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A Decision Support System for Selecting Sustainable Construction Materials

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DECLARATION

To the best of my knowledge and belief, the material and information collected and used in this thesis were not published earlier by any other person except where acknowledgement has served.

This thesis or any part thereof has not previously been presented in any form for the award of any other degree or diploma in any university.

Muhammad Rashid Minhas

Date: 29/01/2021

ABSTRACT

The construction industry impacts significantly on society, the economy and the environment in today's world. The gap between energy requirements and the generation of energy in the building sector places an enormous emphasis on the selection of sustainable construction materials in the local market. The construction industry continues to have a substantial impact on the usage of natural resources; in addition, the construction industry has prompted much discussion about waste material dumping sites worldwide. In recent years, much work has been undertaken in the area of sustainable building and housing; this includes sustainable building materials, the use of solar panels for electricity generation and rainwater tanks for rainwater harvesting. The selection of appropriate sustainable building materials is the most important phase during the building design and construction process. Extensive efforts are needed to improve awareness factors among decision-makers when selecting construction materials. Limited technical support is available to assist technical experts, including estimators, architects, designers, draftsmen and others in the decision-making process when it comes to searching for and selecting new sustainable construction materials for different building components. However, some experts are reluctant to replace conventional practices with new innovative techniques.

This research, proposed as part of the study, aims to develop an effective system to address this problem. To address this research issue, two different research methods are adopted. Firstly, qualitative research is undertaken in which technical experts are interviewed to understand how they currently locate and select construction materials for a project, the selection criteria on which they focus when making the selection and the system that they would envision could assist them to more effectively carry out this job. The data collected are analysed with Microsoft Excel, Qualtrics and SPSS software. The qualitative study findings lay the foundation for the second part of the research, in which a decision support system is developed to search for and select sustainable construction materials. The second phase of the research adopts design science theory to develop an interactive system that technical experts can use to search for and select the construction materials available in the marketplace. Existing Multi-Criteria Decision Making (MCDM) techniques are evaluated to assess their suitability and hybrid MCDM techniques are developed as part of the decision support system. To demonstrate the

utility and practical benefit of this system, it is implemented as a proof-of-concept prototype. To check the validity and efficacy of the proposed system, results from the prototype are evaluated by technical experts, with changes incorporated within the prototype.

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DEDICATION

I humbly dedicate this effort to my late Parents.

May Allah (SWT) bless them with the highest places in Jannah (Ameen)

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LIST OF ABBREVIATIONS

ABCB	Australian Building Codes Board
ABSA	Australian Building Sustainability Association
ACT	Australian Capital Territory
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
AR	Augmented Reality
BEES	Building for Environmental and Economic Sustainability
BIM	Building Information Modelling
CABS	Climate Adaptive Building Shells
CC	Collaborative Coefficient
CFD	Computational Fluid Dynamics
CI	Collaboration Index
COPRAS	Complex Proportional Assessment
DC	Degree of Collaboration
DSS	Decision Support System
DT	Doubling Time
ECO	Environmental Care Organization
EER	Energy Efficiency Rating
ELECTRE	*Elimination et Choix Traduisant La Realité*
FS	Fuzzy Set
GBCA	Green Building Council of Australia
GDP	Gross Domestic Product
GHGs	Greenhouse Gas Emissions
GIS	Geographical Information System
GST	Grey System Theory
HIA	Housing Industry Association
IEA	International Energy Agency
LCA	Life Cycle Analysis
LDA	Latent Dirichlet Allocation
LEED	Leadership in Energy and Environmental Design
MAUT	Multi-Attribute Utility Theory
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
NABERS	National Australian Built Environment Rating System
NZEB	Net Zero Energy Building

PRNRM	Perth Region Natural Resource Management
RFID	Radio Frequency Identification System
RGR	Relative Growth Rate
SIPS	Structural Insulated Panel System
SLR	Systematic Literature Review
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VIKOR	*Visekriterijumska Optimizacija I Kompromisno Resenje*
VIP	Vacuum Insulation Panel
WoS	Web of Science
ZCB	Zero Carbon Building

PUBLICATIONS ARISING FROM THIS RESEARCH

<u>Published Conference Article</u>

A Decision Support System for Selecting

Sustainable Materials in Construction Projects

Published in (2018, 32nd International Conference on Advanced Information Networking and Applications Workshops held at Pedagogical University of Cracow, Poland)

<u>Published Journal Articles</u>

A Bibliometric Analysis based Review of Decision Support Systems in Construction

Published in (Buildings, International journal in 2020)

Development of an effective system for selecting construction materials for sustainable residential housing in Western Australia

Published in (Applied Mathematics, International journal in 2020)

CHAPTER 1

INTRODUCTION

This chapter covers:

- Introduction to sustainability in the Australian construction industry
- The emerging trend of sustainability in the Australian construction industry
- Materials selection
- The main objectives of this research
- Thesis structure

1.1 Chapter Introduction

Sustainability is the most widely discussed topic in the modern construction industry. In the last two decades, this concept has emerged as a new business and living strategy. For developed countries, it is becoming more important to improve the sustainability rate and developing countries are attempting to implement sustainable methods as quickly and widely as possible to compete with global market trends and policies (Papargyropoulou, Padfield, Harrison, & Preece, 2012). The construction industry has significant environmental, social and financial impacts on society. Green building is one of the major factors considered to mitigate the issue of global climate change. New standards and specifications are being implemented to increase the efficiency and progress of the implementation of the sustainability concept, especially in the construction industry. The construction industry is incredibly significant to overall society from providing places for people to live and work to employing over 1 million Australians with jobs; in Australia, the construction industry also contributes 7.5% of the total Annual GDP (Gross Domestic Product) (Zuo & Zhao, 2014). The World Business Council for Sustainable Development states that the building sector accounts for 40% of the world's total energy use. The building sector also produces a significant amount of greenhouse gases. Carbon emissions of the global building sector will rise each year until reaching an estimated 42.4 billion tonnes in 2035. Construction sites are also creating waste materials which will reach approximately 16.6 million tonnes, accounting for 38.8% of the total waste produced; of which 43% will go to landfills. The International Energy Agency says that commercial and institutional buildings will double in number between now and 2050 (Zuo & Zhao, 2014).

There is a sizeable gap between the knowledge of sustainable practices and the actual practices used in the selection of construction material. Decision-makers are unable to reach a clear verdict about their knowledge of sustainability and awareness in regard to material selection during the design and the execution phases of the construction process (L.-y. Shen, Tam, Tam, & Ji, 2010). There are still large issues when incorporating sustainability issues during the construction of a building project.

There is a definite need to develop a system that can provide a sustainable material selection for all stages of construction.

This research will help to develop a collaborative approach for integrating sustainability and material selection decision making specifically at the design stage.

This chapter explains the research background, objectives, methods and the overall structure of the thesis.

1.2 Sustainable Construction Progress in Australia

The Australian construction industry has shown rapid development in the use of sustainable construction materials and techniques. The concerned departments and associations, including the Department of Housing and Public Works, the Australian Building Codes Board (ABCB), the Housing Industry Association (HIA), Master Builders Australia (MBA), the Green Building Council of Australia (GBCA) and the Australian Building Sustainability Association (ABSA), have all developed a good range of standards and specifications. All Australian institutes currently involved in training offer related long and short courses in sustainability and green building. The construction industry has also been injected with new and innovative sustainable construction materials in the local market. The 5th edition of the Environmentally Sustainable Homes Guide has recently been published; this is a comprehensive product listing to inform end-users of the latest updates in sustainability and green housing in Australia. Buildings in Australia are assessed both by Government and other independent rating systems. The Green Building Council of Australia (GBCA) has developed their "Green Star" rating system. The first "Green Star" ranked building was Brindabella Circuit at Canberra Airport in the ACT. Energy Efficiency Rating (EER) was launched in 1996 to rank different buildings according to the criteria of energy consumption management. The National Australian Built Environment Rating System (NABERS) is the Government initiative to compare the environmental performance of Australian buildings.

1.2.1 Sustainability in building techniques

Several different techniques have been used for sustainability in a building environment, some of these techniques are summarised here.

Passive design

Passive design in the housing and building sector has created a new style of building design in a way to reduce the overall usage of natural resources, rather than relying on artificial sources of energy management and water consumption re-usable and natural sources are preferred (Rodriguez-Ubinas et al., 2014). Most of the energy consumption used to create interior comfort inside a house comes from active sources.

Passive design works in such a way to improve the overall energy management through natural resources, this includes the thermal properties of the building surroundings, geometric parameters, ratios, evaporative cooling systems, solar energy and light gains, night ventilation and cooling (Pacheco, Ordóñez, & Martínez, 2012). Small dwellings are more flexible in adapting passive benefits across different orientations (Morrissey, Moore, & Horne, 2011). The passive design shows a great impact on the integration of energy efficiency and comfort. Creating shade for a building in new and innovative ways not only appeals to the customer but can also improve the overall efficiency and aesthetic features of the building. Passive heating and cooling systems using solar energy are increasing the overall demand for solar systems. It is estimated that half of the peak load of energy consumption is used to satisfy air conditioning facilities in residential buildings. The usage of passive cooling techniques can save up to 53% of hours in discomfort and can save up to 826 kWh during the summer season (Dabaieh, Wanas, Hegazy, & Johansson, 2015).

Vertical planting

Vertical planting and using solar panels as shades are becoming more popular and –in-demand parts of the building design and orientation, as solar panels can be used as dynamic solar shading devices used to tackle seasonal changes. This technique has been used for some time to maintain the micro-climatic conditions of a building, and in recent years research has revealed many additional benefits of vertical climbing plants, such as Virginia creepers (Ip, Lam, & Miller, 2010). These benefits include a like bio-shading co-efficient and indoor environmental moderators among others. These are considered as design features to keep the overall internal building cool, lower the energy consumption of the building and facilitate the alteration of urban environmental warming conditions (Hunter et al., 2014). Plants work as solar filters and also prevent heat transfusion and heat radiations from the building materials. During the summer season, plants act as energy savers through their cooling properties and in winter they act as an insulation layer to prevent energy loss (Perini, Ottelé, Fraaij, Haas, & Raiteri, 2011).

Cooling

Cooling is carried out using the latest techniques of solar heat control, heat optimization and heat dissipation. This includes increasing the heat storage capacity of the building structure, and by heat dissipation, which means transferring the excessive heat to the natural heat sink (Santamouris & Kolokotsa, 2013). Cooling energy demand is mainly affected by thermal transmittance and the thermal envelope of the building. Many factors can impact this problem such as the proper use of natural ventilating facilities, overall building orientation and horizontal shading services (Imessad et al., 2014). Cross ventilation is the best technique used to solve indoor cooling problems. The cooling issue can be tackled very well by adopting natural ventilation techniques, such as thermal simulation and airflow network monitoring. This can be implanted by using advanced Computational Fluid Dynamics (CFD) techniques during the building simulation (Ohba & Lun, 2010).

Building insulation

Building insulation plays a vital role in energy management and in increasing the overall thermal efficiency of a building. Modern thermal insulating materials are now available to deal with the thermo-dynamics of building structures, these include mineral wool, expanded polystyrene, extruded polystyrene, vacuum insulation panels and structural insulated panels (Jelle, 2011). In recent years a lot of research has been undertaken on the usage of Phase Change Materials (PCM) for maintaining the balance of thermal energy storage in buildings. Latent heat storage can also be used for the cooling and heating of buildings. Salt hydrates, paraffin and paraffin waxes, and fatty acids have the required latent fusion heat that can be used for solar applications (Cabeza, Castell, Barreneche, De Gracia, & Fernández, 2011).

Glazing

Glazing is also an important factor to deal with the preservation of latent heat. The glass industry has improved its quality and innovation in glazing. The performance of the window depends upon the heat transmittance, air tightness and solar glazing transmittance. Building thermal balance is more likely related term is used for glazing properties of the window (Gasparella, Pernigotto, Cappelletti, Romagnoni, & Baggio, 2011).

1.3 Materials Selection Issue

Materials selection is considered as the most important factor, after the design of the building. It is generally believed that the initial inflated cost of building is due to choosing the wrong materials; inefficient building materials can also affect this cost during the operating process of the whole life of the building. The most attractive building materials are considered to have better energy efficiency and less installation and maintenance costs. Many of the latest materials available in the local market represent all of these characteristics. When constructing walls, Structural Insulated Panel Systems (SIPS) are now being used; they are quickly installed and energy-efficient but still a bit more expensive than traditional wall building materials. In Sydney, a detached house is optimised using the building energy simulation process to reduce the annual heating and cooling cost, even removing the heating or cooling system completely if it is no longer required (Bambrook, Sproul, & Jacob, 2011). The houses with the best performance were compared with simulated houses and it was found that 94% of the required energy can be reduced by using innovative construction materials and the latest construction techniques. Vacuum insulation panels (VIPs) are also considered one of the most energy-efficient materials, much more efficient than conventional building insulation materials (Alam, Singh, & Limbachiya, 2011). Aerogel is considered one of the most promising thermal insulation materials in the current market; it reduces the thermal conductivity by 13mW/(mK) when compared to traditional insulating materials. Aerogel proved its supremacy in the insulation and heat control materials competition (Baetens, Jelle, & Gustavsen, 2011). There is no doubt that materials selection is one of the most important parts of construction, however, the local market is reluctant to adapt to these latest materials and innovative techniques due to the lack of knowledge and the cost. In this research, this problem has been resolved by providing a ranking system for the selection of sustainable construction materials.

1.4 Green Buildings

Green buildings are also denoted as Net Zero Energy Buildings (NZEB) or Zero Carbon Buildings (ZCB); they can be defined as a "building in which the net energy consumed is roughly equal to the amount of renewable energy created on the site."(Sartori, Napolitano, & Voss, 2012), (D. H. Li, Yang, & Lam, 2013). Green buildings help to improve employee productivity, reduce health and safety costs, save energy, and reduce construction, maintenance and operational costs (Horman et al., 2006), (Ogunkah & Yang, 2012). Hence, it is important to have buildings that abide by international reference tools, such as LEED[1], CASBEE[1], BREEAM[1] (H. Wu, 2012), (Ding, 2008) as selecting the appropriate materials plays a very important role in increasing the overall energy rating of the building (Castro-Lacouture, Sefair, Flórez, & Medaglia, 2009). Hence, Ali and Al-Nasairat (Ali & Al Nsairat, 2009)state that "Green building has now become the flagship in this century that takes the responsibility of long term economic, environmental and social health." Ries et al. (Ries, Bilec, Gokhan, & Needy, 2006) reported that using precast concrete in construction resulted in a 25% improved productivity and 30% drop in energy usage. Ogunka and Yang (Ogunkah & Yang, 2012) validated (using MCDM) that using low-cost green building materials can save up to 30-50% of annual energy usage. Miller (Miller, Spivey, & Florance, 2008) reported that LEED-certified buildings provide a higher payoff when compared to non-certified buildings, even if they were done purely with motive of profit. Further, Eichhoitz said that the demand for green buildings is not affected by market volatility (Eichholtz, Kok, & Quigley, 2013). What is noticeable is that the choice of construction materials plays a very important role in ensuring energy saving within a green building. Three of the main concepts of green building follow:

1.4.1 Energy conservation in buildings

Energy conservation refers to the reduction in the level of energy consumption while keeping the human comfort level at an acceptable level. Brounen (2012) discussed the fact that consumer behaviour is a major determinant in the energy conservation process.

[1] LEED: Leadership in Energy Management and Environmental Design. CASBEE: Comprehensive Assessment System for Building Environment Efficiency. BREEAM: Building Research Establishment Environmental Assessment Method

They sampled 300,000 houses and found that residential gas consumption was determined by the structural characteristics of the dwelling, i.e. walls (single leaf or double), flooring, frame or rigid structure) while the electricity consumption was directly related to the household composition and the family's economic status (Brounen, Kok, & Quigley, 2012). This has driven research in the area of reliable energy monitoring and energy management systems (Woolard, Fong, Dell'Era, & Gipson, 2001). Leon R. (Glicksman, Norford, & Greden, 2001)reported that an increase in the awareness of energy conservation amongst inhabitants can result in a noticeable decrease in energy consumption. This has major implications, especially in a country like China where 4.7 million homes are constructed every year.

1.4.2 Energy efficiency in buildings

The International Energy Agency (IEA) defines energy efficiency as "a way of managing and restraining the growth in energy consumption. Something is more energy-efficient if it delivers more services for the same energy input or the same services for less energy input." On an academic front, numerous researchers have investigated this matter. Diakaki et al. proposed a decision model for the measurement of energy efficiency in buildings. Nguyen and Aiello evaluated the physical and economic parameters of the occupants and their reservations regarding energy efficiency, they found that the occupant's presence in the building affects the cooling, heating, lighting and ventilation demands of the building (Diakaki et al., 2010). Uninformed behaviour can add an extra third to the total energy consumption (Nguyen & Aiello, 2013). In 2012, Harris and Co. found the most alarming fact about the proper selection of materials or appliances; they found that artificial lighting is the key threat to biodiversity as it adds up 1900 million tons of CO_2 to the atmosphere in a year, more than three times than that of the aviation industry (Stone, Jones, & Harris, 2012). This finding demonstrates how proper materials selection can have a large impact on overall energy efficiency and be good for the environment.

1.4.3 Energy management in buildings

Energy Management is the proper allocation of resources to get the maximum value of satisfaction and comfort from the building (Yang & Wang, 2013), (Abras, Ploix, Pesty, & Jacomino, 2007). Amory Lovins, Chief Scientist of the Rocky Mountain Institute (RMI) USA, once said "Using energy more efficiently offers an economic bonanza—not because of the benefits of stopping global warming but because saving fossil fuel is a lot cheaper than buying it.” Numerous aspects of this problem have been researched in-depth, such as energy management based on energy pricing, customised energy management using evolutionary algorithms (Allerding, Mauser, & Schmeck, 2014), energy efficiency visualization tools for a decision support system (O'Hare, Sweeney, & Wilby, 2014), use of wireless sensor networks for energy management (Kazmi, O'grady, Delaney, Ruzzelli, & O'hare, 2014), people occupancy detection and profiling using sensors for energy management (Diraco, Leone, & Siciliano, 2015), choice of building insulation materials for preventing energy dissipation (Joudi, Svedung, & Rönnelid, 2011), (Sadineni, Madala, & Boehm, 2011), retrofitting insulation on existing buildings (Gustafsson, 2000), and the use of double/triple glazed windows (J.-W. Lee, Jung, Park, Lee, & Yoon, 2013).

1.5 Green Building Certifications

There are many certifications and monitoring authorities are working to make buildings green, sustainable and energy-efficient. Leadership in Energy and Environmental Design (LEED) introduced a numbering system for different components. In the process of the LEED certification designers and engineers have to conduct in-depth sustainability analysis on the materials, shapes and Mechanical-Electrical-Plumbing (MEP) systems. Building Information Modelling (BIM) allows its users to superimpose different utilities on the same frame of the model. It can be used to simplify the work of the technical stakeholders when performing a LEED sustainable design check (Azhar, Carlton, Olsen, & Ahmad, 2011). The green building movement is considered a game-changer, as the implementation of sustainable construction results in technical, environmental, social, economic and financial benefits. The mixed-integer optimization model is used to help decision-makers to make the appropriate sustainable materials selection when using the LEED system (Castro-Lacouture et al., 2009). BREEAM is a voluntary, consensus-based, market focussed assessment method developed in the UK. Buildings certified by BREEAM will have a single score of overall assessment (Crawley & Aho, 1999). This is calculated by the formula (Chew & Das, 2008):

$$\text{Average Score} = \sum_{1}^{n} \left[\frac{(Individual\ score\ of\ the\ house\ N) X (No.\ of\ units\ of\ type\ N)}{Total\ No.\ of\ house\ Units} \right].$$

Where n = the total number of house types

N = each individual house type

The Hong Kong Building Environmental Assessment Method (HK-BEAM) was launched in December 1996. It has two versions that cover the overall environmental, local and internal impact of a building. It has assessed more buildings and square areas than any other assessment scheme in the world (W. Lee & Burnett, 2008).

Eco Effect is an assessment tool introduced in Sweden in 2005 to provide an assessment tool to everyone. It works in two states, the first state being a quantitative description of the environmental and health effects of the built environment and the second to provide a comparison and decision making tool to reduce the environmental impact. Its major working tool is based upon the life cycle assessment methodology (LCA) (Wallhagen, Glaumann, Eriksson, & Westerberg, 2013). This is a small list as there are many more assessment methods being applied all over the world for building assessment.

1.6 Problem of Sustainable Materials Selection

The problem of sustainable materials selection has different aspects that need to be addressed. Those are discussed in detail in the following sections.

1.7 Construction Informatics

Building information modelling (BIM) is a modern trend in design, documentation, delivery and life cycle assessment processes of the building construction sector. It has the power to change the architecture, engineering and construction (AEC) industry altogether. It correlates the building project information database with object-based modelling. It has a great impact on the Australian AEC industry although there are some limitations such as the lack of expertise, resistance to change and the lack of information in system implementations (Gerrard, Zuo, Zillante, & Skitmore, 2010). Radio frequency identification system (RFID) is also used later in the construction industry to handle complex materials selection problems. RFID is used to deal with incomplete and inaccurate materials information flow, inventory and site materials management and to control problems on work-sites (Zhaomin Ren, Anumba, & Tah, 2011). Distributed data collection framework systems are also implemented in the construction industry to coordinate and process accurate information in construction projects (Vasenev, Hartmann, & Doree, 2014). Augmented reality (AR) is becoming popular in regular life and within the construction industry as well. It is considered to be the latest trend in the modern world, operating under the umbrella of natural user interface (NUI), cloud computing, localization and mobile devices. All these technologies can change the classic face of the construction industry (Chi, Kang, & Wang, 2013). Construction laser scans and 3D/4D printing has changed traditional construction techniques by being more accurate and optimizing time reduction management. The planes can be separated from the model by using cloud computing data techniques (Bosché, 2012). There are currently several materials selection products that are involved in the different states across the country i.e. Beam, Data-build, 12D etc.

1.8 Research Motivations

One of the main issues faced by people trying to buy or build a new home is the large cost involved in the traditional construction method and the usage of traditional construction materials. There is a huge gap between conventional materials selection practice and the application of sustainability principles in the current decision-making process. To bridge this gap, provide cost relief for new homeowners and promote innovation in the field of residential building construction, this research will provide a new selection model by incorporating the existing principal determinants of sustainability into the decision-making process using multi-criteria decision making (MCDM) techniques.

1.8.1 Slow

The building of a house takes a significant amount of time due to traditional building methods, such as double-leaf wall construction, and other delays in the construction process. Approximately 50% of the total construction time can be saved if newer techniques, such as insulated panel construction, are used instead; this is because insulated panels can be installed as a complete wall assembly rather than placing separate pieces of framing, insulation and sheathing. Its insulating values are also much better than the traditional brick wall system. Pre-built panels also reduce costs due to delays, waste, and theft of uninstalled materials at the construction site (Medina, King, & Zhang, 2008).

1.8.2 Construction waste

Construction waste materials being sent to the landfill, during both the construction and demolition processes, is one of the most discussed problems in the construction industry. Serious concerns have been raised in regard to environmental pollution and the effect it has on global temperature rise. The main waste material is concrete, creating almost 81%

of the overall waste generated in the Australian construction industry. Recycling used concrete is therefore the best way to solve this issue (V. W. Tam, 2009). The construction industry in Australia is contributing to the 15% of total waste generated by the construction industry all over the world. The Australian Government is taking this issue seriously with the collaboration of the other countries but there is still a long way to go. In the year 2000, there was the landmark achievement of generating 50% less waste (Mcdonald & Smithers, 1998).

1.8.3 High labour cost

In addition to the busy schedule of the labour force, it is also more expensive when compared to the other construction practices like sips, earth construction and bottled homes. As per the 2009 stats, the average weekly rate of a construction labourer is AUD 989.50, this is considered to be one of the highest rates for workers (Wright & Lansbury, 2014). Construction labour expenses have added more difficulties for the house buyer or new house building owner.

1.8.4 Scarcity of labour

As there is so much work available and there are no alternative methods of construction being applied to the construction industry in Australia, the labour force are continually occupied. A new home owner often has to wait for 6 months or more for construction to begin on their house. Quality issues can also occur as the labour force rush to catch up with the demand for new work or unskilled and unwell people are used to meet the demand of the new construction.

1.8.5 Reluctance to change

Due to heavy investment and long-standing traditions both the owner and the labour force are often reluctant to accept new technology to replace the classic ways of construction. The stakeholders stick to the old fashioned way of construction due to major two reasons; firstly, they do not want to take the risk of investing in new technology and practices. Secondly, the local labour force is not well versed with these new techniques and they have less knowledge and experience with the new innovative and sustainable construction materials. This research work will help to find out the detailed literature review and process to rank the sustainable construction materials in detail.

1.8.6 Limited innovation

In the local construction industry, there are very few attempts to develop the knowledge of innovation and new technology for both the construction techniques and the new innovative and sustainable materials.

New construction trends are being introduced through collaboration and by sharing these techniques among builders. Studies have proved that by this process better and more augmented productivity results are achieved. The design process should include the value engineering and lifecycle costing, procedures and information should be formalised, and more emphasis should be made on value-added project management (Fulford & Standing, 2014). Low carbon prefabricated modular construction system using solid wood panels, such as cross-laminated timber panels, is the new growing trend in the modern construction industry however, the local market is still disinclined to adopt this change despite this process being introduced in Europe in 1996. This method can be used to create buildings from 4 to 10 storeys (Lehmann, 2013). The prefabrication housing industry is creating a new impression in the residential construction industry in Australia; it has proved its prominence by being systematically profiled and guided by theoretical systems (Steinhardt, Manley, & Miller, 2013). Some of the latest sustainable construction methods and materials selection trends are also being introduced include cladding systems, concrete slab floors, insulating concrete forms, autoclaved aerated concrete, precast concrete, mud bricks, rammed earth, straw bales, and green roofs and walls.

1.9 Research Aims and Objectives

The primary objective of this research is to develop an effective system for assisting technical experts (estimators, architects, engineers, draft persons, and designers) in the decision making process of selecting construction materials in an automated/semi-automated way, for different building components, such as the walls, roof, and slab, under given constraints of cost, time, site orientation and sustainability, to improve their work processes. This will require a comprehensive analysis of the existing decision making approaches used in the market. A decision-making model will be developed to deal with the issue of sustainability during the design and execution stages of construction.

1.10 Research Primary Objectives

The following are the key research questions that will be investigated as part of this research:

1. To understand how the technical experts, such as estimators, architects, designers, and draftsmen, evaluate and select construction materials for a project.

2. To identify the basic selection criteria used by the technical experts in construction materials selection.

3. To assess the current materials selection practice and identify problems that can be solved to enable technical experts to make effective decisions.

4. To develop a method/system to recommend appropriate construction materials in an automated/semi-automated way.

1.11 Research Significance

1.11.1 Social

The proposed system will provide the end-user with leverage to make an economical and sustainable selection of construction materials. The social effects are long-lasting as the materials used will be in place permanently. The estimators and architects will able to select the most appropriate materials as per their requirements more easily and the end-user (customer) will have the satisfaction that their money is being best utilized by choosing the best products. This system will help society to improve overall living standards and peace of mind.

1.11.2 Economic

The implementation of sustainability in the choice of construction materials and techniques will also increase the overall economic strength by providing cheap sources of energy generation (solar panels) and using sustainable construction materials for operational savings. Many of those materials are derived from materials already in use making them more cost-effective, resulting in more savings for the end-user i.e. ash concrete, husk panels, mud brick and straw bale. These homes are more sustainable and are overall more aesthetically pleasing.

1.11.3 Technical

Architects can input their building plan in the proposed system, which will then parse the building plan and identify the features of the building including different wall structures, windows, doors, and architraves to make a categorised list. This research will theoretically introduce the major artefacts for the selection of appropriate construction materials based upon given constraints such as cost, energy efficiency and sustainability. This will develop a new, significant and innovative approach in the materials selection domain. This will then advance the body of knowledge in the area of energy-efficient buildings, smart buildings, and technology support for energy optimization in buildings.

