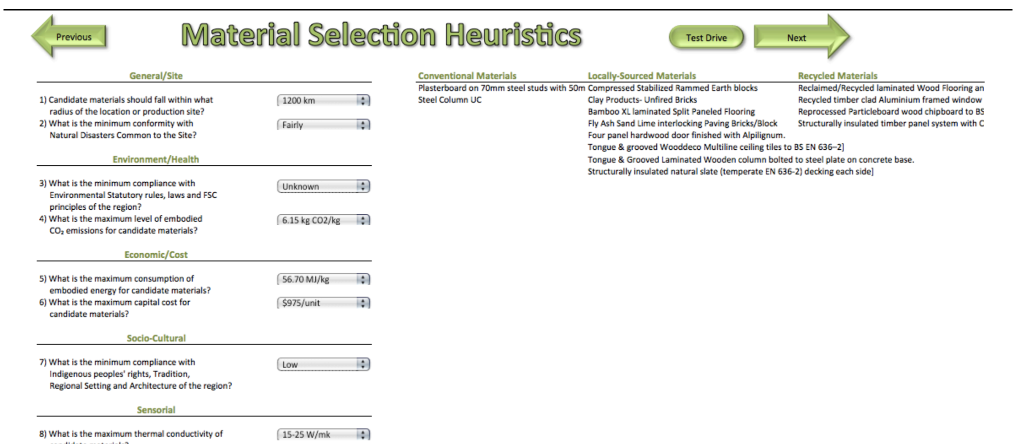


Figure 4. An illustrative example of the selection heuristics for the elected design element

Step 2: Performing Pair-wise Comparisons of Parent Factors

• Thereafter was to perform pair-wise comparisons between the parent elements in the adjacent upper level. At this point, an acceptable Consistency Ratio (CR) ≤ 0.10 had been achieved before proceeding. In exceptional cases respondents had to re-evaluate the factor-weightings until consistency was achieved. The individual judgments were then aggregated, basing its analysis on the geometric mean technique as Saaty (2001) suggested.

Pair-Wise Analysis of the main or parent factors

• To determine the relative importance of each parent element in the adjacent upper level, the five (5) respondents had to fill out the weightings for each parent factor based on their aprioristic knowledge and individual weighting preference (see **Figure 5** and **6**). The results of the pair-wise comparison matrices obtained from the 5 respondents were combined using the geometric mean approach at each hierarchy level to obtain the corresponding consensus pair-wise comparison matrices, as shown in **Table 3**.

• This was then automatically translated into the corresponding largest eigenvalue problem, to find the normalised and unique priority weights for each factor (as shown in **Table 4**).

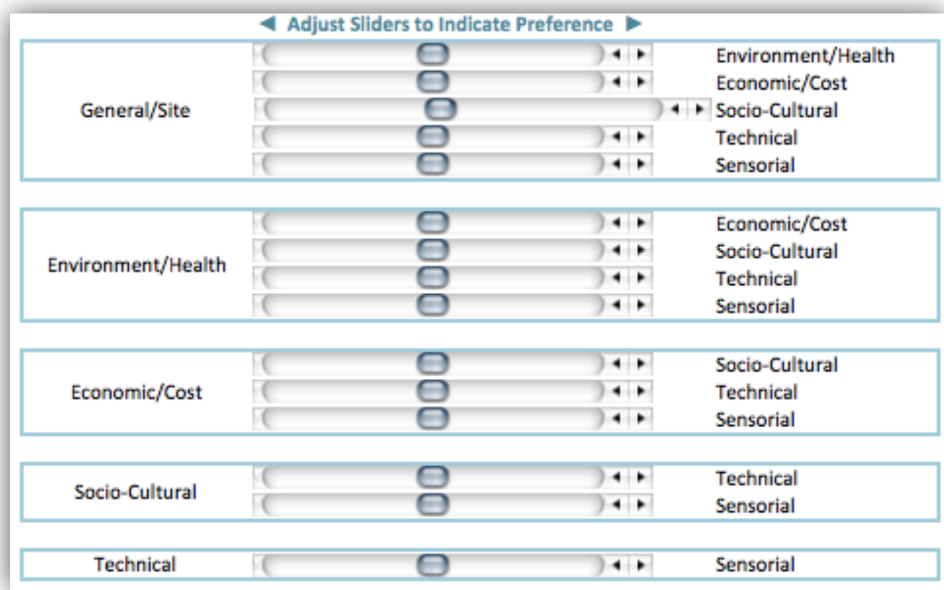


Figure 5. Corresponding consensus pair-wise comparison matrices for main factors

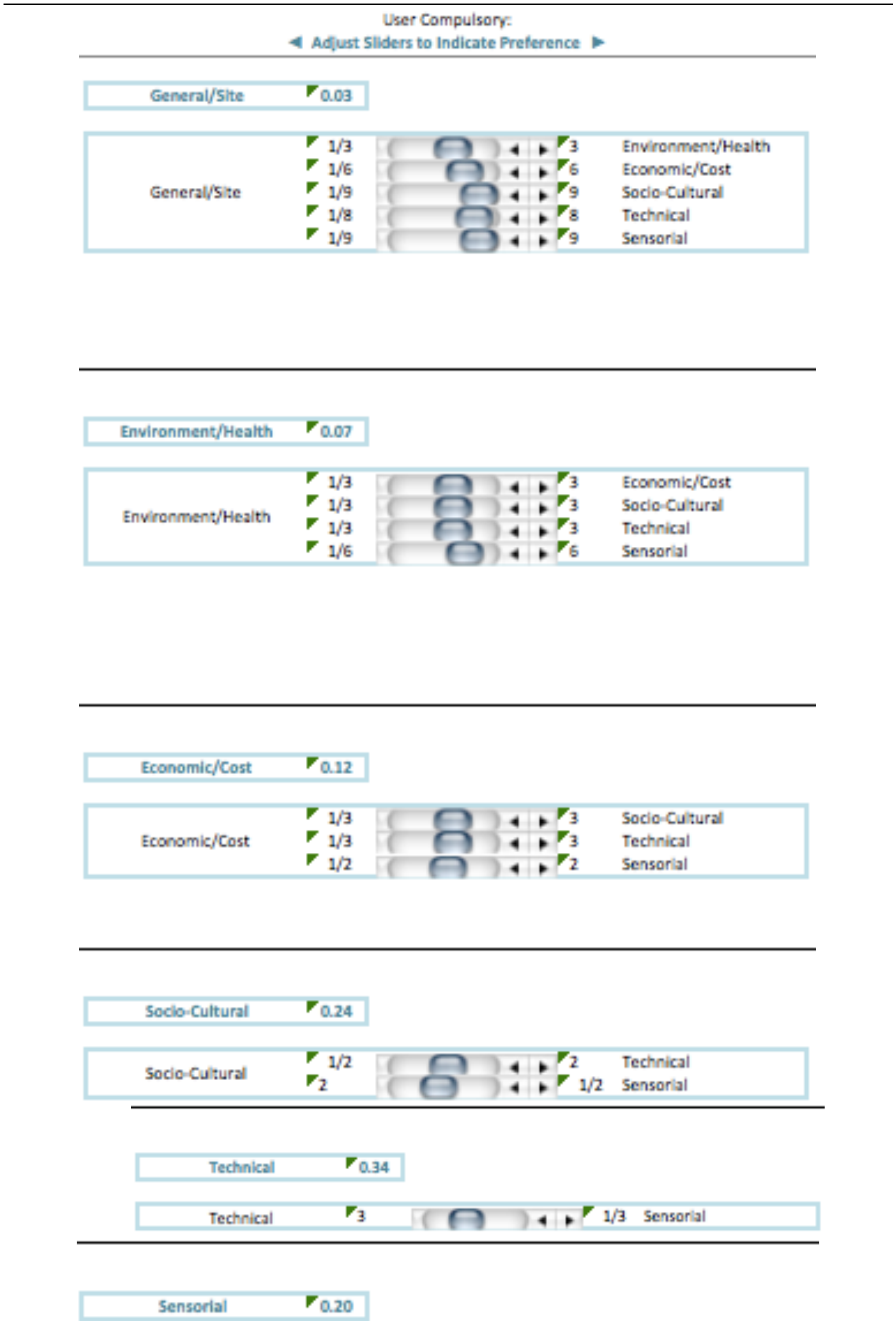


Figure 6. Corresponding consensus pair-wise comparison matrices for main factors

From **Figure 6**, it is possible to observe that factor SC is 3 times more important than factor EH. As a logical consequence, factor EH is 3 times less important than factor SC.

Table 3: Corresponding consensus pair-wise comparison matrices for main factors

Weighted Criteria Matrix

	General/Site	Environment	Economic/Cost	Socio-Cultural	Technical	Sensorial
General/Site	1.00	0.33	0.17	0.11	0.13	0.11
Environment/Health	3.00	1.00	0.33	0.33	0.33	0.17
Economic/Cost	6.00	3.00	1.00	0.33	0.33	0.50
Socio-Cultural	9.00	3.00	3.00	1.00	0.50	2.00
Technical	8.00	3.00	3.00	2.00	1.00	3.00
Sensorial	9.00	6.00	2.00	0.50	0.33	1.00
Total	36.00	16.33	9.50	4.28	2.63	6.78

Table 3 represents the principal matrix of comparison of the main/parent factors in relation to the overall objective of the problem

- Subsequently, the system normalised the matrices of each parent factor (by dividing each cell value by the sum of each column) as shown in **Table 3**.
- This then generated a range of matrices for each parent factor on each column of the matrix, and then averaged across the rows to produce the local priority vector representing the relative importance of each parent factor. The resulting priority vectors were given in **Table 4**.

Table 4: Computing the relative priority scores of main/parent factors

Normalised Average Criteria Matrix

	General/Site	Environment/Health	Economic/Cost	Socio-Cultural	Technical	Sensorial	Av.	λ_{MAX}
General/Site	0.03	0.02	0.02	0.03	0.05	0.02	0.03	0.934297901
Environment/Health	0.08	0.06	0.04	0.08	0.13	0.02	0.07	1.113775203
Economic/Cost	0.17	0.18	0.11	0.08	0.13	0.07	0.12	1.162609985
Socio-Cultural	0.25	0.18	0.32	0.23	0.19	0.30	0.24	1.04719097
Technical	0.22	0.18	0.32	0.47	0.38	0.44	0.34	0.880596922
Sensorial	0.25	0.37	0.21	0.12	0.13	0.15	0.20	1.377336489
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	6.52
							Matrix Size	6
							RI	1.24
							CI	0.103
							CR	0.083064516

Table 4: Relative priority of criteria

Factor/Criterion	Relative priority
General/Site	0.030
Environmental/Health	0.070
Economic/Cost	0.120
Socio Cultural	0.240
Technical	0.340
Sensorial	0.200

- The CR was then calculated with the knowledge of the consistency index (CI= 0.103) and knowing that the relative index for matrix of the order of six (6) is (RI= 1.24).
- This was calculated as CR = CI/RI = 0.103/1.24= 0.08306. With a CR of 0.083 less than 0.10, the matrix was considered to be consistent.

Step 3: Pair-Wise Analysis of the Sub-Factors

- The next task was to perform pair-wise comparisons among factors of the sub-categorical level as shown from table 5 -16.
- The system automatically generated a range of matrices for each sub-factor on each column of the matrix based on the individual weighting preference of the respondents.
- The mean of the matrices across each row were then calculated to produce the local priority vector representing the relative importance of each sub-factor.

Table 5: Pair-wise matrix & priority scores for General/Site Factors

	Score	GS1	GS2	GS3	GS4	GS6	GS8	GS9	GS10	GS11	GS12
GS1- Location (Mph)	0.197	1.00	2.00	3.00	2.00	4.00	2.00	2.00	2.00	3.00	3.00
GS2- Material Availability	0.158	0.50	1.00	2.00	2.00	2.00	3.00	3.00	3.00	2.00	3.00
GS3-Distance to Market (km/h)	0.127	0.33	0.50	1.00	2.00	2.00	2.00	3.00	3.00	3.00	2.00
GS4-Building Certification code	0.115	0.50	0.50	0.50	1.00	2.00	2.00	3.00	2.00	4.00	2.00
GS6-Withstand site natural disaster	0.083	0.25	0.50	0.50	0.50	1.00	2.00	2.00	2.00	2.00	2.00
GS8-Conforms to site geometry	0.114	0.50	0.33	0.50	0.50	0.50	1.00	3.00	7.00	3.00	4.00
GS9-Conforms to spatial structure	0.069	0.50	0.33	0.33	0.33	0.50	0.33	1.00	3.00	3.00	2.00
GS10-Conforms to all spatial activities	0.053	0.50	0.33	0.33	0.50	0.50	0.14	0.33	1.00	2.00	2.00
GS11-Conforms to design geometry	0.044	0.33	0.50	0.33	0.25	0.50	0.33	0.33	0.50	1.00	2.00
GS12-Mat. Spatial scale/Size (sq./m)	0.040	0.33	0.33	0.50	0.50	0.50	0.25	0.50	0.50	0.50	1.00
CR	0.09										

Table 6: Normalised matrices for General/Site Factors

Normalised Matrix										λ_{MAX}	λ_{MAX}	11
0.210	0.315	0.333	0.208	0.296	0.153	0.110	0.083	0.127	0.130	0.935	**Matrix Size**	10
0.105	0.157	0.222	0.208	0.148	0.229	0.165	0.125	0.085	0.130	0.999	**CI**	0.14
0.070	0.078	0.111	0.208	0.148	0.153	0.165	0.125	0.127	0.086	1.147	**RI**	1.49
0.105	0.078	0.055	0.104	0.148	0.153	0.165	0.083	0.170	0.086	1.103	**CR**	0.09
0.052	0.078	0.055	0.052	0.074	0.153	0.110	0.083	0.085	0.086	1.123		
0.105	0.052	0.055	0.052	0.037	0.076	0.165	0.291	0.127	0.173	1.486		
0.105	0.052	0.037	0.034	0.037	0.025	0.055	0.12	0.127	0.086	1.248		
0.105	0.052	0.037	0.052	0.037	0.010	0.018	0.041	0.085	0.086	1.265		
0.070	0.078	0.037	0.026	0.037	0.025	0.018	0.020	0.042	0.086	1.042		
0.070	0.052	0.055	0.052	0.037	0.019	0.027	0.020	0.021	0.043	0.920		

C.I. =0.14, R.I. =1.49, C.R. =0.09

Table 7: Pair-wise matrix & priority scores for Environmental/Health Factors

	Score	EH1	EH2	EH3	EH4	EH5	EH6	EH7	EH8	EH9	EH10
EH1 -Env. Statutory Compliance	0.202	1.00	4.00	3.00	2.00	2.00	3.00	3.00	2.00	2.00	2.00
EH2-Embodied C02 Emission (KgC02/m2)	0.124	0.25	1.00	2.00	3.00	2.00	2.00	2.00	2.00	3.00	0.50
EH3- Human Toxicity-Users Safety level	0.113	0.33	0.50	1.00	2.00	2.00	2.00	3.00	3.00	3.00	0.50
EH4- Ozone depletion rate	0.086	0.50	0.33	0.50	1.00	2.00	2.00	2.00	2.00	2.00	0.33
EH5- Amt. of Pesticide Treatment (l/m2)	0.078	0.50	0.50	0.50	0.50	1.00	2.00	3.00	2.00	0.33	0.50
EH6- Complies with the Climate of the region	0.067	0.33	0.50	0.50	0.50	0.50	1.00	2.00	2.00	2.00	0.50
EH7- Env. Toxicity (land, water, Animals)	0.053	0.33	0.50	0.33	0.50	0.33	0.50	1.00	2.00	2.00	0.33
EH8- Fossil fuel/Habitat depletion	0.058	0.50	0.50	0.33	0.50	0.50	0.50	0.50	1.00	4.00	0.25
EH9- Nuclear waste rate	0.057	0.50	0.33	0.33	0.50	3.00	0.50	0.50	0.25	1.00	0.33
EH10- Waste Disposal rate	0.162	0.50	2.00	2.00	3.00	2.00	2.00	3.00	4.00	3.00	1.00
CR	0.10										

Table 8: Normalised matrices for Environmental/Health Factors

Normalised Matrix										λ_{MAX}	λ_{MAX}	11
0.210	0.393	0.285	0.148	0.130	0.193	0.15	0.098	0.089	0.32	0.960	**Matrix Size**	10
0.052	0.098	0.190	0.222	0.130	0.129	0.1	0.098	0.134	0.08	1.257	**CI**	0.15
0.070	0.049	0.095	0.148	0.130	0.129	0.15	0.148	0.134	0.08	1.191	**RI**	1.49
0.105	0.032	0.047	0.074	0.130	0.129	0.1	0.098	0.089	0.05	1.162	**CR**	0.10
0.105	0.049	0.047	0.037	0.065	0.129	0.15	0.098	0.014	0.08	1.191		
0.070	0.049	0.047	0.037	0.032	0.064	0.1	0.098	0.089	0.08	1.038		
0.070	0.049	0.031	0.037	0.020	0.032	0.05	0.098	0.089	0.05	1.068		
0.105	0.049	0.031	0.037	0.032	0.032	0.025	0.049	0.179	0.04	1.178		
0.105	0.032	0.031	0.037	0.195	0.032	0.025	0.012	0.044	0.05	1.273		
0.105	0.196	0.190	0.222	0.130	0.129	0.15	0.197	0.134	0.16	1.010		