1.11.4 Environmental

The proposed system will assist estimators and architects in selecting environmentally friendly products for construction. This system will also offer assistance to others in selecting an appropriate combination of materials that is environmentally friendly, sustainable and energy-efficient. As a result of using this system, adverse health-related issues can be minimized as the proposed system will not recommend the use of harmful products e.g. asbestos, which can cause respiratory and skin diseases. The theoretical significance can be measured using the facts and detailed literature review in the field of sustainable materials selection process. The basics provided for the ranking of sustainable construction materials used in the pilot project can also be used in practical professional projects. This study syndicates the missing link in the literature regarding the current practices used in the local market for the classic building materials selection process and the sustainable materials selection process.

1.12 Chapter Summary

This chapter gives the background information of this research and explains why this research is undertaken and its significance to the construction industry. It illuminates the research aims, objectives, research questions and methods adopted to carry out this research. This research involves quantitative and qualitative data and the method adopted in this research is comprised of a combination of both strategies. This chapter contains the research significance concerning the different facets such as social, economic, technical and environmental. The overall thesis structure is explained in flow chart form.

1.13 Thesis Structure

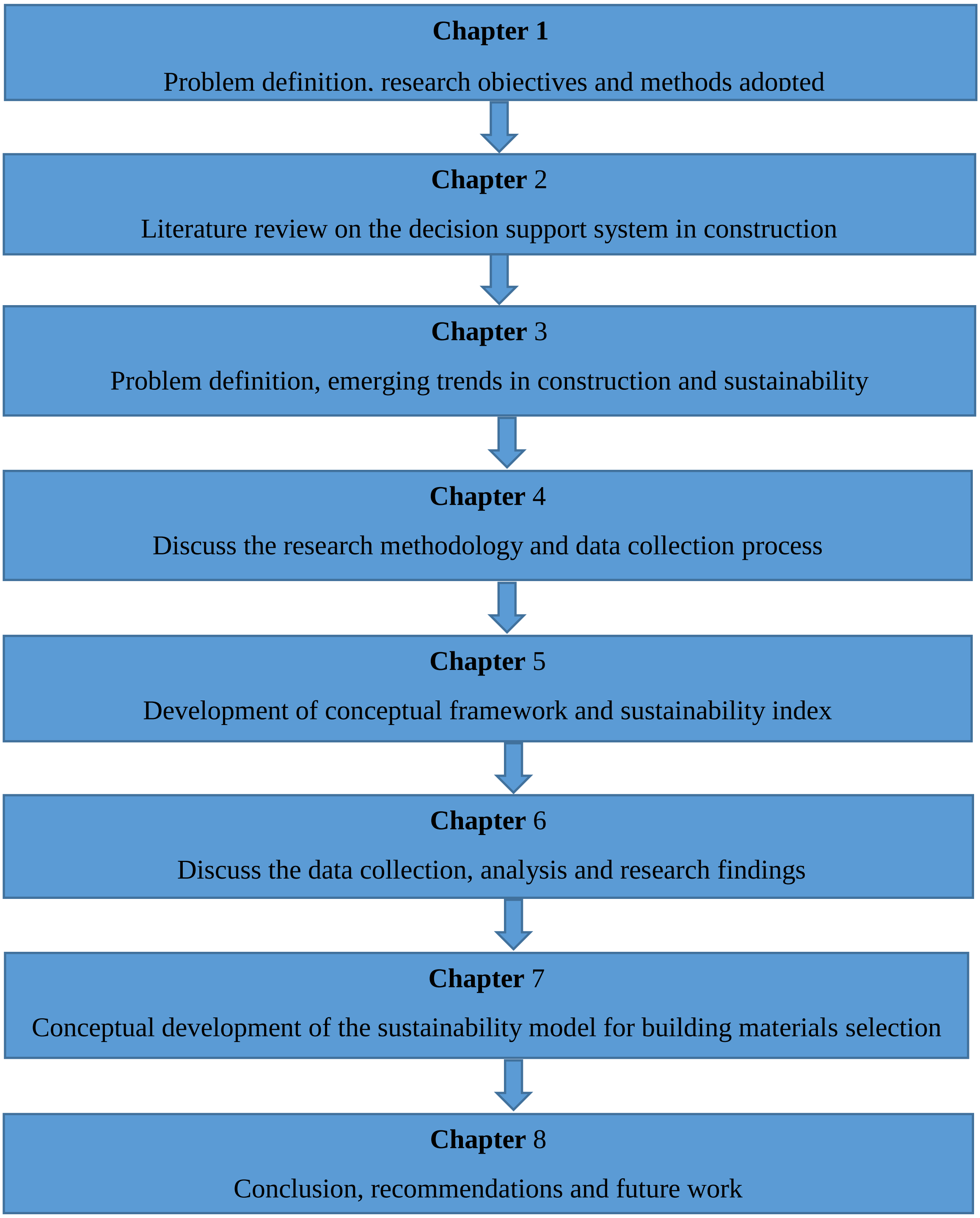

Figure 1.1: Thesis structure

CHAPTER 2

LITERATURE REVIEW

This chapter covers:

- Introduction to decision support system in construction
- Distribution of publications based upon different categories
- Data collection and methodology adopted
- MCDM techniques, usage in construction

2.1 Chapter Introduction

The construction industry has completely changed its orientation by adopting the latest technologies for different phases including the design, execution and operation. Each phase has its importance; the selection of the right design parameters is considered as the backbone of the construction phase, and the selection of appropriate construction materials satisfying the design and operational specifications has its unique value as well. The technological shift has made the construction process more demanding in terms of excellence and perfection, thereby making the jobs of the technical personnel more demanding and challenging. The construction industry is currently undergoing significant innovations. A bibliometric analysis approach is used to review the progress in data management of decision support systems in the construction industry. Research hotspots in the area of decision support systems are also identified. Future research directions in the field of decision support systems in construction are proposed by using the data from two major databases: Scopus and Web of Science (WoS).

Information technology is playing an unprecedented role in making construction tasks more precise, accurate and fast. By utilising innovative information systems, neural networks, decision support and expert systems, the work of technical stakeholders and managers has become much easier and more accurate. Right from the start, the design software has been injecting new spirit into the modern construction practices; some of the software includes AutoCAD (Rosenman & Wang, 2001), BIM (Elmualim & Gilder, 2014), (Volk, Stengel, & Schultmann, 2014), SAP 2000 (Moon, 2008), Etabs (Bank, Thompson, & McCarthy, 2011), and Revit. For construction execution, control and monitoring, Primavera (S. H. Lee, Peña-Mora, & Park, 2006) and Build soft (Williams, 2015) are good examples of the applicable software This extraordinary pace and innovativeness has made the decision-makers' job more hectic and tedious. Thus, information technology has to assist them by developing decision support systems that will make their tasks easier and the outcomes more accurate. This can also be done by providing the evaluation and fusion of construction alternatives by means of technical, financial, managerial, and economical support.

Over the last two decades, a significant number of scientific articles have been published concerning decision support systems in construction. These have addressed several critical issues such as optimal cost analysis using multi-objective optimization of building energy performance. These researches have been conducted to determine the most appropriate and most cost-effective combination of energy management measures (Ascione, Bianco, De Stasio, Mauro, & Vanoli, 2015). Since the construction industry is a large consumer of energy, concerted efforts are being made to monitor this energy management. In the construction industry, life cycle analysis (LCA) is a much-discussed issue. LCA requires diverse approaches as buildings have different functions, sizes, materials and locations. This method is based on ISO 14040 standards with different scopes, aims and limitations (Rashid & Yusoff, 2015). The retrofitting of façades is also intended to address the issue of energy saving and management. Architects and engineers must make critical decisions during the design phase. Nowadays, LCA is widely used to manage energy conservation from the outset. This has led to the inclusion of a number of the latest technologies in new constructions such as double-faced ventilation, improved cooling and heating, integrated photovoltaics and green facades (Ochoa & Capeluto, 2015). Both construction design and management are central to decision making in construction. Cost-benefit analysis is considered the best approach to adopt for appropriate decision-making (Turskis, Zavadskas, & Peldschus, 2009). Time, cost, and quality are important criteria that must be applied during the planning phase of construction, using an evidential reasoning approach (Monghasemi, Nikoo, Fasaee, & Adamowski, 2015).

However, what is missing is a thorough bibliometric analysis of the literature to systematically study the field and understand the research growth and research trends over the last two decades.

Bibliometric analysis is basically "a set of mathematical and statistical methods used to analyse and measure the quantity and quality of the books, articles and other forms of publications" (Durieux & Gevenois, 2010). This is also described by Henk F. Moed as a "subfield of quantitative science and technology studies aimed to construct the indicators of research performance from a quantitative research analysis of scientific-scholarly documents" (Moed, 2009).

There are three types of bibliometric indicators: "1) quantity indicators which measure the productivity of particular researcher, 2) quality indicators, which measure the quality (or performance) of a researcher's output, and 3) structural indicator which measure the connections between publications, authors, and areas of research" (Durieux & Gevenois, 2010).

At times it is difficult to forecast the emerging technologies because there no historical data is available, in which case a bibliometric analysis is the best tool to forecast emerging technologies and future research directions (Daim, Rueda, Martin, & Gerdsri, 2006).

A bibliometric analysis is intended to explore insights on a specific topic utilizing statistical data analysis and content analysis to determine future research directions. Such an in-depth analysis provides a better understanding of the quantitative, qualitative and structural aspects of literature as several aspects are investigated: the total number of articles published per year, annual growth, doubling time, top contributing countries, most occurring keywords, well-known researchers, most cited articles, average citations, international collaborations etc.

The key objectives of this work are: 1) to conduct quantitative analysis of the literature in the area of decision support systems for the construction industry (e.g. identifying major contributing countries, authors, institutes, etc.); 2) to conduct a qualitative analysis of the literature (e.g. keyword analysis, degree distributions etc.); 3) to conduct structural/network analysis of the literature (e.g. citation analysis, complex network analysis); 4) to develop a taxonomy/classification of literature based upon content analysis, and 5) to identify future research directions for this field.

The remaining sections are organized as follows: the "literature review" gives a comprehensive account of research progress up until the year 2016. "Data collection and methodology" explains the data collection and research processes adopted in this study. "Results and discussion" explains the key findings from the analysis and future research direction. The "Conclusion" includes a discussion of the contributions made by this study to the existing body of literature in this field.

Construction is a strong indicator of the level of progress of any country. In recent years, the selection and use of sustainable construction materials in building and commercial construction projects have received a great deal of attention. Decision support systems assisted a lot in this process. To analyse this topic in-depth and provide insights, a systematic bibliometric analysis of the literature is carried out in this study, based on the papers published between 2000 and 2016. The data is collected from the two major databases: Web of Science (WoS) and Scopus, consisting of 2185 and 3233 peer-reviewed articles, respectively. The analysis includes a general bibliometric analysis comprising publications output, the country-specific research output of the data, authorship and collaboration pattern of these published articles. It also covers the citation analysis included (keywords, most cited keywords, organizations, most cited articles and average citations per article) and network analysis (authors, countries). The major highlights of this analysis are as follows: 1) three of the top 10 authors are from China, accounting for 1.125% of 5418 articles; 2) the total citation for Scopus was 21605 and for the WoS 15950 with an average annual citation per paper of 5.216 and 5.75, further the average citation per paper per year were 5.21 and 5.75 respectively; 3) the total number of related articles published has increased gradually; China is at the top with 1030 articles, the USA is second with 991, followed by the UK, Canada and Germany making the top five countries for publications; 4) in the last 17 years (2000-2016) Chinese authors contributed an average of 10.85% of articles in Scopus and 8.15% of articles in WoS; 5) the most-cited articles and the keyword distribution indicate the trends in this field of research. Overall, this study's bibliometric analysis offers valuable insights and future research directions to researchers and practitioners in the field of decision support systems in the construction industry.

2.2 Literature Review

The progress of any country can be measured by the amount of construction that has taken or is taking place. It indicates development in overall GDP value, the involvement of skilled persons in improving their skills, infrastructure betterment and overall improvement of living standards of the general community. Modern ideas of orientation, sustainable construction practices, green buildings and energy management have taken construction standards to new heights. Many certifications and specifications are being applied so that perfection and harmony are ensured in modern-world construction. A great deal of research has been carried out to ensure that the field of construction is evolving to meet current needs and desires. Decision making is crucial in this industry since better and more appropriate decisions can improve the quality of a building and increase profits.

The success or otherwise of a construction project hinges on decision making, which can be challenging given that many of the construction activities may be conflicting in nature and require careful management (Jato-Espino, Castillo-Lopez, Rodriguez-Hernandez, & Canteras-Jordana, 2014). Several key issues must be considered during the decision making about a construction project. These include: energy conservation (Robert & Kummert, 2012) and energy management, as energy consumption, can be reduced by 20% to 30% by optimizing operations and management without changing the building structure and the hardware configuration of an energy supply system (Guan, Xu, & Jia, 2010) during the construction and operational phases of the building (A. Sharma, Saxena, Sethi, & Shree, 2011), (Gustavsson & Joelsson, 2010).

In developed nations, more than 40% of energy (electricity, gas, water) is consumed by the building sector, which raises serious concerns about ways to ensure that buildings become more energy efficient (Gulbinas, Jain, & Taylor, 2014). Energy conservation within a building is also a major influential criterion to consider when planning a precise and profitable construction project. Energy consumption is a critical issue as more than 70% of electricity is consumed by the building sector.

Energy retrofitting reconciles this issue to a greater extent (Syal et al., 2013). Energy retrofitting is the physical or operational change of the building's energy-consuming equipment and devices. Retrofitting involves the upgrade or replacement of old systems within a building with new and improved energy-saving technology and processes (Energy, 2012), (Fulton et al., 2012).

A hybrid decision support system is preferable when office buildings are being renovated and energy-reduction improvements are being made, rather than relying on just one technique because a single technique has its boundaries and limitations (Juan, Gao, & Wang, 2010).

System dynamics is also used as a decision-making tool in building construction. As many diverse technical disciplines are involved in building and construction (i.e., architectural, structural, mechanical and electrical, land development, security etc.), the actual performance of the building cannot be judged by a single metric; hence, a hybrid and robust method needs to be adopted. This can be accomplished by using a system dynamics approach by modelling it as a feedback system of its subsets (Thompson & Bank, 2010).

The latest concepts are also being used in the decision support systems such as data mining which is the process of extracting previously unknown information from textual data. Data and knowledge make up the resources of such a system and are a key link (Gajzler, 2010).

The uncertainty and sensitivity analysis approach is used to validate the simulation tools for the design of buildings because of the need to conserve energy. This is required to evaluate the reliability of simulation and measurement of uncertainty to improve the building design (Hopfe & Hensen, 2011).

The decision-making regarding design can be based on uncertainty assessment (Hopfe, Augenbroe, & Hensen, 2013). An impressive amount of work has been accomplished to revolutionise the construction industry, particularly regarding the development of sustainable industrial areas and the establishment of decision support systems that utilise geographical information systems (GISs) (Ruiz, Romero, Pérez, & Fernández, 2012).

During the operational phase of the building, maintenance is the major resource-consuming factor. Corrective, preventive and condition-based maintenance can solve this issue (W. Shen et al., 2010). The use of alternative techniques and methods are also used extensively to improve construction effectiveness. A multi-attribute decision-making technique can be used to optimize these processes. (Kanapeckiene, Kaklauskas, Zavadskas, & Raslanas, 2011).

The estimate-at-completion (EAC) approach estimates the final cost and compares the estimated construction cost with the actual cost, and assists with decision-making for future construction projects (M.-Y. Cheng, Peng, Wu, & Chen, 2010). Research in modelling and simulation in the construction industry helps the decision-makers to obtain a futuristic insight into the automated project planning and control of construction projects (AbouRizk, Halpin, Mohamed, & Hermann, 2011).

Building sustainability is also an emerging concept being used in the construction world. Sustainability assessment involves a large amount of data sets, parameters and uncertainties. Due to its flexibility, multi-criteria decision analysis (MCDA) has been considered as an appropriate method for carrying out performance evaluation (Cinelli, Coles, & Kirwan, 2014). This analysis enables conclusions to be drawn about the tools, processes, specifications, procedures and methodologies required for consistent performance under the umbrella of sustainability (Poveda & Lipsett, 2011). Green roofing has attracted much interest over the last two decades. The number of articles published during this period increased dramatically, with European countries and the USA driving this research direction (Blank et al., 2013). Vernacular construction pertains more to European countries, particularly those with limited infrastructure development and different landscapes. The recovery of Spanish bioclimatic architecture adopted different materials and construction methods that were more appropriate for local areas (Cañas & Martín, 2004).

2.3 Methodology

The bibliometric analysis describes and analyses up-to-date research and indicates future directions for researchers and practitioners. The latest approaches for the upcoming technologies and spectrum of results-oriented procedures is not a debatable fact. Some researchers find bibliometric analysis to be a useful tool for acquiring comprehensive insights into a specific research area, while others question the validity and reliability of this approach.

Giovanni Abramo said that bibliometric analysis is much more reliable than peer reviews (Abramo & D'Angelo, 2011). Rodrigo Costas stated that bibliometric indicators are very useful for developing research policies and monitoring technological activities (Costas, Van Leeuwen, & Bordons, 2010). Briger related bibliometric method is responsible to recognise the candidate terms and organise the knowledge by relating the scientific papers to their authors and indicating their relatedness and semantic differences (Hjørland, 2013). Diana referred to it as an unparalleled opportunity to take advantage of rich information embedded in the written records of scientific work to track down the output and influence of funded scholars (Hicks & Melkers, 2013). However, other researchers have identified several major disadvantages of this technique. Lutz mentioned that percentile and percentile ranking has limited use when there is the same number of citations for an article. The size of the reference set is always an important factor when setting up the classes for ranking (Bornmann, Leydesdorff, & Mutz, 2013). The H-Index is another measurement that has been debated in terms of its ability to give a true picture of facts and efficacy. This is also limited to the number of articles that are produced over a protracted period, cannot exceed the number of publications produced for even a modest number of papers (Norris & Oppenheim, 2010).

Overall, the biometric analysis provides a vast canvas of knowledge from the micro-level (i.e., institutes, researchers and campuses) to the macro-level (i.e., countries and continents) (Mryglod, Kenna, Holovatch, & Berche, 2013). This technique enables the research directions of various universities to be seen and compared. Citation and content analysis is the most widely-used criteria, and can 1) indicate the citations and trends in a specific field of knowledge, and 2) describe the direction of modern research by showing the most widely used author keywords. In this paper, we ascertained the following major trends: relative growth rate (RGR), doubling time (DT), collaboration index (CI), collaborative coefficient (CC), international collaboration papers (ICP), and most productive institutes and authors under the heading of (TP) and (TC) plot.

The text analysis approach is applied to find out the major research hotspots (Xiaozhong Liu, Zhang, & Guo, 2013). Frequency analysis is used to find the most cited and most frequently occurring keywords in a research area. A topic density plot for the control terms is also drawn to show the major research trends in a particular field. Science mapping is carried out through the VOS viewer tool (N. J. Van Eck, Waltman, Dekker, & van den Berg, 2010), (Cobo, López-Herrera, Herrera-Viedma, & Herrera, 2011).

2.3.1 Data sources and collection

In this study, a bibliometric analysis is conducted of selected journal articles focusing on decision support systems in the construction industry. These articles were obtained from the Scopus and WoS databases, with database access provided by Curtin University, Australia. Bibliometric citation and content analysis were performed to achieve our research objectives. A systematic approach was adopted to search for the articles with the following keywords “Decision support systems in construction”. The search was restricted to the engineering, computer science, environmental science, decision science, soil science, applied energy, applied physics and materials science areas. These fields are the most related to construction and the decision MCDM techniques used for decision support systems. We restricted our data collection to include only articles, reviews, proceedings papers and book chapters published between 2000 and 2016. This research strategy yielded 3233 and 2185 articles from Scopus and WoS respectively. These articles were further narrowed down to construction-related activities and trades involvement, making it easier to handle and direct related and unit-directional literature review.

2.3.2 Data analysis tool

We used the VOS viewer tool to develop certain types of graphs such as those for international collaborations and keywords density distribution. We also used NAILS (Network Analysis Interface for Literature Studies) to categorise the literature data according to subjects, keywords, authors, citations, frequency of occurrence, affiliations, institutes and locations (Knutas, Hajikhani, Salminen, Ikonen, & Porras, 2015).

2.4 Results and Discussion

In this section, various parameters are computed to obtain information from the collected data such as the number of annual publications within the selected time frame, the growth rate, doubling time, authorship and collaboration patterns, major publication areas, and distribution according to the subject.

2.4.1 Publications output (2000–2016)

The publications output is shown in Fig. 1 which depicts the annual number of publications in both Scopus and WoS on decision support systems in construction. In 2000 and 2001, Scopus had 60 articles while WoS had 55 and 51. 2002 showed good improvement with 116 articles in Scopus and 72 in WoS. A dip occurred again in 2003 and 2004, but thereafter the number of publications per year has increased. One interesting observation is that in 2015, more publications appeared in WoS than in Scopus. 2016 showed again the dominance of Scopus articles (279) compared to the WoS (171). Fig.1 shows that there is a continuous increase in the amount of research being undertaken in the field of decision support systems in construction. Although there are some downward trends as well within this stipulated time frame, overall there is a remarkable increase in the number of publications over time.

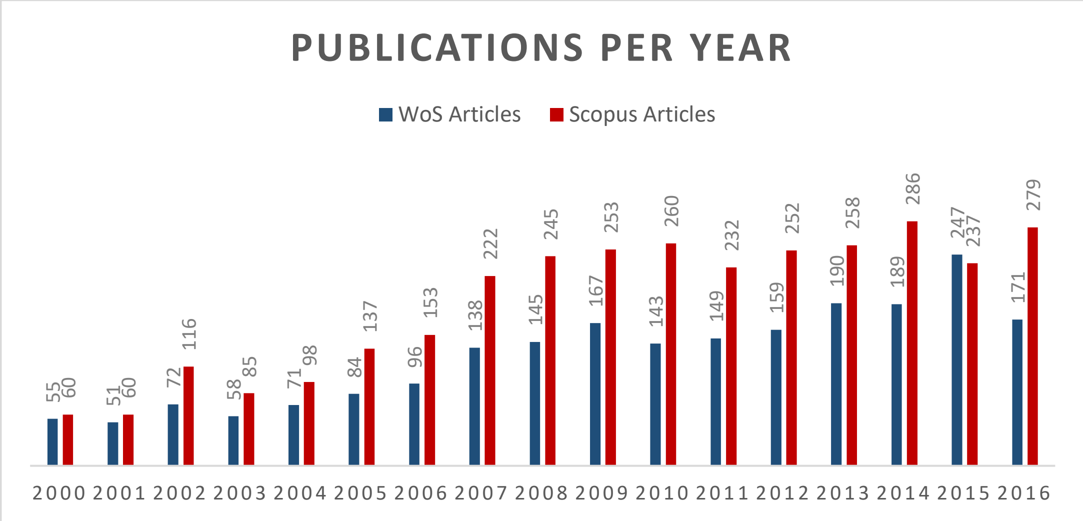

Figure 2.1: Annual research publications in Scopus and WoS on decision support systems

2.4.2 Relative growth rate (RGR)

The growth rate per annum is calculated to find the incremental trend of yearly output and the doubling time of the published articles: that is, the time required to double the total number of articles. In the two databases, both of these parameters are calculated using the formulas mentioned below (V. K. Singh, Banshal, Singhal, & Uddin, 2015). It was used by Mahapatra to find the RGR parameter and its significance (Mahapatra, 1985).

$$\text{Relative Growth Rate (RGR)} = \ln \frac{CN_2}{CN_1}$$

Where CN2 and CN1 are the cumulative numbers of publications each year.

2.4.3 Doubling time (DT)

The doubling time (TD) has a direct relationship with the relative growth rate (RGR). It gauges the time required for the number of publications to double and is Note previous comment. Doubling time shows the growth rate to double the actual number in the subject time (Zhu & Lin, 2004).

$$\text{Doubling Time (DT)} = \frac{\ln 2}{\text{RGR}}$$

Table 2.1 below shows the sequential increment in the research output by cumulative number, relative growth rate (RGR) and the doubling time (DT).

It is evident from the tabular values that there is a significant increase in overall research output. The RGR and DT values are impressive following some fluctuations. RGR and

DT values are showing a clear upward trend for Scopus as well as WoS. This trend shows the significance of this topic and the increasing research interest. WoS shows the incremental increase and decreases as well. Collectively, the table clearly shows that, apart from 2015, most of the articles are in the Scopus database.

Table 2.1: Relative growth rate (RGR) and doubling time (DT)

	Scopus Articles				WoS Articles			
Year	Records	Cumulative	RGR	DT	Records	Cumulative	RGR	DT
2000	60	60	-	-	55	55	-	-
2001	60	120	0.69315	1.00000	51	106	0.65611	1.05646
2002	85	205	0.53552	1.29435	72	178	0.51834	1.33723
2003	98	303	0.39072	1.77401	58	236	0.28205	2.45755
2004	116	419	0.32414	2.13843	71	307	0.26302	2.63538
2005	137	556	0.2829	2.45017	84	391	0.24186	2.86590
2006	153	709	0.24309	2.85143	96	487	0.21956	3.15703
2007	222	931	0.2724	2.54456	138	625	0.24949	2.77828
2008	232	1163	0.2225	3.11528	145	770	0.20864	3.32223
2009	237	1400	0.18547	3.73726	167	937	0.19629	3.53119
2010	245	1645	0.16127	4.29810	143	1080	0.14203	4.88018
2011	252	1897	0.14253	4.86305	149	1229	0.12924	5.36326
2012	253	2150	0.12519	5.53658	159	1388	0.12166	5.69727
2013	258	2408	0.11333	6.11626	190	1578	0.12829	5.40279
2014	260	2668	0.10253	6.76026	189	1767	0.11312	6.12727
2015	279	2947	0.09946	6.96920	247	2014	0.13084	5.29769
2016	286	3233	0.09262	7.48355	171	2185	0.08149	8.50560

2.4.4 Major contributor countries

Table 2.2 shows the top 15 countries that are contributing to research in this field. It is clear from the table that of the 5418 articles, China is leading with a total of 1030 (588, 442) articles, accounting for 19.01% of all contributions. This is to be expected as China has a very high population and its housing and infrastructure extend over a vast region, affecting the overall economy. Being so crowded, it was not easy for China to adopt the construction designs of other countries and be sustainable at the same time. China has a higher population and building density and less reusable energy per square metre of floor area (Zhu & Lin, 2004). Hence, a massive amount of research work has been done in China to find the best solution to this problem. Next is the USA with a total of 991 (602, 389) articles, contributing 18.29%. England is third, contributing 388 (7.161%) articles. Canada contributes 5.44%, Germany 3.82%, and Australia 3.61%. The other contributing countries are shown in Table 2.2. One thing to note is that European countries are predominant in the top 15 major contributors. Europe is the same as China in terms of having less available land with advanced infrastructure. One major problem is the lack of information, necessitating strategies to raise clients' awareness of the latest, innovative and sustainable methods of construction (Häkkinen & Belloni, 2011). The use of natural materials for residential buildings construction is far better than bricks and other processed materials. Timber houses are 7.5% better than brick houses (Medineckiene, Turskis, & Zavadskas, 2010). Many European countries are producing great amounts of waste materials due to demolition and construction work, and its disposal is causing serious environmental problems. Hence, various strategies and laws have been devised to tackle this issue, opening new doors for research on sustainable construction (del Río Merino, Izquierdo Gracia, & Weis Azevedo, 2010).

Table 2.2: Top 15 countries by number of papers published

Number	Country	Scopus Articles	WoS Articles	Total	% of 5418
1	China	588	442	1030	19.01070
2	USA	602	389	991	18.29088
3	England	247	141	388	7.16131
4	Canada	189	106	295	5.44481
5	Germany	127	80	207	3.82059
6	Australia	103	93	196	3.61757
7	Spain	99	89	188	3.46991
8	Italy	103	76	179	3.30380
9	Taiwan	93	74	167	3.08231
10	France	91	54	145	2.67626
11	South Korea	81	61	142	2.62089
12	Poland	73	62	135	2.49169
13	Brazil	83	48	131	2.41786

14	Greece	70	56	126	2.32558
15	Netherlands	69	53	122	2.25175

Fig. 2.2 shows the international collaboration network evident in International Collaboration Papers (ICPs). The graph shows seven clusters each one indicated by a different colour. It shows that China has strong ties with England and Australia, the USA with Spain, Germany with Canada and Canada with Taiwan. Furthermore, China has high ICP instances involving several other countries such as Iran, Singapore, North Ireland and Scotland. Both of the major contributors, i.e., China and the USA, also have close ties and research collaborations in the specific area of decision support systems. Stevan D. Glaser from the University of California USA and researchers at the Hui Li Harbin University of Technology in China and others work in collaboration to design sensor technology innovations to assess and monitor the structural soundness of buildings.

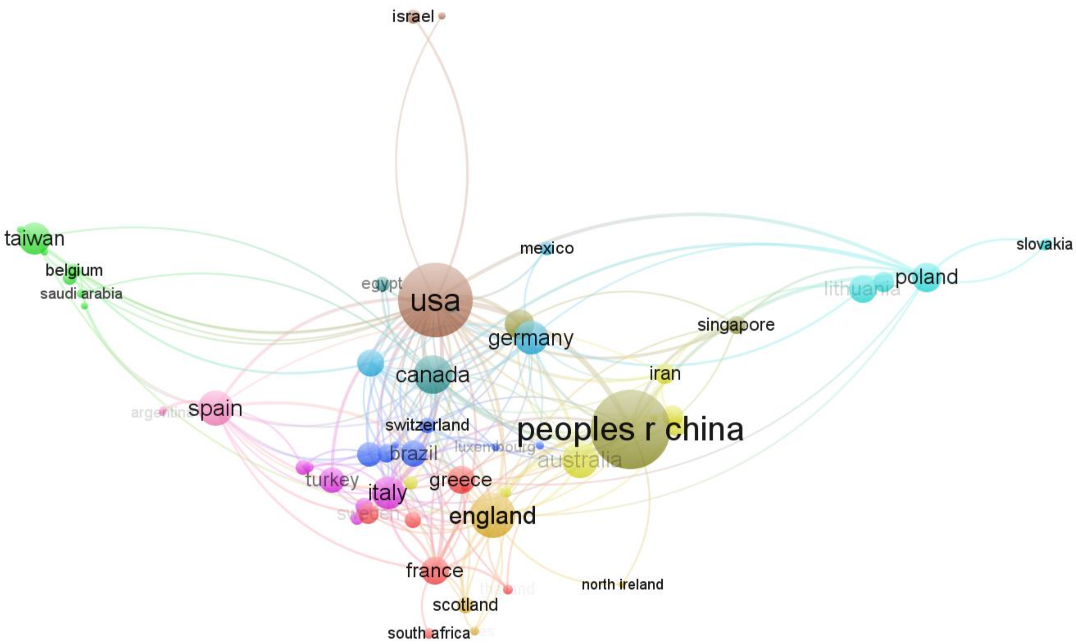

Figure 2.2: International collaboration of countries with at least two published papers and two citations

2.4.5 Authorship and collaboration pattern

To analyse the authorship and collaboration patterns, several important parameters are determined: Collaboration index (CI), Degree of collaboration (DC) and Collaborative Coefficient (CC). These are computed with these formulas:

Collaboration index:

$$\mathrm{CI} = \frac{\sum_{j=1}^{k} fj_j}{N}$$

Degree of collaboration:

$$\mathrm{DC} = 1 - \frac{f_1}{N}$$

Collaborative co-efficient:

$$\mathrm{CC} = 1 - \frac{\sum_{j=1}^{k} \frac{1}{j} f_j}{N}$$

CI measures the mean number of authors per year and has no upper limit. Hence, it cannot be interpreted as a degree (C. H. Liao & Yen, 2012). It gives a non-zero weight for single-authored papers for non-collaborative papers.

Table 2.3: Authorship and collaboration patterns in WoS

No of Publications	**Year**	Authors **1**	Authors **2**	Authors **3**	Authors **4**	Authors **5**	Authors **6**	Authors **7**	Authors **8**	**CI**	**DC**	**CC**	**N>3**
55	2000	10	16	11	10	5	1	1		2.78182	0.81818	0.53680	17
51	2001	9	20	8	9	4			1	2.68627	0.82353	0.51291	14
72	2002	11	27	19	7	4	2	2		2.72222	0.84722	0.52774	15
58	2003	5	20	16	7	3	3	1	1	2.91379	0.91379	0.59567	15
71	2004	8	14	29	11	6	1	1		2.95775	0.88732	0.59259	19
84	2005	12	23	23	8	6	8	1	2	3.09524	0.85714	0.57032	25
96	2006	12	35	32	12	3	1	1		2.64583	0.87500	0.54087	17
138	2007	12	47	33	27	7	10	2		3.05797	0.91304	0.58984	46
145	2008	15	30	50	26	14	5	2	1	3.11034	0.89655	0.60544	48
167	2009	20	49	38	30	19	5	2		2.94012	0.88024	0.58332	56
143	2010	23	35	46	22	8	3	3	1	2.83916	0.83916	0.55254	37
149	2011	28	47	36	20	8	7		1	2.68456	0.81208	0.52086	36
159	2012	20	40	40	29	19	6			2.93711	0.87421	0.58878	54
190	2013	19	56	47	34	14	9	4	4	3.11579	0.90000	0.59717	65

189	2014	18	39	54	45	20	8	2	2	3.25926	0.90476	0.61577	77
247	2015	26	57	72	42	22	17	7	1	3.21053	0.89474	0.60584	89
171	2016	14	41	33	39	25	8	3	5	3.42105	0.91813	0.63370	80

DC measures the multi-authored papers, while f1 is the number of papers written by a single author. Since DC has a value range between 0-1, this can be interpreted as degree (Subramanyam, 1983). It gives the weight of 0 for the single-author papers and 1 for the multi-authored collaborative papers.

CC is used to quantify the collaboration, values range between 0-1 and are shown in Table 3 (Matthiessen, Schwarz, & Find, 2010), where fj is the number of research papers in a specific field of study having j authors. N is the number of research papers, and k is the maximum number of collaborating authors in that field of study. CC differentiates the papers based on multiple authors.

Most of the articles are written by several authors but there is not such a hard line to draw that some specific articles related to some specific fields which are written by some specific numbers of authors as some articles are written by a single author and some are written by one or several authors. The same trend can be observed on both databases. Normally the articles in which experimentation is involved is written by two or more two authors.

Table 2.4: Authorship and collaboration pattern in Scopus

No of Publications	Year	Authors 1	Authors 2	Authors 3	Authors 4	Authors 5	Authors 6	Authors 7	Authors 8	CI	DC	CC	N>3
60	2000	5	9	12	7	3				1.70000	0.91667	0.73583	10
60	2001	6	21	7	6	1	1		1	1.86667	0.90000	0.65292	9
85	2002	9	21	11	8	7	3	1		2.07059	0.89412	0.67989	19
98	2003	7	24	15	4	3	1	1		1.46939	0.92857	0.73562	9
116	2004	15	19	23	11	2			2	1.65517	0.87069	0.69339	15
137	2005	8	26	29	6	8	4		1	1.77372	0.94161	0.74775	19
153	2006	9	30	29	11	5	2		1	1.60131	0.94118	0.75245	19
222	2007	8	53	26	21	12	4	1	1	1.68919	0.96396	0.76689	39
232	2008	15	30	51	22	11	4	2	2	1.83190	0.93534	0.75904	41
237	2009	23	52	38	30	8	5	1	1	1.88186	0.90295	0.69676	45
245	2010	15	23	38	23	10	1	2		1.37551	0.93878	0.80666	36
252	2011	10	36	40	22	9	5	1	2	1.53968	0.96032	0.80214	39
253	2012	7	40	36	32	14	5		2	1.73518	0.97233	0.79888	53
258	2013	12	34	45	35	10	4	2	1	1.74806	0.95349	0.78361	52
260	2014	9	26	29	33	17	3	2		1.52692	0.96538	0.83038	55

279	2015	25	58	65	48	31	16	8	4	3.10753	0.91039	0.64811	107
286	2016	22	61	51	44	31	15	2	2	2.61538	0.92308	0.68624	94

2.4.6 Top 10 contributory authors

Table 3 shows the top 10 contributing authors together with their affiliated institutes. Interestingly, this table shows that the top three authors are from Lithuania and Canada, which rank low in the list of contributing countries. "Zavadskas Ek" is at the top with 42 articles accounting for .77% of all 5418 articles considered for the period of interest. This is followed by Abourizk, S. and Kaklauskas, A. Both of them share second place, having produced 32 articles each, or .59% of the total. Cheng, M.Y. is in third place with 25 (.46%) articles. These top 10 authors have contributed 4.59% of the total 5418 articles.

Table 2.5: Top 10 authors with publications and affiliations

Authors	Affiliation	Scopus	WoS	Total	% of 5418
Zavadskas Ek	Vilnius Gediminas Tech University, Vilnius, Lithuania	19	23	42	0.77519
Abourizk, S.	University of Alberta, Hole School Construct Engineering & Management, Department of Civil & Environment Engineering, Canada	24	8	32	0.59062
Kaklauskas, A.	Vilnius Gediminas Tech University, Vilnius, Lithuania	11	21	32	0.59062
Cheng, M.Y.	National Taiwan University of Science & Technology, Department Construct Engineering, Taipei, Taiwan	13	12	25	0.46142
Skibniewski, M.J.	Department of Civil & Environmental Engineering University of Maryland, College Park, USA	13	11	24	0.44297
Zhang, L.	Huazhong University of Science & Technology, School of Civil & Mechanical Engineering, Wuhan, Hubei, China	12	9	21	0.38760
Shen, Q.	Hong Kong Polytech University, Department Building & Real Estate, Kowloon, Hong Kong, China	8	13	21	0.38760
Wu, X.	Huazhong University of Science & Technology, School of Civil & Mechanical Engineering, Wuhan, Hubei, China	9	10	19	0.35068
Papageorgiou, E.I.	Technological Education Institute Lamia, Department of Information & Computer Technology, Lamia, Greece	9	9	18	0.33223
Fan, H.	Yonsei University, Department of Civil & Environmental Engineering, Seoul, South Korea	7	8	15	0.27685
Total		125	124	249	4.59578

The following Fig. 2.3 indicates the international collaboration of authors who have at least two published articles with a minimum of two citations in 14 clusters represented by different coloured spheres. The collaboration graph shows clearly that Skibniewski, M.J. has collaborated with Hong T. and Zang C., while there is strong collaboration between Shen Q. and Li H.

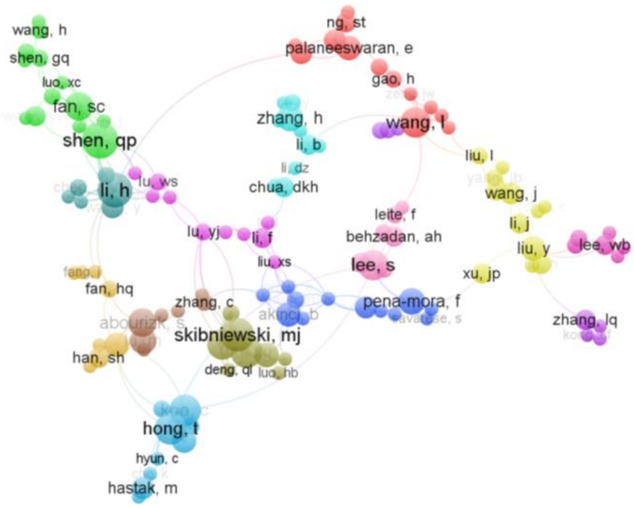

Figure 2.3: International collaboration of authors with at least two published papers and two citations

2.4.7 Top 10 contributing institutes

Table 4 shows the top 10 institutes that have contributed the highest number of articles during the research period of 2000 to 2016, with corresponding percentages. Interestingly, Hong Kong universities are included in the top 10, although Hong Kong does not appear in the list of the top 15 contributing countries. Hong Kong Polytechnic University (45, 1.39%) shares the first position with the University of Alberta, Canada (45, 1.39%); of the rest, The University of Hong Kong (26, 0.80%) is at number six and the City University of Hong Kong is at number nine with 22 (0.68%) articles in Scopus while Hong Kong Polytechnic University (39, 1.78%) is at number two, City University of Hong Kong (24, 1.10%) is at number four, and University of Hong Kong (21, .96%) is at number six in the WoS database. Vilnius Gediminas Technical University, Lithuania (51, 2.33%) is at the top in WoS. Huazhong University of Science and Technology, China (30, 0.93%) is at number three and Tsinghua University, China (24, 0.74%) is at number seven in the Scopus database. The Huazhong University of Science Technology, China (23, 1.05%) is in the fifth position and the Chinese Academy of Sciences, China (21, 0.96%)

is at number eight in WoS. Purdue University, USA (29, 0.90%) is at number four and the University of Maryland, USA (23, .071%) is at number eight in Scopus. Florida State University System, USA (21, 0.96%) is at number seven and the University System of Maryland, USA (19, 087%) is in 10th position. China and the USA are both in top positions in the Scopus and WoS databases. The remaining institutions in the top ten list include those in Taiwan and Singapore.

Table 2.6: Top 10 contributing institutions

Scopus	Articles	% of 323	Web of Science	Articles	% of 2185
Hong Kong Polytechnic University, Hong Kong	45	1.39	Vilnius Gediminas Technical University, Lithuania	51	2.33
University of Alberta, Canada	45	1.39	Hong Kong Polytechnic University, Hong Kong	39	1.78
Huazhong University of Science and Technology, China	30	0.93	National Taiwan University of Science Technology, Taiwan	28	1.28
Purdue University, USA	29	0.90	City University of Hong Kong, Hong Kong	24	1.10
National Taiwan University of Science and Technology, Taiwan	29	0.90	Huazhong University of Science Technology, China	23	1.05
The University of Hong Kong, Hong Kong	26	0.80	University of Hong Kong, Hong Kong	21	0.96
Tsinghua University, China	24	0.74	Florida State University System, USA	21	0.96
University of Maryland, USA	23	0.71	Chinese Academy of Sciences, China	21	0.96
City University of Hong Kong, Hong Kong	22	0.68	Yonsei University, South Korea	19	0.87
National University of Singapore, Singapore	22	0.68	University System of Maryland, USA	19	0.87

2.4.8 Citation details of articles

Figure 2.4 shows that of the total number (5418) of relevant articles published during the period of interest, Scopus has 21605 citations, while WoS has 15950; per year, Scopus has an average of 1270.88 citations, and WoS has 938.23.

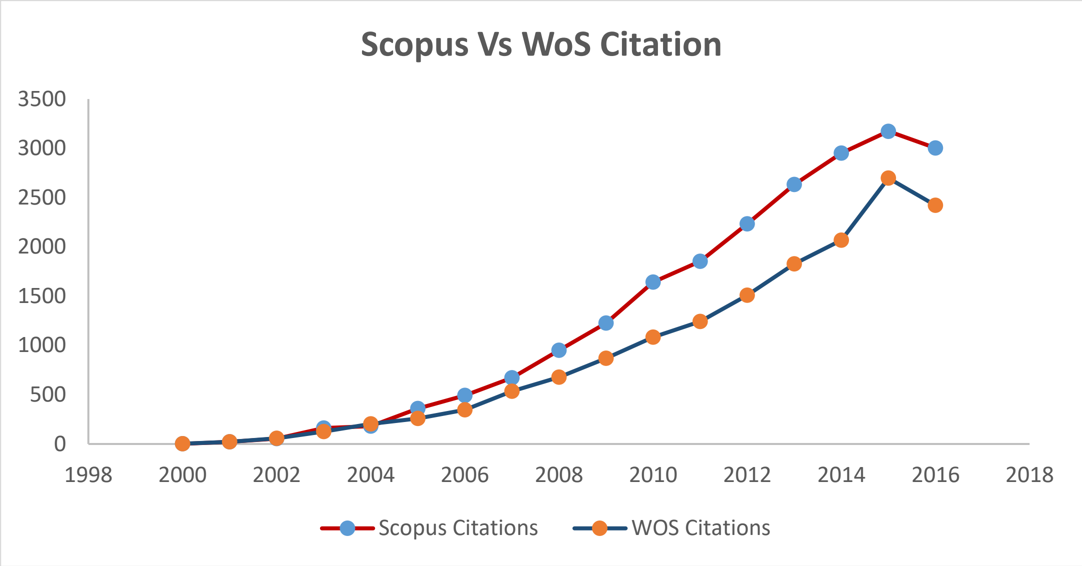

Figure 2.4: Total number of citations per year during 2000–2016

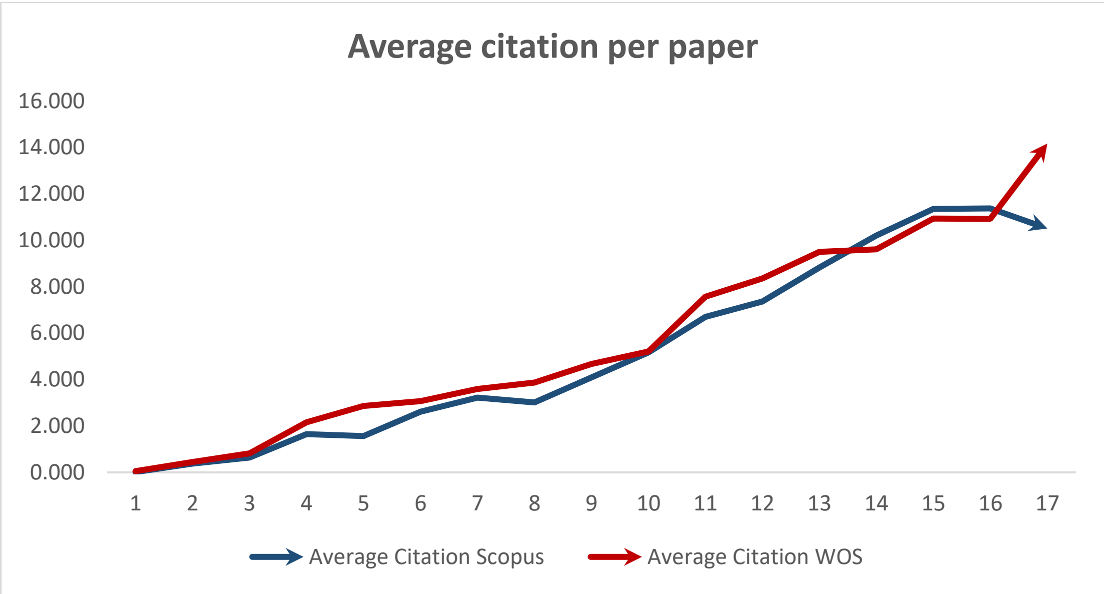

Figure 2.5: Average citations per year per article: Scopus with 5.216 and WoS with 5.75

2.4.9 Top 25 most frequently occurring keywords

Table 2.7 shows the top 25 most frequently-occurring keywords in both Scopus and WoS during 2000-2016, arranged in descending order. We identified high-frequency significant terms (control terms). It is evident from the table that “decision support system”, decision support systems” and “decision support” are the most frequently occurring keywords in both Scopus and WoS. These are followed by “data mining”, “decision making” and “simulation”. We used the VOS viewer tool to visualize the density of occurring of the keywords. Fig. 2.6 represents the density visualization of

Scopus, and Fig 2.7 shows that of WoS; both have at least five occurrences. It also shows significant research keywords appeared in both databases.

Table 2.7: Top 25 author keywords from Scopus and WoS

Keywords	Scopus	Keywords	WoS.
Decision support system	116	Decision support system	141
Decision Support	96	Decision support systems	120
Decision support systems	88	Decision Support	80
Data mining	47	Decision making	53
Decision making	44	Construction	48
Simulation	44	Simulation	47
Construction management	38	GIS	41
GIS	35	Construction management	36
Construction management	34	Ontology	35
Ontology	29	Fuzzy logic	33
Project management	26	Sustainability	32
Construction Industry	26	Knowledge management	31
Fuzzy logic	25	Project management	30
Optimization	24	Decision-making	30
Artificial Intelligence	23	Artificial Intelligence	29
Sustainability	23	Optimization	24
Expert system	20	Construction industry	23
Classification	20	Expert System	20
Uncertainty	18	DSS	19
Automation	15	Data warehouse	18
Data warehouse	15	System dynamics	18
BIM	14	Database	14
Information management	13	Model	13
Planning	13	Planning	11
Risk	11	Risk	11

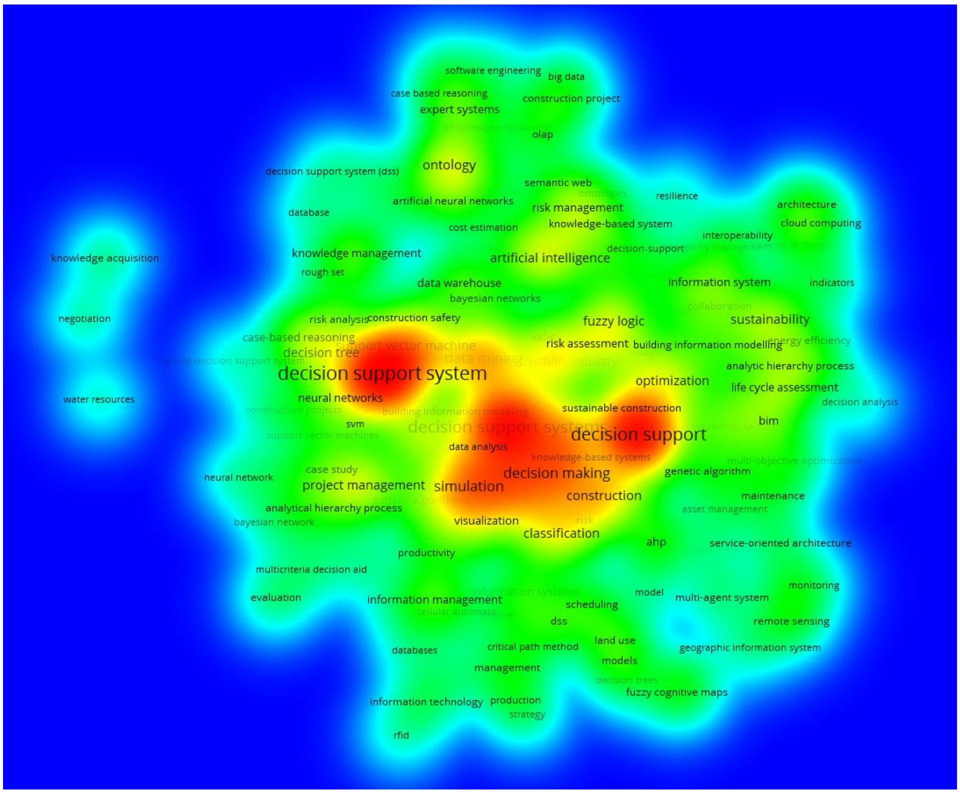

Figure 2.6: Scopus density visualisation of keywords showing at least five occurrences

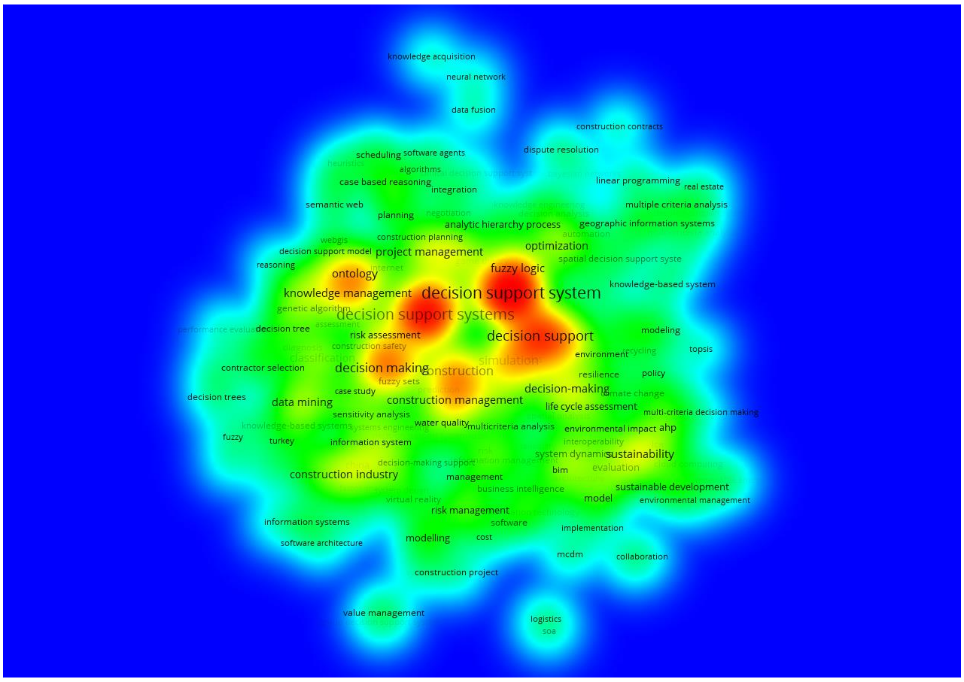

Figure 2.7: WoS density visualisation of keywords showing at least five occurrences

2.4.10 Inter-topic distance map (Latent Dirichlet Allocation [LDA])

We used the Latent Dirichlet Allocation (LDA) technique which is based upon the notion that the probability of words can be expressed as a mixture of topics where each topic is a probability distribution over words. We utilized the popular LDA model proposed by Blei et al. in 2003 (Blei, Ng, & Jordan, 2003). In LDA, data collection is carried out in three major steps: for given papers, a distribution over the topic is sampled from Dirichlet distribution. For each word, a single topic is selected according to this distribution, each word is sampled from a multinomial distribution of words specific to the sampled topic (Hassan & Haddawy, 2015). Figure 2.7 shows an inter-topic distance map via multidimensional scaling. It shows a graph with six circles representing different topic selections. We expanded each topic and found the frequency distribution of each word that appears in each topic selection. Fig. 2.8 shows the ten words that most frequently appear for each topic, and the top 30 most salient terms. The words 'clinical', 'cycle', 'decision', 'information', 'maintenance' 'model', 'projects', 'sustainability', and 'systems' appeared in almost every topic distribution and feature strongly under each selected topic.