C.I. =0.15, R.I. =1.49, C.R. =0.10

Table 9: Pair-wise matrix & priority scores for Economic/Cost Factors

	Score	C1	C2	C3	C4	C5	C6
C1- Total life-cycle cost ($)	0.347	1.00	2.00	2.00	3.00	5.00	9.00
C2- Material embodied energy cost ($)	0.247	0.50	1.00	2.00	4.00	4.00	3.00
C3- Material capital cost ($)	0.186	0.50	0.50	1.00	2.00	4.00	6.00
C4- Labour/Installation cost ($/sqft)	0.120	0.33	0.25	0.50	1.00	3.00	5.00
C5- Material replacement cost ($)	0.063	0.20	0.25	0.25	0.33	1.00	3.00
C6- Material Maintenance cost ($)	0.037	0.11	0.33	0.17	0.20	0.33	1.00
CR	0.07						

Table 10: Normalised matrices for Economic/Cost Factors

Normalised Matrix						λ_{MAX}		
0.378	0.461	0.338	0.284	0.288	0.333	0.919	λ_{MAX}	6
0.18	0.230	0.338	0.379	0.230	0.111	1.069	**Matrix Size**	6
0.18	0.115	0.169	0.189	0.230	0.222	1.101	**CI**	0.09
0.12	0.057	0.084	0.094	0.173	0.185	1.267	**RI**	1.24
0.075	0.057	0.042	0.031	0.057	0.111	1.086	**CR**	0.07
0.042	0.076	0.028	0.018	0.019	0.037	1.001		

C.I. =0.09, R.I. =1.24, C.R. =0.07

Table 11: Pair-wise matrix & priority scores for Socio-Cultural Factors

	Score	SC1	SC2	SC3	SC4	SC5
SC1- Material compatibility with traditions	0.164	1.00	2.00	0.33	0.50	2.00
SC2- Material compatibility with region	0.102	0.50	1.00	0.50	0.50	0.33
SC3- Cultural restriction on usury	0.362	3.00	2.00	1.00	2.00	3.00
SC4- Client's preference rating	0.227	2.00	2.00	0.50	1.00	2.00
SC5- Conforms to Knowledge of custom	0.146	0.50	3.00	0.33	0.50	1.00
CR	0.08					

Table 12: Normalised matrices for Socio-Cultural Factors

Normalised Matrix					λ_{MAX}		
0.142	0.2	0.125	0.111	0.24	1.147	λ_{MAX}	5
0.071	0.1	0.187	0.111	0.04	1.020	**Matrix Size**	5
0.428	0.2	0.375	0.444	0.36	0.964	**CI**	0.09
0.285	0.2	0.1875	0.222	0.24	1.022	**RI**	1.12
0.071	0.3	0.125	0.111	0.12	1.213	**CR**	0.08

C.I. =0.09, R.I. =1.12, C.R. =0.08

Table 13: Pair-wise matrix & priority scores for Technical Factors

	Score	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T17
T1-Recyclable	0.09	1.00	2.00	2.00	3.00	0.50	2.00	2.00	0.50	0.50	2.00	3.00	2.00	2.00	2.00	3.00	0.50	0.33	0.50
T2-Ease to remove	0.10	0.50	1.00	0.33	0.33	0.33	3.00	2.00	3.00	0.50	2.00	3.00	2.00	2.00	3.00	2.00	3.00	2.00	2.00
T3- Maintenance level	0.06	0.50	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T4-Expansion Tolerance	0.06	0.33	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T5- Conforms to skills	0.06	2.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T6- Ease of fixing	0.05	0.50	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T7- Fire resistance	0.04	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.11	1.00	0.14	1.00	1.00	1.00
T8- Thermal resistance	0.05	2.00	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.14	1.00	1.00
T9- Moisture resistance	0.06	2.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T10- Scratch resistance	0.05	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T11- Weather resistance	0.05	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T12- Chemical resistance	0.05	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T13- Resistance to decay	0.07	0.50	0.50	1.00	1.00	1.00	1.00	9.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T14- Weight of material	0.05	0.50	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T15- Life expectancy	0.07	0.33	0.50	1.00	1.00	1.00	1.00	7.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25	1.00	1.00
T16- Biodegradable	0.08	2.00	0.33	1.00	1.00	1.00	1.00	1.00	7.00	1.00	1.00	1.00	1.00	1.00	1.00	4.00	1.00	1.00	1.00
T17-UV Resistance	0.06	3.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T18-Compatibility	0.05	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 14: Normalised matrices for Technical Factors

		Normalised Matrix																λ_{MAX}	λ_{MAX}	21
0.05	0.11	0.11	0.17	0.02	0.11	0.11	0.02	0.02	0.11	0.17	0.11	0.11	0.11	0.17	0.02	0.01	0.02	1.602	**Size**	18
0.02	0.05	0.01	0.01	0.01	0.17	0.11	0.17	0.02	0.11	0.17	0.11	0.11	0.17	0.11	0.17	0.11	0.11	1.778	**CI**	0.15
0.02	0.17	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.083	**RI**	1.69
0.01	0.17	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.074	**CR**	0.09
0.11	0.17	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.167		
0.02	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.935		
0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.05	0.01	0.05	0.05	0.05	0.847		
0.11	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.05	0.05	0.971		
0.11	0.11	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.111		
0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.944		
0.01	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.926		
0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.944		
0.02	0.02	0.05	0.05	0.05	0.05	0.51	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.389		
0.02	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.935		
0.01	0.02	0.05	0.05	0.05	0.05	0.4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.05	0.05	1.227		
0.11	0.01	0.05	0.05	0.05	0.05	0.05	0.4	0.05	0.05	0.05	0.05	0.05	0.05	0.22	0.05	0.05	0.05	1.519		
0.17	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.083		
0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.972		

Table 15: Pair-wise matrix & priority scores for Sensorial Factors

	Score	SN1	SN2	SN3	SN4	SN5	SN6	SN7	SN8	SN9	SN10	SN11	SN12	SN13
SN1- Aesthetics	0.077	1.00	1	1	1	1	1	1	1	1	1	1	1	1
SN2- Texture	0.077	1.00	1.00	1	1	1	1	1	1	1	1	1	1	1
SN3- Colour	0.077	1.00	1.00	1.00	1	1	1	1	1	1	1	1	1	1
SN4- Temperature	0.077	1.00	1.00	1.00	1.00	1	1	1	1	1	1	1	1	1
SN5- Acoustics	0.106	1.00	1.00	1.00	1.00	1.00	2	0	4	0	2	0	2	2
SN6- Odour	0.087	1.00	1.00	1.00	1.00	0.50	1.00	2	1	0	2	1	2	2
SN7- Thickness/Thinness	0.107	1.00	1.00	1.00	1.00	3.00	0.50	1.00	2	2	2	3	0	0
SN8- Glossiness/fineness	0.075	1.00	1.00	1.00	1.00	0.25	2.00	0.50	1.00	1	1	1	1	1
SN9- Strength/Hardness	0.109	1.00	1.00	1.00	1.00	3.00	5.00	0.50	1.00	1.00	1	1	1	1
SN10- Lighting effect	0.068	1.00	1.00	1.00	1.00	0.50	0.50	0.50	1.00	1.00	1.00	1	1	1
SN11- Translucence	0.108	1.00	1.00	1.00	1.00	6.00	2.00	0.33	1.00	1.00	1.00	1.00	1	1
SN12- Structure	0.089	1.00	1.00	1.00	1.00	0.50	0.50	4.00	1.00	1.00	1.00	1.00	1.00	1
SN13- Thermal	0.083	1.00	1.00	1.00	1.00	0.50	0.50	3.00	1.00	1.00	1.00	1.00	1.00	1.00
CR	0.10													

Table 16: Normalised matrices for Sensorial Factors

Normalised Matrix													λ_{MAX}
0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	1.000
0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	1.000
0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	1.000
0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	1.000
0.076	0.076	0.076	0.076	0.076	0.153	0.025	0.307	0.025	0.153	0.012	0.153	0.153	1.372
0.076	0.076	0.076	0.076	0.038	0.076	0.153	0.038	0.015	0.153	0.038	0.153	0.153	1.131
0.076	0.076	0.076	0.076	0.230	0.038	0.076	0.153	0.153	0.153	0.230	0.019	0.025	1.391
0.076	0.076	0.076	0.076	0.019	0.153	0.038	0.076	0.076	0.076	0.076	0.076	0.076	0.981
0.076	0.076	0.076	0.076	0.230	0.384	0.038	0.076	0.076	0.076	0.076	0.076	0.076	1.423
0.076	0.076	0.076	0.076	0.038	0.038	0.038	0.076	0.076	0.076	0.076	0.076	0.076	0.885
0.076	0.076	0.076	0.076	0.461	0.153	0.025	0.076	0.076	0.076	0.076	0.076	0.076	1.410
0.076	0.076	0.076	0.076	0.038	0.038	0.307	0.076	0.076	0.076	0.076	0.076	0.076	1.154
0.076	0.076	0.076	0.076	0.038	0.038	0.230	0.076	0.076	0.076	0.076	0.076	0.076	1.077

λ_{MAX}	15
Matrix Size	13
CI	0.15
RI	1.5551
CR	0.10

C.I. =0.15, R.I. =1.5551, C.R. =0.10

- The criteria matrices of each sub-factor were then normalised (by dividing a cell value by the sum of each column) and then checked for consistency as shown in tables 6, 8, 10, 12, 14 and 16.

Step 4: Determining the Weighting Scores of the Factors

- The next stage of the assessment process was to find the final global weightings of both the parent and sub-factors that will be used subsequently with the normalized priority weights for each pair-wise comparison judgment matrices of each floor material alternative.

- To determine the final or amalgamated weightings of factors, the priority vectors (1) of the parent factors were multiplied by the corresponding relative priority vectors of each sub-criterion weighting vectors (2) to obtain the (amalgamated/final) weighting (3) as shown in **Table 17**.

The following steps describes the ways by which the various weighting vectors of each criterion are derived

- Main factor weight 1 (or the main/parent factor) is derived from users' judgement with respect to a single main criterion. The selected value serves as the priority vector of the main criteria needed for evaluating material choice. The selected value as shown in **Table 17** include: GS=0.026, EH=0.068, C=0.122, SC=0.245, T=0.335 and SN=0.203

- Sub-Factorial weight 2 (or the sub-factor) is derived from user's judgment with respect to each sub-factor. Some of the selected values that serve as the corresponding relative priority vectors include: Location=0.197; Env. Compliance=0.202; Life-Cycle Cost=0.347; Compatibility with Traditions=0.164; Recyclability=0.092; Aesthetics= 0.77.

- Amalgamated/Final weighting (3) is derived from multiplying the selected value of the main factor-weighting vector by the selected value of the priority vector of the sub-factor. This entry is obtained for the general/site suitability group as follows: 0.026 x 0.197= 0.005122

After deriving the local priorities for each sub-factor against the alternatives through pair-wise comparisons, the priorities of the factors are synthesized to calculate the overall priorities for each material alternative in step 5

Table 17: Derived final global weightings scores of sub-factors used for the hypothetical case study

Parent/Main-Factor	Parent/Main Factor weight (1)			Sub-Factors	Sub-Factor weight (2)			Final weight (3)
	User Value	Value Used	CR		User Value	Value Used	CR	
General/Site Suitability Factor	0.03	0.026	0.08	GS1- Location	0.197	0.197	0.09	0.0051
				GS2-Material Availability	0.158	0.158		0.0041
				GS3-Distance	0.127	0.127		0.0033
				GS4-Certification Code	0.115	0.115		0.0030
				GS5-Disaster Prone	0.083	0.083		0.0022
				GS6-Site Geometry	0.114	0.114		0.0030
				GS7-Design Geometry	0.044	0.044		0.0012
				GS8-Spatial Structure	0.069	0.069		0.0018
				GS9-Spatial Activities	0.053	0.053		0.0014
				GS10-Material Scale	0.000	0.000		0.0000
				GS11-Bldg Orientation	0.000	0.000		0.0000
				GS12-Spatial Scale	0.040	0.040		0.0010
Env./Health Impact Factor	0.07	0.068	0.08	EH1- Env. Compliance	0.202	0.202	0.10	0.0138
				EH2-CO2 Emissions	0.124	0.124		0.0084
				EH3-Users' Safety	0.113	0.113		0.0077
				EH4-Ozone Depletion	0.086	0.086		0.0059
				EH5-Pesticide Treatment	0.078	0.078		0.0053
				EH6-Climate	0.067	0.067		0.0046
				EH7-Env-Toxicity	0.053	0.053		0.0036
				EH8-Fossil Depletion	0.058	0.058		0.0040
				EH9-Nuclear Waste	0.057	0.057		0.0039
				EH10-Waste Disposal	0.014	0.014		0.0110
Economic/Cost Impact Factor	0.12	0.122	0.08	C1-Life-Ccycle Cost	0.347	0.347	0.07	0.0425
				C2-Embodied Energy Cost	0.247	0.247		0.0302
				C3-Capital Cost	0.186	0.186		0.0228
				C4-Labour Cost	0.120	0.120		0.0147
				C5- Maintenance Cost	0.037	0.037		0.0077
Socio-Cultural impact Factor	0.24	0.245	0.08	SC1-Compatibility			0.08	
				(Tradition)	0.164	0.164		0.0401
				SC2-Compatibility (Region)				
				SC3-Resistriction on Usury	0.102	0.102		0.0250
				SC4-Clients' Preference				
				SC5-Custom Knowledge	0.362	0.362 0.227		0.0885
					0.227	0.146		0.0556
					0.146			0.0356
Technical Performance Factor	0.34	0.335	0.08	T1-Recyclability	0.092	0.092	0.09	0.0307
				T2-Ease to remove	0.102	0.102		0.0341
				T3-maintenance Level	0.062	0.062		0.0208
				T4-Contraction Tolerance	0.061	0.061		0.0206
				T5-Skills Availability	0.067	0.067		0.0224
				T6-Speed of Fixing	0.053	0.053		0.0179
				T7-Fire Resistance	0.048	0.048		0.0162
				T8-Thermal Resistance	0.055	0.055		0.0186
				T9-Moisture Resistance	0.063	0.063		0.0213
				T10-Scratch Resistance	0.054	0.054		0.0181
				T11-Weather Resistance	0.053	0.053		0.0177
				T12-Chemical Resistance	0.054	0.054		0.0181
				T13-Resistance to Decay	0.079	0.079		0.0266
				T14-Weight/Mass	0.053	0.053		0.0179
				T15-Life Expectancy	0.070	0.070		0.0235
				T16-Renewable	0.087	0.087		0.0291
				T17-UV Resistance	0.062	0.062		0.0208
				T18-Compatibility with other Materials	0.056	0.056		0.0186
Sensorial impact Factor	0.20	0.203	0.08	SN1-Aesthetics	0.077	0.077		0.0156
				SN2-Texture	0.077	0.077		0.0156
				SN3-Colour	0.077	0.077		0.0156
				SN4-Temperature	0.077	0.077		0.0156
				SN5-Acoustics	0.106	0.106		0.0214
				SN6-Odour	0.087	0.087		0.0177
				SN7-Thick/Thin	0.107	0.107		0.0181
				SN8-Glosiness	0.075	0.075		0.0177
				SN9-Hardness	0.109	0.109		0.0217
				SN10-Lighting Effect	0.068	0.068		0.0153
				SN11-Translucence	0.108	0.108		0.0222
				SN12-Structure	0.089	0.089		0.0138
				SN13-Thermal Condition	0.083	0.083		0.0220
								0.0180
								0.0168
Σ	**1.000**				**Σ**			**1.000**

Step 5: Performing Pair-Wise Comparison of the Selected Material Alternatives Against Each Sub-Factor

- The next phase of the exercise was to conduct pair-wise comparisons for the selected alternatives against each sub-factor based on the importance attached to the dominance of each alternative relative to other alternatives under that sub-factor. For each sub-factor (e.g., location), a separate factor matrix was developed to relatively compare the given candidate materials for that sub-factor. These matrices were also normalized and checked for consistency as shown in **Tables 18-41**.