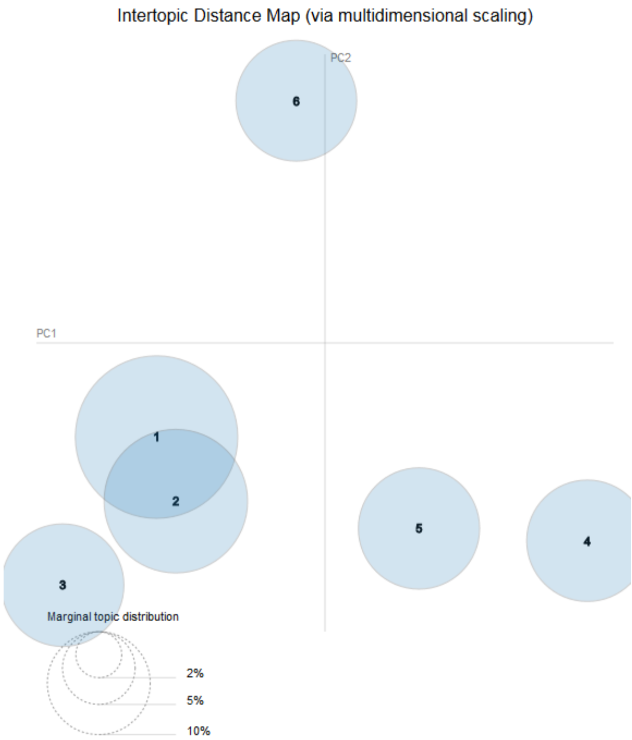

Figure 2.8: Depiction of inter-topic distance

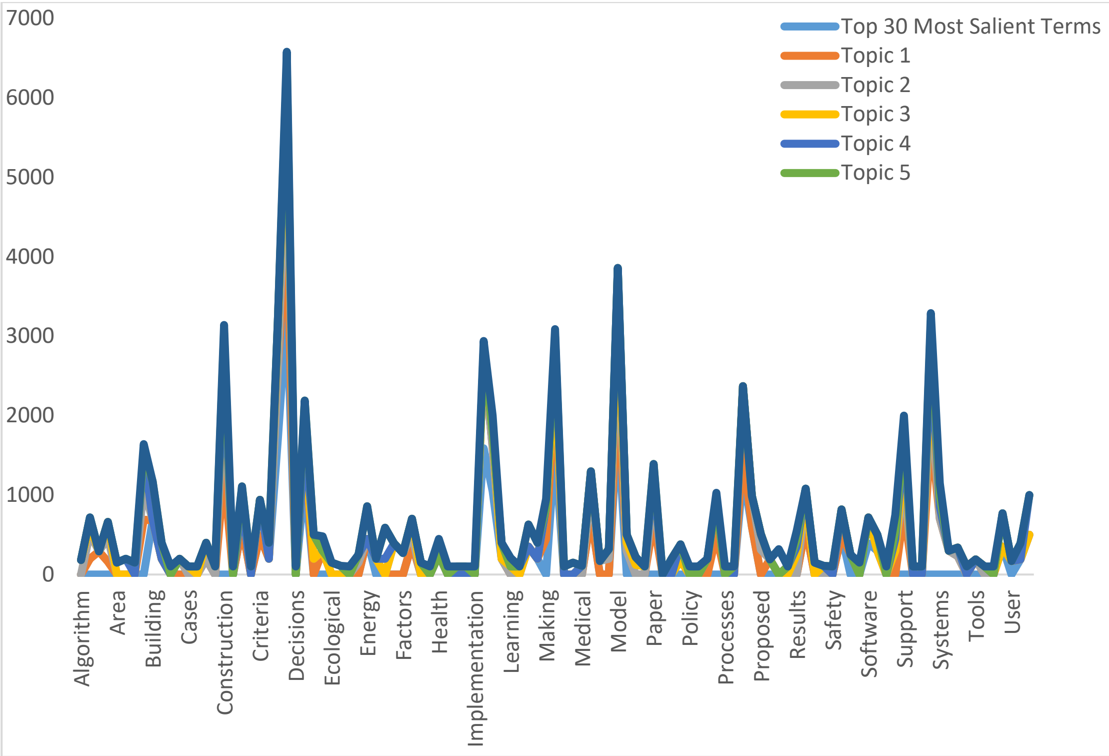

Figure 2.9: Topic distribution

2.5 Detailed Analysis of the Literature

2.5.1 Multi-criteria decision making (MCDM)

Multi-criteria decision-making techniques have been used in diverse disciplines. They have also been adopted in the building and construction sector to address several different problems such as supplier evaluation (Ho, Xu, & Dey, 2010), contractor prequalification (Ho et al., 2010), (Plebankiewicz, 2012) tower crane selection (Prasad, Zavadskas, & Chakraborty, 2015), construction equipment selection (Shapira & Goldenberg, 2005), (Hadi-Vencheh & Mohamadghasemi, 2015) decreasing inherent risk in construction projects (KarimiAzari, Mousavi, Mousavi, & Hosseini, 2011), people occupancy detection and profiling with 3D detection sensors for the energy management of the buildings (Yazdani-Chamzini, 2014).

Table 2.8 lists the MCDM techniques that we have derived from the literature. The table shows the approach, lists the relevant literature and outlines the problem that is being addressed. These methods are listed alphabetically. Each method and the relevant literature are described to gain in-depth insights into the current state-of-the-art research.

Table 2.8: Survey of multi-criteria decision-making techniques

Method	Description	Problems Addressed
Analytic Hierarchy Process (AHP)	Used as MCDM problems pairwise comparison scale.	(Darvish et al., 2009)➔ contractor selection (Ho, Xu, & Dey, 2010) ➔ supplier evaluation (Pan, 2008) ➔ construction method's preferences by using AHP + FSs (Akadiri, Olomolaiye, & Chinyio, 2013) ➔ sustainable building materials selection
Analytic Network Process (ANP)	Generalization of AHP and enables the existence of interdependencies among criteria	(Ho et al., 2010) ➔ supplier evaluation (R. Venkata Rao, 2008) ➔ materials selection for polymer electrolyte fuel cell (Bobylev, 2011) ,` (K. F. R. Liu & Lai, 2009) ➔ environment impact assessment by using ANP+FSs
Complex proportional assessment (COPRAS)	A stepwise method of ranking alternatives according to significance and degree of utility.	(Chatterjee & Chakraborty, 2012), (Chatterjee, Athawale, & Chakraborty, 2011) ➔ materials selection for gear manufacturing and Cryogenic storage tank, (Bitarafan, Hashemkhani Zolfani, Arefi, & Zavadskas, 2012) ➔ worked on the utility of usage of cold form steel structures using AHP+COPRAS+GST
Dominance based rough set approach (DRSA)	It defines the MCDM problem through a series of inference rules of type if ….then.	(Ullah & Harib, 2008), (Kadziński et al., 2016) ➔ worked on materials selection for Robotics manufacturing
Elimination et choix traduisant la realite (ELECTRE)	Group of techniques used to outrank a set of alternatives by determining their concordance and discordance.	(Chatterjee, Athawale, & Chakraborty, 2009) (Shanian & Savadogo, 2006) ➔ materials selection for mass-produced non-heat-treatable cylindrical cover, sailing boat (Ka, 2011) ➔ worked on construction site selection using ELECTRE+FSs+AHP
Fuzzy sets (FSs)	Extension of the traditional concept of crisp sets states that the belongingness of an element to a set may vary within the interval.	(Cicek & Celik, 2010), (Kumar & Singal, 2015) ➔ materials supplier selection model (Golestanifar, Goshtasbi, Jafarian, & Adnani, 2011) ➔ rock excavation model (Lam et al., 2010) ➔ construction project selection model
Grey System theory (GST)	Philosophy of handling the data according to the information contained in them from black (no information) to white (complete information).	(Maity, Chatterjee, & Chakraborty, 2012) ➔ worked on cutting tools materials selection model (Bitarafan et al., 2012) ➔ worked on the usage of cold form steel for remedial works using AHP+COPRAS-G+GST
Multi-attribute	Methodologies are used to make the decisions by comparing the utility	(R. V. Rao & Patel, 2010) ➔ worked on materials selection for high-speed naval craft

Method	Description	Problems Addressed
utility theory (MAUT)	values in the set of risks and uncertainty.	(Sanayei, Farid Mousavi, Abdi, & Mohaghar, 2008) ➔ suppliers selection
Multi-attribute value theory (MAVT)	It converts the attributes forming an MCDM problem into a single value through the so-called value function.	(Shanian & Savadogo, 2009) ➔ worked on materials selection of mass-produced non-heat-treatable cylinder (Hostmann, Bernauer, Mosler, Reichert, & Truffer, 2005) ➔ river rehabilitation modelling
Preference ranking organization method for enrichment of evaluations (PROMETHE)	Family of outranking methods based on the selection of a preference function for each criterion of each attribute multiplied by their weights.	(Pohekar & Ramachandran, 2004) ➔ energy planning (Chatterjee & Chakraborty, 2012)➔ materials selection for gear manufacturing (Gervásio & Simões da Silva, 2012) ➔ bridge assessment using Fuzzy+AHP+PROMETHE
Technique for order of preference by similarity to ideal solution (TOPSIS)	It gives a relationship of alternative with closest to ideal solution.	(Maniya & Bhatt, 2010), (Shanian & Savadogo, 2006), (Jee & Kang, 2000) ➔ materials selection of flywheel using FSs+TOPSIS (Şimşek, İç, & Şimşek, 2013) ➔ worked on self-compacting concrete
Visekriterijumska optimizacija I kompromisno resenje (VIKOR)	Method for determining the compromise ranking-list of a set of alternatives according to the measure of closeness to the ideal solution.	(Chatterjee et al., 2009) ➔ materials selection of flywheel case study (H. Liu & Yan, 2007) ➔ contractor selection using AHP+VIKOR (San Critobal, 2012) ➔ worked on critical path process assessment for construction projects by using AHP+FSs+PROMETHEE approach

Analytic Hierarchy Process (AHP): AHP provides a pairwise comparison scale. This technique is considered to be the most common, preferred and user-friendly technique (Jaskowski, Biruk, & Bucon, 2010). AHP has been used for solving numerous construction-related problems as well as materials selection problems. In the context of construction-related problems AHP has been used to solve problems including:

1) The assessment of composite materials for structural civil engineering projects (Chajes, Thomson Jr, & Farschman, 1995)

2) Development of a life cycle benefit-cost assessment of composite materials in construction (Van Den Einde, Zhao, & Seible, 2003)

3) Selection of construction contractors (D. Singh & Tiong, 2005), (E. W. Cheng & Li, 2004)

4) Supplier evaluations (Sarkar & Mohapatra, 2006), (Araz & Ozkarahan, 2007)

5) Prequalification of contractors (E. W. Cheng & Li, 2004)

6) Construction equipment selection (C. Tam, Tong, & Wong, 2004), (Onut, Kara, & Mert, 2009)

7) Estimating the cost of pavements maintenance (Moazami, Behbahani, & Muniandy, 2011)

8) Decreasing risks in highway construction projects (Khazaeni, Khanzadi, & Afshar, 2012)

9) Assessing the environmental impacts of using different types of flooring systems (Reza, Sadiq, & Hewage, 2011).

AHP has often been used in combination with almost all other MCDM techniques such as FS, Delphi, MIVES, MCS, PROMETHE, VIKOR, ELECTRE, COPRAS, SAW, DEA and UT. A hybrid fuzzy AHP model was proposed in an attempt to assess the appropriateness, practicality and suitability of different bridge construction methods (N.-F. Pan, 2008). Fire hazard prevention on construction sites is a critical problem and fuzzy AHP was used to solve this problem (Ali Jahan, Ismail, Shuib, Norfazidah, & Edwards, 2011). Fuzzy AHP was also used for the selection of sustainable building materials for construction projects (Akadiri, Olomolaiye, & Chinyio, 2013). AHP was used in conjunction with Delphi and Fuzzy Sets for a rock classification system which was to be implemented in slope stability assessments (Y.-C. Liu & Chen, 2007).AHP provides a pairwise comparison scale. This technique is commonly used and preferred as it is very user-friendly. P. Jaskowski, S. Biruk, and R. Bucon applied it for the economic and technical evaluation of a tower crane before selection. Since then, AHP has been used to solve numerous problems associated with construction and materials selection. In construction, AHP is being used for issues such as the: 1) assessment of composite materials for structural civil engineering projects (Chajes et al., 1995); 2) development of a life cycle benefit-cost assessment of composite materials in construction (Van Den

Einde et al., 2003); 3) selection of construction contractors (D. Singh & Tiong, 2005), (E. W. Cheng & Li, 2004); 4) supplier evaluations (Sarkar & Mohapatra, 2006), (Araz & Ozkarahan, 2007); 5) prequalification of contractors (E. W. Cheng & Li, 2004); 6) construction equipment selection (Onut et al., 2009), 7) estimation of the cost of pavement maintenance (Moazami et al., 2011); 8) decrease of risks in highway construction projects (Khazaeni et al., 2012); and 9) assessment of the environmental impacts of using different types of flooring systems (Reza et al., 2011), to name just a few.

Analytic Network Process (ANP): ANP is a generalized version of the AHP method that enables the existence of interdependences among criteria. Given the specific nature of the ANP technique, only two research works within the construction sector have been undertaken using ANP in the building and construction domain. ANP was used to determine the risk involved in bridge construction (Y.-C. Liu & Chen, 2007); it was also used for multiple criteria assessment in the example of the construction of a 700m underground sewer in the city centre of Osnabruck in Germany (Bobylev, 2011). Outside the construction sector, ANP was for supplier selection (R. V. Rao, 2008) and also used for the selection of the materials of a polymer electrolyte fuel cell (Dey, 2006). Existing literature also shows hybrid approaches of ANP where it is used in conjunction with fuzzy sets for fuzzy decision making to assist in environmental impact assessment approvals (K. F. Liu & Lai, 2009) and Monte Carlo Simulations for contract selection involving interdependency and uncertainty (El-Abbasy, Zayed, Ahmed, Alzraiee, & Abouhamad, 2013).

Complex Proportional Assessment (COPRAS): COPRAS ranks a set of alternatives according to their significance and degree of utility. It adopts a step wise approach to rank the alternatives. The use of COPRAS on its own is limited as it is often used in combination with other MCDM techniques such as AHP, GST, MEW or SAW. However, we found examples of independent use of COPRAS in the literature on materials selection and manufacturing where P. Chatterjee, V. M. Athawale, and S. Chakraborty demonstrated the use of COPRAS for the manufacturing of gears and cryogenic storage tanks. It validated the importance, applicability and usefulness of the COPRAS-G in the materials selection process for gear manufacturing and demonstrated its strong potential to solve complex materials selection problems. M. Bitarafan, S. Hashemkhani Zolfani, S. L. Arefi, and E. K. Zavadskas worked on the hybrid form of AHP and COPRAS-G techniques and found that cold form steel structures are the most suitable for repairing parts of buildings. They used AHP to weigh the criteria and COPRAS-G to evaluate the alternatives.

Elimination et choix traduisant la realité **(ELECTRE):** ELECTRE is a group of techniques used to rank a set of alternatives by determining their concordance and discordance first introduced by G. van Huylenbroeck in 1995 (Van Huylenbroeck, 1995). Real-time examples of many waste management projects carried out in Finland were used to determine an assessment procedure (Hokkanen & Salminen, 1997; Martin, Ruperd, & Legret, 2007). ELECTRE was also used for stormwater management policies (MM Marzouk, 2011). They constructed a selection matrix and with the help of preferences and a veto threshold proved which policy was the best suited (Martin et al., 2007). ELECTRE was also used by A. Shanian and O. Savadogo as a tool for contractor selection. This selection was comprised of an ascending and descending arrangement of contractors based on their characteristics. It was also shown to be useful for glass materials selection based on the different characteristics of glass. ELECTRE was used for the selection of the materials of a non-heat-treatable cylindrical cover (A Shanian & O Savadogo, 2006). A decision matrix was introduced for the selection of materials. Here weighted coefficients were introduced for every attribute using the entropy method. The decision matrix and the weighted coefficient were used as inputs to keep the cost constant. This ranked the candidate materials from best to worst (A Shanian & O Savadogo, 2006). B. Ka used these techniques to compare the location of site selection with simple quantitative and qualitative techniques to avoid the reduplication of the port construction process (Ka, 2011).

Fuzzy Sets: Fuzzy Sets: Fuzzy sets (FS) tell us that the data belonging to any particular set may vary in the very next interval (Lam, Tao, & Lam, 2010). Its application was also discussed by Liao in 1996 by taking an example of nozzle needles that needed to be designed as part of a jet fuel system. They found such an integrated system can help the engineers to solve the problem of materials selection at the design phase (T. W. Liao, 1996). Fuzzy rules can be implemented to select the optimal materials for materials with a higher value of tensile strength from the given set of alternatives (Ullah & Harib, 2008), (Maniya & Bhatt, 2010). The novel model of the preference selection index (PSI) was improved by identifying the goal for obtaining the preference selection index and ranking the alternatives in ascending order in a given set of materials for the engineering design problem. The hybrid technique was used for the selection of the materials of small hydro power (SHP) projects pen stock (Ravi Kumar & Singal, 2015). J. Manag used AHP and TOPSIS for this purpose and ranked this combination as the best suitable for the selection of the materials of such an instrument. In 2013, San Cristobal worked to develop a fuzzy AHP-PROMETHEE model to determine the critical path on a construction project. They examined seven different paths by comparing four major criteria (San Cristobal, 2012). The fuzzy ANP-VIKOR model was used in the study of a two-stage MCDM approach in the construction projects selection (Ebrahimnejad, Mousavi, Tavakkoli-Moghaddam, Hashemi, & Vahdani, 2012). This is done by having expert opinions and then ranking them with the help of the VIKOR technique. This method was also used for the rock excavation process; in this example, seven attributes were used in the comparison (Golestanifar, Goshtasbi, Jafarian, & Adnani, 2011).

Grey-systems theory (GST): is the philosophy of handling data according to the information contained within; ranging from no information to complete information. GST was used for the selection of a proper engineering design project (J. Wang, Xu, & Li, 2009). In this research, the philosophy for handling the data was discussed from the initial information, as at the start of the bidding process it is far more important to select the materials for the project properly, saving both time and money. Cold form steel structures are important for remedial purposes in the case of a natural disaster (Bitarafan et al., 2012). M. Bitarafan used the hybrid form of GST, AHP and COPRAS-G.

MAUT: Multi-attribute utility theory (MAUT) is a technique applied to enable accurate decision-making by comparing the utility values of a series of attributes in terms of risk and uncertainty. The preferential Ranking method was discussed by K. Cicek and M. Celik, which involved the use of MAUT (Athawale, Chatterjee, & Chakraborty, 2010). This article clearly shows the work effectiveness of P. Chatterjee and S. Chakraborty, which has a high potential to solve the problem of materials selection (Chatterjee & Chakraborty, 2012).

PROMETHEE: This is a preference ranking organization method for the enrichment of evaluations (PROMETHEE). S. D. Pohekar and M. Ramachandran used it for energy planning and management. H. Gervásio and L. Simões da Silva worked to discover the best process for assessing the sustainability of bridges by using the probabilistic decision-making approach with examples of three different bridges (Gervásio & Da Silva, 2012).

Technique for order of preference by similarity to ideal solution (TOPSIS): This technique deals with preferential ranking based upon the closeness to the ideal solution. S. Rahman, H. Odeyinka, S. Perera, and Y. Bi developed a knowledge-based, decision-support system for the selection of roofing materials. It appeared as an inference engine of such a technology, as this can save a lot of energy and initial cost at the time of final selection. B. Şimşek, Y. T. İç, and E. H. Şimşek applied this technique for the highly important technical issue in the production of high strength self-compacting concrete. Because concrete is better when compacted, the maximum effort was made to remove any pockets of air from it. Materials selection in such a combination of materials is cost-effective and a time saver. D.-H. Jee and K.-J. Kang introduced decision-making theory to develop criteria for the optimal selection of materials for the manufacturing of flywheels. They made this selection by using the TOPSIS technique which involves the construction of a materials properties matrix so that the best combination can be developed. The procedure for systematically mapping the performance index or materials properties was developed by D.-H. Jee and K.-J. Kang to obtain the final ranking or the best-suited materials for this purpose. Y.-M. Wang and T. M. S. Elhag mentioned the discrepancies in results obtained by using the fuzzy approach. They overcame this issue by using the fuzzy TOPSIS hybrid approach. The alpha cut method was used to assess the results obtained for a bridge assessment problem.

VIKOR: The *Visekriterijumaska Optimizacija kompromisno resenje* (VIKOR) method is used to determine the compromised ranking list of a set of alternatives according to their closeness to the ideal solution. In engineering design, alternative materials are evaluated according to certain criteria depending upon the type of problem and the suitability of the available materials. Performance ratings were discussed by Jahan (2011) using the VIKOR method for materials selection for the manufacturing of metallic bi-polar plates. Jahan proposed an improved compromise ranking method for the selection of materials for the production of a similar bi-polar metallic plate. This study introduced a logical method for materials selection. Simsek worked on the AHP-VIKOR model to deal with the problem of bidding for construction projects. They took four candidates based on five attributes: design, competence, time, quotation and quality of work. San Critobal again in 2012 compared the consistency of the results produced by TOPSIS and VIKOR method in which AHP was used to weigh the criteria.

2.5.2 Systematic literature review (SLR)

Introduction: There are many research methodologies available for the analysis and review of the literature. For this study, we chose a systematic literature review (SLR) of articles related to the decision support systems in the construction industry. In the following sections, this methodology is described in detail to show that it can be used to extend the research canvas to formulate the research questions, determine the relationship among the different variables, provide different solutions, and address the gaps in the literature on this topic. The grey picture shows this area has a lot of room for improvement and exploration of new directions as DSS is being used in many other ways for the selection of construction equipment (Mohamed Marzouk & Abubakr, 2016), contractor selection and procurement management (Tserng & Lin, 2002), although this still requires much attention when it comes to selecting sustainable construction materials.

A systematic literature review is mainly used for data collection, elucidation and clarification of already-published literature. In the domain of Information Systems, researchers tend to be unaware of a formal, structured literature review (Okoli & Schabram, 2010). According to Fink *"A systematic, explicit and reproducible method for identifying, evaluating and synthesizing the existing body of completed and recorded work produced by researchers, scholars and practitioners" (Fink, 2019).* This has also been used over the past last two decades in vital domains such as medical research; now it is being used in many other fields as it provides evidence-based analysis as outmoded methods deal with specific subjects but lack comprehensiveness and cohesion, hence diminishing a sense of relevance and the spirit of the literature (Tranfield, Denyer, & Smart, 2003). Several issues must be considered when conducting a literature review. Top management information systems found that 27% of data is gathered from surveys, and self-reports are a prime source of information that provides insights into issues. In determining the most appropriate method of conducting a literature review, method bias must be avoided (Podsakoff, MacKenzie, & Podsakoff, 2012). Hence, this study circumvents this problem by a methodology consisting of four main steps:

1) Materials / data collection
2) Descriptive analysis
3) Category selection
4) Evaluation

This method was suggested by (Govindan, Shankar, & Kannan, 2016). These steps are described in detail in the following sections.

Materials/data collection

In this section, the major emphasis is on the sources used for data collection. One hundred relevant, top-most frequently cited articles from Scopus and Web of Science search engines were found. These articles are selected based on various criteria such as titles, keywords, areas of research and year of publication. An Excel spreadsheet was used to separate and categorise these articles, and to determine new distributions, pertinence and references. This process was carried out using a systematic approach to find the most relevant materials. The steps involved are in order of execution:

Step 1: Choose an online database search engine. For this study, we selected Scopus and Web of Science; and validations and reference findings were carried out through Google scholar.

Step 2: Scrutinise the top best-rated journals to obtain quality data that are most relevant to the topic of interest – in this case, the decision support systems for the selection of sustainable construction materials.

Step 3: Select keywords to begin the search for relevant articles. An important task is to determine the relevance of the keywords. This is a bit tricky because sometimes the wrong selection can lead to altogether different materials and distractive data.

Step 4: Select the appropriate time frame for the published articles or papers. This is necessary to reduce the number of articles related to the field of study. This criterion gives a snapshot of publications in relation to the time of publication and can indicate when research in a field was intense, and the circumstances which increased or decreased the number of publications in a particular year.

Step 5: Enrich and refine the research by selecting only the published research articles and papers by avoiding the conference papers and book chapters can help to find the latest research topics and suggest current research trends.

Step 6: match papers with their specific corresponding area of study as many papers are related to DSS and other aspects of construction but are not directly related to the selection of sustainable materials.

2.5.3 Descriptive analysis

Descriptive analysis is an important means of deriving rich and relevant material/data from the raw data obtained via web search engines. At this stage, an inter-code reliability test (which is effective and, easy to conduct) was performed. This was done by grouping the articles according to their authors to ensure the relevance and reliability of the research (De Wever, Schellens, Valcke, & Van Keer, 2006).

The first step involves collecting specific information about each article, including the title, name of the journal, year of publication, problems, recommended solutions, industry, methodologies, limitations, future work and findings. It was found that in most studies, the researcher(s) used more than one methodology to collect and analyse data and conclude the research.

The second step involves categorizing the first and second authors to narrow down the relevance of the articles to the particular field of study.

Category selection

Categorization at this stage involves analysing the targeted field based upon the characteristics of the articles reviewed. The main process entails a type of sieve analysis whereby the most relevant articles will fall under one category such as the subject of articles in the same field (e.g., DSS for materials selection), and the rest of the criteria such as methodologies and subject are considered as the second most important elements of this stage. As discussed by Long Duy, project success factors in construction are timely completion, meeting of specifications, profitability, absence of claims, and functional satisfaction (Duy Nguyen, Ogunlana, & Thi Xuan Lan, 2004).

Materials/data evaluation

This is the final stage to prove that the article's legitimacy and true research domain is kept relevant and intact by coding the others. Excel was used to manage the adequacy and verification process between authors. Data validation utilizing Excel guided the data inserted in spreadsheets; this ensured that entry rules were followed and required that the researcher re-enter data that did not comply with an established rule (Jelen, 2014).

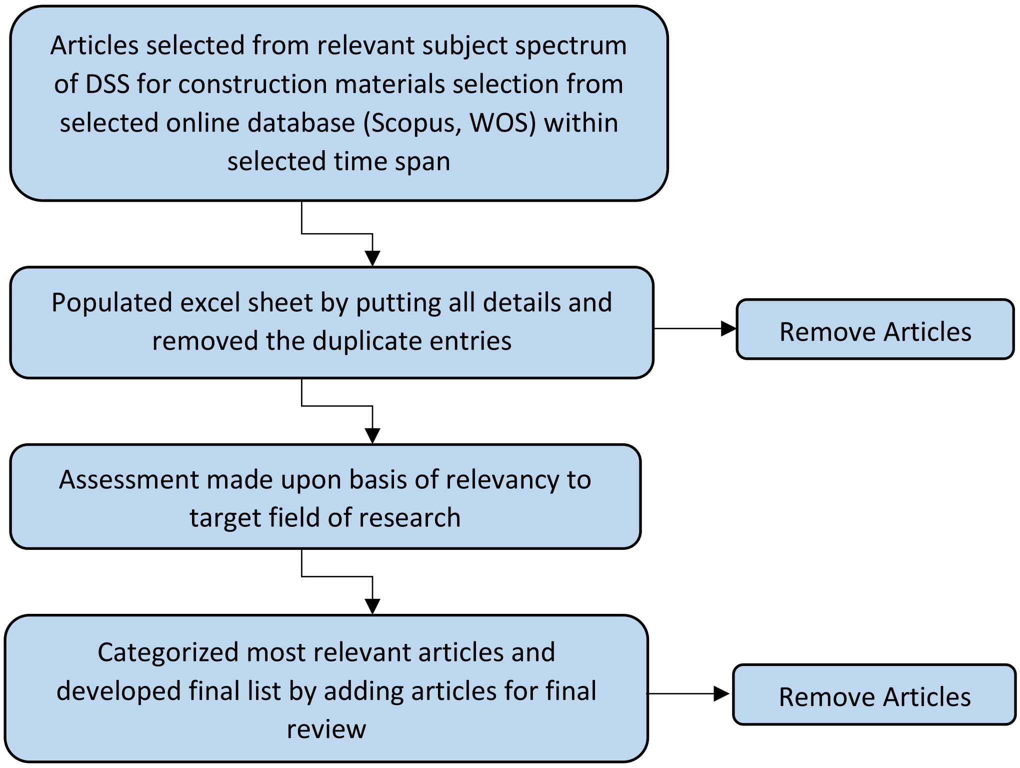

Figure 2.10: Flow diagram for article selection and evaluation

Under the following headings, we will discuss in detail the whole SLR process.

Materials/data collection (Stage 1)

This section explains the step-by-step process of extracting the data/material from the existing literature using the different keywords to obtain a thorough insight into the decision support systems used for deciding on construction materials. Our data indicated that a very small area of this research is being covered in the literature. The analysis is carried out by removing the duplications and extraneous articles. The number of overall papers which we obtained is enormous as depicted in the following tables. Scopus contained 3233 relevant papers and WoS offered 2185 papers in which similar keywords were used. The number of papers that appeared per year in each database is presented in the following tables. It is quite evident from this comparison that, since 2007, the magnitude of this research interest has increased immensely.

Table 2.9 (a, b): Occurrences of most related number of papers in both databases

Year	WoS Articles
2000	55
2001	51
2002	72
2003	58
2004	71
2005	84
2006	96
2007	138
2008	145
2009	167
2010	143
2011	149
2012	159
2013	190
2014	189
2015	247
2016	171
Total	**2185**

Year	Scopus Articles
2000	60
2001	60
2002	85
2003	98
2004	116
2005	137
2006	153
2007	222
2008	232
2009	237
2010	245
2011	252
2012	253
2013	258
2014	260
2015	279
2016	286
Total	**3233**

The keywords “decision support system in construction” and other keywords are used for each database: decision support system, decision support systems, decision support, decision making, construction, simulation, GIS, construction management, ontology and fuzzy logic. The very satisfactory amount of data yielded offered detailed insights.

Table 2.10: Occurrences of most common keywords in both databases

Keywords	WOS	Scopus
Decision support system	141	116
Decision support systems	120	96
Decision Support	80	88
Decision making	53	44
Construction	48	42
Simulation	47	44
GIS	41	35
Construction management	36	34
Ontology	35	29
Fuzzy Logic	33	25

Duplication sources of materials/data

It is quite normal to find duplications in such a vast amount of data, particularly when it is collected from two search engines. The two sources are very reputable, so data purification needs to be conducted carefully since many of the articles were found in both databases. This problem was addressed by using Excel commands to detect duplication and for data cleaning.

The other type of duplication was the duplication of the keyword which is usual for such a large amount of data. The main keywords were 'decision support systems in construction' which appeared in most of the articles. These duplications were removed using the Excel commands since all related articles and mainstream articles contained almost all the major keywords.

Descriptive analysis (Stage 2)

Descriptive analysis is the second stage of the systematic literature review (SLR) methodology. This contains a specific analytic technique known as the inter-code reliability test pertaining to the main reliability features of scrutinised articles.

Table 2.11: Number of publications per category

	No.	References
Quantitative Methodology	**07**	(Lin, Tsai, Lin, & Yang, 2016), (Ellingwood, 2005), (Oyetunji Adetokunbo A. & Anderson Stuart D., 2006), (Tserng & Lin, 2002), (Ng S. Thomas & Zhang Yanshuai, 2008), (Henry, Amoros, & Roset, 2002), (Behzadian, Khanmohammadi Otaghsara, Yazdani, & Ignatius, 2012)
Qualitative Methodology	**09**	(Kovacic, Waltenbereger, & Gourlis, 2016), (Su, Chen, & Yang, 2016), (Petrillo et al., 2016), (Huang, Bird, & Heidrich, 2009), (Medineckiene, Turskis, & Zavadskas, 2010), (Nelson, Nadkarni, Narayanan, & Ghods, 2000), (Tangsubkul, Beavis, Moore, Lundie, & Waite, 2005),
Mixed Methodology	**10**	(Lin et al., 2016), (Laryea, 2016), (Guo Brian H. W. & Yiu Tak Wing, 2016), (Taillandier, Taillandier, Hamzaoui, & Breysse, 2016), (Doukas et al., 2016), (Mierswa, Wurst, Klinkenberg, Scholz, & Euler, 2006), (Zavadskas, Kaklauskas, Turskis, & Tamošaitiene, 2008), (Soares-Filho et al., 2004), (Leu, Yang, & Huang, 2000), (Wang, Zhang, Chau, & Anson, 2004),
Literature Review	**11**	(Magrassi, Del Borghi, Gallo, Strazza, & Robba, 2016), (Argent, Perraud, Rahman, Grayson, & Podger, 2009), (Michaels, 2009), (Alanne, 2004), (Palaneeswaran & Kumaraswamy, 2001), (Bentivegna et al., 2002), (Laurent et al., 2014), (Pinto, Nunes, & Ribeiro, 2011), (Kaplinski & Tupenaite, 2011), (Timor & Sipahi, 2010), (Ortiz, Castells, & Sonnemann, 2009)
Comparison Papers	**16**	(Omran Behzad Abounia, Chen Qian, & Jin Ruoyu, 2016), (Marzouk & Abubakr, 2016), (Rackes, Melo, & Lamberts, 2016), (Kegelmeyer, Banfield, Hall, & Bowyer, 2007), (Khoury & Kamat, 2009), (Singh D. & Tiong Robert L. K., 2005)kamat, (Chua D. K. H. & Li D., 2000), (AbouRizk Simaan, 2010), (El-Diraby T. A., Lima C., & Feis B., 2005), (Kaklauskas, Zavadskas, & Trinkunas, 2007), (Attalla Mohamed & Hegazy Tarek, 2003), (Zare, Pourghasemi, Vafakhah, & Pradhan, 2013), (Haapio, 2012), (Banias, Achillas, Vlachokostas, Moussiopoulos, & Tarsenis, 2010), (Cheng, Chan, & Huang, 2003), (Jiang Xiaomo & Adeli Hojjat, 2003)

Conceptual Papers	**15**	(Bardos et al., 2016), (Kamat Vineet R. & Martinez Julio C., 2001), (Renschler & Harbor, 2002), (Al-Hussein, Athar Niaz, Yu, & Kim, 2006), (Liu & Lai, 2009), (Guo Sy-Jye, 2002), (Aminbakhsh, Gunduz, & Sonmez, 2013), (Madlener & Stagl, 2005), (Chau, Anson, & Zhang, 2005), (Tam C. M., Tong Thomas K. L., Leung Arthur W. T., & Chiu Gerald W. C., 2002), (Molina, Bromley, García-Aróstegui, Sullivan, & Benavente, 2010), (Doğan Sevgi Zeynep, Arditi David, & Günaydın H. Murat, 2006), (Falagario, Sciancalepore, Costantino, & Pietroforte, 2012), (Molloy et al., 2008), (Sanayei, Farid Mousavi, & Yazdankhah, 2010)
Case Study	**19**	(Li et al., 2009), (Smith & Tardif, 2009), (Leavesley, Markstrom, Restrepo, & Viger, 2002), (Vanier D. J. “Dana,” 2001), (Ortiz, Bonnet, Bruno, & Castells, 2009), (Seely et al., 2004), (Hassanzadeh, Zarghami, & Hassanzadeh, 2012), (Dockerty, Lovett, Appleton, Bone, & Sünnenberg, 2006), (Anastaselos, Giama, & Papadopoulos, 2009), (Imteaz, Shanableh, Rahman, & Ahsan, 2011), (Fung, Tam, Lo, & Lu, 2010), (Hauck Allan J., Walker Derek H. T., Hampson Keith D., & Peters Renaye J., 2004), (Pohl, 2002), (Bouchlaghem, 2000), (P. K. Dey, 2004), (Liao & Perng, 2008), (Fouladgar, Yazdani-Chamzini, & Zavadskas, 2011), (Yang, Reichert, Abbaspour, Xia, & Yang, 2008), (Hessburg & Agee, 2003),
DDS	**13**	(Arnott, 2006), (Low, Hwang, & Zhao, 2016), (Marzouk & Abubakr, 2016), (Topcu, 2004), (Chau, Cao, Anson, & Zhang, 2003), (Kumaraswamy & Dissanayaka, 2001), (Gomes da Silva, Figueira, Lisboa, & Barman, 2006), (Liston, Fischer, & Winograd, 2003), (Prasanta Kumar Dey, 2006), (Zavadskas, Vainiūnas, Turskis, & Tamošaitienė, 2012), (Šelih, Kne, Srdić, & Žura, 2008), (Juan, Shih, & Perng, 2006), (Cain et al., 2003)

This categorical distribution is depicted in Figure 2.11 below.

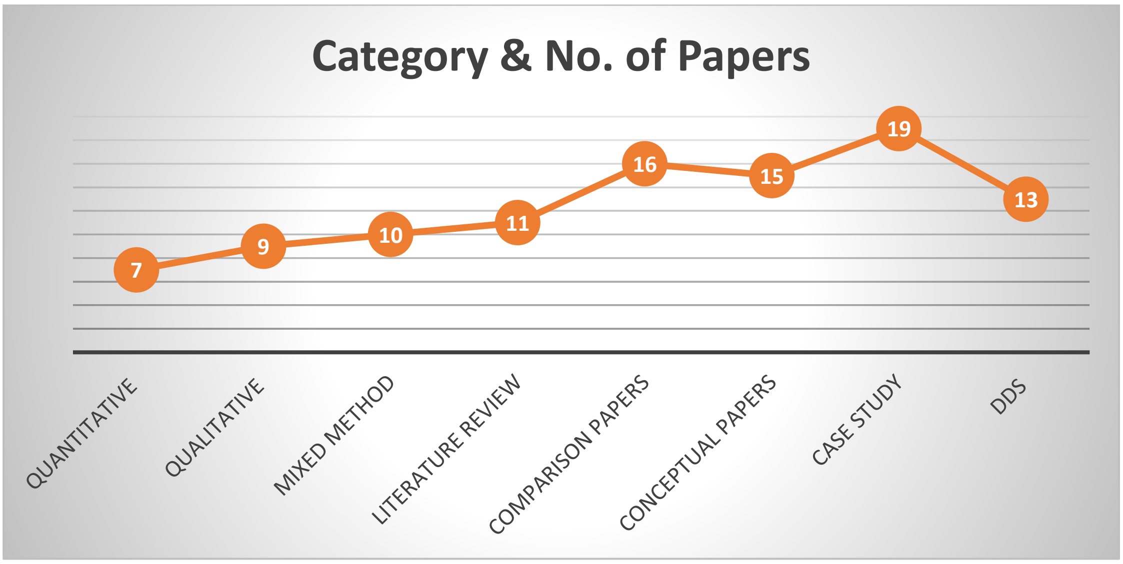

Figure 2.11: Number of publications per year in WoS

2.6 Development of Hypotheses

This study identifies major concerns for sustainable construction practices, with relationships developed among the factors in the form of the following hypotheses:

> Hypothesis 1: There is a positive relationship between project stakeholders and the adoption of sustainable construction practices.
>
> Hypothesis 2: There is a positive relationship between designer's concerns and the adoption of sustainable construction practices.
>
> Hypothesis 3: There is a positive relationship between environmental regulations and the adoption of sustainable construction practices.

2.7 Chapter Summary

The basic aim of this work is to open new horizons of research on decision support systems in the construction industry. By offering detailed and precise information, it provides a foundation for future work undertaken by researchers, practitioners and students. This work presents information about the authors and countries that have contributed the most to research in this field, enabling interested parties to find information easily and, in the case of practitioners, to exercise better decision-making practices.

The data obtained from two major database sources helped us to analyse various issues related to the research topic. Details were given of the annual research output, country output, and the pattern of collaboration between countries and between researchers, authorship, important keywords, and the visualization of those keywords in terms of their frequency.

All these analytical outcomes include the computation of the latest bibliometric characteristics i.e., RGR, DT, CI, DC and CC. We presented information about the top contributing countries, the authors, and their respective institute affiliations. We identified important control terms, conducted a comprehensive analysis, and presented an up-to-date bibliometric characterization of literature in this research field.

In the last section, detailed information is presented regarding the systematic literature review (SLR) including the major steps involved in this process. The chapter concludes by outlining the hypotheses developed by this study.

CHAPTER 3

PROBLEM DEFINITION

This chapter covers:

- Detailed definition of the problem
- Emerging trends in construction
- Sustainable material selection and construction practices
- Basic principles of sustainable construction

3.1 Introduction

The modern construction industry has changed its face altogether as traditional techniques have been replaced by new and innovative ideas. More concerns are being expressed all over the world regarding the pollution caused by the construction industry both during and after the building construction. A life cycle analysis gives some indication of the overall energy consumption during the construction and operational phases of the building, and during and after demolition. Energy management is a crucial issue as the building industry consumes 32% of the overall energy used globally, reaching up to 40% in developed countries (Karunanithy & Shafer, 2016). Hence, in terms of sustainability, the building sector is not performing well (Piette, Kinney, & Haves, 2001), (Ardehali, Smith, House, & Klaassen, 2003). This concern led to a focus on the energy consumption of buildings and effective energy management. This unidirectional analysis and research approach can have a massive impact on overall energy monitoring and management. Energy efficiency must be improved by focussing on and improving the energy conservation measures in the building sector since existing buildings have a life cycle of 30 to 50 years and will contribute to the consumption of 70% of the total building stock by 2050 (Kelly, 2010). Buildings are very complex structures, with the major areas of concern being demand response controls for lighting and heating, ventilation and air conditioning (HVAC) (Goyal, Ingley, & Barooah, 2013). The building automation systems (BAS) have played a vital role in energy management, control and savings. The next robust level of energy conservation involves building retrofitting so that existing buildings can save energy through measures that improve the building environment and monitor the overall energy consumption (Güçyeter & Günaydın, 2012). New buildings can be constructed to be energy efficient by careful consideration being given to sustainable construction materials and using local, alternative innovative materials to save energy (i.e. vernacular architecture). This process can begin from the outset during the planning and design stages by considering flexible building designs and orientations (N. Li, Yang, Becerik-Gerber, Tang, & Chen, 2015).

3.2 Key Concepts

The section on key concepts includes the latest trends emerging in construction innovation and the amalgamation of science and building construction technology. These latest trends have changed the overall approach to building construction by improving the economic, time, energy and environmental fronts in the form of better management and monitoring of these factors. We will discuss the latest emerging trends and techniques developed in the modern construction world to build sustainable buildings, and correlate our research to deal with upcoming challenges in the construction industry.

3.2.1 Emerging trends in sustainable building construction

The creation of successful building design has become quite a tedious and complex task nowadays due to mounting pressure to implement sustainability and satisfy the three pillars of sustainability: environmental, social, and economic. The design and construction of climate adaptive building shells (CABS) is the latest trend that can be a good alternative to achieve the target of highly sustainable and energy-efficient buildings. These structures offer better energy efficiency and improved inside/indoor environments compared to the conventional façade system by applying active and passive building technologies and an improved building envelope (Loonen, Trčka, Cóstola, & Hensen, 2013).

The development of sustainable building construction practices and the selection of sustainable construction materials is becoming a strong trend in the building construction industry globally. For example, geo-polymer concrete is considered one of the best sustainable construction materials due to its high performance and operational energy savings. It is a mixture of lightweight foam concrete and derivatives from fly ash. The geopolymer binder is more fire-resistant and its aluminosilicate nature improves temperature stability. Although the standardization of feed-stocks and the control of efflorescence are major hindrances in the commercial use of these items which require more research and experimentation, they are still considered the best alternative sustainable construction materials (Zuhua Zhang, Provis, Reid, & Wang, 2014).

Building information modelling (BIM) is one of the latest tools used to improve sustainable construction practices. The best feature of BIM is that a virtual building can be constructed to check all the design features including the selection and performance of construction materials. It enables any building utility disparities to be avoided or fixed, limits the amount of building waste, and optimizes efficient energy usage. The application of passive design strategies during the design phase prevents time-wasting and financial loss in the real-world construction process (Bynum, Issa, & Olbina, 2012).

Energy consumption has increased exponentially in recent times due to increased industrialization, growing population and improvement in living standards. This energy demand has reached an all-time high. According to the International Energy Agency (IEA), the developing countries are consuming energy more rapidly than developed countries and will require double the capacity of their installed energy generation plants by 2020 (Türkay & Telli, 2011). To tackle this increasing problem, alternate methods/sources of energy have been found such as solar photovoltaic systems. One major issue with this energy source is its efficiency which for a normal solar photovoltaic system can vary from 10% to 23%, so different types of technically robust and most feasible photovoltaic systems have been produced such as building-integrated photovoltaics (BIPV), photovoltaic thermal (PV/T) and concentrated photovoltaics (CPV). Recently manufactured concentrated photovoltaics (CPV) is considered the most promising and cost-effective with respect to others (Pandey et al., 2016).

To counter the effects of urbanization and land scarcity, building materials are being developed that can increase sustainability and green efficiency. These include green roofs and walls. Bearing in mind the growth substrate, drainage layer and vegetation process, the green roofs are considered preferable to green walls. Green roofs have many economic, social, aesthetical and environmental benefits as well as many technical advantages such as rainwater management, decreased energy consumption, improved water and air quality, and reduced heat island effects (Getter, Rowe, Robertson, Cregg, & Andresen, 2009). However, considering the dead load and seepage issues, more research and practical implementation are required to construct green roofs on a commercial scale. The two major types of roofs used in sustainable buildings are Extensive green roofs, and semi-intensive green roofs (Vijayaraghavan, 2016).

Buildings are considered to be the major consumers of energy and, thus, bigger producers of CO_2. Scientists and technical practitioners all over the world are working on energy modelling and control. In Australia, the residential sector consumes 11% of the country's total energy consumption and produces 13% of greenhouse gas emissions (GHG). The average annual GHG increase in the industrial sector is 1.2%; the transportation sector contributes 1.9%, while the residential sector is one of the fastest-growing sources of GHG emissions (Zhengen Ren et al., 2013). These reasons motivated us to carry out this research to find out the current practices regarding material selection and knowledge about sustainability among the local technical stakeholders, their attitude towards the implementation of sustainability.

3.2.2 Materials selection and sustainable construction practices

Urbanization and globalization have led to rapid developments in the building construction industry all over the world. Many models and strategies have been developed to improve the overall working environment and cost-effectiveness. However, the cost concerns have been associated with sustainability and sustainable construction practices, both of which have forced technical stakeholders to explore alternative sustainable construction materials. This concept is explained by using the MCDM technique and the flowchart explains the procedural sequence of selecting sustainable construction materials for building construction using TOPSIS, the same technique adopted for this research work. This model framework consists of eight sequential phases. The first step is to accurately identify the problem; once this is done, it is easier to find a solution. The problem feasibility and endorsement were obtained from the field experts and technical stakeholders. Their proposals for improvement and the current practice of materials selection validated the problem identification. Phases three and four comprising the selection criteria and the alternative materials available, respectively, are considered the most critical phases that will ensure that the material meets the criteria for suitability. The selection of MCDM techniques to seek a solution and confirm the appropriateness of criteria are checked in phase five. In phase six, the proposed model is applied to a real-case example. The obtained results are validated and explored in phase seven, which also includes the selection of sustainable construction materials.

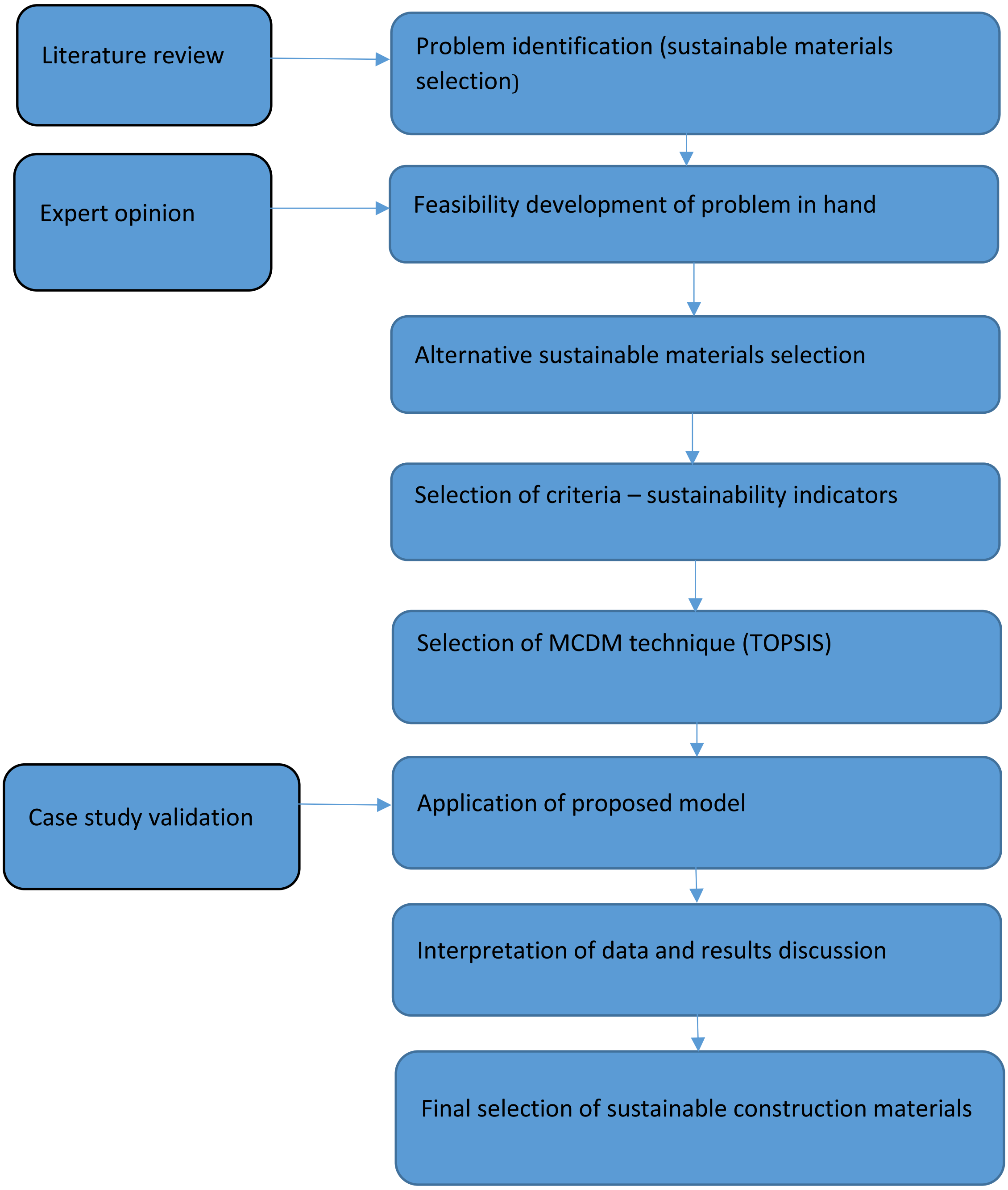

Figure 3.1: Model framework
Source: Derived from Govindan et al. (2016)

Reinforced concrete (RC) and steel structures (SS) in building construction have proven to be materials that fulfil the criteria of economic sustainability, environmental sustainability and constructability performance. All of these indicators are considered important when making decisions about construction materials. The RC buildings are better than SS buildings in terms of basic structural cost, maintenance cost and financial cost. However, SS buildings outperform RC buildings when it comes to increased area, internal space, recycling feasibility, waste rate, water consumption and labour saving by offering quicker completion time. There are no differences between them in terms of noise pollution and safety (Zhong & Wu, 2015).

The process of selecting sustainable materials can be shortened right from the start by choosing "green architecture" also known as "sustainable architecture", and designing green buildings in accordance with environmentally friendly principles. Green architecture attempts to use a minimum amount of resources during and after the building construction. The operational phase of the building is a game-changer if designed according to sustainable design practices. The conservation of energy or efficient energy management plays a key role in minimizing the waste which is generated during the construction, operation and demolition of a building, if the design complies with all the legal and technical specifications, rules and regulations. In brief, in order to safeguard the environment, green architecture systems must be properly introduced, understood and adopted (Ragheb, El-Shimy, & Ragheb, 2016).

3.2.3 Basic principles of sustainable construction

In the construction industry, sustainability is associated with meeting the triple bottom line so that the construction of a building takes into account environmental, economic and social impacts.

Urban development planning is key to ensuring that cities are sustainable. The increase in urbanization will see an increase of an estimated 2.5 billion in the number of urban dwellers by 2050, and it is also estimated that over 60% of the urban areas need to develop by 2050 (Seto et al., 2014).

The evolution of sustainable design and construction has produced a significant amount of literature on environmental sustainability and development. However, the more advancements there are in construction sustainability and improved living standards, the greater are the challenges facing designers, engineers, and architects, landscapers who are pressured to find ways of making buildings more attractive and sustainable. This requires a properly built and tested framework that is aligned with environmentally friendly policies and procedures (Obi, 2017). This motivates research to find ways to streamline the materials selection process and make it easy for the aforementioned stakeholders.

Recycling of construction waste is a major concern in regard to sustainable building construction and infrastructure development. For example, the concrete produced and used for construction each year is disproportionate to the demand. Its complete processing would make it possible to generate secondary aggregates. This reuse of recovered concrete debris can resolve this gigantic issue. This can help to conserve the natural resources used for producing concrete for sustainable and structurally sound buildings and safeguard society, the economy and the environment (Nalewajko, 2018).

The strong relationship between sustainability and lean construction has encouraged scientists, architects and construction engineers (the AEC field) to develop strategies and policies to introduce, manage and apply lean construction which aligns with the triple bottom line concept by reducing the harmful impacts of the construction phase (Carvajal-Arango, Bahamón-Jaramillo, Aristizábal-Monsalve, Vásquez-Hernández, & Botero, 2019). It has been found that the construction industry has damaged natural resources by generated vast amounts of waste and consuming a great deal of water and energy. Therefore, the construction industry must align its practices with sustainability principles to conserve and reuse environmental and natural resources for social benefit and development. This requires a balance between the environmental/natural resources and the built environment and create spaces that affirm human dignity and promote equity (Aigbavboa, Ohiomah, & Zwane, 2017).

3.3 Problem Definition

- To understand how technical experts such as estimators, architects, designers, draftsmen etc. evaluate and select construction materials for a building project.
- To identify and validate the basic selection criteria used by the technical experts when selecting construction materials.
- To analyse the current materials selection practices and identify problems that can be solved to enable technical experts to make optimal decisions when selecting construction materials.
- To investigate a method/system that enables appropriate construction materials to be discovered in an automated/semi-automated way.

3.3.1 Problems with evaluation and selection of construction materials for building projects

During our data collection and interviewing process, it was found that the main problem was that most of the technical stakeholders do not know about sustainability and alternative materials selection. This was confirmed by the analysis results.

Social and economic concerns (practical problems)

The aforementioned problem creates many economic and social issues. Most building practitioners were found to be very inflexible when choosing construction materials as they were very reluctant to accept and implement any innovative changes. A significant number were unaware of the latest techniques and inspection process, causing the homeowners to bear the extra cost of traditional building design, construction technique and construction materials. For example, a normal three bedroom and two bathroom house of approx. 300 m^2 costs \$320,000 to \$375,000 in Western Australia and at least 25% to 35% more in Eastern states, which can be reduced significantly by using alternative sustainable construction materials. Till 2003 the overall 3% rise in the house prices with the boost in four significant boom times between 1970 to 2003 (Abelson, Joyeux, Milunovich, & Chung, 2005).

Existing solutions

Currently, the technical stakeholders are using the word of mouth (the selection of most famous) product or their traditional construction materials, which are considered quite outdated and are more expensive for the end-user.

Technical problems

There are no practical systems available that can help decision-makers to make appropriate selections of construction materials. In most cases, construction companies are using the same materials that they have always used. However, there are a few contractors who are showing a favourable attitude towards the adoption of sustainable construction techniques and materials.

3.3.2 Problems with an investigation of a method/system for selection of appropriate construction materials in an automated/semi-automated way

The local market is extensively using different comprehensive, modern and innovative methods/systems that can be used for the selection of sustainable and alternative construction materials. This automated/semi-automated system can help the decision-makers to make the appropriate selection that is justified with the triple bottom theory of sustainability (economic, environmental and social factors).

Social and economic concerns (practical problems)

The lack of an automated/semi-automated system creates a discrepancy between the actual buying power of customers and affordability. The availability of alternative materials can attract more business and create jobs, while the market competition will make the products cheaper and competitive. The need to provide innovative and more affordable products can lead to an extensive product range.

Existing solutions

Currently, the construction industry lacks a comprehensive system that can rank the available construction materials by giving a preferred list of sustainable and alternative construction materials.

Technical problems

Several construction companies in Australia are using a partially automated system but it is limited to the estimation and quantity take-offs. The system does not enable a comparison of products and their components or features.

The overall increase in the final product price affects not only the environment but also the behaviour of various economic variables. Moreover, the additional cost affects small-business owners who may face collateral barriers in accessing credit.

3.4 Research Issues

The construction industry has become the largest user of energy and natural resources. Its exact volume and the consumption percentage is still an arguable topic but one thing is quite evident: the construction industry has to not only comply with ever-growing environmental rules and regulations but has to perform outstandingly well to meet the environmental criteria as do other industrial sectors (Horvath, 2004). The research issues are discussed under the following main topics.

Improbability in the decision-making process: Environmental decisions are genuinely uncertain because ecological systems and social behaviours keep changing with the new requirements over time. So, ultimately, these issues cannot be anticipated today as, globally, the environmental issues that have appeared in today's world were not considered as issues previously (Wolff, 1998).

It is very easy to envision that construction materials which are difficult to recycle will be expensive to dispose of in future for technical and economic reasons such as increased taxes, political decisions and other external factors such as the sourcing of raw materials, consumption, and the suppliers' monopoly, all of which can change prevailing conditions. Customers and real estate owners are obtaining more and more information about sustainability and other environmental issues that will eventually be game-changers (Gluch & Baumann, 2004).

Irreversible decisions: The consequences and results of decision-making, especially in the construction industry, are irreversible as the age of building projects comprises 6 to 8 decades and the overall investment and outcomes are irreversible as well. Building construction requires a hefty consumption of natural resources, finance and human resources in the form of man-hours, which can change the overall topography of the land and the living standards of a community. Therefore, there is a gap between environmental realities and basic knowledge in the selection process of sustainable construction materials in a building project. A large number of alternative materials cannot be used due to the unavailability of enough stock or due to high capital cost value. The investment process, therefore, involves sequential and subsequent decisions, which means that early decisions can make a major difference to the overall efficiency of the building project. Similarly, irreversible decisions create irreversible effects on the ecology of an area, so it is a very basic and important rule to assess all the aspects and impacts of materials selection in building construction (Gluch & Baumann, 2004).