Table 18: GS1- Pair-wise matrix & priority scores for Location

GS1- Location (km)	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concre	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing
Recycled crushed concrete block	1	0.3	1	2	0.5	1	0.5	2	4	1	0.5	2	3	6	6	2	2	2	7	2	5	0.5	2	4
Compressed Stabilized Rammed Earth blocks	3	1	3	4	2	3	2	4	6	3	2	4	5	8	8	4	4	4	9	4	7	2	4	6
Aerated concrete or "aircrete" block	1	0.3	1	2	0.5	1	0.5	2	4	1	0.5	2	3	6	6	2	2	2	7	2	5	0.5	2	4
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	0.5	0.3	0.5	1	0.3	0.5	0.3	1	3	0.5	0.3	1	2	5	5	1	1	1	6	1	4	0.33	1	3
Clay Products- Unfired Bricks	2	0.5	2	3	1	2	1	3	5	2	1	3	4	7	7	3	3	3	8	3	6	1	3	5
Aerated concrete or "aircrete" block	1	0.3	1	2	0.5	1	0.5	2	4	1	0.5	2	3	6	6	2	2	2	7	2	5	0.5	2	4
Reclaimed/Recycled laminated Wood Flooring and Panelling	2	0.5	2	3	1	2	1	3	5	2	1	3	4	7	7	3	3	3	8	3	6	1	3	5
Bamboo XL laminated Split Paneled Flooring	0.5	0.3	0.5	1	0.3	0.5	0.3	1	3	0.5	0.3	1	2	5	5	1	1	1	6	1	4	0.33	1	3
Fly Ash Cement concrete Floor slab	0.3	0.2	0.3	0.3	0.2	0.3	0.2	0.3	1	0.25	0.2	0.33	0.5	3	3	0.3	0.33	0.3	4	0.3	2	0.2	0.3	1
Recycled Porocom Pebble Stone Pavers	1	0.3	1	2	0.5	1	0.5	2	4	1	0.5	2	3	6	6	2	2	2	7	2	5	0.5	2	4
Fly Ash Sand Lime interlocking Paving Bricks/Block	2	0.5	2	3	1	2	1	3	5	2	1	3	4	7	7	3	3	3	8	3	6	1	3	5
Concrete Pavers	0.5	0.3	0.5	1	0.3	0.5	0.3	1	3	0.5	0.3	1	2	5	5	1	1	1	6	1	4	0.3	1	3
Recycled timber clad Aluminium framed window unit	0.3	0.2	0.3	0.5	0.3	0.33	0.25	0.5	2	0.33	0.3	0.5	1	4	4	0.5	0.5	0.5	5	0.5	3	0.3	0.5	2
Four panel hardwood door finished with Alpilignum.	0.2	0.1	0.2	0.2	0.1	0.2	0.1	0.2	0.3	0.2	0.1	0.2	0.3	1	1	0.2	0.2	0.2	2	0.2	0.5	0.1	0.2	0.3
Stainless Steel Entry Door.	0.2	0.1	0.2	0.2	0.1	0.2	0.14	0.2	0.33	0.17	0.1	0.2	0.3	1	1	0.2	0.2	0.2	2	0.2	0.5	0.14	0.2	0.33
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.5	0.3	0.5	1	0.3	0.5	0.3	1	3	0.5	0.3	1	2	5	5	1	1	1	6	1	4	0.33	1	3
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	0.5	0.3	0.5	1	0.3	0.5	0.3	1	3	0.5	0.3	1	2	5	5	1	1	1	6	1	4	0.33	1	3
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.5	0.3	0.5	1	0.3	0.5	0.3	1	3	0.5	0.3	1	2	5	5	1	1	1	6	1	4	0.33	1	3
Recycled Scrap steel bolted sections	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.3	0.14	0.1	0.17	0.2	0.5	0.5	0.2	0.17	0.2	1	0.2	0.3	0.13	0.2	0.25
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.5	0.3	0.5	1	0.3	0.5	0.3	1	3	0.5	0.3	1	2	5	5	1	1	1	6	1	4	0.33	1	3
Steel Column UC	0.2	0.1	0.2	0.3	0.2	0.2	0.17	0.25	0.5	0.2	0.2	0.3	0.3	2	2	0.3	0.3	0.3	3	0.3	1	0.17	0.3	0.5
Structurally insulated timber panel system with OSB/3 each side, roofing under	2	0.5	2	3	1	2	1	3	5	2	1	3	4	7	7	3	3	3	8	3	6	1	3	5
Structurally insulated natural slate (temperate EN 636-2) decking each side]	0.5	0.3	0.5	1	0.3	0.5	0.3	1	3	0.5	0.3	1	2	5	5	1	1	1	6	1	4	0.33	1	3
Roofing underlay concrete interlocking tiles	0.3	0.2	0.3	0.3	0.2	0.3	0.2	0.33	1	0.25	0.2	0.33	0.5	3	3	0.3	0.3	0.3	4	0.3	2	0.2	0.3	1
Total	20.5	7.4	20.5	34.0	11.9	20.5	11.9	34.0	71.4	20.5	11.9	34.0	52.0	114.5	114.5	34.0	34.0	34.0	138	34.0	92.3	11.9	34.0	71.4

Table 19: GS1-Normilised matrices for Location

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concre	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.04
0.05	0.05	0.05	0.06	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.05	0.06	0.05	0.04	0.06	0.06	0.05	1.08	RI	1.70
0.15	0.14	0.15	0.12	0.17	0.15	0.17	0.12	0.08	0.15	0.17	0.12	0.10	0.07	0.07	0.12	0.12	0.12	0.07	0.12	0.08	0.17	0.12	0.08	0.12	0.88	CR	0.02
0.05	0.05	0.05	0.06	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.05	0.06	0.05	0.04	0.06	0.06	0.05	1.08		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.10	0.07	0.10	0.09	0.08	0.10	0.08	0.09	0.07	0.10	0.08	0.09	0.08	0.06	0.06	0.09	0.09	0.09	0.06	0.09	0.06	0.08	0.09	0.07	0.08	0.97		
0.05	0.05	0.05	0.06	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.05	0.06	0.05	0.04	0.06	0.06	0.05	1.08		
0.10	0.07	0.10	0.09	0.08	0.10	0.08	0.09	0.07	0.10	0.08	0.09	0.08	0.06	0.06	0.09	0.09	0.09	0.06	0.09	0.06	0.08	0.09	0.07	0.08	0.97		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.03	0.03	0.01	0.01	0.01	0.03	0.01	0.02	0.02	0.01	0.01	0.01	1.06		
0.05	0.05	0.05	0.06	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.05	0.06	0.05	0.04	0.06	0.06	0.05	1.08		
0.10	0.07	0.10	0.09	0.08	0.10	0.08	0.09	0.07	0.10	0.08	0.09	0.08	0.06	0.06	0.09	0.09	0.09	0.06	0.09	0.06	0.08	0.09	0.07	0.08	0.97		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.02	0.03	0.02	0.01	0.02	0.02	0.02	0.01	0.03	0.02	0.02	0.01	0.02	0.03	0.03	0.01	0.01	0.01	0.04	0.01	0.03	0.02	0.01	0.03	0.02	1.10		
0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.94		
0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.94		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.01	0.02	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.89		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	1.00		
0.10	0.07	0.10	0.09	0.08	0.10	0.08	0.09	0.07	0.10	0.08	0.09	0.08	0.06	0.06	0.09	0.09	0.09	0.06	0.09	0.06	0.08	0.09	0.07	0.08	0.97		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.03	0.03	0.01	0.01	0.01	0.03	0.01	0.02	0.02	0.01	0.01	0.01	1.06		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.9		

Table 20: GS2- Pair-wise matrix & priority scores for Material Availability

GS2- Material Availability	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structi	Structi	Roofing
Recycled crushed concrete block	1	0.1	1	1	0.2	1	0.2	0.5	1	1	0.2	1	0.2	3	4	0.3	0.5	0.3	0.3	0.5	2	0.33	0.2	1
Compressed Stabilized Rammed Earth blocks	7	1	7	7	3	7	2	6	7	7	3	7	3	9	9	5	6	5	4	6	8	5	3	7
Aerated concrete or "aircrete" block	1	0.1	1	1	0.2	1	0.2	0.5	1	1	0.2	1	0.2	3	4	0.3	0.5	0.3	0.3	0.5	2	0.33	0.2	1
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	1	0.1	1	1	0.2	1	0.2	0.5	1	1	0.2	1	0.2	3	4	0.3	0.5	0.3	0.3	0.5	2	0.33	0.2	1
Clay Products- Unfired Bricks	5	0.3	5	5	1	5	1	4	5	5	1	5	1	7	8	3	4	3	2	4	6	3	1	5
Aerated concrete or "aircrete" block	1	0.1	1	1	0.2	1	0.2	0.5	1	1	0.2	1	0.2	3	4	0.3	0.5	0.3	0.3	0.5	2	0.33	0.2	1
Reclaimed/Recycled laminated Wood Flooring and Panelling	5	0.5	5	5	1	5	1	4	5	5	1	5	1	7	8	3	4	3	2	4	6	3	1	5
Bamboo XL laminated Split Paneled Flooring	2	0.2	2	2	0.3	2	0.25	1	2	2	0.3	2	0.3	4	5	0.5	1	0.5	0.3	1	3	0.5	0.3	2
Fly Ash Cement concrete Floor slab	1	0.1	1	1	0.2	1	0.2	0.5	1	1	0.2	1	0.2	3	4	0.3	0.5	0.3	0.3	0.5	2	0.3	0.2	1
Recycled Porocom Pebble Stone Pavers	1	0.1	1	1	0.2	1	0.2	0.5	1	1	0.2	1	0.2	3	4	0.33	0.5	0.33	0.25	0.5	2	0.33	0.2	1
Fly Ash Sand Lime interlocking Paving Bricks/Block	5	0.3	5	5	1	5	1	4	5	5	1	5	1	7	8	3	4	3	2	4	6	3	1	5
Concrete Pavers	1	0.1	1	1	0.2	1	0.2	0.5	1	1	0.2	1	0.2	3	4	0.3	0.5	0.3	0.3	0.5	2	0.3	0.2	1
Recycled timber clad Aluminium framed window unit	5	0.3	5	5	1	5	1	4	5	5	1	5	1	7	8	3	4	3	2	4	6	3	1	5
Four panel hardwood door finished with Alpilignum.	0.3	0.1	0.3	0.3	0.1	0.3	0.1	0.3	0.3	0.3	0.1	0.3	0.1	1	2	0.2	0.3	0.2	0.2	0.3	0.5	0.2	0.1	0.33
Stainless Steel Entry Door.	0.3	0.1	0.3	0.3	0.1	0.3	0.1	0.2	0.3	0.3	0.1	0.3	0.1	0.5	1	0.2	0.2	0.2	0.1	0.2	0.3	0.17	0.1	0.25
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	3	0.2	3	3	0.3	3	0.3	2	3	3	0.3	3	0.3	5	6	1	2	1	0.5	2	4	1	0.3	3
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	2	0.2	2	2	0.3	2	0.3	1	2	2	0.3	2	0.3	4	5	0.5	1	0.5	0.3	1	3	0.5	0.3	2
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	3	0.2	3	3	0.3	3	0.3	2	3	3	0.3	3	0.3	5	6	1	2	1	0.5	2	4	1	0.3	3
Recycled Scrap steel bolted sections	4	0.3	4	4	0.5	4	0.5	3	4	4	0.5	4	0.5	6	7	2	3	2	1	3	5	2	0.5	4
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	2	0.2	2	2	0.3	2	0.3	1	2	2	0.3	2	0.3	4	5	0.5	1	0.5	0.3	1	3	0.5	0.3	2
Steel Column UC	0.5	0.1	0.5	0.5	0.2	0.5	0.2	0.3	0.5	0.5	0.2	0.5	0.2	2	3	0.3	0.3	0.3	0.2	0.3	1	0.25	0.2	0.5
Structurally insulated timber panel system with OSB/3 each side, roofing under	3	0.2	3	3	0.3	3	0.3	2	3	3	0.3	3	0.3	5	6	1	2	1	0.5	2	4	1	0.3	3
Structurally insulated natural slate (temperate EN 636-2) decking each side]	5	0.3	5	5	1	5	1	4	5	5	1	5	1	7	8	3	4	3	2	4	6	3	1	5
Roofing underlay concrete interlocking tiles	1	0.1	1	1	0.2	1	0.2	0.5	1	1	0.2	1	0.2	3	4	0.33	0.5	0.33	0.25	0.5	2	0.33	0.2	1
Total	60.1	5.7	60.1	60.1	12.3	60.1	11.3	42.8	60.1	60.1	12.3	60.1	12.3	104.5	127	29.8	42.8	29.8	20.0	42.8	81.8	29.8	12.3	60.1

Table 21: GS2- Normalised matrices for Material Availability

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structi	Structi	Roofing unde	Average	Lambda Max	CI	0.05
0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	1.02	RI	1.70
0.12	0.18	0.12	0.12	0.24	0.12	0.18	0.14	0.12	0.12	0.24	0.12	0.24	0.09	0.07	0.17	0.14	0.17	0.20	0.14	0.10	0.17	0.24	0.12	0.15	0.86	CR	0.03
0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	1.02		
0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	1.02		
0.08	0.06	0.08	0.08	0.08	0.08	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.10	0.09	0.10	0.10	0.09	0.07	0.10	0.08	0.08	0.08	1.04		
0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	1.02		
0.08	0.09	0.08	0.08	0.08	0.08	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.10	0.09	0.10	0.10	0.09	0.07	0.10	0.08	0.08	0.09	0.97		
0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.02	0.03	0.02	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.03	0.03	1.16		
0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	1.02		
0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	1.02		
0.08	0.06	0.08	0.08	0.08	0.08	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.10	0.09	0.10	0.10	0.09	0.07	0.10	0.08	0.08	0.08	1.04		
0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	1.02		
0.08	0.06	0.08	0.08	0.08	0.08	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.10	0.09	0.10	0.10	0.09	0.07	0.10	0.08	0.08	0.08	1.04		
0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.87		
0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.84		
0.05	0.04	0.05	0.05	0.03	0.05	0.03	0.05	0.05	0.05	0.03	0.05	0.03	0.05	0.05	0.03	0.05	0.03	0.02	0.05	0.05	0.03	0.03	0.05	0.04	1.22		
0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.02	0.03	0.02	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.03	0.03	1.16		
0.05	0.04	0.05	0.05	0.03	0.05	0.03	0.05	0.05	0.05	0.03	0.05	0.03	0.05	0.05	0.03	0.05	0.03	0.02	0.05	0.05	0.03	0.03	0.05	0.04	1.22		
0.07	0.04	0.07	0.07	0.04	0.07	0.04	0.07	0.07	0.07	0.04	0.07	0.04	0.06	0.06	0.07	0.07	0.07	0.05	0.07	0.06	0.07	0.04	0.07	0.06	1.18		
0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.02	0.03	0.02	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.03	0.03	1.16		
0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.92		
0.05	0.04	0.05	0.05	0.03	0.05	0.03	0.05	0.05	0.05	0.03	0.05	0.03	0.05	0.05	0.03	0.05	0.03	0.02	0.05	0.05	0.03	0.03	0.05	0.04	1.22		
0.08	0.06	0.08	0.08	0.08	0.08	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.10	0.09	0.10	0.10	0.09	0.07	0.10	0.08	0.08	0.08	1.04		
0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	1.02		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25.1		

Table 22: EH1- Pair-wise matrix & priority scores for Environmental Statutory Compliance

EH1 -Env. Statutory Compliance	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structi	Structi	Roofing
Recycled crushed concrete block	1	1	1	7	7	1	2	7	1	1	3	1	0.5	0.5	2	2	7	2	2	2	2	2	7	0.5
Compressed Stabilized Rammed Earth blocks	1	1	1	7	7	1	2	7	1	1	3	1	0.5	0.5	2	2	7	2	2	2	2	2	7	0.5
Aerated concrete or "aircrete" block	1	1	1	7	7	1	2	7	1	1	3	1	0.5	0.5	2	2	7	2	2	2	2	2	7	0.5
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	0.1	0.1	0.1	1	1	0.1	0.2	1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.2	1	0.2	0.2	0.2	0.2	0.2	1	0.1
Clay Products- Unfired Bricks	0.1	0.1	0.1	1	1	0.1	0.2	1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.2	1	0.2	0.2	0.2	0.2	0.17	1	0.13
Aerated concrete or "aircrete" block	1	1	1	7	7	1	2	7	1	1	3	1	0.5	0.5	2	2	7	2	2	2	2	2	7	0.5
Reclaimed/Recycled laminated Wood Flooring and Panelling	0.5	0.5	0.5	6	6	0.5	1	6	0.5	0.5	2	0.5	0.3	0.3	1	1	6	1	1	1	1	1	6	0.33
Bamboo XL laminated Split Paneled Flooring	0.1	0.1	0.1	1	1	0.1	0.2	1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.2	1	0.2	0.2	0.2	0.2	0.17	1	0.13
Fly Ash Cement concrete Floor slab	1	1	1	7	7	1	2	7	1	1	3	1	0.5	0.5	2	2	7	2	2	2	2	2	7	0.5
Recycled Porocom Pebble Stone Pavers	1	1	1	7	7	1	2	7	1	1	3	1	0.5	0.5	2	2	7	2	2	2	2	2	7	0.5
Fly Ash Sand Lime interlocking Paving Bricks/Block	0.3	0.3	0.3	5	5	0.3	0.5	5	0.3	0.3	1	0.3	0.3	0.3	0.5	0.5	5	0.5	0.5	0.5	0.5	0.5	5	0.25
Concrete Pavers	1	1	1	7	7	1	2	7	1	1	3	1	0.5	0.5	2	2	7	2	2	2	2	2	7	0.5
Recycled timber clad Aluminium framed window unit	2	2	2	8	8	2	3	8	2	2	4	2	1	1	3	3	8	3	3	3	3	3	8	1
Four panel hardwood door finished with Alpilignum.	2	2	2	8	8	2	3	8	2	2	4	2	1	1	3	3	8	3	3	3	3	3	8	1
Stainless Steel Entry Door.	0.5	0.5	0.5	6	6	0.5	1	6	0.5	0.5	2	0.5	0.33	0.33	1	1	6	1	1	1	1	1	6	0.3
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.5	0.5	0.5	6	6	0.5	1	6	0.5	0.5	2	0.5	0.3	0.3	1	1	6	1	1	1	1	1	6	0.3
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	0.1	0.1	0.1	1	1	0.1	0.2	1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.2	1	0.2	0.2	0.2	0.2	0.2	1	0.1
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.5	0.5	0.5	6	6	0.5	1	6	0.5	0.5	2	0.5	0.3	0.3	1	1	6	1	1	1	1	1	6	0.3
Recycled Scrap steel bolted sections	0.5	0.5	0.5	6	6	0.5	1	6	0.5	0.5	2	0.5	0.3	0.3	1	1	6	1	1	1	1	1	6	0.33
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.5	0.5	0.5	6	6	0.5	1	6	0.5	0.5	2	0.5	0.3	0.3	1	1	6	1	1	1	1	1	6	0.33
Steel Column UC	0.5	0.5	0.5	6	6	0.5	1	6	0.5	0.5	2	0.5	0.3	0.3	1	1	6	1	1	1	1	1	6	0.33
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.5	0.5	0.5	6	6	0.5	1	6	0.5	0.5	2	0.5	0.3	0.3	1	1	6	1	1	1	1	1	6	0.33
Structurally insulated natural slate (temperate EN 636-2) decking each side]	0.1	0.1	0.1	1	1	0.1	0.2	1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.2	1	0.2	0.2	0.2	0.2	0.17	1	0.13
Roofing underlay concrete interlocking tiles	2	2	2	8	8	2	3	8	2	2	4	2	1	1	3	3	8	3	3	3	3	3	8	1
Total	18.0	18.0	18.0	131	131	18.0	32.3	131	18.0	18.0	51	18.0	10.0	10.0	32.3	32.3	131	32.3	32.3	32.3	32.3	32.3	131	10.0