Classic practice and change rebound: Decision-makers and technical stakeholders are quite reluctant to accept change and innovation in the modern building construction environment in the Australian construction market. Sustainable consumption of materials and energy patterns normally rely on the current ecological rationality where the emphasis is mainly on making current practices sustainable, rather challenge the status quo for the future improvement and betterment of the quality of life. Consequently, sustainable energy policies black box the demand-side, often resulting in abstracting efficiency strategies from social organizations that are directly affected by these policies (Jensen, Røpke, Goggins, & Fahy, 2019). This gives the end-user the responsibility of insisting on the implementation of sustainable construction practices. As a result, energy policies tend to focus on making current trends and behaviours biased in favour of sustainability.

Monetary unit: The practical perspective gives us more simplified results of bit complex issues i.e. LCC aims at placing all impacts including the environmental impact under a single measure monetary unit (Peças, Ribeiro, Folgado, & Henriques, 2009). In this regard, the multi-criteria analysis (MCA) technique has given the best solution to accommodating the environmental issues to address during the decision-making process. This technique enables qualitative, quantitative and mixed data to be dealt with for both discrete and continuous choice of problem. MCA is a more realistic approach when dealing with the complex nature of building projects, as this is structured in such a way that public participation can easily be accommodated in terms of criteria selection, evaluation of alternatives and weighting assignments through a questionnaire. This technique can be used to solve the complex issue of the tedious process of sustainable materials selection.

3.5 Aims of the Research

The aim of this research work will be achieved through deductive reasoning combined with an extensive literature review and a comprehensive range of expert opinions obtained through the questionnaire and live interviews. The major aim is to develop the theoretical background of the problem: sustainable construction materials selection and final decision-making. The research will obtain insights into several issues regarding sustainable development from the current literature and the substantive findings from the data analysis. All the data will help to reveal the current trends regarding the selection of construction materials by technical stakeholders. The research also investigates the wider range of impacts and environmental issues produced by the construction industry, while emphasizing the need for an integrated approach and an understanding of the different components of sustainable construction practice. The most important aims are of the research are:

- To investigate whether architects and designers are aware of the environmental impacts of building design.
- To gauge the awareness of architects and designers of the importance of sustainability at the conceptual design stage.

- To develop an understanding of what constitutes the process of decision-making for materials selection.
- To know the percentage of knowledge to implementation of sustainability in practical scenarios.
- To develop an integrated selection model with techniques to improve the effective usage of the system.

Due to the diversity of the research aims, both qualitative and quantitative methods were used, and the findings from the data were analysed thoroughly using the SPSS technique and the selection model was developed using TOPSIS.

3.6 Chapter Summary

This chapter explains the problem of materials selection in the construction industry and looks at the current major developments in innovative and sustainable construction. The problem definition and reason for adopting an integrated approach to determining the components of a sustainable system are given. To achieve sustainability in construction, intelligent decision making is required when considering the effects of the materials chosen for building construction. Information provided in this chapter clarifies the research issues and how to resolve them.

CHAPTER 4

RESEARCH METHODOLOGY

This chapter covers:

- Detailed analysis of research design
- Benefits and shortcomings of the selected methodology
- The choice of methodology and reasons for this choice
- Basic co-relations between the methodology and research objectives

4.1 Chapter Introduction

The selection of the appropriate research method is a key factor in ensuring the authenticity and validity of the research. It involves achieving the research objectives, which can extend and validate the results of the research. The research methodology plays an important role in producing research findings, addressing possible limitations, and presenting the outcomes accurately. Research can be considered as a “voyage of discovery” whether or not anything new is discovered. Any discovery will be the result of the investigation of a specific topic or phenomenon. Hence, the choice of methodology is crucial to the success of the research (Ranjit Kumar, 2018). The research design and methodology are presented in this chapter, together with a description of various research methods, their advantages and their shortcomings. Reasons will be given for the choice of research method for this study and its relevance to achieving the research objectives.

4.2 Research Approach

The selection of the research topic, its outcome and objectives, and the required resources inform the research design and research methodology. To achieve the research aims, deductive reasoning was applied to data sourced from the literature, seminars, workshops, internet discussion forums etc. The data established the theoretical framework and facilitating the achievement of the research goals and objectives. This chapter elaborates on the critical points, aims and findings which are discussed in chapter two. A comprehensive review is conducted of the literature regarding environmental impacts upon the selection of the materials; the current situation and trends in the local market are also discussed here. It is quite evident that natural resources are becoming scarce in this modern era. Hence, the construction industry must share responsibility with other industrial and technological sectors to preserve those resources as much as possible. In Western Australia, a community-run organization – Perth Region Natural Resource Management (PRNRM) – is working to manage these issues. Its working domain is based upon the collaboration of many Environmental Care Organizations (ECOs) which are involved in managing and restoring natural resources.

There are many environmental issues associated with the construction industry, but the review revealed that there is a stark need to develop an integrated approach and understanding of the selection of sustainable construction materials. The success of this approach depends on how well this understanding is delivered to the decision-makers and must include full deliberation and information about all construction materials. The ultimate goal of achieving a sustainable environment and world is not an easy task; it is a long journey to achieve the ultimate goals. Information from the literature can be used as an initial starting point but there is a long way to before all our buildings are sustainable. This can happen only if all our technical stakeholders and decision-makers have a complete understanding of sustainability and the future functionality of a building. Environmental analysis is conducted to calculate the emissions of gases such as CO_2 and SO_2, which make up the major portion of primary energy intensity (PEI). Results prove that environmental impacts can be reduced by up to 61% and up to 10.5% overall using specific sustainable construction materials (Akeiber et al., 2016).

4.3 Comparison of Research Methods

Research designs are types of inquiry that can consist of qualitative, quantitative, or mixed-method approaches that provide specific direction for procedures in the research design. Some researchers have called them ‘strategies of inquiry’ (Denzin & Lincoln, 2011). The new era of modern technology has opened new horizons enabling researchers to explore the latest research directions. These new and innovative techniques guide initial research objectives and ultimately lead to the research conclusion(s). It is generally thought that a combination of different techniques can be more effective in producing reliable results. The characteristics, merits and demerits of a single technique used, often are inadequate to depict the complete picture of the research outcome (Amaratunga, Baldry, Sarshar, & Newton, 2002). Research methodologies are theoretical arguments that researchers used to justify their research methods and designs. The more unequivocal engagement with methodologies can be determined by expanding the research approach and research questions.

Table 4.1 Basic elements of scientific research methodology

Laws	Verified hypothesis; used to assert a predictable association among variables can be empirical or theoretical
Principles	A law or general truth which provides a guide to the thought of action
Hypothesis	A formal proposition which though untested are amendable to testing is usually expressed in causal form.
Conjectures	An informal proposition is not testable form nor is a causal relationship known or even necessarily implied.
Concepts and constructs	Concepts are the inventions of the human mind to provide means for organizing and understanding observations, perform several functions, all of which are designed to form logical and systematic relationships among data. Constructs are theoretical creations that are based on observations but which cannot be seen either directly or indirectly, things such as IQ, Leisure, Satisfaction etc. are constructs.
Facts	A phenomenon that is true or generally held to be true.
Data	The collection of facts, achieved either through direct observations or through garnering from records, observation is the process by which facts become data.

Source: Adapted from Buckley et al. (1996)

4.3.1 Bibliometric analysis (literature review)

Bibliometric analysis is used widely to prove the authenticity and accuracy of the research work. Scientific work, both theoretical and practical, is usually published in journals. The number of citations that a paper receives over time is, therefore, a direct measure of its usefulness to other scientists. Impact factor (IF) and *h* index are considered the relevant entities to prove the authenticity of the research work. Many countries are moving towards research policies that focus on excellence. Bibliometric researchers have developed and validated many methods for evaluating research and the researchers to make it easy to develop a research policy. These methods are also used as tools to allocate proper funding to a specific field of research. Many countries have developed evaluation systems to identify the researchers, universities or research groups and rank them according to their level of excellence (Bar-Ilan, 2017). The ultimate goal of purifying data and research output is acquired by an evaluation process to obtain areas of specific funding allocation, stimulating better search performance and reducing any information asymmetry. A comprehensive evaluation is carried out using factors such as accuracy, robustness, validity, functionality, time and cost. The evolution in research trends in the field of civil engineering is also mapped out using the bibliometric technique which shows that the quantity of research in this field has tripled in volume since 1997. According to the WoS, the civil engineering category pertains to areas of planning, design, construction and operation of fixed structures on ground and occupancy, transportation and use of water resources. Construction and building technologies in the international context is also being discussed, and a substantial amount of research is found using a bibliometric technique (Cañas-Guerrero, Mazarrón, Calleja-Perucho, & Pou-Merina, 2014). There are many tools and software that can be used directly or indirectly to observe some of the major trends in bibliometric techniques, such as VOS viewer that is a freely available software developed to construct bibliometric maps. It focuses on depicting the maps and values in a graphical manner that is easy to understand and interpret by its users (N. Van Eck & Waltman, 2009).

Bibliometric analysis conducted in this study provided us with a true archetypal illustration of the research and technology shift in the field of construction informatics and helped us to understand the overall revolutionary impact which information systems (IS) and information technology (IT) have had in the field over the last two decades. The results also indicate an ongoing growth in research output in this area since 2007. However, numerous independent studies were found to lack cohesion, mostly because researchers followed their research trajectories in isolation rather than in collaboration with other researchers. This has led to isolated objects of knowledge in specific areas within this field of research. The majority of the research is dominated by China, followed by the USA. Some European countries are also actively engaged in this area of research; in particular, individual researchers from Lithuania are responsible for a significant amount of research output.

4.3.2 Quantitative approach (survey)

This method of research comprises the collection, analysis, interpretation and recording of the results of the study. Some specific methods are survey and experimental research. This research method is defined by Creswell as "The explaining phenomenon by collecting numerical data that are analysed using mathematically based methods." (Creswell, 2002). "An inquiry into a social or human problem, based on testing a hypothesis or theory composed of variables, measured with numbers, and analysed with statistical procedure determine whether the hypothesis or theory holds true"(Briskorn & Dienstknecht, 2018).

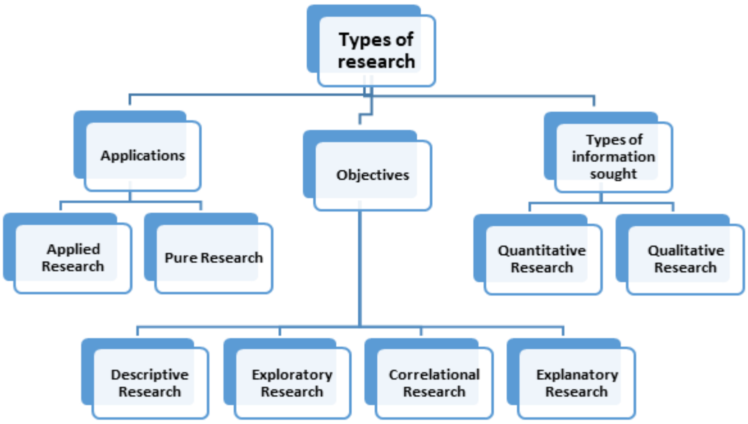

Figure 4.1: Types of research
Source: adapted from Kumar (1996)

The selected research method and its effectiveness depend upon the type of research being conducted. The survey technique is widely used which can be either cross-sectional or longitudinal studies using questionnaires or interviews. A survey can be conducted using different modes of distribution, so responses can be obtained via a variety of media. In general, five different forms of the survey can be used: face-to-face, post, email, online (Web) and telephone. In this scenario, the actual comparison is between the latest technologies and the traditional ones. It has been found that online surveys via email or the internet are better than traditional surveys (e.g., paper-based). There are many advantages of online surveys: they are cheaper, faster, eliminate the need for individual posts, are less likely to be ignored as junk mail, and are environmentally friendly. However, the response rate can vary; it can be as low as 30% and can be as high as 70%

or more depending upon the content and the interest in the topic. The questionnaire was circulated among the technical stakeholders in the local Australian construction market and interstate technical personals. The data abstained is considered the viewpoint of the decision-makers for construction materials selection which were included from the client, consultants and contractors.

4.3.3 Qualitative approach (interview)

Qualitative research is an approach that can gather data about people’s experiences, and their ideas and opinions about a certain issue. Qualitative data can be obtained through in-depth interviews, focus group interviews and discussions, content analysis, observations, visual-aided analysis, life histories or biographies. It is not so easy to apply qualitative methods, although there is great value in obtaining the perspectives of participants, and understanding the meanings and interpretations which they give to the objects, events and behaviours of the research components (Robinson, 2014). The interview method is one way of getting closer to the participant and obtaining his/her views. The actual crux of the issues is found by conducting a comprehensive interview. The sheer range of terms available to extract the various formats of qualitative interviews. The purpose of the interview is to obtain a close, clear and precise statement of a problem. In this study, the interviews were conducted with the local technical stakeholders' managers, estimators, contractors that were considered the major/pre-dominant decision-makers in the construction materials selection process.

There are many advantages and disadvantages of the qualitative research method. It offers an in-depth study as detailed information is obtained. However, the disadvantages are that it takes longer to collect the data, and interpretation can cause biased outcomes (Hennink, Hutter, & Bailey, 2020). A comparison of qualitative and quantitative research methods is presented in the table below.

Table 4.2: Comparison of qualitative and quantitative research methods

Source; Amaratunga et al. (2002)

Points of Comparison	**Qualitative Research**	**Quantitative Research**
Alternative labels	Naturalistic, constructivist, ethnographic or interpretative.	Rationalistic or functionalist, positivist.
Scientific reasoning	Inductive in nature	Deductive
Data Classification	Subjective	Objective
Objective/Purpose	To provide insight into the problem, generating new ideas/hypotheses for future quantitative research. To gain an understanding of the hidden reasons and motives. To uncover predominant trends in thought and opinion.	To measure the occurrence of various views and options in the chosen sample. To quantify data and generalise results from a sample to the population of interest.
Sample	Usually a small number of non-representative cases. Responded selected to fulfil a given quota or requirement.	Usually, a large number of cases representing the population of interest. Randomly-selected responses.
Data Collection	Participant observation, semi and unstructured interviews, focus groups, conversation and dissertation analysis	Structured interviews, self-administered questionnaires, Structured observations, experiments, content analysis or statistical analysis
Data Analysis	Non-statistical	Statistical Findings are conclusive usually descriptive in nature.
Outcome	Findings are not conclusive and cannot be used to generalise. Exploratory and/ or investigative.	Used to recommend a final course of action.

4.3.4 Multi-criteria decision making (MCDM)

Design science research is "Research that invents a new purposeful artefact to address a generalised type of problem and evaluates its utility for solving problems of that type" (Arnott & Pervan, 2016).

Design science is an important method of research as it provides an orientation for the creation of a new and useful artefact. Although it is a relatively new research concept, it has become more popular in recent years (Hevner & Chatterjee, 2010). The lack of methodology and an ambiguous template for its presentation may be considered as the main reason for its slow uptake by researchers. Its major advantages are that it incorporates principles, practices and procedures to meet three major objectives: 1). It is consistent with prior literature. 2). It provides a nominal process model for research. 3). It provides a model for presenting and evaluating design science research.

Design science includes the following steps:

Problem identification and motivation: This is the most important factor in a research process as the problem is a major force that drives the researcher to undertake research. It can be a current or foreseeable future problem.

Definition of objectives for a solution: A set of all possible solutions to the problem at hand is prepared, and all the solutions are ranked. Possible advantages and disadvantages are studied by experimentation. This practice indicates the best solution to the problem, so a clear picture of solution objectives is drawn.

Design and development of a solution: It is always important to find the most appropriate solution paradigm by estimating the probability of adoption of methods given the possible solutions to the problem.

Solution implementation: The recommended solution is then implemented in the pilot project to test its results. Initially, a prototype is tested under ideal conditions or in a laboratory. This can be tested later in real-world scenarios.

Solution evaluation: Once the implemented artefact is installed or being used regularly, it requires proper monitoring which is done through the evaluation. The results are collected and compared with the ideal set of acquired results. Most of the time, redesign gives the best possible results.

Communication: These final results are communicated as a new artefact and presented in the literature (Hevner & Chatterjee, 2010).

The idea to adopt the best artefact is to compare those with some of the standards and relevant among those two strategies are compared by Juhani. He developed an IT meta-artefact as a general solution concept and compared it with the client's specific problem by building a concrete IT artefact. These strategies are compared in terms of sixteen different traits to address a specific class of problems and suggested that various risks are involved in dealing with the client's specific problems. Hence, it is the researcher's responsibility to adopt an appropriate strategy, but apply a critical eye to its advantages and disadvantages. Artefact evaluation is considered a crucial issue in the design science research process. This tedious work of artefact evaluation is carried out by using both ex-ante and ex-post patterns (Sonnenberg & Vom Brocke, 2012). Design science research is considered the most relevant and important strategy in decision support systems. Recent work clarifies that there is a need to improve the relevance and quality of work in this field as it can change the entire face of the industry and the profession in intellectually important projects. Havner, March, Park and Ram's (HMPR) guidelines for the conduct and assessment of information systems design science research are used as the best way of assessing design science research (Arnott & Pervan, 2012).

4.4 Selected Research Methodologies

There is no perfect way to select a research methodology directly; rather, it depends upon the research question(s) and ultimately the research objectives. This area of research is a bit broader and more complex. To achieve the required results, we narrowed down this research to the residential building context. The multi-method research approach is particularly important for exploring new ideas associated with information systems. A case study and survey research method integration were presented by Gable to articulate the importance of this amalgam (Gable, 1994).

Quantitative:

The quantitative method is adopted for this research as the materials selection process is influenced by different criteria. The competitiveness of the local materials market and the easy access to global markets make it more vital to select the appropriate materials for specific engineering applications. To study in detail and manage most of these factors, the quantitative research method is the best choice. The ranking of materials is best accomplished by MCDM techniques; TOPSIS been selected for this purpose (Chatterjee et al., 2011). Energy consumption is another major criterion to consider when making the selection of materials. The heating load (HL) and cooling load (CL) of a residential building can be easily calculated using the accurate quantitative estimation process (Tsanas & Xifara, 2012). The selection of the research method is predominantly influenced by the research questions and potential outcomes, not only by the methodological and epistemological considerations. Although every method has its strengths and weaknesses, a combination of the two can address this issue (Kelle, 2006).

Bibliometrics:

To understand the basic relationship between construction and sustainable materials selection, we used the bibliometric research method. It resides between the social and physical sciences. It gives an idea of the relationships within a body of literature or describes literature (Sengupta, 1990), which means the main ideas discussed during a specific period of time and how a transformational shift is made over that time period.

This is basically a combination of quantitative and statistical analysis. It can be descriptive to make a comparison, rousing to evaluate the factors governing a specific study over a span of time in terms of years, and able to demonstrate publication patterns over a wide range of laws and methodologies (McBurney & Novak, 2002). This combination is able to develop a relational association towards the direct targeted results and to give a broad and in-depth knowledge about a topic. This motivated us to use these research techniques.

Table 4.3: Research techniques addressing different criteria

Strategy	Research questions	Required control	Focus on current events
Action Research	Who, What, Why, How many, how much	Yes/No	Yes
Case Study	How, Why	No	Yes
Survey	Who, What, Where, How many, How much	No	Yes
Archival analysis	Who, What, Where, How many, How much	No	Yes/No

Modelling	Who, what, how many, How much	No	Yes/No
History	How, Why	No	No
Experiments	How, Why	Yes	Yes

This subsection describes and rationalises the selection of research methods used in this study. It also gives a clear picture of the research output which may include the sustainability index, the model for the selection of construction materials, research papers to be published and the thesis itself. Dina also tried to solve the problem of research methodology selection by introducing several logical choices. It starts with an overview of research paradigms as fundamental beliefs that affect the ways to conduct the research including the choice of research methodology.

Despite recent advancements in information systems, there is an end to the usage of mixed methods in this field of practical research. This problem is dealt with by exploring the mixed-methods technique applied in two recently published papers on IS.

In the qualitative research method, purposeful sampling is also an important factor to discover information about a phenomenon of interest. Criterion sampling is used most commonly for implementation research. However, again the combination of different methodologies is used for implementation research due to recent improvements in qualitative research methods (Seale, Gobo, Gubrium, & Silverman, 2004).

4.4.1 Survey

The survey is one of the most widely-used research methods for collecting data from different sources and a range of participants, especially in the social sciences domain. It is a method for collecting information to describe, compare or explain knowledge, attitudes and behaviours (Fink, 1995). A survey is different from a scale that measures one particular concept or variable of interest in a study. A scale has a total score and all the items have been included to find the importance of a variable for that particular person. It is designed on the basis of previous knowledge, laws and theories to find the relevance of the current study. Survey research basically involves eliciting information from respondents in regard to a specific issue or research topic.

This research method is a relatively young method of research compared with the other scientific domains. It has already witnessed three major eras of growth and evaluation. In the first era (1930-1960) the founders invented the basic components of the design of data collection and tools to derive the information from statistical analysis of data. During the second era (1960-1990), they focused on defining its practicality the effects of an investment in human and physical infrastructure, the growth of quantitative social sciences and the use of information to explore customer behaviour. The third era (1990-forward) witnessed the decline in the survey participation rate, an alternative means of data collection, a weakening of sampling frames, and continuous growth of digital data generation (Behrend, Sharek, Meade, & Wiebe, 2011).

Many qualitative studies describe the diversity of certain intellects and behaviours in certain groups of people by means of semi-structured interviews (Marsland, Wilson, Abeyasekera, & Kleih, 2000). The statistical analysis survey analyses the frequencies of characteristics in the sample participants, while the qualitative survey analyses the diversity of characteristics of members within a population.

Different scales are used to determine the participant's alignment with or diversion from the research topic. Likert scales are useful in social science and attitude research projects. The original instrument has 10 efficacy items and uses a 4-point Likert scale. This instrument is used in large research studies and data analysis programs (Allen & Seaman, 2007).

Telephone surveys are also considered important because they can be used to examine the cross-sectional characteristics of subgroups in a population, ascertain predominant trends and risk behaviours over time, and assess the effects of interventions. Digital dialling makes it easy to obtain responses from participants, although answering machines and caller ID reduced the overall response rate and the increased cost of telephonic surveys (Marsland et al., 2000).

The online contract labour portals (i.e., crowdsourcing) are becoming an increasing trend in the modern world by involving participants to reduce the cost of data collection. The university's pool of respondents was replaced by people who are more mature, have more experience and are ethnically diverse to give more reliable sourced data (Behrend et al., 2011).

The survey research design was adopted in this work to give a quantitative portrayal of knowledge, trends, attitudes and opinions of people (engineers, architects, estimators, and managers) who belong to a specific sample of the population. A cross-sectional questionnaire survey was designed to find out:

- Awareness of sustainability during the selection of materials, and barriers preventing the use of sustainable materials in the local construction market.
- Technical stakeholder's views about the factors involved in implementing sustainable construction practices.
- The relative importance and prioritization of the sustainability criteria for the selection of building materials as investigated from the literature review to develop the sustainability model.

4.4.2 Questionnaire development

A questionnaire survey is considered one of the most cost-effective ways to reach a large number of people to get their feedback and results of studies related to a certain topic. The questionnaire is also a popular data collection tool. Its success depends on various factors: optimal design features, language (unambiguous), distribution method and ways to get the maximum results, reliability, validity and feedback from the participants (Boynton & Greenhalgh, 2004). Questionnaires provide an objective way of collecting information about people's knowledge, beliefs, attitudes and behaviours. During the process of developing a questionnaire, the researcher must ask and address these questions?

- What information am I trying to collect from respondents?
- Is it appropriate to ask these sorts of questions?
- Can any existing instrument be used for this purpose?
- Is this questionnaire valid and reliable?
- How should I present my questions?
- What else can be included i.e. (introductory letter, information sheet etc.)?
- How should it look?
- How should I approach the participants i.e. (online, telephone, mail etc.)?
- What formal approvals must be obtained before starting the research?

All these factors must be considered before drafting and distributing the questionnaire (Ergu & Kou, 2012).

However, during the questionnaire development, several common error factors (i.e. tedious design format, lengthy questions, laid off content and inconsistency in format) can reduce the effectiveness of the questionnaire (Ahn, Pearce, Wang, & Wang, 2013; Glynn, Taasoobshirazi, & Brickman, 2009). The maximum number of returns can be obtained if simple rules are followed such as questions must be easy to understand and unambiguous, received responses must be accurately recorded and transformed to the appropriate file format to code them and subject them to statistical data analysis. The ethical clearance and selection of data collection methods were presented to the university committee and got the clearance. To give participants an idea about the research work and to get their consent for information disclosure a cover letter was also presented to all.

4.4.3 Environmental and sustainability awareness

To gauge the knowledge and awareness of technical stakeholders about the acceptance of environmental and sustainable materials at the design level, a section with questions related to this issue is included in the questionnaire. The purpose is to explore the fundamentals in design decisions and the level of importance they have during their normal working practice. Sustainability in built environments has become a prominent concept in efforts to attain maximum social and environmental benefits. The imperative factors are: improving overall energy management, indoor environment, waste reduction and resource conservation. The major barriers include capital cost, payback period fear, traditional work practices, and lack of knowledge (Ahn et al., 2013).

4.4.4 Application of sustainable principles in building design and materials selection process

There is a close connection between building design and materials selection. There are some key issues associated with sustainable intelligent buildings; these can be environmental, economic, technological and social and, ultimately, the perception of stakeholders. One most recent and appropriate method is offsite construction, where different parts of the building are constructed off-site and then assembled at the building’s location. These are known as modular buildings. This is sustainably acceptable, relatively cheaper and time effective as well. These buildings are likely to achieve a sustainable harmony between design and construction practice (Häkkinen & Belloni, 2011).

4.4.5 Development of the materials selection criteria

A complete set of sustainable assessment criteria is developed to assist the stakeholders to select sustainable construction materials more easily. To manage all these tasks easily and professionally, a questionnaire was developed and distributed among circulated among a wide range of relevant technical stakeholders. This is an effective and inexpensive way of collecting data and enabling participants to have their say.

4.4.6 Sampling for the survey

Sampling is the core factor involved in qualitative research methods. A four-step approach to sampling is described by Robinson and Oliver et al. The steps are 1. defining the sample; 2. deciding upon a sample size; 3. selecting a sampling strategy; and 4. sample sourcing (Robinson, 2014). Address-based sampling is also an innovative and modern trend in sample collection. ABS can help to make person-to-person interviews a practicable mode of data collection. For large scale studies, it can enable the transfer of resources from frame development to activities like training for refusal conversation, an examination of total survey error or a non-response follow-up study (Iannacchione, 2011).

4.5 Chapter Summary

This chapter described the framework of the research methodology. Combinations of different methods were applied to obtain insights about sustainability and materials selection. This is considered a milestone in achieving our research goal by fine-tuning the literature review and the questionnaire. This study explored the local market leaders' knowledge and understanding of sustainability. Major trends and the barriers which influence the materials selection process were discussed. Data collected from the surveys and face-to-face interviews were analysed using different statistical methods to draw conclusions pertaining to the research objectives.

CHAPTER 5

CONCEPTUAL FRAMEWORK DEVELOPMENT

This chapter covers:

- Detailed information about the single criterion models
- Importance of the sustainability model usage
- Conceptual development of the sustainability model
- A detailed discussion of the multi-dimensional assessment model

5.1 Chapter Introduction

The construction industry has the serious problem of consuming significant natural resources and generating a significant substantial amount of waste during and after construction. These concerns can be addressed by developing different frameworks to assist the technical stakeholders and decision-makers in the selection of sustainable construction materials and scientifically ascertaining and appraising the insinuations and relative qualities of a range of alternative sustainable technologies and skills (Nelms, Russell, & Lence, 2007). The importance of sustainability in the construction industry is heightened by the inclusion of major features such as economic growth, social progress and effective environmental protection. These factors rely on the basic principles of resource management to minimize wastage and avoid the scarcity of natural resources, and to create a life cycle design by keeping a close observation on the design, construction, operation and final disposal of the structure, giving foremost importance to human comfort and environmental safety (Sev, 2009).