Table 23: EH1- Normalised matrices for Environmental Statutory Compliance

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainl	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Structu	Structu	Roofing unde	Average	Lambda Max	CI	0.03
0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.06	1.02	RI	1.70
0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.06	1.02	CR	0.01
0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.06	1.02		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.96		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.96		
0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.06	1.02		
0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	1.09		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.96		
0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.06	1.02		
0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.06	1.02		
0.02	0.02	0.02	0.04	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	1.14		
0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.06	1.02		
0.11	0.11	0.11	0.06	0.06	0.11	0.09	0.06	0.11	0.11	0.08	0.11	0.10	0.10	0.09	0.09	0.06	0.09	0.09	0.09	0.09	0.09	0.06	0.10	0.09	0.92		
0.11	0.11	0.11	0.06	0.06	0.11	0.09	0.06	0.11	0.11	0.08	0.11	0.10	0.10	0.09	0.09	0.06	0.09	0.09	0.09	0.09	0.09	0.06	0.10	0.09	0.92		
0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	1.09		
0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	1.09		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.96		
0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	1.09		
0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	1.09		
0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	1.09		
0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	1.09		
0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	1.09		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.96		
0.11	0.11	0.11	0.06	0.06	0.11	0.09	0.06	0.11	0.11	0.08	0.11	0.10	0.10	0.09	0.09	0.06	0.09	0.09	0.09	0.09	0.09	0.06	0.10	0.09	0.92		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.6		

Table 24: EH2- Pair-wise matrix & priority scores for Embodied CO2 Emission

EH2-Embodied C02 Emission (KgC02/m2)	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainl	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing
Recycled crushed concrete block	1	0.5	3	3	0.5	3	4	0.5	2	0.3	0.5	1	4	4	7	1	0.5	3	5	4	5	4	0.5	4
Compressed Stabilized Rammed Earth blocks	2	1	4	4	1	4	5	1	3	0.5	1	2	5	5	8	2	1	4	6	5	6	5	1	5
Aerated concrete or "aircrete" block	0.3	0.3	1	1	0.3	1	2	0.3	0.5	0.2	0.3	0.3	2	2	5	0.3	0.3	1	3	2	3	2	0.3	2
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	0.3	0.3	1	1	0.3	1	2	0.3	0.5	0.2	0.3	0.3	2	2	5	0.3	0.3	1	3	2	3	2	0.3	2
Clay Products- Unfired Bricks	2	1	4	4	1	4	5	1	3	0.5	1	2	5	5	8	2	1	4	6	5	6	5	1	5
Aerated concrete or "aircrete" block	0.3	0.3	1	1	0.3	1	2	0.3	0.5	0.2	0.3	0.3	2	2	5	0.3	0.3	1	3	2	3	2	0.3	2
Reclaimed/Recycled laminated Wood Flooring and Panelling	0.3	0.2	0.5	0.5	0.2	0.5	1	0.2	0.3	0.2	0.2	0.3	1	1	4	0.3	0.2	0.5	2	1	2	1	0.2	1
Bamboo XL laminated Split Paneled Flooring	2	1	4	4	1	4	5	1	3	0.5	1	2	5	5	8	2	1	4	6	5	6	5	1	5
Fly Ash Cement concrete Floor slab	0.5	0.3	2	2	0.3	2	3	0.3	1	0.3	0.3	0.5	3	3	6	0.5	0.3	2	4	3	4	3	0.3	3
Recycled Porocom Pebble Stone Pavers	3	2	5	5	2	5	6	2	4	1	2	3	6	6	9	3	2	5	7	6	7	6	2	6
Fly Ash Sand Lime interlocking Paving Bricks/Block	2	1	4	4	1	4	5	1	3	0.5	1	2	5	5	8	2	1	4	6	5	6	5	1	5
Concrete Pavers	1	0.5	3	3	0.5	3	4	0.5	2	0.3	0.5	1	4	4	7	1	0.5	3	5	4	5	4	0.5	4
Recycled timber clad Aluminium framed window unit	0.3	0.2	0.5	0.5	0.2	0.5	1	0.2	0.3	0.2	0.2	0.3	1	1	4	0.3	0.2	0.5	2	1	2	1	0.2	1
Four panel hardwood door finished with Alpilignum.	0.3	0.2	0.5	0.5	0.2	0.5	1	0.2	0.3	0.2	0.2	0.25	1	1	4	0.25	0.2	0.5	2	1	2	1	0.2	1
Stainless Steel Entry Door.	0.1	0.1	0.2	0.2	0.1	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.3	0.3	1	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.1	0.3
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	1	0.5	3	3	0.5	3	4	0.5	2	0.3	0.5	1	4	4	7	1	0.5	3	5	4	5	4	0.5	4
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	2	1	4	4	1	4	5	1	3	0.5	1	2	5	5	8	2	1	4	6	5	6	5	1	5
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.3	0.3	1	1	0.3	1	2	0.3	0.5	0.2	0.3	0.3	2	2	5	0.3	0.3	1	3	2	3	2	0.3	2
Recycled Scrap steel bolted sections	0.2	0.2	0.3	0.3	0.2	0.3	0.5	0.2	0.3	0.1	0.2	0.2	0.5	0.5	3	0.2	0.2	0.3	1	0.5	1	0.5	0.2	0.5
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.3	0.2	0.5	0.5	0.2	0.5	1	0.2	0.3	0.2	0.2	0.3	1	1	4	0.3	0.2	0.5	2	1	2	1	0.2	1
Steel Column UC	0.2	0.2	0.3	0.3	0.2	0.3	0.5	0.2	0.3	0.1	0.2	0.2	0.5	0.5	3	0.2	0.2	0.3	1	0.5	1	0.5	0.2	0.5
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.3	0.2	0.5	0.5	0.2	0.5	1	0.2	0.3	0.2	0.2	0.3	1	1	4	0.3	0.2	0.5	2	1	2	1	0.2	1
Structurally insulated natural slate (temperate EN 636-2) decking each side]	2	1	4	4	1	4	5	1	3	0.5	1	2	5	5	8	2	1	4	6	5	6	5	1	5
Roofing underlay concrete interlocking tiles	0.3	0.2	0.5	0.5	0.2	0.5	1	0.2	0.3	0.2	0.2	0.3	1	1	4	0.3	0.2	0.5	2	1	2	1	0.2	1
Total	21.9	12.5	47.9	47.9	12.5	47.9	66.3	12.5	33.7	7.4	12.5	21.9	66.3	66.3	135	21.9	12.5	47.9	88.3	66.3	88.3	66.3	12.5	66.3

Table 25: EH2- Normalised matrices for Embodied CO2 Emission

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainl	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.04
0.05	0.04	0.06	0.06	0.04	0.06	0.06	0.04	0.06	0.04	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.06	0.06	0.06	0.06	0.06	0.04	0.06	0.05	1.15	RI	1.70
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99	CR	0.02
0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.02	1.15		
0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.02	1.15		
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99		
0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.02	1.15		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99		
0.02	0.03	0.04	0.04	0.03	0.04	0.05	0.03	0.03	0.03	0.03	0.02	0.05	0.05	0.04	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.03	0.05	0.04	1.21		
0.14	0.16	0.10	0.10	0.16	0.10	0.09	0.16	0.12	0.13	0.16	0.14	0.09	0.09	0.07	0.14	0.16	0.10	0.08	0.09	0.08	0.09	0.16	0.09	0.12	0.87		
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99		
0.05	0.04	0.06	0.06	0.04	0.06	0.06	0.04	0.06	0.04	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.06	0.06	0.06	0.06	0.06	0.04	0.06	0.05	1.15		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.87		
0.05	0.04	0.06	0.06	0.04	0.06	0.06	0.04	0.06	0.04	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.06	0.06	0.06	0.06	0.06	0.04	0.06	0.05	1.15		
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99		
0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.02	1.15		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.93		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.93		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.9		

Table 26: C1- Pair-wise matrix & priority scores for Total Life-Cycle Cost

C1- Total life-cycle cost ($)	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing
Recycled crushed concrete block	1	1	0.5	1	0.5	0.5	3	0.5	1	6	2	2	7	8	7	7	8	8	6	8	7	7	7	1
Compressed Stabilized Rammed Earth blocks	1	1	0.5	1	0.5	0.5	3	0.5	1	6	2	2	7	8	7	7	8	8	6	8	7	7	7	1
Aerated concrete or "aircrete" block	2	2	1	2	1	1	4	1	2	7	3	3	8	9	8	8	9	9	7	9	8	8	8	2
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	1	1	0.5	1	0.5	0.5	3	0.5	1	6	2	2	7	8	7	7	8	8	6	8	7	7	7	1
Clay Products- Unfired Bricks	2	2	1	2	1	1	4	1	2	7	3	3	8	9	8	8	9	9	7	9	8	8	8	2
Aerated concrete or "aircrete" block	2	2	1	2	1	1	4	1	2	7	3	3	8	9	8	8	9	9	7	9	8	8	8	2
Reclaimed/Recycled laminated Wood Flooring and Panelling	0.3	0.3	0.3	0.3	0.3	0.3	1	0.3	0.3	4	0.5	0.5	5	6	5	5	6	6	4	6	5	5	5	0.3
Bamboo XL laminated Split Paneled Flooring	2	2	1	2	1	1	4	1	2	7	3	3	8	9	8	8	9	9	7	9	8	8	8	2
Fly Ash Cement concrete Floor slab	1	1	0.5	1	0.5	0.5	3	0.5	1	6	2	2	7	8	7	7	8	8	6	8	7	7	7	1
Recycled Porocom Pebble Stone Pavers	0.2	0.2	0.1	0.2	0.1	0.1	0.3	0.1	0.2	1	0.2	0.2	2	3	2	2	3	3	1	3	2	2	2	0.17
Fly Ash Sand Lime interlocking Paving Bricks/Block	0.5	0.5	0.3	0.5	0.3	0.3	2	0.3	0.5	5	1	1	6	7	6	6	7	7	5	7	6	6	6	0.5
Concrete Pavers	0.5	0.5	0.3	0.5	0.3	0.3	2	0.3	0.5	5	1	1	6	7	6	6	7	7	5	7	6	6	6	0.5
Recycled timber clad Aluminium framed window unit	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.14
Four panel hardwood door finished with Alpilignum.	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1	0.5	1	0.5	0.5	1	1	0.3	1	0.5	0.5	0.5	0.13
Stainless Steel Entry Door.	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.14
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.14
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1	0.5	1	0.5	0.5	1	1	0.3	1	0.5	0.5	0.5	0.13
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1	0.5	1	0.5	0.5	1	1	0.3	1	0.5	0.5	0.5	0.1
Recycled Scrap steel bolted sections	0.2	0.2	0.1	0.2	0.1	0.1	0.3	0.1	0.2	1	0.2	0.2	2	3	2	2	3	3	1	3	2	2	2	0.2
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1	0.5	1	0.5	0.5	1	1	0.3	1	0.5	0.5	0.5	0.1
Steel Column UC	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.1
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.1
Structurally insulated natural slate (temperate EN 636-2) decking each side]	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.14
Roofing underlay concrete interlocking tiles	1	1	0.5	1	0.5	0.5	3	0.5	1	6	2	2	7	8	7	7	8	8	6	8	7	7	7	1
Total	16.0	16.0	8.9	16.0	8.9	8.9	38.4	8.9	16.0	78.3	26.5	26.5	96	118	96	96	118	118	78.3	118	96	96	96	16.0

Table 27: C1- Normalised matrices for Total Life-Cycle Cost

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.06
0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06	0.07	1.09	RI	1.70
0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06	0.07	1.09	CR	0.03
0.12	0.12	0.11	0.12	0.11	0.11	0.10	0.11	0.12	0.09	0.11	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.12	0.10	0.89		
0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06	0.07	1.09		
0.12	0.12	0.11	0.12	0.11	0.11	0.10	0.11	0.12	0.09	0.11	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.12	0.10	0.89		
0.12	0.12	0.11	0.12	0.11	0.11	0.10	0.11	0.12	0.09	0.11	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.12	0.10	0.89		
0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.02	0.05	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.04	1.44		
0.12	0.12	0.11	0.12	0.11	0.11	0.10	0.11	0.12	0.09	0.11	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.12	0.10	0.89		
0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06	0.07	1.09		
0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.02	0.02	0.03	0.03	0.01	0.03	0.02	0.02	0.02	0.01	0.02	1.27		
0.03	0.03	0.04	0.03	0.04	0.04	0.05	0.04	0.03	0.06	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.05	1.29		
0.03	0.03	0.04	0.03	0.04	0.04	0.05	0.04	0.03	0.06	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.05	1.29		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.87		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.87		
0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.87		
0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.02	0.02	0.03	0.03	0.01	0.03	0.02	0.02	0.02	0.01	0.02	1.27		
0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.87		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06	0.07	1.09		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25.3		

Table 28: C2- Pair-wise matrix & priority scores for Material Embodied Energy Cost

C2- Material embodied energy cost ($)	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing
Recycled crushed concrete block	1	0.3	2	1	0.3	2	0.5	0.3	1	1	0.3	1	2	0.3	7	2	0.3	3	5	0.5	5	3	1	2
Compressed Stabilized Rammed Earth blocks	3	1	4	3	1	4	2	1	3	3	1	3	4	1	9	4	1	5	7	2	7	5	3	4
Aerated concrete or "aircrete" block	0.5	0.3	1	0.5	0.3	1	0.3	0.3	0.5	0.5	0.3	0.5	1	0.3	6	1	0.3	2	4	0.3	4	2	0.5	1
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	1	0.3	2	1	0.3	2	0.5	0.3	1	1	0.3	1	2	0.33	7	2	0.33	3	5	0.5	5	3	1	2
Clay Products- Unfired Bricks	3	1	4	3	1	4	2	1	3	3	1	3	4	1	9	4	1	5	7	2	7	5	3	4
Aerated concrete or "aircrete" block	0.5	0.3	1	0.5	0.3	1	0.3	0.3	0.5	0.5	0.3	0.5	1	0.3	6	1	0.3	2	4	0.3	4	2	0.5	1
Reclaimed/Recycled laminated Wood Flooring and Panelling	2	0.5	3	2	0.5	3	1	0.5	2	2	0.5	2	3	0.5	8	3	0.5	4	6	1	6	4	2	3
Bamboo XL laminated Split Paneled Flooring	3	1	4	3	1	4	2	1	3	3	1	3	4	1	9	4	1	5	7	2	7	5	3	4
Fly Ash Cement concrete Floor slab	1	0.3	2	1	0.3	2	0.5	0.3	1	1	0.3	1	2	0.3	7	2	0.3	3	5	0.5	5	3	1	2
Recycled Porocom Pebble Stone Pavers	1	0.3	2	1	0.3	2	0.5	0.3	1	1	0.3	1	2	0.3	7	2	0.3	3	5	0.5	5	3	1	2
Fly Ash Sand Lime interlocking Paving Bricks/Block	3	1	4	3	1	4	2	1	3	3	1	3	4	1	9	4	1	5	7	2	7	5	3	4
Concrete Pavers	1	0.3	2	1	0.3	2	0.5	0.3	1	1	0.3	1	2	0.3	7	2	0.3	3	5	0.5	5	3	1	2
Recycled timber clad Aluminium framed window unit	0.5	0.3	1	0.5	0.3	1	0.3	0.3	0.5	0.5	0.3	0.5	1	0.3	6	1	0.3	2	4	0.3	4	2	0.5	1
Four panel hardwood door finished with Alpilignum.	3	1	4	3	1	4	2	1	3	3	1	3	4	1	9	4	1	5	7	2	7	5	3	4
Stainless Steel Entry Door.	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	1	0.2	0.1	0.2	0.3	0.1	0.3	0.2	0.1	0.17
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.5	0.3	1	0.5	0.3	1	0.3	0.3	0.5	0.5	0.3	0.5	1	0.3	6	1	0.3	2	4	0.3	4	2	0.5	1
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	3	1	4	3	1	4	2	1	3	3	1	3	4	1	9	4	1	5	7	2	7	5	3	4
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.3	0.2	0.5	0.3	0.2	0.5	0.3	0.2	0.3	0.3	0.2	0.33	0.5	0.2	5	0.5	0.2	1	3	0.25	3	1	0.3	0.5
Recycled Scrap steel bolted sections	0.2	0.1	0.3	0.2	0.1	0.3	0.2	0.1	0.2	0.2	0.1	0.2	0.3	0.1	3	0.3	0.1	0.3	1	0.2	1	0.3	0.2	0.3
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	2	0.5	3	2	0.5	3	1	0.5	2	2	0.5	2	3	0.5	8	3	0.5	4	6	1	6	4	2	3
Steel Column UC	0.2	0.1	0.3	0.2	0.1	0.3	0.2	0.1	0.2	0.2	0.1	0.2	0.3	0.1	3	0.3	0.1	0.3	1	0.2	1	0.3	0.2	0.3
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.3	0.2	0.5	0.3	0.2	0.5	0.3	0.2	0.3	0.3	0.2	0.3	0.5	0.2	5	0.5	0.2	1	3	0.3	3	1	0.3	0.5
Structurally insulated natural slate (temperate EN 636-2) decking each side]	1	0.3	2	1	0.3	2	0.5	0.3	1	1	0.3	1	2	0.3	7	2	0.3	3	5	0.5	5	3	1	2
Roofing underlay concrete interlocking tiles	0.5	0.3	1	0.5	0.3	1	0.3	0.3	0.5	0.5	0.3	0.5	1	0.3	6	1	0.3	2	4	0.3	4	2	0.5	1
Total	31.7	11.0	48.7	31.7	11.0	48.7	19.6	11.0	31.7	31.7	11.0	31.7	48.7	11.0	159	48.7	11.0	68.9	112.3	19.6	112.3	68.9	31.7	48.7