These bearings created a gradual shift in government and private sectors to concentrate on achieving the environmental performance targets through instigating sustainable construction practices and encouraging the construction of sustainable, green buildings (Ding, 2008). These targets can easily be achieved if the rudimentary concept of sustainable construction can be considered at the conceptual stage of the building construction, the design can be moulded accordingly, the selection of sustainable materials during construction can raise the sustainability rating and final disposal can make it easier to reuse the dismantled materials. This describes the proper sustainability chain process of the construction of a sustainable building.

These concepts are basically cantered upon the sustainable triple bottom line i.e. the conservation of resources, cost efficiency and desire for human adaptation. Each principle is tested against the fundamental rule of economic, social and environmental balance and is used in combination to support each other. This test can be carried out by building industry practitioners who have a great opportunity to reduce the construction-related damage to the environment, as current strategies and processes mainly focus on global aspirations and strategic objectives (Akadiri, Chinyio, & Olomolaiye, 2012).

The construction materials selection process can easily be tailored by using the simple alternate materials selection vector. The comparison between ecological friendly materials and conventional construction materials can clearly demonstrate how much energy and finances can be saved. Accordingly, a comparison carried out between environmental and financial criteria proposed that a wood-based house is 7.5% more cost-efficient than a brick house (Medineckiene et al., 2010).

This gap urged us to make an effort to develop a model for the selection of sustainable construction materials in order to achieve sustainability objectives. The criteria for building materials selection differs greatly between stakeholders as all of the stakeholders have different perspectives from which to rank the building materials. The selection of sustainable building materials is favoured by all of the stakeholders but sometimes the time, availability of skilled labour and alternate materials cause stakeholders to deviate from the standard procedure of selecting sustainable construction materials. For illustration: the building owner will usually prefer the quickest solution and the most affordable materials, and the technical stakeholders will prefer durable and technically approved materials, while the final building users will focus on aesthetics, health and safety (Cole, 1998). It is difficult to find a single assessment method that can address all of the criteria and preference patterns. Many organizations are working to find and define the classification of different construction materials according to their sustainability ratings. The major emphasis is on the building material's environmental and life cycle performance. During data collection and analysis a clear gap was found between the knowledge of sustainability and its application due to the lack of awareness and a classic mindset. This instigated the current research to develop a comprehensive assessment tool that can provide an exhaustive appraisal of building materials performance against the important environmental criteria. At the moment many assessment models are in use, including ATHENA, BEES, BREEAM, BEPAS, CPA, ENVEST, EPM, BPAC, LEED, BEQUEST and GBC. All of these assessment models have some strengths and weaknesses. The following section will briefly mention those attributes.

ATHENA: This is a lifecycle assessment LCA tool developed at the ATHENA Sustainable Materials Institute in Ontario, Canada (Clements-Croome & Croome, 2004). This method calculates the environmental impact of processes. The impact estimator measures the environmental impact of a newly constructed building on the basis of different criteria such as global warming potential, ozone depletion, weighted resource usage, primary energy, air quality assessment, water pollution and air pollution (Stek, DeLong, McDonnell, & Rodriguez, 2011).

BEES: The Building for Environmental and Economic Sustainability (BEES) project was started at the National Institute of Standards and Technology (NIST) in 1994. Its main functional area belongs to the computerised selection of environmentally preferred building materials (Lippiatt & Ahmad, 2004). The BEES hybridization effectively uses the supply and use tables, also known as item-level data, particularly for construction. This specifically works in two steps, the first is economic behaviour and the second is environmental behaviour (Suh & Lippiatt, 2012).

BREEAM: BRE Environmental Assessment Method was the first environmental assessment based model developed by Building Research Establishment (BRE) in 1990 and it is widely used (Larsson, 1998). This method is used for the critical Green Building Rating Systems (GBRS) all over the world. GBRS focuses on building performance and is based on reducing energy consumption and overall energy management. This assessment is carried out considering more refined criteria i.e. water, energy, safety, site selection and comfort. This method gives the final user a deeper knowledge of sustainability and green buildings (Mattoni et al., 2018).

BEPAS: Building Environmental Performance Analysis System is based on the LCA framework. Environmental impacts were scrutinized considering three major aspects of the building i.e. building facilities, building materials and building location. This method can be used for both newly constructed and existing buildings (Zhihui Zhang, Wu, Yang, & Zhu, 2006).

CPA: Comprehensive Project Evaluation Assessment was developed by the Royal Institute of Chartered Surveyors (RICS) and Environmental Agency (Ding, 2008). This method includes all costs and social and environmental related benefits of building construction. This method provides a contrivance to evaluate the nature of the impacts by incorporating the most appropriate analysis method and sustainability analysis into a single framework. CPA is a dynamic system of green building evaluation, considering the fitness of the construction environment and the durability of the system (Xia, Pan, & Wang, 2010).

ENVEST: This method was devised for estimating the life cycle environmental impacts of a building from the design to execution (Erlandsson & Borg, 2003). Initially, this method was designed to deal with commercial buildings. This deals with the environmental impacts of the materials used and the energy consumption during and after construction. This is a very robust model, which helps the technical stakeholders to determine the influential factors of the total environmental performance of the building. This method deals with two major problems faced by the construction practitioners; first, the assessment is based on the sustainability principles and second by assigning weights to the relevant assessment criteria (Akadiri et al., 2012). This tool also deals with the eco-efficiency evaluation of construction materials by using a linear programming based mathematical approach (Tatari & Kucukvar, 2011).

EPM: The Environmental Preference Method was developed by Woon energy in the Netherlands in 1991 within the program of sustainable living in housing. The basic use of this method was to rank construction materials according to their environmental performance (Anderson, SHIERS, & SINCLAIR, 2009). This was developed to enable the end-user to develop a choice vector using the ecological friendly construction materials available in the local market to construct a residential building. This method addresses different factors involved in damaging the eco-system i.e. energy consumption, resource consumption, environmental pollution and global warming.

BPAC: Building Environmental Performance Assessment Criteria was developed by the University of British Colombia in 1993 (Ding, 2008). It has a set of environmental criteria based upon objective performance standards. A standard procedure is followed to evaluate new and existing office buildings, considering the environmental merits of commercial buildings using a simple point system (Kibert, 2016).

LEED: The Leadership in Energy and Environmental Design system is basically based on determining the environmental impact of the building as a whole. It was designed by the US Green Building Council in 1998. This system works for both newly constructed buildings and existing buildings, considering all embodied and operational environmental impacts of the building (Crawley & Aho, 1999). This system uses the whole building approach that heartens the alliance of design and construction process during the venture of building construction. This system is very simple but comprehensively evaluates the building performance using sustainable construction materials.

BEQUEST: Built Environment Quality Evaluation for Sustainability through the Time system is a pan-European system of physical, economic and social sciences practitioners supported by the European Union research directorate devised in 1997. The basic task assigned to that technical personnel was to develop a guide and literature for local practitioners to get easy access to the literature on sustainability of urban development and important factors. The decision-makers needed to develop a framework almanack of assessment methods (Curwell & Cooper, 1998).

GBC: The new impetus to construct more and more sustainable buildings have steered to cultivate more development indicators. The combination of building rating systems and their main functional bodies are considered proxy variables to the evaluation of sustainable construction and selection of sustainable construction materials. This amalgam of different approaches gave multi-dimensional thought-provoking ideas to assess and rank buildings using their energy consumption and the selection of sustainable construction materials as unambiguous criteria (Berardi, 2012).

5.2 Importance and Usage of Building Assessment Methods

In recent times, building assessment methods have gained much more attention and there is higher importance on being more precise and robust as the construction industry continues to devour the majority of the world's resources. As this has become a public issue assessment tools need to be more diverse and consider multiple criteria rather than focussing on a single one i.e. energy consumption, energy management, comfort, aesthetics and indoor health. This problem is worsening day by day, so different tools are used to consider these criteria. This excessive usage of natural resources not only directly affects the related environment but the overall environmental chain feels its effects, like the emission of greenhouse gases increasing due to excessive fossil fuel which affects air pollution. There is a growing trend to determine the challenges in identifying, evaluating and allocating social and economic costs in the pursuance of urbanization (Xing, Horner, El-Haram, & Bebbington, 2009).

The building performance mainly relates to the consideration of sustainability at the design, construction and operational phases of the building. The practitioners aim to improve the building performance using a sustainable design and by gauging the effects of the environmental impacts of the buildings, whether they are natural or artificial (Tan, Shen, & Yao, 2011). The environmental impact is greatly related to the early design decisions. The decision-makers have to face many challenges and sometimes they have to modify their design decisions to manage those unforeseen challenges. Life Cycle Assessment (LCA) can help to make early decisions appropriate depending upon the environmental impacts. Some methodologies can also help to make them understand the relative environmental impacts and the implications of selecting sustainable construction materials in order to significantly reduce their carbon footprint (Basbagill, Flager, Lepech, & Fischer, 2013).

One of the benefits of the assessment method is to comment on building information and overall environmental performance, to define the direction of a building project and curtail the design parameters to achieve a high standard in sustainability-related results. In a broader perspective, there is a swiftly growing trend to use a Neighbourhood Sustainability Assessment tool (NSA). There are several NSA tools that can be categorized into two major streams; one consists of a third party assessment tool that assesses the sustainability beyond a single building and the other consists of neighbourhood scale plans and sustainability initiatives to assess sustainability (Sharifi & Murayama, 2013).

In most of the assessment tools, the data is gathered and put under the chosen ranking process. This data can be used for the fed back information, for design investigation, and the behaviour of the available construction materials. This information can contribute to generating greater combinations of sustainable construction materials, to achieve the maximum sustainability outcome and development of an elaborated decision-making framework. Sustainability is basically an integrative concept among social, economic and environmental interests and initiatives (Gibson, 2010). The environmental building assessment methods enrich the sustainability and environmental awareness among the building practitioners and end-users.

The usage of building assessment methods to understand the relationship between building and environment, nevertheless, the relationship among the phases of building construction and environmental impacts are still debatable. The assessment methods have some limitations which can cause doubt about their usage and effectiveness. Those assessment methods can contribute immensely during and after the design process, and undoubtedly can be used as design tools by considering the environment as an important pillar of building design, helping to reduce and recover from existing environmental damage (Edwards, 2004).

The building façade develops a blockade to light, air and heat so its careful design consideration can help improve these factors and can achieve a high building performance by selecting new and improved insulation, glazing and fire-resistant materials. In construction optimization, basic factors include the gross shape of the building and aspect ratios; however, the main factor of heat content is managed by using a dynamic thermal model in the Passive House Planning Package (PHPP).

The thermal conductance and thermal capacity are managed by the lumped parameter model, which is based on the combination of a generic algorithm and human judgments (Evins, 2013). The operative approach of achieving sustainability in building materials assessment is to consider the environmental factors before the building design, this is called pre-conceptualization consideration. Therefore, to make assessment methods more useful and effective, the recommendations are introduced to the design teams right at the start. Some of the assessment methods do have a weighting system that can assess existing buildings; however, it is an expensive practice to make these buildings environmentally friendly as per the recommendations.

5.3 Limitations of Building Assessment Methods

There are some limitations or barriers in each of the assessment methods. Some of the important and imminent limitations are discussed in the following paragraphs.

The major limitation is the economic factor. Financial issues are always considered as the main deciding force in building construction and during the assessment process. These tools deal with the scarcity of resources i.e. air, energy, water and land but some do not contract with the major driving force of economy/finance. The major assessment methods, such as BREEAM, BEPAC and LEED, do not consider financial limitations in their assessment process (Shi & Xie, 2009). This is one of the basic factors to tackle while planning building construction and the selection of sustainable/alternative materials. Both environmental and financial considerations must be undertaken while planning for building construction. The alliance limitations are still in the process of resolution i.e. LCA, globalization and standardisation. Second generation assessment methods, tools and protocols are now emerging and are trying to deal with issues on a priority basis. This includes a generalized framework that allows for the revision of explicit criteria and increased prominence on building performance over life cycles (Cole, 1998). The affordability for sustainable building is an aligned factor with economics, the environment and social criteria. The result cannot be isolated from a range of social and environmental criteria as they can immensely affect the affordability of sustainable building construction (Mulliner, Smallbone, & Maliene, 2013).

The environmental building assessment methods cannot dismiss the effects of regional and national concerns while assessing any building. However, it is quite difficult to define the boundaries of regional, social and cultural boundaries while making this assessment (Ding, 2008). Many countries made associative changes to curtail the assessment tools accordingly, such as HK-BEAM and the total environmental assessment of buildings in Australia, these changes included economic, social, cultural and environmental considerations.

The GBC is considered as the first to make changes to some of the basic criteria in order to use them according to the state and regional basis, it further required improvements and refinements as the frameworks and their working are so complex to be used easily by end-users (Ding, 2008). Some of the methods are complex and lengthy to use, such as BEPAC which is comprised of 30 criteria, C-2000 which consists of 170 criteria and GBTOOL that has 120 criteria (Cole, 1999). It is evident that there is still a need to develop an assessment method that can combine coverage, completeness and efficient usage.

The assessment methods accommodate the qualitative and quantitative criteria of building performance. As discussed in earlier chapters, the qualitative criteria include health and safety, aesthetics, and raw materials extraction, while the quantitative criteria consisted of energy consumption, water consumption and greenhouse gas emissions (Ding, 2008). For instance, BREEAM allocates 8 points if a building emits CO2 in the range of 140-160 kg/m2, similarly, greater points will be allocated if less CO2 is emitted (W. Lee & Burnett, 2008).

The Green Building Challenge (GBC) framework gives users the option to change weights according to their regions and the importance of criteria usage, and the users can manipulate the data according to their requirements to get the required results (Willetts, Burdon, Glass, & Frost, 2010). There is still only limited literature available to give the weighting protocols according to the criteria, as performance score is obtained using the simple aggregation techniques and are dependent upon the importance of the criteria. This factor is determined using a thorough understanding of the environmental impact of the building materials and the purpose of the building. The important factor would not be the same for the private and public buildings as their weighting factors depend upon the objectives of the building.

The measurement scale is different for the different assessment methods as is the overall score obtained to determine the building performance. Most of the assessment methods have their own assessment and point measurement procedures. Although having some limitations and knowledge gaps these assessment methods helped to achieve the systematic approach to measure and monitor the environmental performance of the building.

5.4 Conceptual Development of a Sustainability Model

The basic idea of sustainability in building construction is based upon developing the building construction practice under a healthy environment and having the best energy management for the whole lifecycle of the building. One main aspect is the building construction method and materials selection. When considering the construction method there is a comparison between off-site productions, also called prefabricated construction and the conventional or in-situ construction method. The comparison can be made using basic criteria such as cost, time, health and safety, aesthetics, sustainability, processing and the procurement of materials. The cost is tiered, as the most important criteria are linked to quality and time (W. Pan, Dainty, & Gibb, 2012). There is a gap found between the knowledge and practical enactment of the sustainability practices in our data analysis outcome. The decision-maker often uses multiple objective criteria for making their choice of building materials during the selection process. The basic purpose of this exercise is to simplify the complex and lengthy data set to make the most appropriate and best selection among the locally available sustainable construction materials. The sustainability of the modern world needs to improve especially in the construction sector as it utilises 40% of the overall energy consumption (Zuo & Zhao, 2014).

“A green material is termed as an ecological, health-promoting, recycled or high-performance building material that impacts the selection of materials to cover all three pillars of sustainability" (Khoshnava, Rostami, Valipour, Ismail, & Rahmat, 2018). It is quite evident from this simple definition that at least these three criteria should be considered when making the selection of sustainable construction materials. The decision-makers employ the complex dataset from an assessment method viewpoint to form a simple and meaningful form of information. To achieve this, the requirements may include a hefty amount of effort and a reasonable time frame to carry out the research in a controlled milieu.

One of the most effective assessment tools is to assess the building using Life Cycle Cost (LCC). This operative technique is used for the retrofitting of an existing building, as this technique can convert existing buildings into good sustainability rating buildings by making some deep-seated changes, such as improvement of insulation cladding, replacement of windows, and controlling the airflow into the buildings. However, the assessment methods differ so broadly that it is difficult to make a comparison of results among several studies (Pombo, Rivela, & Neila, 2016). Life Cycle Cost is linked to the engineering process as the cost factor plays a pivotal role in the development of systems. The cost analysis must be carried out before the engineering design phase, as the engineering process cannot be modified much after the design completion (Utne, 2009). The decision-making process is complex and it cannot be completed considering a single criterion, as a single-dimensional approach leads to an inappropriate decision and materials selection.

The multiple criteria approach in the building materials evaluation process is necessary in today's world as more and more research is carried out to find new and innovative ways of sustainable materials production and processing. The triple bottom line concept considering the environmental impact, financial performance and social benefits of construction materials are tied together to achieve the best results of building performance with regard to sustainability. To achieve sustainability a commodity must deliver environmental quality, prosperity and social justice. One of the cases to take into consideration is the example of Australian rural communities; they are facing a decline in resources, including human and intellectual resources, due to the closure of small businesses and cash management and regulatory institutions i.e. banks and private and public sector resource development initiatives (Rogers & Ryan, 2001).

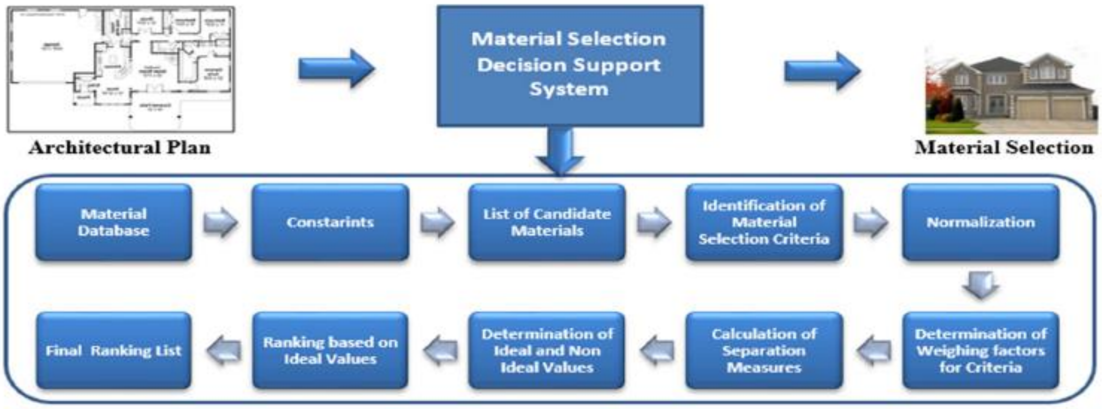

Figure 5.1: Conceptual framework development

5.5 Multi-Dimensional Assessment Model (Basic Approach)

The importance and limitations mentioned above show a clear deficiency in the development of a unique decision-making tool, which can consider and evaluate multi-dimensional criteria. The materials selection process goes through a wide range of complex stages, including considering the sustainability triple bottom line. The materials are the basic ingredients of the building construction. Some of the most valuable considerations are:

- Pollution impacts during the materials manufacturing process
- The extent of use of recycled materials
- Energy reduction in the transportation process
- Materials depletion presentation
- Reduce and manage the dust and construction waste at the construction site
- Maximum usage of natural ingredients rather than plant manufactured materials
- Low maintenance usage of materials

The materials evaluation process is not an easy and straightforward task to carry out, each step contributes new information which is considered, updated and synchronised with the basic information (Nijkamp, Rietveld, & Voogd, 2013), (Ding, 2008).

The technical stakeholders have the propensity to consider multiple criteria in the materials evaluation process, which instigates the idea to develop a model to facilitate the multi-dimensional evaluation process and an aid to make appropriate decisions regarding the selection of sustainable construction materials. The basic inkling is to convert the single objective approach to a multi-objective approach to tackle environmental issues in a better and innovative way. The four major criteria/values as discussed above are economic, environmental, technical and social. The sustainability index derived in previous sections is based upon the absolute assessment approach to generate a relatively complex and composite index that considers other criteria as well. This mathematical approach will also help to rank the alternative materials in a chronological method. Each stage adds more information to support the feedback loop and gives more precise results.

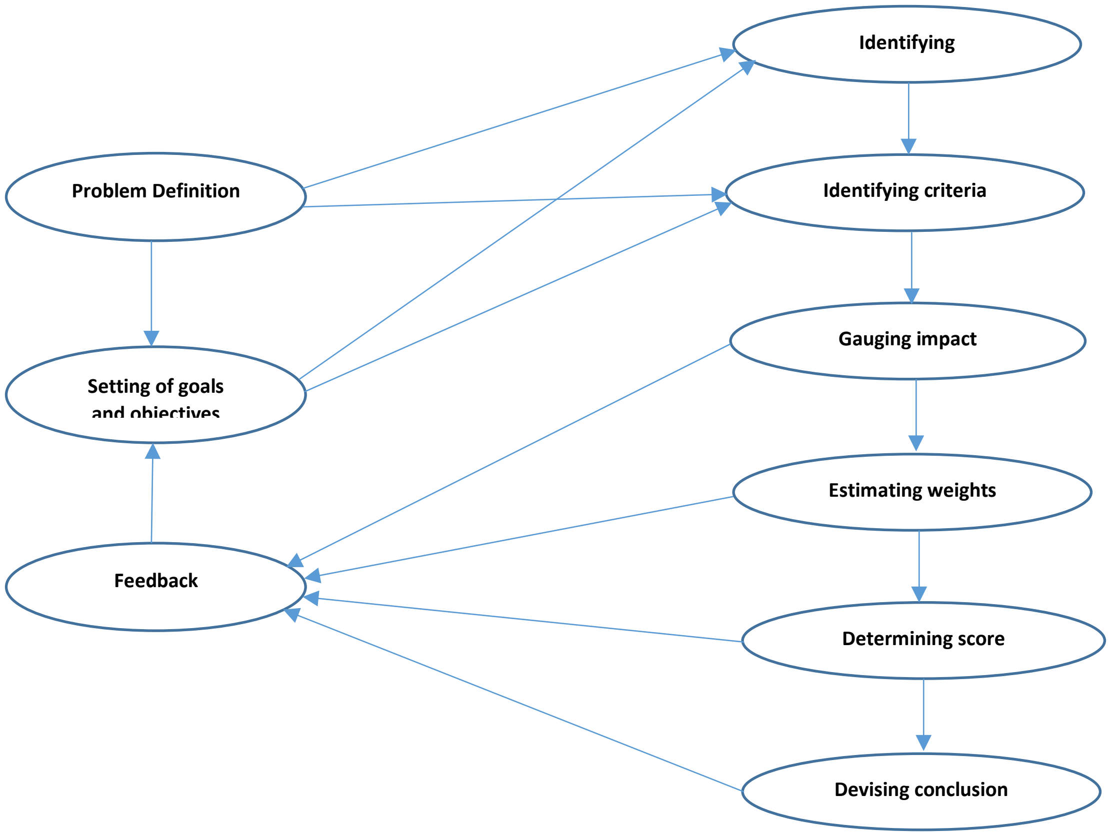

Figure 5.2: Multi-dimensional model for building materials selection
Source: derived from Nijkamp et al. (2013)

The processing of this model is based upon the direct science research process including the problem definition, formulating the attributes of the materials and setting the goals and objectives to be obtained by exercising this whole process (RICS, 2001). The problem must be properly structured and formulated to achieve the desired results. The housing and building entities come under the direct impact of this problem. The solution must be precise, low-cost and aligned with health and safety guidelines. The volatile organic compounds are selected at first as those are the most common materials to be used inside buildings including plaster, painted gypsum plasterboards, vinyl flooring, carpets and laydowns. The results revealed that there were strong correlations among equilibrium partition coefficients and effective diffusion coefficients from the sink diffusion model (Xiaoyu Liu, Guo, Sparks, & Roache, 2011). These problem definitions are mostly derived by different factors, such as financial factors that are involved in the selection of alternative sustainable construction materials, political constraints that hinder when a public building needs to be inaugurated as this will be constructed from the public funds and budgets, and the external factors generated through the environmental and natural resources scarcity themes.

The second milestone process is the identification of the alternate solutions or in the context of this literature the alternative construction materials. The general notion is restricted to the materials alternatives only, while the alternative location, orientation and alternative design play as important a role as the materials do. The pivot objective revolves around the selection of either renewable or non-renewable resources. Energy consumption per capita determines the Human Development Index (HDI). This energy consumption will ultimately exhaust all-natural resources, energy conservation and sustainability/ re-usage/ passive reservation of energy are the latest and modern goals of a new sustainable world. This objective of developing energy-efficient buildings has a new horizon to design the buildings using building envelope techniques. “A building envelope is the surface that separates the outdoor and indoor environment of the building.” Therefore, different components of this envelope i.e. walls, roofs, external cladding, thermal mass, thermal insulation and thermal entropy play an important role in the development of Energy Efficient Buildings (EEB) (Srivastava, 2018).

Evaluation criteria define the materials characteristics or the identification of alternative materials availability. This is the set of rules to qualify the materials for contention or alternatives to achieve the ultimate goal of sustainable building construction. In this regard, the construction method also plays a vital role to increase the chances of achieving a better sustainability performance of a building, such as the modular building construction method which is recognised as one of the prime methods for sustainable off-site construction. The sustainability evaluation criteria are again based upon the triple bottom line (TBL) i.e. economic, environmental and social where each category can have many and unique Sustainability Performance Indicators (SPI) (Kamali & Hewage, 2017). The results inferred from the data analysis of current research work, through survey and interviews, is validated by Kamali’s working that the economic dimension of sustainability was the most profound and influential factor on achieving building sustainability, followed by the social and environmental dimension respectively.

The impact of the proposed criteria can be categorised into two main streams, objective and subjective. The objective impacts can be dealt with as there are several techniques available however the subjective impacts have limited impact evaluation access as they are mostly related to social or environmental issues. The results in current research (analysed and discussed in Chapter 6) aligned with the same dilemma that most of the practitioners and decision-makers have very limited access to knowledge about sustainability or alternative materials, leading to only a small amount of implementation. The quantification of subjective impacts is a major point of concern, to deal with this issue several different methods are used to get the desired results. Each criterion is measured using a unique method in its nature to get the relative importance against each alternative. The materials selection and comprehensive enhancements to meet new innovation is the key to success in this new age, for example, the qualitative selection of green decoration materials for a building. These complex criteria are tested and verified using different MCDM techniques i.e. AHP and TOPSIS. A weights vector of hierarchical index structure is developed using the environmental characteristics of the green materials (Tian et al., 2018). Qualitative impact measurement is always involved with complex mathematical and numerical data analysis (Ding, 2008).

In a list of criteria, there are always some with more importance than others that result in receiving higher weights in the selection process. As in sustainable materials selection, the economic criteria may have more importance than the social and environmental criteria in alternate solution 1 and this may be the reverse in the alternative solution 2 situation. The selection of materials from a list of alternatives must have some more important features and weights than other alternate materials where each weight represents the ultimate priority of the criteria in the list. This process is governed by two major approaches, direct and indirect estimation, based upon the relative importance of the response provided by the participant or the expert in the field. In a survey or questionnaire, direct estimation is gauged by the implementation of techniques such as rating method, ranking method, trade-off, Likert or paired approach to make a comparison between two alternatives only, all of these methods provide great results up to a certain limited number of criteria; for complex and larger numbers they are still considered problematic (Hobbs & Meier, 2012). The indirect approach has a nominal way to get the responses using the actual previous behaviour, the rankings and ratings which are already assigned to certain criteria are used by asking indirect questions from the participants. The aggregation methods range from simple averaging to sophisticated approaches, but the prioritised aggregates within the prioritized relationships between attributes must be considered (Omar & Fayek, 2016). This work may encompass the usage of multi-criteria analysis to fetch the values together for each alternative to help in the decision-making process. This exercise gives realistic results based upon the factual ratings and scores for each alternative materials, where the higher the value of the score/rating the more likely it is that the materials will be selected among the available list of alternative sustainable construction materials.