Table 29: C2- Normalised matrices for Material Embodied Energy Cost

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.04
0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	1.12	RI	1.70
0.09	0.09	0.08	0.09	0.09	0.08	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.06	0.08	0.09	0.07	0.06	0.10	0.06	0.07	0.09	0.08	0.09	0.94	CR	0.02
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.03	0.04	0.02	0.04	0.03	0.02	0.02	0.02	1.08		
0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	1.12		
0.09	0.09	0.08	0.09	0.09	0.08	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.06	0.08	0.09	0.07	0.06	0.10	0.06	0.07	0.09	0.08	0.09	0.94		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.03	0.04	0.02	0.04	0.03	0.02	0.02	0.02	1.08		
0.06	0.05	0.06	0.06	0.05	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.06	0.06	0.06	1.09		
0.09	0.09	0.08	0.09	0.09	0.08	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.06	0.08	0.09	0.07	0.06	0.10	0.06	0.07	0.09	0.08	0.09	0.94		
0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	1.12		
0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	1.12		
0.09	0.09	0.08	0.09	0.09	0.08	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.06	0.08	0.09	0.07	0.06	0.10	0.06	0.07	0.09	0.08	0.09	0.94		
0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	1.12		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.03	0.04	0.02	0.04	0.03	0.02	0.02	0.02	1.08		
0.09	0.09	0.08	0.09	0.09	0.08	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.06	0.08	0.09	0.07	0.06	0.10	0.06	0.07	0.09	0.08	0.09	0.94		
0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.90		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.03	0.04	0.02	0.04	0.03	0.02	0.02	0.02	1.08		
0.09	0.09	0.08	0.09	0.09	0.08	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.06	0.08	0.09	0.07	0.06	0.10	0.06	0.07	0.09	0.08	0.09	0.94		
0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.03	0.01	0.02	0.01	0.03	0.01	0.03	0.01	0.01	0.01	0.02	1.04		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.96		
0.06	0.05	0.06	0.06	0.05	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.06	0.06	0.06	1.09		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.96		
0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.03	0.01	0.02	0.01	0.03	0.01	0.03	0.01	0.01	0.01	0.02	1.04		
0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04	1.12		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.03	0.04	0.02	0.04	0.03	0.02	0.02	0.02	1.08		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.9		

Table 30: SC1- Pair-wise matrix & priority scores for Material Compatibility with Traditions

SC1- Material compatibility with traditions	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing
Recycled crushed concrete block	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Compressed Stabilized Rammed Earth blocks	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Aerated concrete or "aircrete" block	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	0.3	0.3	0.3	1	0.3	0.3	1	0.3	3	0.3	0.3	3	0.3	0.3	3	1	0.3	1	1	0.3	0.3	1	0.3	3
Clay Products- Unfired Bricks	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Aerated concrete or "aircrete" block	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Reclaimed/Recycled laminated Wood Flooring and Panelling	0.3	0.3	0.3	1	0.3	0.3	1	0.3	3	0.3	0.3	3	0.3	0.3	3	1	0.3	1	1	0.3	0.3	1	0.3	3
Bamboo XL laminated Split Paneled Flooring	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Fly Ash Cement concrete Floor slab	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.2	1	0.2	0.2	1	0.2	0.2	1	0.3	0.2	0.3	0.3	0.2	0.2	0.33	0.2	1
Recycled Porocom Pebble Stone Pavers	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Fly Ash Sand Lime interlocking Paving Bricks/Block	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Concrete Pavers	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.2	1	0.2	0.2	1	0.2	0.2	1	0.3	0.2	0.3	0.3	0.2	0.2	0.3	0.2	1
Recycled timber clad Aluminium framed window unit	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Four panel hardwood door finished with Alpilignum.	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Stainless Steel Entry Door.	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.2	1	0.2	0.2	1	0.2	0.2	1	0.3	0.2	0.3	0.3	0.2	0.2	0.3	0.2	1
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.3	0.3	0.3	1	0.3	0.3	1	0.3	3	0.3	0.3	3	0.3	0.3	3	1	0.3	1	1	0.3	0.3	1	0.3	3
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.3	0.3	0.3	1	0.3	0.3	1	0.3	3	0.3	0.3	3	0.3	0.3	3	1	0.3	1	1	0.3	0.3	1	0.3	3
Recycled Scrap steel bolted sections	0.3	0.3	0.3	1	0.3	0.3	1	0.3	3	0.3	0.3	3	0.3	0.3	3	1	0.3	1	1	0.3	0.3	1	0.3	3
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Steel Column UC	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.3	0.3	0.3	1	0.3	0.3	1	0.3	3	0.3	0.3	3	0.3	0.3	3	1	0.3	1	1	0.3	0.3	1	0.3	3
Structurally insulated natural slate (temperate EN 636-2) decking each side]	1	1	1	3	1	1	3	1	5	1	1	5	1	1	5	3	1	3	3	1	1	3	1	5
Roofing underlay concrete interlocking tiles	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.2	1	0.2	0.2	1	0.2	0.2	1	0.3	0.2	0.3	0.3	0.2	0.2	0.33	0.2	1
Total	16.8	16.8	16.8	49.3	16.8	16.8	49.3	16.8	92	16.8	16.8	92	16.8	16.8	92	49.3	16.8	49.3	49.3	16.8	16.8	49.3	16.8	92

Table 31: SC1- Normalised matrices for Material Compatibility with Traditions

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.01
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99	RI	1.70
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99	CR	0.01
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	1.09		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	1.09		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.96		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.96		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.96		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	1.09		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	1.09		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	1.09		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	1.09		
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.99		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.96		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.3		

Table 32: Pair-wise matrix & priority scores for SC3-Cultural Restriction on Usury

SC3- Cultural restriction on usury	Recycl	Compi	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Asl	Recycl	Fly Asl	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Struct	Struct	Roofing
Recycled crushed concrete block	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Compressed Stabilized Rammed Earth blocks	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Aerated concrete or "aircrete" block	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Clay Products- Unfired Bricks	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Aerated concrete or "aircrete" block	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Reclaimed/Recycled laminated Wood Flooring and Panelling	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Bamboo XL laminated Split Paneled Flooring	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Fly Ash Cement concrete Floor slab	5	7	5	5	7	5	7	7	1	5	7	1	5	5	3	7	7	5	7	7	1	7	7	5
Recycled Porocom Pebble Stone Pavers	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Fly Ash Sand Lime interlocking Paving Bricks/Block	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.14	0.33	0.33	0.2	1	1	0.33	1	1	0.1	1	1	0.3
Concrete Pavers	5	7	5	5	7	5	7	7	1	5	7	1	5	5	3	7	7	5	7	7	1	7	7	5
Recycled timber clad Aluminium framed window unit	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Four panel hardwood door finished with Alpilignum.	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Stainless Steel Entry Door.	3	5	3	3	5	3	5	5	0.3	3	5	0.3	3	3	1	5	5	3	5	5	0.3	5	5	3
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Recycled Scrap steel bolted sections	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Steel Column UC	5	7	5	5	7	5	7	7	1	5	7	1	5	5	3	7	7	5	7	7	1	7	7	5
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Structurally insulated natural slate (temperate EN 636-2) decking each side]	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Roofing underlay concrete interlocking tiles	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Total	30.7	64	30.7	30.7	64	30.7	64	64	6.7	30.7	64	6.7	30.7	30.7	15.2	64	64	30.7	64	64	6.7	64	64	30.7

Table 33: Normalised matrices for SC3-Cultural Restriction on Usury

Recycl	Compi	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Asl	Recycl	Fly Asl	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.03
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18	RI	1.70
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92	CR	0.02
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.16	0.11	0.16	0.16	0.11	0.16	0.11	0.11	0.15	0.16	0.11	0.15	0.16	0.16	0.20	0.11	0.11	0.16	0.11	0.11	0.15	0.11	0.11	0.16	0.14	0.93		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.16	0.11	0.16	0.16	0.11	0.16	0.11	0.11	0.15	0.16	0.11	0.15	0.16	0.16	0.20	0.11	0.11	0.16	0.11	0.11	0.15	0.11	0.11	0.16	0.14	0.93		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.10	0.08	0.10	0.10	0.08	0.10	0.08	0.08	0.05	0.10	0.08	0.05	0.10	0.10	0.07	0.08	0.08	0.10	0.08	0.08	0.05	0.08	0.08	0.10	0.08	1.24		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.16	0.11	0.16	0.16	0.11	0.16	0.11	0.11	0.15	0.16	0.11	0.15	0.16	0.16	0.20	0.11	0.11	0.16	0.11	0.11	0.15	0.11	0.11	0.16	0.14	0.93		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
1	1	1	1	1	1	1	1	1.00	1	1	1.00	1	1	1	1	1	1	1	1	1.00	1	1	1	1	24.8		

Table 34: T1- Pair-wise matrix & priority scores for Recyclability/Reusability

T1- Renewable/Recyclable/Reusable	Recycl	Compi	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Asl	Recycl	Fly Asl	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Struct	Struct	Roofing
Recycled crushed concrete block	1	1	1	1	2	1	2	3	1	2	2	1	2	3	3	2	3	2	2	3	1	2	3	1
Compressed Stabilized Rammed Earth blocks	1	1	1	1	2	1	2	3	1	2	2	1	2	3	3	2	3	2	2	3	1	2	3	1
Aerated concrete or "aircrete" block	1	1	1	1	2	1	2	3	1	2	2	1	2	3	3	2	3	2	2	3	1	2	3	1
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	1	1	1	1	2	1	2	3	1	2	2	1	2	3	3	2	3	2	2	3	1	2	3	1
Clay Products- Unfired Bricks	0.5	0.5	0.5	0.5	1	0.5	1	2	0.5	1	1	0.5	1	2	2	1	2	1	1	2	0.5	1	2	0.5
Aerated concrete or "aircrete" block	1	1	1	1	2	1	2	3	1	2	2	1	2	3	3	2	3	2	2	3	1	2	3	1
Reclaimed/Recycled laminated Wood Flooring and Panelling	0.5	0.5	0.5	0.5	1	0.5	1	2	0.5	1	1	0.5	1	2	2	1	2	1	1	2	0.5	1	2	0.5
Bamboo XL laminated Split Paneled Flooring	0.3	0.3	0.3	0.3	0.5	0.3	0.5	1	0.3	0.5	0.5	0.3	0.5	1	1	0.5	1	0.5	0.5	1	0.3	0.5	1	0.3
Fly Ash Cement concrete Floor slab	1	1	1	1	2	1	2	3	1	2	2	1	2	3	3	2	3	2	2	3	1	2	3	1
Recycled Porocom Pebble Stone Pavers	0.5	0.5	0.5	0.5	1	0.5	1	2	0.5	1	1	0.5	1	2	2	1	2	1	1	2	0.5	1	2	0.5
Fly Ash Sand Lime interlocking Paving Bricks/Block	0.5	0.5	0.5	0.5	1	0.5	1	2	0.5	1	1	0.5	1	2	2	1	2	1	1	2	0.5	1	2	0.5
Concrete Pavers	1	1	1	1	2	1	2	3	1	2	2	1	2	3	3	2	3	2	2	3	1	2	3	1
Recycled timber clad Aluminium framed window unit	0.5	0.5	0.5	0.5	1	0.5	1	2	0.5	1	1	0.5	1	2	2	1	2	1	1	2	0.5	1	2	0.5
Four panel hardwood door finished with Alpilignum.	0.3	0.3	0.3	0.3	0.5	0.3	0.5	1	0.3	0.5	0.5	0.3	0.5	1	1	0.5	1	0.5	0.5	1	0.3	0.5	1	0.3
Stainless Steel Entry Door.	0.3	0.3	0.3	0.3	0.5	0.3	0.5	1	0.3	0.5	0.5	0.3	0.5	1	1	0.5	1	0.5	0.5	1	0.3	0.5	1	0.3
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.5	0.5	0.5	0.5	1	0.5	1	2	0.5	1	1	0.5	1	2	2	1	2	1	1	2	0.5	1	2	0.5
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	0.3	0.3	0.3	0.3	0.5	0.3	0.5	1	0.3	0.5	0.5	0.3	0.5	1	1	0.5	1	0.5	0.5	1	0.3	0.5	1	0.3
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.5	0.5	0.5	0.5	1	0.5	1	2	0.5	1	1	0.5	1	2	2	1	2	1	1	2	0.5	1	2	0.5
Recycled Scrap steel bolted sections	0.5	0.5	0.5	0.5	1	0.5	1	2	0.5	1	1	0.5	1	2	2	1	2	1	1	2	0.5	1	2	0.5
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.3	0.3	0.3	0.3	0.5	0.3	0.5	1	0.3	0.5	0.5	0.3	0.5	1	1	0.5	1	0.5	0.5	1	0.3	0.5	1	0.3
Steel Column UC	1	1	1	1	2	1	2	3	1	2	2	1	2	3	3	2	3	2	2	3	1	2	3	1
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.5	0.5	0.5	0.5	1	0.5	1	2	0.5	1	1	0.5	1	2	2	1	2	1	1	2	0.5	1	2	0.5
Structurally insulated natural slate (temperate EN 636-2) decking each side]	0.3	0.3	0.3	0.3	0.5	0.3	0.5	1	0.3	0.5	0.5	0.3	0.5	1	1	0.5	1	0.5	0.5	1	0.3	0.5	1	0.3
Roofing underlay concrete interlocking tiles	1	1	1	1	2	1	2	3	1	2	2	1	2	3	3	2	3	2	2	3	1	2	3	1
Total	15.5	15.5	15.5	15.5	30	15.5	30	51	15.5	30	30	15.5	30	51	51	30	51	30	30	51	15.5	30	51	15.5

Table 35: T1- Normalised matrices for Recyclability/Reusability

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel (	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.00
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.99	RI	1.70
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.99	CR	0.00
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.99		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.99		
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	1.03		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.99		
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	1.03		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.98		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.99		
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	1.03		
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	1.03		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.99		
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	1.03		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.98		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.98		
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	1.03		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.98		
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	1.03		
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	1.03		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.98		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.99		
0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	1.03		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.98		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.06	0.06	0.99		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.1		

Table 36: T2- Pair-wise matrix & priority scores for Ease to Remove/Reaffix/Replace

T2-Ease to remove/reaffix/replace	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel (	Struct	Struct	Roofing
Recycled crushed concrete block	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Compressed Stabilized Rammed Earth blocks	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Aerated concrete or "aircrete" block	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	0.3	0.3	0.3	1	0.2	0.3	0.1	0.1	0.3	0.2	0.2	0.3	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.1
Clay Products- Unfired Bricks	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Aerated concrete or "aircrete" block	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Reclaimed/Recycled laminated Wood Flooring and Panelling	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Bamboo XL laminated Split Paneled Flooring	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Fly Ash Cement concrete Floor slab	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Recycled Porocom Pebble Stone Pavers	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Fly Ash Sand Lime interlocking Paving Bricks/Block	4	4	4	6	2	4	0.5	0.5	4	2	1	4	0.5	0.5	2	0.5	0.5	2	2	0.5	2	0.5	0.5	0.5
Concrete Pavers	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Recycled timber clad Aluminium framed window unit	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Four panel hardwood door finished with Alpilignum.	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Stainless Steel Entry Door.	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Recycled Scrap steel bolted sections	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Steel Column UC	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Structurally insulated timber panel system with OSB/3 each side, roofing under	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Structurally insulated natural slate (temperate EN 636-2) decking each side]	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Roofing underlay concrete interlocking tiles	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Total	78.3	78.3	78.3	125	40.2	78.3	13.8	13.8	78.3	40.2	25.7	78.3	13.8	13.8	40.2	13.8	13.8	40.2	40.2	13.8	40.2	13.8	13.8	13.8

Table 37: T2- Normalised matrices for Ease to Remove/Reaffix/Replace

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel (	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.02
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99	RI	1.70
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99	CR	0.01
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99		
0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.90		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.04	1.13		
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.5		

Table 38: SN2- Pair-wise matrix & priority scores for Texture

SN2- Texture	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structu	Structu	Roofing
Recycled crushed concrete block	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.3	0.3	0.3
Compressed Stabilized Rammed Earth blocks	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Aerated concrete or "aircrete" block	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Clay Products- Unfired Bricks	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Aerated concrete or "aircrete" block	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Reclaimed/Recycled laminated Wood Flooring and Panelling	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Bamboo XL laminated Split Paneled Flooring	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Fly Ash Cement concrete Floor slab	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Recycled Porocom Pebble Stone Pavers	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.3	0.3	0.3
Fly Ash Sand Lime interlocking Paving Bricks/Block	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Concrete Pavers	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Recycled timber clad Aluminium framed window unit	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Four panel hardwood door finished with Alpilignum.	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Stainless Steel Entry Door.	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Recycled Scrap steel bolted sections	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Steel Column UC	2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1	0.3	0.3	0.3
Structurally insulated timber panel system with OSB/3 each side, roofing under	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Structurally insulated natural slate (temperate EN 636-2) decking each side]	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Roofing underlay concrete interlocking tiles	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	3	1	1	1
Total	88	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	88	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	65	21.8	21.8	21.8

Table 39: SN2- Normalised matrices for Texture

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structu	Structu	Roofing unde	Average	Lambda Max	CI	0.00
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99	RI	1.70
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00	CR	0.00
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.03		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	1.00		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.0		

Table 40: SN5- Pair-wise matrix & priority scores for Acoustics Performance

SN5- Acoustics Performance	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structu	Structu	Roofing
Recycled crushed concrete block	1	6	2	1	2	2	3	2	0.5	4	2	0.5	4	2	6	3	3	3	3	3	3	3	6	2
Compressed Stabilized Rammed Earth blocks	0.2	1	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.3	0.2	0.1	0.3	0.2	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1	0.2
Aerated concrete or "aircrete" block	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	1	6	2	1	2	2	3	2	0.5	4	2	0.5	4	2	6	3	3	3	3	3	3	3	6	2
Clay Products- Unfired Bricks	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Aerated concrete or "aircrete" block	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Reclaimed/Recycled laminated Wood Flooring and Panelling	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Bamboo XL laminated Split Paneled Flooring	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Fly Ash Cement concrete Floor slab	2	7	3	2	3	3	4	3	1	5	3	1	5	3	7	4	4	4	4	4	4	4	7	3
Recycled Porocom Pebble Stone Pavers	0.3	3	0.3	0.3	0.3	0.3	0.5	0.3	0.2	1	0.3	0.2	1	0.3	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	3	0.3
Fly Ash Sand Lime interlocking Paving Bricks/Block	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Concrete Pavers	2	7	3	2	3	3	4	3	1	5	3	1	5	3	7	4	4	4	4	4	4	4	7	3
Recycled timber clad Aluminium framed window unit	0.3	3	0.3	0.3	0.3	0.3	0.5	0.3	0.2	1	0.3	0.2	1	0.3	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	3	0.3
Four panel hardwood door finished with Alpilignum.	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Stainless Steel Entry Door.	0.2	1	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.3	0.2	0.1	0.3	0.2	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1	0.2
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Recycled Scrap steel bolted sections	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Steel Column UC	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Structurally insulated natural slate (temperate EN 636-2) decking each side]	0.2	1	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.3	0.2	0.1	0.3	0.2	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1	0.2
Roofing underlay concrete interlocking tiles	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Total	13.2	102	22.3	13.2	22.3	22.3	37.8	22.3	8.2	58	22.3	8.2	58	22.3	102	37.8	37.8	37.8	37.8	37.8	37.8	37.8	102	22.3

Table 41: SN5- Normalised matrices for Acoustics Performance

Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel (	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.02
0.08	0.06	0.09	0.08	0.09	0.09	0.08	0.09	0.06	0.07	0.09	0.06	0.07	0.09	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.06	0.09	0.08	1.02	RI	1.70
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.92	CR	0.01
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.08	0.06	0.09	0.08	0.09	0.09	0.08	0.09	0.06	0.07	0.09	0.06	0.07	0.09	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.06	0.09	0.08	1.02		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.15	0.07	0.13	0.15	0.13	0.13	0.11	0.13	0.12	0.09	0.13	0.12	0.09	0.13	0.07	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.07	0.13	0.11	0.92		
0.02	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.02	1.02		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.15	0.07	0.13	0.15	0.13	0.13	0.11	0.13	0.12	0.09	0.13	0.12	0.09	0.13	0.07	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.07	0.13	0.11	0.92		
0.02	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.02	1.02		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.92		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.92		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.5		

Step 6: Amalgamating the Results

- The final phase, after deriving the local priorities of the various floor material alternatives relative to each sub-factor was to calculate the overall priorities for the floor material alternatives.

- Once the normalised matrices of the floor material alternatives and various sub-factors were obtained, the values derived from the analysis were multiplied with the resultant value of the final weighting (3) in table 17. This means that the final weighting scores [3] (obtained from multiplying the local priorities vectors of the parent factor [1] with that of individual sub-factors [2] are multiplied by the priorities derived through pairwise comparisons of the material alternatives and each sub-factor.

- Afterwards, the priorities derived from multiplying the final weightings [3] with the priorities derived through pairwise comparisons of the material alternatives and each sub-factor were then summed to obtain the overall global composite priority weights of the material alternatives in the fourth level of the AHP model as shown in **Table 42**.

- This then yielded a single green utility index of alternative worth, which allowed the material options to be ranked according to their overall priorities, and the material with the highest score becoming the selected candidate material (see **Figures 7**).

Table 42: Green utility index scores of all selected material alternatives against the parent factors

GREEN UTILITY INDEX

Score	Rank	General/Sit	Environme	Economic/I	Socio-Cultu	Technical	Sensorial
0.037855	19	0.004952	0.004967	0.006239	0.006298	0.006712	0.008687
0.050647	1	0.01002	0.010753	0.009447	0.008751	0.006369	0.005307
0.035424	24	0.005088	0.004493	0.005597	0.006298	0.006455	0.007494
0.037318	21	0.005838	0.003893	0.007538	0.005068	0.007363	0.007618
0.043354	10	0.008787	0.004586	0.008016	0.008751	0.006874	0.00634
0.035424	24	0.005088	0.004493	0.005597	0.006298	0.006455	0.007494
0.041201	13	0.01019	0.005719	0.006945	0.004271	0.005931	0.008145
0.044375	5	0.006891	0.00446	0.010084	0.008751	0.007316	0.006873
0.04916	2	0.006587	0.012803	0.005178	0.009827	0.006262	0.008503
0.040657	14	0.005708	0.005561	0.008219	0.006298	0.008423	0.006448
0.044211	6	0.008625	0.004837	0.006645	0.008751	0.007442	0.00791
0.046499	3	0.005447	0.012644	0.004425	0.009827	0.006095	0.00806
0.038958	18	0.008574	0.006298	0.004235	0.006298	0.00554	0.008013
0.043709	8	0.005361	0.007747	0.007166	0.009547	0.0074	0.006488
0.039533	17	0.006993	0.006326	0.004439	0.00505	0.009014	0.007711
0.04013	16	0.007736	0.005737	0.009544	0.004271	0.006164	0.006677
0.043046	11	0.006891	0.00446	0.010982	0.008751	0.006418	0.005544
0.035779	22	0.007736	0.005264	0.006717	0.005068	0.004317	0.006677
0.04024	15	0.006765	0.005038	0.008766	0.004271	0.008133	0.007268
0.043747	7	0.006365	0.008738	0.007576	0.008751	0.006468	0.00585
0.042326	12	0.005086	0.009646	0.005143	0.007768	0.007906	0.006776
0.037496	20	0.009098	0.005304	0.003992	0.004271	0.009675	0.005156
0.045289	4	0.007052	0.007309	0.009361	0.008751	0.007471	0.005346
0.043622	9	0.005785	0.015593	0.004816	0.00468	0.006468	0.00628
1							

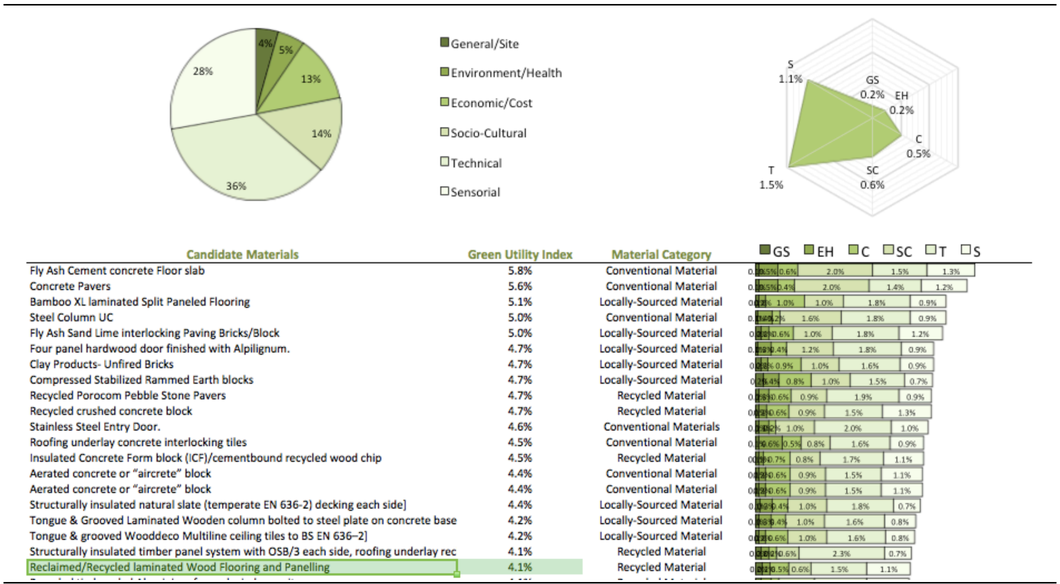


Figure 7. Charts showing ranked floor material alternatives and corresponding indices

The green utility index as calculated for the three material alternatives summed up as M(C) =0.058, M(A)= 0.051 and M(B)= 0.041 for material options C- concrete flooring, A-paneled flooring and B- laminated flooring respectively.

Looking at **Figures 7** and 8, Material option (A) turned out to be the most preferable material among the three materials, with an overall priority score of 0.058. The choice of Material (C) being the best option for the client was based on the concept of the higher the green utility index, the better the option.

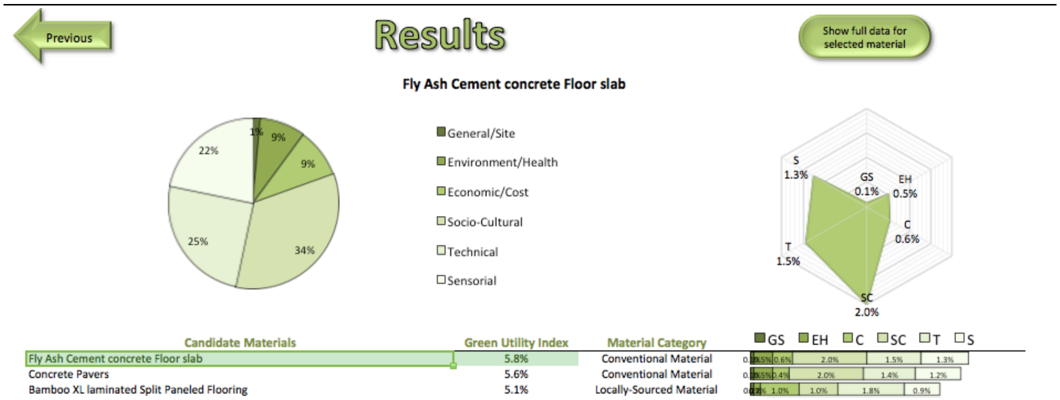


Figure 8. Charts showing details of the best material option selected after the analysis

Conclusion: From the illustrated example it can be deduced that the MSDSS model is able to provide rankings in low-cost green building material assessment combining site, economic, technical, social-cultural, sensorial and environmental criteria into a composite index system based on the AHP technique. This model is therefore, based on the presumption that decision makers, given full knowledge of all possible consequences of all possible alternatives, will select the alternative with the highest-ranking score.

The following section discusses the findings that emerged from the model evaluation exercise.

System Evaluation: Results from the Surveyed Questionnaire

After the evaluation of the MSDSS model, an online semi-structured survey questionnaire (which can be found in **Appendix J**) was deployed to receive final feedbacks from the practitioners who had engaged in the expert evaluation exercise. The final survey invited 10 knowledgeable participants to comment on what should be done to increase the integration of the MSDSS tool in housing design practice, and other matters of importance that ought to have been considered in the development of the tool for further studies.

The following sections set out the analysis of the returned questionnaires, including a summary of the responses to the various questions in the questionnaire. The names of the participants were undisclosed to respect their anonymity.

Participants Profile

The online survey exercise was conducted by 10 leading design and building professionals, all of them holding specific positions in the housing industry, and having high to very high experience in the specification of building products for housing projects. The selection of participants for the evaluation exercise was based on the proposed sampling methods in section 4.5.2.9 of chapter 4. Eight (8) respondents including; two (2) architects, three (3) material analysts, two (2) building engineers and one (1) research consultant, out of a total of ten (10) experts contacted, responded to the survey questionnaires. **Table 43** shows the profile of the participants.

Table 43. Profile of experts for the evaluation exercise

Position /Designation	Type of Organisation	Area of Expertise	Years of experience	No. of housing projects undertaken
1.Material Specifier and Program Designer	Building and construction firm	Material analyst	15	> 10
2. Researcher and Senior Building Construction Consultant	Building Research and development firm	Research and Development	27	> 20
3. Building Engineer	Housing construction firm	General practice	7	>10
4. Material Specifier	Architectural and construction firm	Material analyst on capital projects	23	>25
5. Project Architect and engineer	Housing construction firm	General practice	30	>12
6. Senior Architect and Chief designer	Architectural and sustainable design firms	Full architectural service	26	> 15
7. Senior Quantity Surveyor	Quantity surveying outfit	Material advice	35	>30
8. Architect and Builder	Lands and Housing Firm	General practice	17	>13

Structure of the Organisation

Analysis of the returned questionnaire showed that 90% of respondents work in residential housing and material specification firms. Of this lot, 10% work in the private sector while 80% work in public sector (e.g. government agency). Response from the public sector dominated the exercise as more design and building professionals are easily employed in the public sector than in the private sectors. Therefore, the views obtained through this survey tend to be more representative of respondents working in the public sector.

Result Analysis of Online Survey

In the first question, the participants were asked to express their views as to whether or not they see a potential of the MSDSS model in supporting informed decision making, to address the problems associated with sustainable material evaluation and selection of LCGBMCs. Some of the experts (50%) agreed that the MSDSS model has the capability of making a valuable contribution in the area of sustainable material selection and green building practices. One respondent noted; *"The MSDSS model addresses what is missing in the housing industry such as the need for more accessible data needed for evaluating a range of LCGBMCs. A clear decision-making method, opportunities for a software that can produce customizable reports, and the need for a better understanding of attributes considering the lifecycle and interdependency of material selection with other building systems"*. Another respondent stated; *"The system relates to issues concerned with local knowledge, local and recycled materials data, and local climate know-how, which are hardly considered in other systems: I think it shows great promise and the mechanics are very well developed and user-friendly"*.

However, others (50%) were unable to comment on the impacts of the model on decision-making in terms of material selection, as they felt that more conventional and green products would need to be included before they could comment on the capability of the model. The justification for the suggestion is understandable even though it was mentioned prior to the survey that the purpose of this study was to develop a scalable prototype version to demonstrate the proposed selection methodology for assessing LCGBMCs, as opposed to developing fully equipped commercial software. The overall impression perhaps suggests that practitioners would regard the model as a very useful tool for sustainable material selection in the Nigerian housing industry, should it be commercialised.

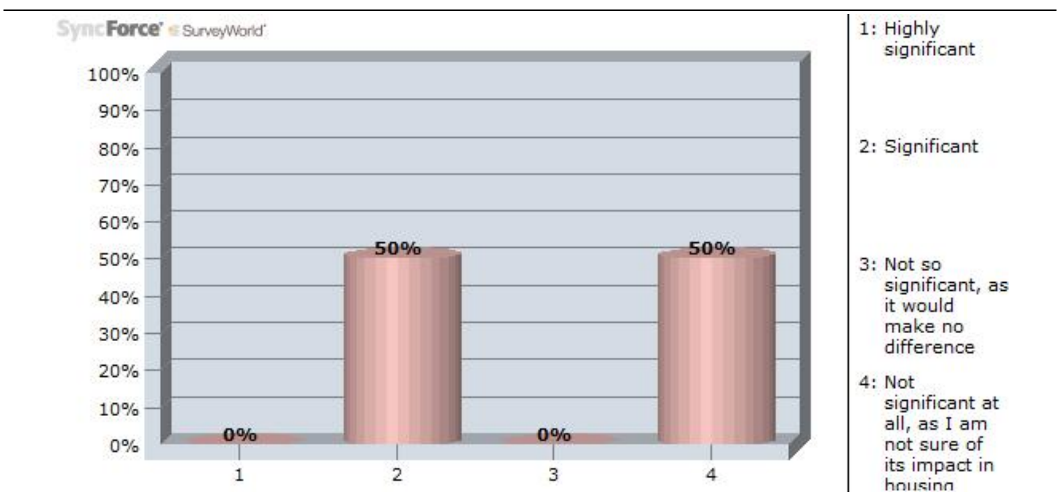


Figure 9. Illustration of the percentage of the potential of the MSDSS model to support sustainable material selection based on practitioners' perception

In another question, the participants were asked what their views would be on the resources to be used if the model were to be applied in real life evaluation and selection exercises. Most experts felt that the model would not be too costly to implement at current resource level. One expert commented that its implementation would not consume great resources and time, and consequently its benefit would outweigh the costs.

Another respondent remarked; *"It depends on what resources you are referring to; if referring to the underlying database, those are considerable. If referring to the resource needs of the organisation that would use the model, not too costly to operate.*"

However, others made some critical suggestions about the MSDSS model. Another respondent noted; *"In terms of its operation, interoperability, flexibility, usability and applicability, per se, it is very clear and straightforward; it's the underlying premise and data that needs some clarification in order for the user to fully appreciate its efficiency".* The percentage of the cost value of the MSDSS model is shown in **Figure 10.**

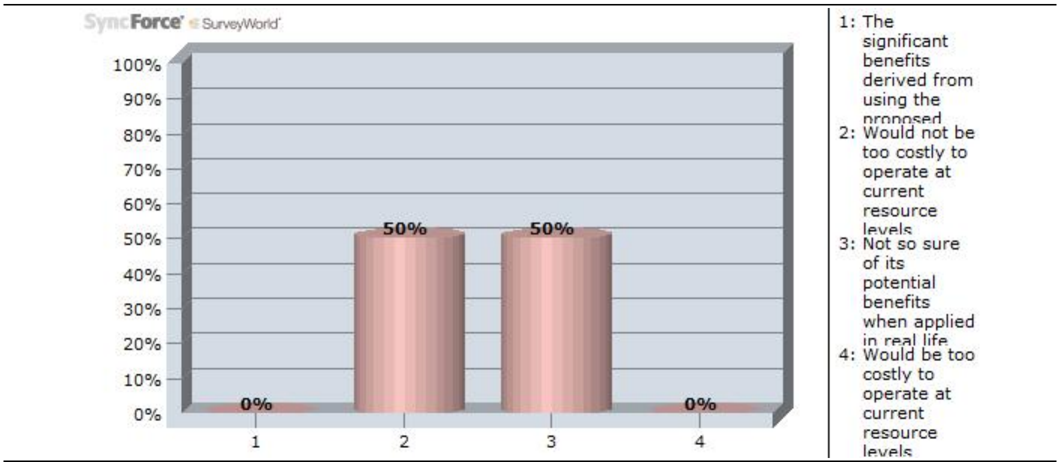


Figure 10. Illustration of the percentage of the cost value of the model based on practitioners' feedback

In the question: Do you think that the interface layout of the MSDSS model in general provides the possibility to communicate input and output data to design and building team members? 50% of the participants strongly agreed that the MSDSS model is comprehensive and should provide the possibility to support easy communication. Another number (50%) somewhat agreed to its adequacy. The overall impression however, is that almost 90% of the users agreed on it being very adequate to integrate in material selection problems. The view about its adequacy in terms of communication is shown in **Figure 11**.

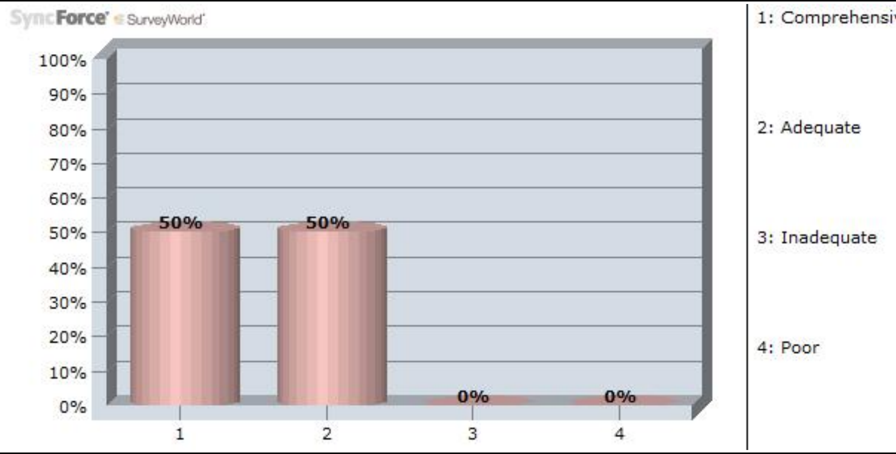


Figure 11. Illustration of the percentage of the reliability and appreciation of the model layout

In another question, participants were asked to express their views regarding the simplicity, user friendliness, flexibility, clarity, ease to understand and ease of use of the prototype model in conducting material database queries. The importance of the model in terms of its simplicity and flexibility varied significantly. In terms of comprehensibility, most experts found the model to be clear and simple to understand and implement.

One expert noted; "*it has covered a very complex aspect of LCGBMCs material assessment in a simple and logical manner, which I think would not be difficult to apply in practice*".

However, other respondents thought otherwise. One respondent remarked; *"The interface is very well-designed and easy to navigate. However, I personally think that there is a need for more explanatory material to allow the user to understand what s/he is actually doing, and how to operate some parts of the model appropriately".*

It can also be noticed from **Figure 12** that the feedback about the simplicity and ease of use of the model is relatively on the average, as 50% of the respondents agreed to have had minor issues with its clarity. Remarks given by the practitioners were perhaps due to their reluctance in following the work-through process provided by the system's instruction demo.

One expert mentions; *"the pairwise judgments in AHP are ambiguous, and the weights so determined may be meaningless".* Another stated that the presented AHP selection methodology seems somehow complex and time consuming. He notes; *"Pair-wise comparison is quite cumbersome and so takes a lot of time to maintain the consistency of the response, as this point to the efficiency of the system can lead to serious questions".* Perhaps the reason for this remark was that very few of the participants had sound knowledge of the AHP method of decision-making, as a result consideration for further research was acknowledged in the recommendation section to address the underlying limitations in the model.

Even though the AHP concept seems subjective in principle, it is reasonable to note that the weightings have sufficient objectivity, rigour and basis for generalisation since they were views expressed by practitioners with many years of experience on housing projects. While some of the respondents found the process a bit demanding, they were somewhat comfortable with the idea of assigning weightings to rank preferences.

One respondent noted; *"I think with a more elaborate guidance through the AHP methodology, the appreciation would be much higher".*

This perhaps suggests the need for a more comprehensive guide manual on how to undertake intended tasks related to the AHP concept of decision-making.

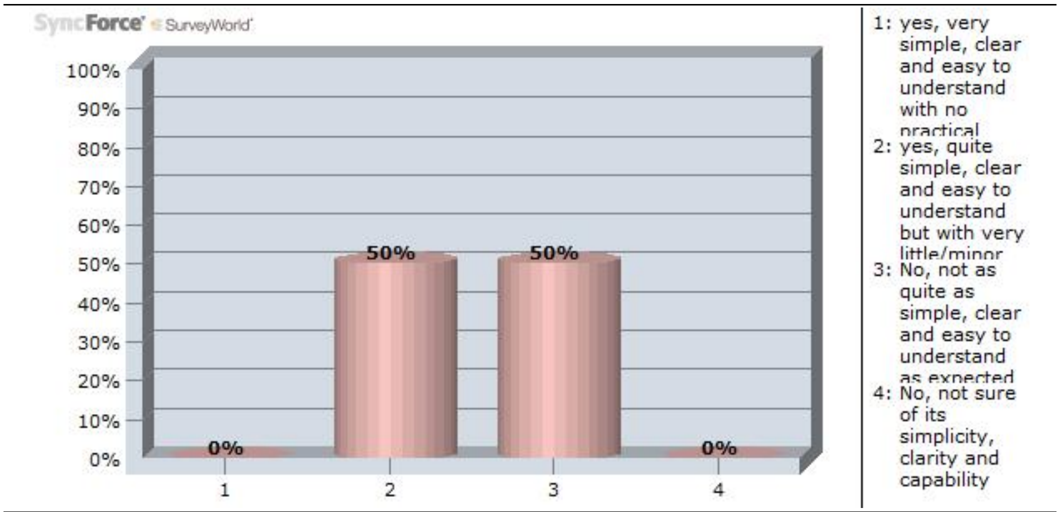


Figure 12. Illustration of the percentage of the user-friendliness and clarity of the model

Finally, when asked to provide further matters of importance that ought to have been considered in the development of the MSDSS tool and suggest areas that might need further improvement, respondents suggested some other features and capabilities that were not included in the model. A critical suggestion was made regarding the currency of the database.

A respondent noted; *"To make the model more efficient and effective, I suggest that all the materials for the database are always to be kept up to date. In the proposed system, however, it does not seem to consider how to update the material database".*

It is understandable that materials change in their innovation, composition, price and availability and most tools find it challenging to update information relating to products. In the MSDSS prototype model however, the materials and the corresponding performance of the selected products would be updated through links to suggested manufacturers web pages, where users should be able to access more information on a variety of other selected products if upgraded to a commercial-based tool.

Since the purpose of this research study was to develop a model to demonstrate the proposed step-by-step methodology for selecting LCGBMCs based on the impacts of the identified sustainability principle indicators, the issue of data currency –though very crucial in terms of information currency in model development, was thought to be one of a minor issue in this case as recommendation would be made in terms of further improvements for data update should it be developed into a commercial-based tool.

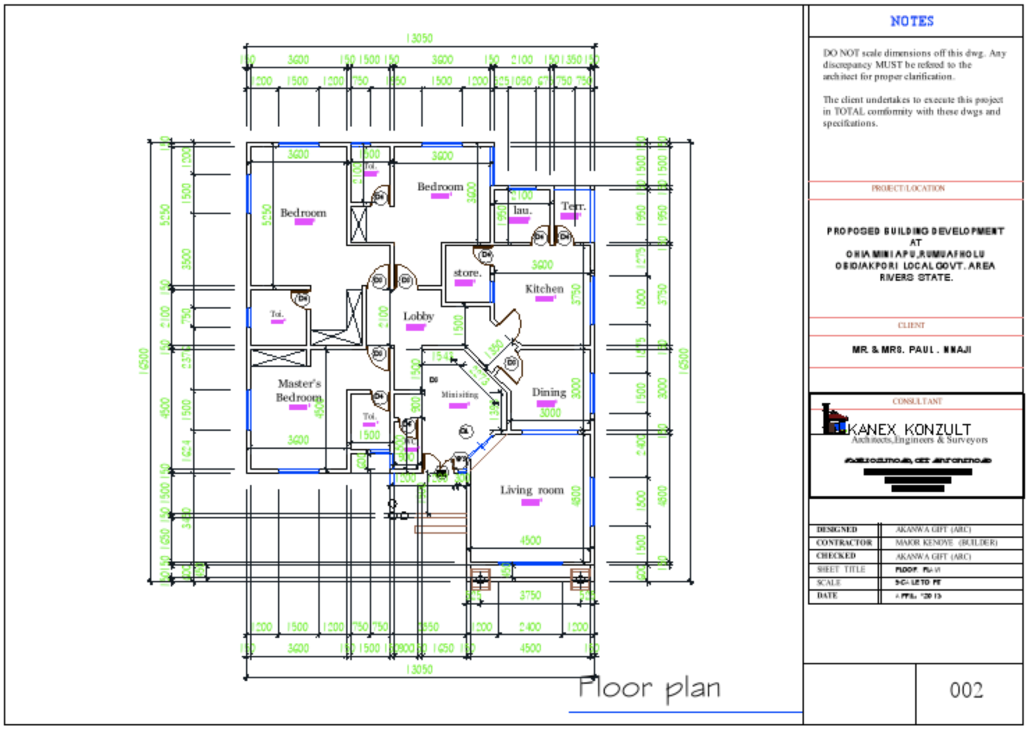
Apart from the issue of updating the information in the database, no outcome of the MSDSS model was perceived as not having an added value for supporting the evaluation of LCGBMCs in the design of LIGHDs.

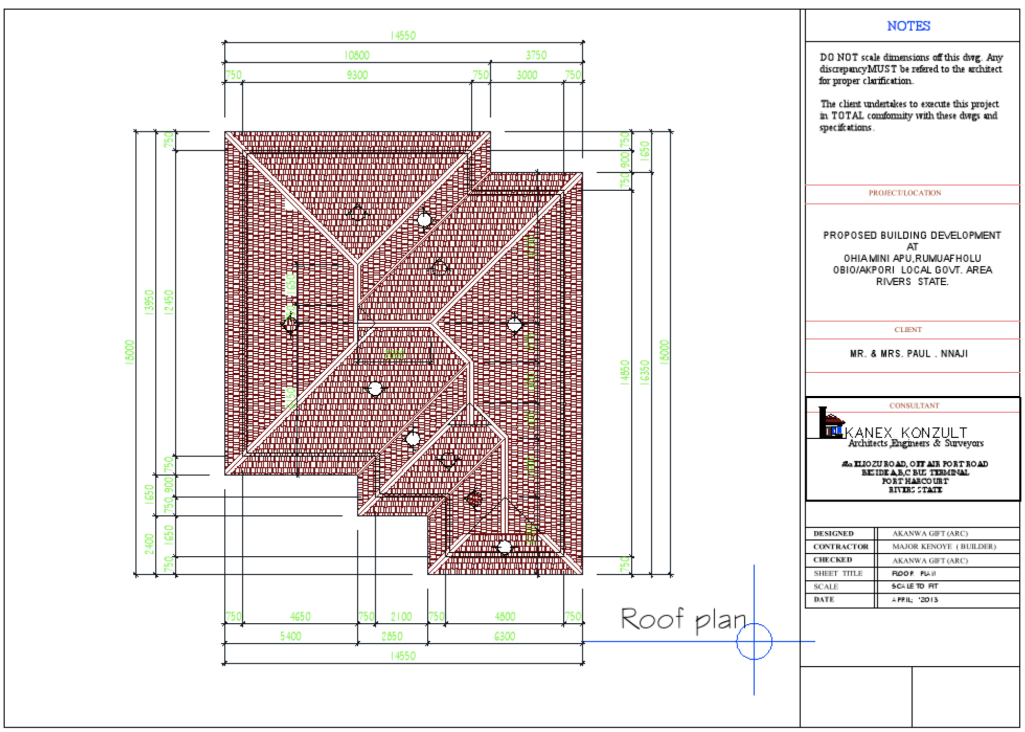
In summary, this section of the study has demonstrated the use of the model to rank material alternatives by applying it to a hypothetical case study. A total of thirteen (13) out of twenty (20) industrial practitioners in the housing construction industry, on separate cases of the evaluation exercises-five on the first survey exercise and eight on the second exercise, took part in the studies.

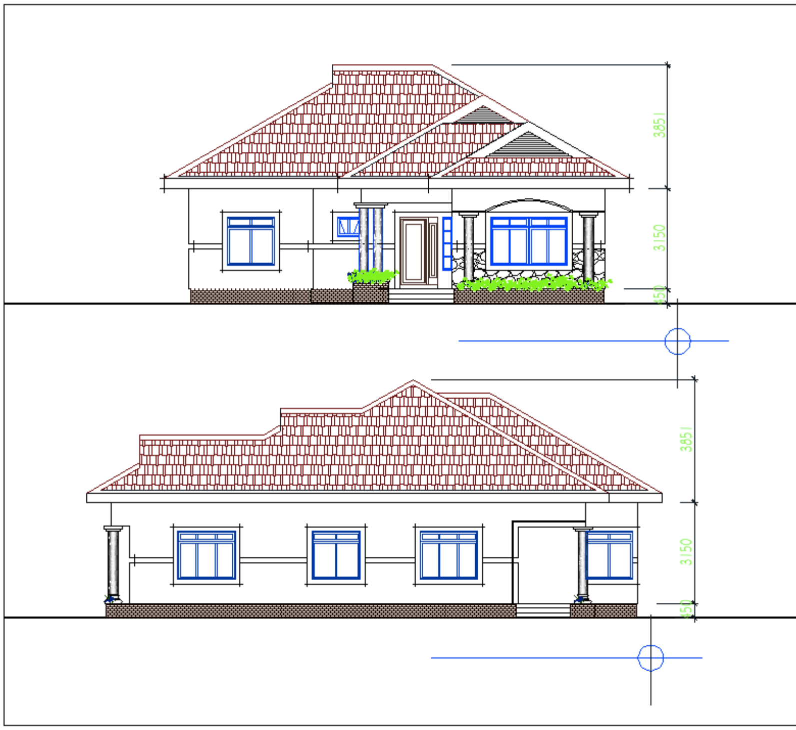
The evaluation exercise was carried out in three (3) segments consisting of a presentation, a hands on' user demo tutorial and a reflective questionnaire. The results of the user evaluation exercise were positive in aiding sustainable low-cost green building material selection.

In order to examine the outcome of the model for its applicability and efficiency, chapter six demonstrates the detailed procedure of the validation exercise and the findings from the validation exercise based on participants' views- using an on-going live project located in Port Harcourt, in Nigeria.

Appendix L: Case Study







DO NOT scale dimensions off this dwg. Any discrepancy MUST be refered to the architect for proper clarification.

The client undertakes to execute this project in TOTAL comformity with these dwgs and specifcations.

PROJECT/LOCATION

PROPOSED BUILDING DEVELOPMENT
AT
OHIA MINI APU,RUMUAFHOLU
OBIO/AKPORI LOCAL GOVT. AREA
RIVERS STATE.

CLIENT

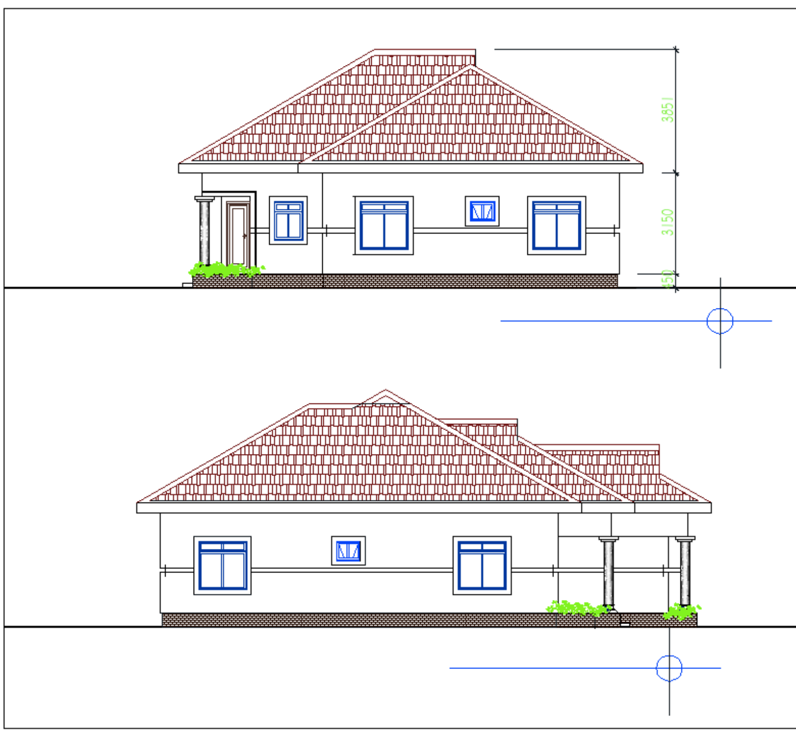
MR. & MRS. PAUL . NNAJI

CONSULTANT

KANEX KONZULT
Architects ,Engineers & Surveyors

#6a ELIOZU ROAD, OFF AIR PORT ROAD
BESIDE A,B,C BUS TERMINAL
PORT HARCOURT
RIVERS STATE

DESIGNED	AKANWA GIFT (ARC)
CONTRACTOR	MAJOR KENOYE (BUILDER)
CHECKED	AKANWA GIFT (ARC)
SHEET TITLE	ELEVATION
SCALE	SCALE TO FIT
DATE	APRIL; '2013



DO NOT scale dimensions off this dwg. Any discrepancy MUST be refered to the architect for proper clarification.

The client undertakes to execute this project in TOTAL comformity with these dwgs and specifcations.

PROJECT/LOCATION

PROPOSED BUILDING DEVELOPMENT
AT
OHIA MINI APU,RUMUAFHOLU
OBIO/AKPORI LOCAL GOVT. AREA
RIVERS STATE.

CLIENT

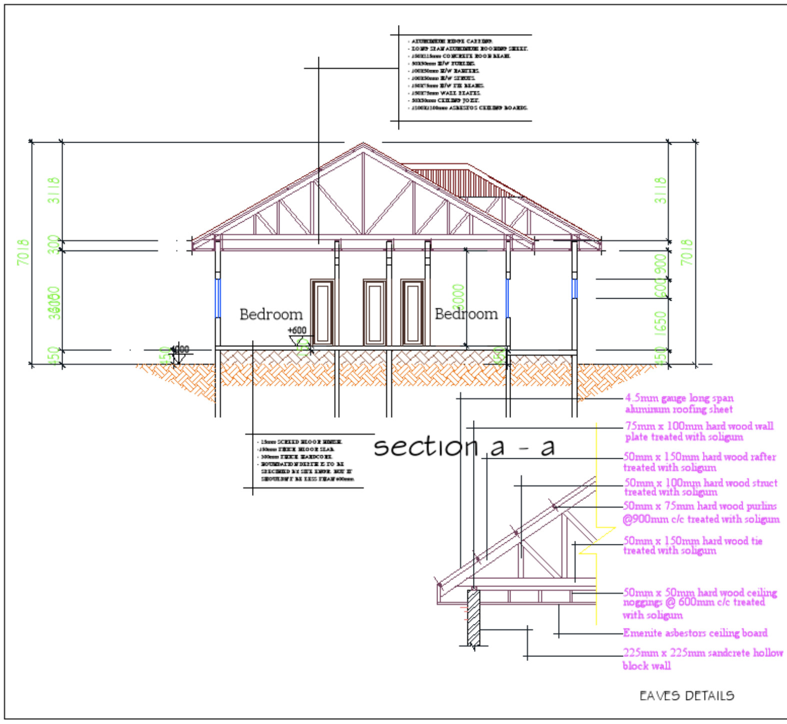
MR. & MRS. PAUL . NNAJI

CONSULTANT

KANEX KONZULT
Architects ,Engineers & Surveyors

#6a ELIOZU ROAD, OFF AIR PORT ROAD
BESIDE A,B,C BUS TERMINAL
PORT HARCOURT
RIVERS STATE

DESIGNED	AKANWA GIFT (ARC)
CONTRACTOR	MAJOR KENOYE (BUILDER)
CHECKED	AKANWA GIFT (ARC)
SHEET TITLE	ELEVATION
SCALE	SCALE TO FIT
DATE	APRIL; '2013



NOTES

DO NOT scale dimensions off this dwg. Any discrepancy MUST be refered to the architect for proper clarification.

The client undertakes to execute this project in TOTAL comformity with these dwgs and specifications.

PROJECT/LOCATION

PROPOSED BUILDING DEVELOPMENT
AT
OHIA MINI APU,RUMUAFHOLU
OBIO/AKPORI LOCAL GOVT. AREA
RIVERS STATE.

CLIENT

MR. & MRS. PAUL . NNAJI

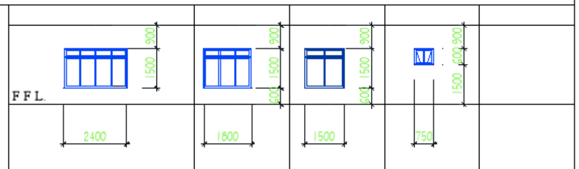
CONSULTANT

KANEX KONZULT
Architects ,Engineers & Surveyors

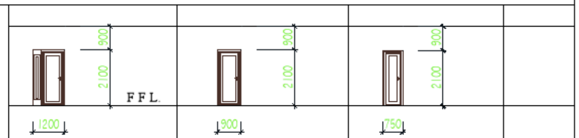
DESIGNED	AKANWA GIFT (ARC)
CONTRACTOR	MAJOR KENOYE (BUILDER)
CHECKED	AKANWA GIFT (ARC)
SHEET TITLE	SECTION
SCALE	SCALE TO FIT
DATE	APRIL '2013

004

DOORS AND WINDOWS SCHEDULE



NOTATION	W1	W2	W3	W4
DESCRIPTION	Sliding aluminium profile window coupled as shown in the profile and glazed with 5mm thick plain glass with accessories	Same as W1	Same as W1	Same as W1
QUANTITY	2no.	1nos.	7nos.	3nos.



NOTATION	D1/2	D3	D4
DESCRIPTION	Sliding aluminium profile door coupled as shown in the profile and glazed with 5mm thick plain glass with accessories	two panel powder coated paint finish aluminium triple hinge single swing door coupled as shown in the profile and glazed with 5mm thick tinted glass with accessories	flush door hung on 150mm x 75mm and installed complete with accessories
QUANTITY	2no.	8no.	6nos.

DOOR / WINDOW SCHEDULE

NOTES

DO NOT scale dimensions off this dwg. Any discrepancy MUST be refered to the architect for proper clarification.

The client undertakes to execute this project in TOTAL comformity with these dwgs and specifications.

PROJECT/LOCATION

PROPOSED BUILDING DEVELOPMENT
AT
OHIA MINI APU,RUMUAFHOLU
OBIO/AKPORI LOCAL GOVT. AREA
RIVERS STATE.

CLIENT

MR. & MRS. PAUL . NNAJI

CONSULTANT

KANEX KONZULT
Architects ,Engineers & Surveyors

DESIGNED	AKANWA GIFT (ARC)
CONTRACTOR	MAJOR KENOYE (BUILDER)
CHECKED	AKANWA GIFT (ARC)
SHEET TITLE	SCHEDULE
SCALE	SCALE TO FIT
DATE	APRIL '2013

006

Appendix M: Relevant Publications of the Research

A list of publications is listed below.

- Ogunkah. I, Yang, J & Jones, B., (2010): Design Toolkit for Green Vernacular Buildings. In 1st. International Graduate Research Symposium - October 15-16, 2010 - Ankara, Turkey. Peer reviewed and published. http://www.filefactory.com/file/cbe6abe/n/GRSproceedings.pdf

- Ogunkah, I.; Yang, J. Investigating Factors Affecting Material Selection: The Impacts on Green Vernacular Building Materials in the Design-Decision Making Process. *Buildings* **2012**, *2*, 1-32. *Received: 8 December 2011; in revised form: 22 December 2011 / Accepted: 16 January 2012 / Published: 23 January 2012. Buildings* **2012**, *2*(1), 1-32; doi:10.3390/buildings2010001

- Yang, J. and Ogunkah, I. (2013) A Multi-Criteria Decision Support System for the Selection of Low-Cost Green Building Materials and Components. *Journal of Building Construction and Planning Research*, **1**, 89-130. Received September 18th, 2013; revised October 25th, 2013; accepted November 4th, 2013, Published Online December 2013 (http://www.scirp.org/journal/jbcpr) doi: 10.4236/jbcpr.2013.14013

- Ogunkah, I., and Yang, J., (2014). Validation of a Multi-Criteria Decision Support System for Low-Cost Green Building Materials and Components. International Journal of ICT-aided Architecture and Civil Engineering Vol.1, No.2 (2014), pp.11-32 http://dx.doi.org/10.14257/ijiace.2014.1.2.02

Appendix N: Timeline for the PhD Study

	Duration	2012			2013												2014											
Task Name		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
A	FIELD STUDY	■	■	■	■																							
B	ANALYSIS AND SYSTEM DEVELOPMENT				■	■	■	■																				
C	TESTING AND VALIDATION OF THE TOOLKIT							■	■	■	■																	
D	WRITE UP AND CONCLUSION									■	■	■	■															
E	FINALISE SUBMISSION												■	■														
F	SUBMIT TO SUPERVISORS AND AWAIT FEEDBACK													■	■	■												
G	FINAL REVIEW OF DRAFT AND FORMAT FOR SUBMISSION														■	■	■	■	■	■								
H	PRINT, BIND AND SUBMIT.															■	■	■	■	■	■	■						
I	PHD VIVA																■	■	■	■	■	■	■	■	■	■		

Appendix O: Comparative Analysis of Existing Tools

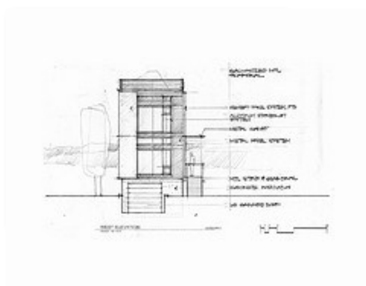
LCA Tool IN DCs	Tool Type	Tool Developer	Collection	Assessment Criteria/Factors	Life-Cycle Phase	Software Application & Tech Support	Users	Positives/ Advantages	Negatives/Limitations/Dis-advantages
ENVEST	Environmental LCA Tool for Building/ Building Products	UKGBC (BRE United Kingdom)		Energy/Resource consumption, Operational Energy, Water Use, Material Consumption, Water Extraction, Fossil Fuel/Minerals Depletion, Waste Disposal	Building design phase	None	Designers	Determines ecopoint/whole life cost ratings for each material, element component, Dynamic with new community, social and economic criteria	Not comprehensive, Uses the database for all impact information with alterable defaults for all element choices,
BEES	Building Product Life-Cycle Assessment (LCA) Tool Building Product Life-Cycle Costing (LCC) Tool	NIST (USA)	230+ building products	Environmental and economic performance	Design phase, and End-of-life phases	Web-based	Designers, Specifiers, Builders, Product Manufacturers, Purchasers, Researchers, and Policy Makers		Limited product options, Limited use for local/ regional impact analysis, Devaluating weighing process
ATHENA	Whole Building Analysis Tool Building Assembly Analysis Tool	ATHENA® Institute	1,200+ building material and assembly combinations	Energy use global warming, solid waste emission, natural resource use	Conceptual design	Web-based	Architects, Engineers, Designers, Environmental Consultants	Easy-to-understand descriptions of technologies that are relatively advanced, with contacts for further information.	Limited assembly options, Fixed assembly dimensions, North American bias in systems selection.
EPM	Building Product Life-Cycle Assessment (LCA) Tool	Wood /Energy (Netherlands)	650+ building material and assembly combinations	Eco system, consumption/exhaustion of resources, energy consumption (in all phases of production, including transport), environmental pollution with different waste and hazardous materials, waste disposal problems, hazardous emissions into the atmosphere, global warming, impact on human beings,	Planning, Design, Operation and Maintenance	Package is published on CD and as booklet.	Designers, architects, regulatory groups, local authorities	Complete environmental assessment of material use in buildings, Clear sheets and easy to communicate. Easy to use and extensive database with the most common materials and products.	Very extensive method, LCA expertise and extensive knowledge of the product required, Time intensive procedure, Calculation does not result in an indication of environmental impact. Only takes energy use and losses into account. Only takes energy use and losses into account.

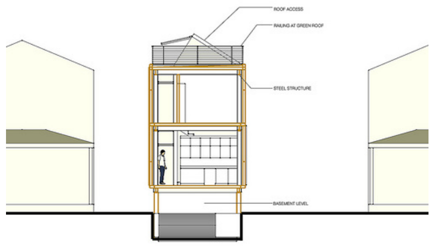
				re-use and recycling possibilities					
BREEAM	Whole Building Analysis Tool . Building Product Life-Cycle Assessment (LCA) Tool	UKGBC (BRE United Kingdom)		Management; Health & Wellbeing Transport; Water- (consumption reduction, metering, leak detection); Materials-; Land Use; Ecology-; Pollution	Planning, Design, Operation and Maintenan ce, and End-of-life	Web-based application	Design / Managem ent team/ assessor	Robust, Detailed, Well Known, Easy to Specify, Independent, Tailored to each building type. Encourages Teamwork, Creates, dialogue between various sectors in the building industry, Translates Data into Numeric, Estimator tools are available free of charge,	Complicated, Inflexible, Poorly Understood, Often Poorly Specified, Extra Cost, Guidance is currently only available to people who attend the training courses.
GREEN-STAR	Whole Building Analysis Tool	GBCA (Australia)	Nil	Environmental efficiency, Greenhouse & Acid Gas, Ozone Depletion, Effluent Reduction, Waste, indoor environment quality, energy, transport, water land use, ecology and emissions	Design, operation and maintenanc e. New and existing buildings	Application language is Visual Basic	Design team, Architects , Constructi on industry profession als, educators researcher s	Scoring system flexible,	Technical manual is available for £224 ($444), Operating energy not included. Doesn't do thermal modeling.
LEED	Whole Building Analysis Tool	USGBC (United States)	Nil	Site, energy, water, materials, indoor environmental quality	Planning, Design, Operation and Maintenan ce, and End-of-life	No software Application	Design / Managem ent team / Accredite d Profession als, Designers, Specifiers, Builders, Product Manufact urers, Purchaser s, Researche rs, and Policy Makers	Relies on a simple, consensus-based point system; a broad-based model for most environmental issues, The tools are available free of charge, Does not require the expertise of a trained assessor to operate, Ensure effective design strategies are accounted for without the overlay of operational management and user	Insufficient Emphasis on Durability; Limited Reach, limited to addressing environmental issues, Number of credits related to each issue is a de facto weighting, Technical guidance is available for £100 ($200), does not translates Data into Numeric, Users of LEED need to obtain accreditation through coursework and exams.

								behaviour	
GBTool	Whole Building Analysis Tool	CGBC (Canada		Energy consumption, resource consumption (salvaged, recycled, bio-based and sustainably harvested, locally produced, designed for disassembly, re-use, or recycling) and water use for irrigation, building systems, and occupant use); environmental loadings- greenhouse gas emissions, other atmospheric emissions, solid wastes, storm water, wastewater, site impacts, and other local and regional impacts); and indoor environmental quality (indoor air quality, ventilation, temperature and relative humidity, daylight and illumination, and noise and acoustics), selection of appropriate site, building controls, compatibility flexibility and adaptability, maintenance of operating performance, and a few social and economic measures	Planning, Design, Operation and Maintenance, and End-of-life	Microsoft Excel-based	Designers and regulatory groups	Encompass the underlying Sustainability principles, translates Data into Numeric, Very adaptable to local conditions and assessments are therefore very meaningful within the region. Extremely comprehensive framework for evaluation.	Tend to require greater technical expertise to implement; Third party team establishes the qualitative and quantitative measures that are used to evaluate sustainable design achievements, Users are expected to use other software tools to simulate energy performance, Requires added initial input from local authorities to establish weights and benchmarks
LCA Tool IN LDCs	Tool Type	Tool Developer	Collection	Assessment Criteria/Factors	Life-Cycle Phase	Software Application & Tech Support	Users	Benefits	Limitations

CASBEE	Whole Building Analysis Tool	JSBC (Japan)		Energy, Resource, Local environments, indoor air quality	Pre-design, Design, Operation and Renovation. Planning, Design, Operation and Maintenance, and End-of-life	Web-based Tool	Used by all Design/management team,	Able to convert raw data into scores,	Not applicable to all of the GSA project types, Requires only the expertise of licensed assessors, relatively unknown, Highly complex weighting system applied at every level, Highly complex weighting system applied at every level,
CEPAS	Whole Building Analysis Tool	HK-BEAM	Nil	Indoor Environmental Quality, Building Amenities, Resources Use, Environmental loadings, Site Impacts, Neighbourhood Impacts, communal interactions, building economics, transportation, heritage conservation,	Pre-design, Design, Construction, Operation and demolition.	Web-based Tool	Used by all Design/management team,	An all-round and robust assessment method, Flexible in applications, Easy to understand indicators, Performance – based, Upgradeable assessment framework, The assessment tool and guidance is available free of charge in Japanese and English,	The use of subjective judgment is very limited, Ratings for most factors are not scalar. Comprehensiveness comes with high implementation costs.
SBAT	Whole Building Analysis Tool	CSIR (Council of Scientific and Industrial Research) in 2001 (South Africa)	Nil	SOCIAL • Occupant Comfort • Inclusive Environments • Access to Facilities • Participation & Control • Education, Health & Safety ECONOMIC • Local Economy • Efficiency of Use • Adaptability & Flexibility • Ongoing Costs • Capital Costs ENVIRONMENTAL • Water • Energy • Waste • Site, • Materials & Components	Briefing, Site Analysis, Target Setting, Design, Design development, Construction, Handover, Operation, Reuse/recycle, is explicitly defined in this context	Web-based Tool	Used by all Design/management team, clients, users and local communities	Performance criteria that acknowledge social and economic issues, divide15 performance areas into 5 performance criteria	

LOW-IMPACT GREEN HOUSING DEVELOPMENTS





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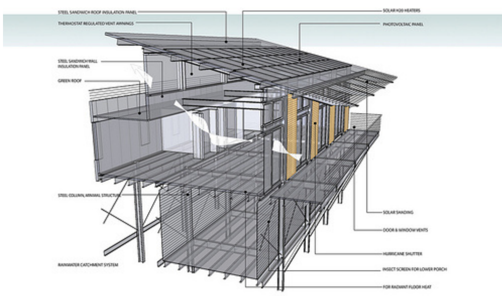

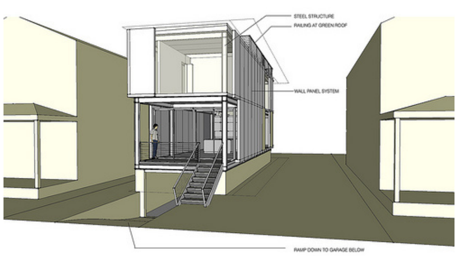

PERSPECTIVE

PERSPECTIVE


ECOSTEEL
Fab-House | Cabana



ECOSTEEL
Fab-House | Cabana