5.6 Chapter Summary

This chapter helped to explain, through literature review, the evolution of the process of materials selection from a unique single criterion to the multi-dimensional approach of the evaluation of sustainable construction building materials. The middle section illuminates the gradual development of a conceptual basic framework to a complex and detailed one that is based upon the triple bottom line concept i.e. economic, environmental and social values. This model provides a systematic and rounded approach for alternative sustainable construction materials using a multi-criteria methodology. This section also discussed the different materials and building assessment methods used in different parts of the world. These methods assess the buildings using different criteria and scoring systems but the ultimate aim of all these methods is to promote the overall awareness of sustainability in the construction industry among decision-makers and building specialists. The discussion mentioned the practicality and usage of different assessment methods from a simple award checklist to a multi-directional framework, to include physical quantification and wellness of diverse criteria for the building assessment. A conceptual framework is discussed with some minutiae and examples that are already being used in the practical field.

CHAPTER 6

DATA COLLECTION, ANALYSIS AND RESEARCH FINDINGS

This chapter covers:

- Data collection techniques and data analysis
- Environmental awareness and design practice by construction practitioners
- Sustainability considerations in building design and construction
- Factors affecting sustainability practices and materials selection process
- Development of materials selection criteria

6.1 Chapter Introduction

This research involved a questionnaire survey to collect data about the environment and sustainability awareness of local technical stakeholders (architects, designers, engineers, estimators and managers) and current practices involved in construction materials selection. The previous chapters portray the complete picture of the literature review and this chapter will discuss the facts about data analysis and the survey outcomes, from distribution to response reception. Each question and its overall response is discussed in detail in order to figure out the current process of materials selection and what are the main factors that can affect the choice of materials. The data analysis is carried out through SPSS. The Likert scale is used in the survey; this is considered a reliable choice to find out the overall perception and experience of a group of relatively homogeneous individuals of the same background and trade (Gliem & Gliem, 2003). The rest of the chapter is composed of the main sectional analysis of the survey i.e. analysis of demographic data, environmental and sustainability awareness gauge, current design and selection practices, factors affecting sustainable building design and construction, decision-making process and influential factors in materials selection and major obstacles, materials assessment and usage practice, development of sustainability criteria for construction materials selection and development of a sustainability index model.

6.2 Survey Response Rate and Validity

Data collection methods are categorised into three main types i.e. postal, online and self-administered surveys. 52 questionnaires were sent with cover letters and participant consent forms to construction companies through the mail with return envelopes. These documents are necessary to clarify the purpose of the survey. From these 52 questionnaires, 11 responses were received back from these companies, giving a response rate of 21.15%. This response rate is adequate as other researchers have concluded that the response rate for a postal survey in the construction industry is between 20% and 30% (Dulaimi, Ling, & Bajracharya, 2003), (Akintoye, McIntosh, & Fitzgerald, 2000), (Chinyio & Olomolaiye, 1999). This rate is due to small construction firms being unable to reply as ordinarily, they are quite busy with their scheduled works. Ofori and Chen received a response rate of 26% (Ofori & Gang, 2001)("ISO 9000 certification of Singapore construction enterprises: its costs and benefits and its role in the development of the industry.

Online surveys were sent to 35 company's respondents and 19 responses were received from them, giving a response rate of 54%. For this method, an online link was sent to all respondents so that they could access an online survey and record their responses. Furthermore, to make it more convenient and maximize the response rate, the survey was created cell phone friendly so respondents were able to access it through their smartphones as well as via a computer. This type of distribution has the capacity to give maximum feedback as the respondents can complete the survey in their own time. Face to face, self-administered surveys were also conducted with 8 company's representatives after sending the request to 23 companies, giving a response rate of 35%. This is considered the most successful way of data collection as actual, true and complete responses were obtained through this method. The total response rate is drawn graphically as follows. All surveys were evaluated before analysis to verify that all the questions were answered, missing values were adjusted by SPSS, some irrational answers we got from the different respondents were removed and some more suggestions and relevant work experience of the respondents were recorded.

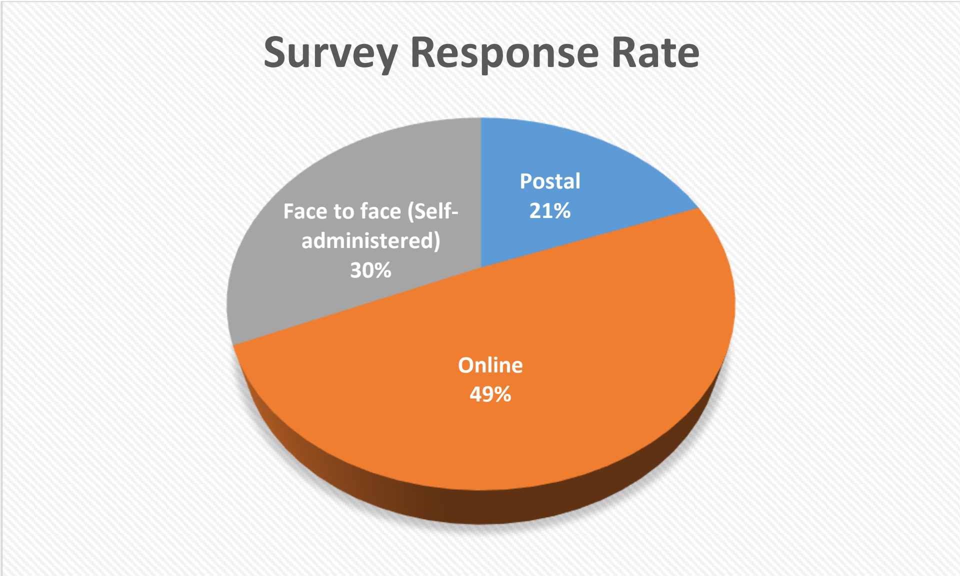

Figure 6.1: Survey response rate

The major benefits obtained from these survey responses were as follows

- The surveys were distributed to as many respondents as possible to obtain a deeper insight into the construction market.
- A unique URL (Uniform Resource Locator) link was generated to send to respondents to make it easier to fill the survey online or even through their cell phones (which was the most successful method to get a data response).
- Three different distribution methods were applied to compensate for any disadvantage of one method.
- Live suggestions were received during the different modes of data collection and accommodated accordingly.
- Consultants and contractors were targeted primarily as they are considered the game changers and perception builders within the construction industry.

6.3 Margin of Error

It is a widely accepted theory that for the inferential statistical analysis a large sample is required, where the average value should be more than 30 (n>30). There are many findings that support this concept in totality (Marshall, Cardon, Poddar, & Fontenot, 2013), (Francis et al., 2010), (Munn & Drever, 1990), (Mason, 2010). The sample size acquired is considered as a good response rate and the data can be used for analysis using the appropriate statistical data analysis tool.

6.4 Data Editing

Data obtained from respondents is often incomplete, with questions being answered incorrectly or not being answered at all, hence the study with no missing data is called exceptional. There are many techniques used for coping with missing data in the literature (J. W. Graham, 2009). Therefore, some time needs to be spent correcting the data where cases and variables are included in data analysis. To verify the replacement of missing data, SPSS used (-99) as a default figure which does not affect the overall results. We verified the results with technical stakeholders after data analysis.

6.5 Data Analysis

The responses were recorded using the intensity measurement of perception and knowledge, otherwise known as the Likert scale, which was developed in 1932 as a five-point bi-polar response. The data obtained through this approach is normally ranked in four categories:

1. Nominal data: The weakest level of measurement representing categories without numerical representation.

2. Ordinal data: Data in which an ordering or ranking of responses is possible but no measure of distance is possible.

3. Interval data: Generally integer data in which ordering and distance measurement are possible.

4. Ratio data: Data in which meaningful ordering, distance, decimals and fractions between variables are possible.

Initial analysis of the Likert scale data should not involve parametric analysis but should rely on the ordinal nature of the data. Converting Likert scale data into indices adds values and variability to data (Allen & Seaman, 2007). The following main techniques were used for data analysis and in all these *Statistical Packages for the Social Sciences (SPSS) and Excel* are used.

6.5.1 Statistical analysis

The SPSS (Statistical Package for the Social Sciences) is used to describe the main features of the collected data. Basic terms are calculated and verified through this, such as frequencies and percentages. These methods were used for open-ended questions and the initial analysis of rating score data.

Most of the known statistical methods such as hypothesis testing, linear regression, analysis of variance and maximum likelihood estimation are mostly designed to solve mechanical calculations, for this survey the traditional methods of mathematical analysis are replaced by specially constructed computer algorithms (Efron & Tibshirani, 1991).

6.5.2 Relative index analysis

This method is used for further analysing the responses related to the rating of research variables. This is extensively used in similar sorts of studies (Braimah & Ndekugri, 2009). SPSS is used to analyse the valid frequencies and to find the respective rank indices.

$$RI = \sum \frac{w}{AxN} \tag{6.1}$$

Where *w* is the weight assigned by the respondent on a Likert scaling using a strength value of 1 to 5 with 1 being the lowest and 5 being the highest. *A* is the highest weight given by the respondent, *N* is the number of samples, and *R* is the relative indices. The ranking index is characterized differently depending upon the context. Factor analysis also helps to find the correlation between the different building criteria such as aesthetic, maintainability and energy-saving, which are considered the most important factors in the sustainability of building materials (Akadiri & Olomolaiye, 2012). The delay factors are also calculated using the same method of analysis by Murat (Gündüz, Nielsen, & Özdemir, 2012).

6.5.3 Concordance and chi-square test

During the survey and direct interaction with the correspondents, it is quite possible they might agree with some questions strongly or they may not agree. This is calculated using Kendall’s coefficient of concordance which gives a measure of agreement between 0 and 1 where 0 means no agreement and 1 means full agreement. Using the data set obtained from each respondent (W) was calculated using the following equation.

$$W = 12 \sum \frac{Ri^2 - 3k^2N(N+1)^2}{k^2N(N^2-1) - k\sum T_j} \tag{6.2}$$

Where $\sum R_i^2$ is the sum of squared sums of the ranks for each of the N objects being ranked, k is the number of sets of ranking, such as the number of respondents in a data set, and T_j is the correction factor for the jth set of ranks for the tied observations obtained from the expression $T_j = \sum_{i=1}^{gj}(t_{i^3} - t_i)$, where t_i is the number of tied ranks in the ith grouping of ties and g_j is the group number of ties in the jth set ranks.

To verify that the degree of agreement is not a matter of coincidence the implication of W was tested using the null hypothesis as being the best disagreement. The Chi-square x^2 approximation of sampling distribution is given in the following equation:

$$x^2 = \mathrm{k(N-1)W} \tag{6.3}$$

The calculated x^2 value greater than its counterpart tabulated value indicates that W was significant at a given value and the null hypothesis is neglected and rejected. This work is supported by Daniel as well to demonstrate the concordance in risks implemented at the guaranteed maximum price and target cost contracts in the construction sector (Chan, Chan, Lam, & Wong, 2010).

6.5.4 Factor analysis

Factor analysis is a multivariate statistical technique for examining the underlying structure of interrelationships or correlations among a large number of variables (Hair, Black, Babin, Anderson, & Tatham, 1998). This study created a set of factors or underlying dimensions which when interpreted and understood describe the data in a more meaningful way than the original individual variables(Glynn et al., 2009). The safety concerns are dealt with using the empirical statistical analysis approach to undergo the factor analysis for 15 major SMPs projects (E. W. Cheng, Ryan, & Kelly, 2012). The factor analysis is used to group the larger data to save a reasonable time, such as in the cement industry many financial ratios are considered to be the reflectors of progress. Around 44 financial ratios were assembled in a group of 7 to analyse the exact situation of the industry. To consolidate the analysis and get better results the factors having low inter-correlation were excluded resulting in 8 underlying factors. To validate the results, cluster analysis was conducted (De, Bandyopadhyay, & Chakraborty, 2011).

6.6 Demographic Data Analysis

Basic factual data was collected relating to the respondent's affiliation with the organization like their position in the company, experience, address, phone number, type of company, size of the company, type of projects and age of organization. Most of the respondents were reluctant to disclose this type of information and therefore the rate of response to these questions was too low. Of the 110 distributed surveys using three (postal, online, self-administered) different means of distribution, 38 responses were received giving a response rate of 35%. Out of these responses, two respondents did not complete the survey so after data cleaning 36 responses remained, giving a response rate of 33% which is still considered a good response rate as it should be more than 30% (Marshall et al., 2013).

6.6.1 Type of organization

Type of organization refers to the major trade of the company to which the respondents belong. Table 6.1 shows the major portion (30.55%) is covered by contractors as they are the most dominant factor in the local market. The rest of the percentages cover all major stakeholders and market leaders. The next largest type of organization was architecture and design, this organization type can recommend sustainable materials. The education sector was the least represented as they are not directly involved in the materials selection process.

Table 6.1 Type of organization

Variable	Frequency	Percent	Cumulative Percent
Type of organization			
Architecture/Design	8	22.22	22.22
Engineering	7	19.44	41.66
Quantity surveying	5	13.88	55.54
Project Management	3	8.33	63.87
Education	2	5.55	69.42
Contractors	11	30.55	100
Total	36	100	

Source: Analysis of survey data 2018

6.6.2 Size of organization

This is determined by knowing the number of employees in the organization. Table 6.2 shows that small to medium firms shared a lot of their experiences making up 41.66% of the total sample size. To get homogeneous data and an equally shared portion of the experience, almost all sizes of organizations were involved in this data gathering process. Furthermore, small contractors are more dominant in the Australian construction industry, as they progress from a "tradie" background to develop their own small business. Mid-size organizations are also an integral part of the industry with their contribution making up 30.55% of the overall response. The bigger companies normally have vast experience and they deal with almost all types of construction activities i.e. housing, commercial, industrial, and even the shipping industry. Their experience is very valuable and their data is quite credible.

Table 6.2: Size of organization

Variable	Frequency	Percent	Cumulative Percent
Size of organization			
<10 staff	15	41.66	41.66
10-50 staff	11	30.55	72.21
51-249 staff	6	16.66	88.87
250-500 staff	1	2.77	91.64
>500 staff	3	8.33	100
Total		100	

Source: Analysis of survey data 2018

6.6.3 Age of organization

The result shows that a major chunk of organizations (44.45%) is in the range of 6 -10 years of age. This means that the mainstream of data respondents is mature and experienced in their field. The second and third position ranked firms are also above 5 years of experience. These figures are quite satisfactory for data source reliability.

Table 6.3 Age of organization

Variable	Frequency	Percent	Cumulative Percent
Age of Organization			
<5 years	7	19.44	19.44
6-10 years	16	44.45	63.89
11-20 years	4	11.12	75.01
21- 30 years	3	8.33	83.34
>40 years	6	16.67	100
Total		100	

Source: Analysis of survey data 2018

6.6.4 Work experience

Work experience result again shows good results for data validity and authenticity. The top two positions in the data results table show that the majority of respondents have between 5 and 10 years of experience sharing 38.88% and 33.33% of the total.

Table 6.4 Work experience

Variable	Frequency	Percent	Cumulative Percent
Work experience			
<5 years	14	38.88	38.88
6-10 years	12	33.33	72.21
11-20 years	7	19.45	91.66
>20 years	3	8.33	100
Total	36	100	

Source: Analysis of survey data 2018

6.6.5 Area of building project’s main focus

This data set shows that the leading response area is residential buildings (30.55%) by the respondents, while commercial (22.22%) and institutional (16.66%) are also contributing a significant portion. Leisure (8.33%) and apartments (8.33%) share an equal participation ratio. The greater response rate from the residential professionals shows the main strength of the research orientation is a residential building and their market share.

Table 6.5: Area of building project's main focus

Variable	Frequency	Percent	Cumulative Percent
Area of Building Projects Main Focus			
Commercial	8	22.22	22.22
Residential	11	30.55	52.77
Institutional	6	16.66	69.43
Industrial	3	8.33	77.76
Leisure	3	8.33	86.09
Apartments	3	8.33	94.42
Hospitals/Health clinics	2	5.55	100
Total		100	

Source: Analysis of survey data 2018

6.6.6 Major client type

Client type is important to show the major trend of client representatives towards getting new knowledge regarding the environment and sustainability practices. The majority of responses being private (41.66%) means that they are more concerned with the latest techniques due to high competition within the market. Most of the time, private clients hire the services of third-party consultants to verify that the work is carried out according to environmental and sustainability standards. The public (25%) sector is improving and this shows more involvement in the implementation of environmental and sustainability standards as they are normally reluctant to adapt to change as they have to follow their classical and traditional specifications and procedures.

Table 6.6 Major client type

Variable	Frequency	Percent	Cumulative Percent
Major Client Type			
Public	9	25	25
Private	15	41.66	66.66

No difference	9	25	91.66
Cannot tell	3	8.33	100
Total		100	

Source: Analysis of survey data 2018

6.7 Environmental Awareness and Design Practices

One of the prime purposes of this research is to explore the environmental and sustainability awareness among the technical stakeholders (architects, designers, engineers, estimators and managers) and to understand their attitude towards adopting environmental and sustainability practices.

6.7.1 Level of awareness of environmental issues

All respondents were aware of these parameters but only 33.34% were extremely aware, and almost 20% were only slightly aware. This may be due to the number of respondents from a "tradie" background, who do not have any formal education or degree in construction.

Table 6.7 Level of awareness of environmental issues in building construction

Awareness Scale	Frequency	Percent	Cumulative Percent
Extremely aware	12	33.34	33.34
Moderately aware	8	22.23	55.57
Somewhat aware	9	25	80.57
Slightly aware	7	19.45	100
Total		100	

Source: Analysis of survey data 2018

Almost all of the respondents (95%) were quite clear about the importance of the selection of environmentally friendly and sustainable materials in construction and agreed that natural resources used in construction deliver a negative impact on the environment. The result in table 6.8 shows that the major portion (66.66%) strongly agreed with the fact that ultimately the large usage of natural construction materials will cause the scarcity of these materials, especially in areas with small or uncontrolled regimes. The respondents that simply agreed may have some reservations but the rest with neutral marks were not quite clear about these facts. This fact is being considered and acknowledged all over the world (Batabyal, Kahn, & O'Neill, 2003).

Table 6.8 Construction impacts negatively on the environment

Agreement Scale	Frequency	Percent	Cumulative Percent
Strongly disagree	0	0	0
Disagree	0	0	0
Neutral	5	13.88	13.88
Agree	7	19.45	33.33
Strongly Agree	24	66.66	100
Total		100	

Source: Analysis of survey data 2018

6.7.2 Addressing environmental issues at the conceptual design stage

A large section of the literature comments and describes the importance of addressing the environmental issues at the first step, the conceptual design stage (L. Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002), (P. Rao & Holt, 2005). To investigate the degree of agreement or disagreement regarding this practice a question was asked from the respondents "*Is it important to consider the environmental issues at conceptual stages?"* a seven-point Likert scale was provided to them to record their viewpoint and practical adaptability (*where 1= Strongly disagree to 7= Strongly agree*). An extended Likert scale was given to get the full spectrum of logic and the general practice currently used in the local market.

Table 6.9: Addressing environmental issues at the conceptual design stage

Agreement Scale	Frequency	Percent	Cumulative Percent
Strongly disagree	0	0	0
Disagree	0	0	0

Somewhat Disagree	0	0	0
Neutral	3	8.33	8.33
Somewhat agree	6	16.66	24.99
Agree	15	41.66	66.65
Strongly agree	12	33.33	100
Total		100	

Source: Analysis of survey data 2018

Table 6.9 shows that most of the respondents (75%) agreed or strongly agreed that the best time for the consideration of environmental or sustainability issues is at the conceptual stage. This concept is observed by other researchers as well (Ding, 2008), that the most effective way is to consider all environmental or sustainability issues at the start which can give us leverage to change our design accordingly. The capital cost can be well managed and abridged by considering these factors at the start of the design stage. These results also validate the research objective that a more efficient and effective way is to accommodate environmental or sustainability issues at the start by establishing a building materials selection model for the local market.

6.7.3 Practical implementation of environmental design

The results of the survey present that most of the respondents agreed or strongly agreed on the fact that all of the stakeholders (architects, designers, engineers, estimators and managers) must have a clear concept while making the selection of construction materials, they must be well aware of the local environmental and sustainable materials lists and suppliers to choose the best available materials for building construction.

Table 6.10: Importance of being conscious that some materials have impacts on the environment

Agreement Scale	Frequency	Percent	Cumulative Percent
Strongly disagree	0	0	0
Disagree	0	0	0
Somewhat Disagree	1	2.77	2.77
Neutral	2	5.55	8.32
Somewhat agree	3	8.33	16.65

Agree	17	47.22	63.87
Strongly agree	13	36.11	100
Total		100	

Source: Analysis of survey data 2018

Table 6.11: Environmental considerations need to be incorporated into materials selection decision making

Agreement Scale	Frequency	Percent	Cumulative Percent
Strongly disagree	0	0	0
Disagree	0	0	0
Somewhat Disagree	0	0	0
Neutral	1	2.77	2.77
Somewhat agree	6	16.66	19.43
Agree	18	50	69.43
Strongly agree	11	30.55	100
Total	36	100	

Source: Analysis of survey data 2018

Table 6.12: Importance of considering a full range of environmental impacts of construction materials by assessing their entire life

Agreement Scale	Frequency	Percent	Cumulative Percent
Strongly disagree	0	0	0
Disagree	0	0	0
Somewhat Disagree	0	0	0
Neutral	2	5.55	5.55
Somewhat agree	8	22.22	27.77
Agree	15	41.66	69.43
Strongly agree	11	30.55	100
Total		100	

Source: Analysis of survey data 2018

6.8 Building Design Priorities

The results of the survey represent that the decision-makers are aware of the importance of the usage of environmentally friendly and sustainable construction materials. The primary objective of this research is further explored by getting notes from respondents about the factors affecting their design decisions and their priorities while selecting construction materials for a specific building project. They were asked to prioritise their objectives to gauge the level of importance they pay to normal and environmentally friendly, sustainable construction materials. Most of the time the choice depends upon the client's need however other core factors such as cost, time and quality and other factors such as building regulations and environmental impact affect their decision-making practice.

Table 6.13 Ranking of project objectives

Project Objective	Weighted total	RI	Rank	Mean Value
Satisfy Client Specifications	140	0.778	1	3.889
Meet Project Deadline	134	0.744	2	3.722
Meet Building Regulation	134	0.744	3	3.722
Sustainability Criteria	130	0.722	4	3.611
Environmental Impacts	126	0.700	5	3.500
Minimize the Cost	125	0.694	6	3.472

Source: Analysis of survey data 2018

These values are obtained from formula 6.4 that is described in the following section.

$$RI = \sum \frac{w}{AxN} \qquad (6.4)$$

Where *RI* = Relative Index, w is the weighting given by respondents ranging from 1-5

A = highest weight (i.e. 5 in the study)

N = total number of respondents

The relative index value ranges from 0-1.

Table 6.13 shows the rating of project objectives, where the number one priority is to satisfy the client's specifications, this shows a satisfactory trend that most of the time all efforts are made to reduce costs even if some of the time the quality is compromised. This trend shows that the overall awareness of clients or the general public towards meeting the specifications is the foremost priority of construction firms.

To meet the project deadline is ranked second (RI=0.744) as it is always important to complete the project in time to earn the maximum benefit and to give value for money. Finishing late can cause penalties and cost variations, which can be drastic if no price escalation clause is mentioned in the contract, this can be controlled by proper performance measurement under a strict environment (Bassioni, Price, & Hassan, 2004), (Cicmil, Williams, Thomas, & Hodgson, 2006).

The third-ranked priority is to meet building regulations (RI=0.744) which shares the same value of RI as meeting project deadlines. The design and construction are always exercised under the confined and strict conditions of legislation, furthermore legal requirements make this more tedious (Glaeser, Gyourko, & Saks, 2005). It also covers the health, safety and environmental aspects to restrict the building practice to certain limits. This high ranking given is not unexpected as the design and construction of buildings and selection of materials must comply with the local government building regulations and codes of standards and practice.

Fourth (RI=0.720) and fifth (RI=0.700) priority rankings are sustainability criteria and environmental impacts which shows that other factors are of more concern in the local market, although they are the key to success and innovation for a bright future (Nidumolu, Prahalad, & Rangaswami, 2015). Green buildings are a fast-growing subject all over the world (Robichaud & Anantatmula, 2010). As far as local firms are concerned they are at a very basic level to use these parameters for building construction. This is showing that despite the respondent's indication of their awareness and their persuasion to use environmental wellness design and construction it is currently at a lower priority. A misconception exists in the local market that those construction materials are more expensive or they are not well equipped and skilled to deal with those products.

The major unexpected ranking that came up was to keep the price low (RI=0.694), as for every client it is quite important to keep the building project under the allocated budget. In most cases, it has been an imperative value in the design and construction of the building, which is controlled and monitored by the client at almost every step. One of the most important factors in cost escalation is a change in order which means variations in the scope of work (Assaf & Al-Hejji, 2006). From the client's perspective it is always considered favourable and in good standing, if the contractor firm completes the building project under a certain budget (Love, 2002).

6.9 Sustainability Considerations in Building Design and Construction

Environmental awareness leads to include the fundamental question of sustainability and innovation. Currently, sustainability shares the modern concepts of a mixed evolution of ecological, economic and social responsibility. In recent times, green building is the concept used to mitigate the environmental effects of buildings. Many attractive themes are discussed within the scope of green buildings, and a quick comparison between green and conventional buildings shows the approaches required to achieve the tag of a green building (Zuo & Zhao, 2014). Green building also serves many types of incentives, some external and some internal. The main external incentives are normally controlled and monitored by the government agencies while the internal is normally dealt with by the building administrations. To achieve these incentives some core strategies are also implemented to attract the owners and for investors to reap the rewards (Olubunmi, Xia, & Skitmore, 2016).

Economic factor plays an important role in driving financial stakeholders towards sustainable building construction. However, there are some gaps in the information delivery to the client which causes organizational and procedural difficulties and ultimately hinders the move to sustainable building construction. New technologies are often opposed due to the requirement of change in the traditional mindset and procedures. There are some risks of unforeseen processes and hidden costs, technical skills shortage and tedious regulations. These are all issues that can be dealt with by providing clear information to the client, providing all specifications in common language, economic growth and spreading the overall awareness to the client and their technical personnel (Häkkinen & Belloni, 2011).

Social considerations must be addressed at all design, planning, construction, and operational phases of the building life cycle as they have the potential to change project performance and efficiency. These directions can be well defined by dividing social sustainability into six major categories including stakeholder engagement, user considerations, team formation, management considerations, impact assessment and place context (Valdes-Vasquez & Klotz, 2012). Local market trends depict the lack of these considerations, as they are still reluctant to replace their traditional procedures, frightened of the skill shortage, scared of hidden costs and wary of time delays. These issues compel us to instigate this research to investigate these problems in detail.

6.9.1 Sustainable design knowledge

The implementation of sustainability depends upon the knowledge and awareness of technical stakeholders (architects, designers, engineers, estimators and managers).

Table 6.14 Sustainable design knowledge

Knowledge Scale	Frequency	Percent	Valid Percent	Cumulative Percent
Excellent	3	8.33	8.33	8.33
Good	6	16.66	16.66	25
Average	19	52.77	52.77	77.76
Poor	8	22.22	22.22	100
Total		100	100	

Source: Analysis of survey data 2018

The data in Table 6.14 shows that although the respondents mentioned they are aware of sustainability and its importance in construction, 52.77% have only an average knowledge of sustainable design and the products currently available in the market. The alarming thing is that poor knowledge (22.22%) is more than good (16.66%). To resolve this deficiency there is an urgent need to tell and teach the key role players about sustainable products and their efficacy and adaptability. Most of the respondents were of the view that clients or their representatives are less concerned about this factor and therefore that’s why they also pay less attention. There were a fewer number of excellent knowledge holders (8.33%), and they mainly belonged to well established and large organizations.

6.9.2 Sustainability assessment consideration

Contrary to the data in Table 6.14, most of the respondents (88.88%) agreed that it is important to select sustainable materials for building construction, and only one person (2.77%) disagreed with the reasons, namely, increased cost and lack of skilled labour.

Table 6.15: Importance of sustainable materials in building development

Knowledge Scale	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	32	88.88	88.88	88.88
No	3	8.33	8.33	97.21
If no give reason	1	2.77	2.77	100
Total		100	100	

Source: Analysis of survey data 2018

Startling results surfaced from the survey data, showing the percentage of the projects handled considering sustainability as an important factor was far less than expected from their initial claim of knowledge about sustainability and its importance.

Table 6.16. Projects with sustainability consideration

Projects	Frequency	Percent	Cumulative Percent
Less than 10%	13	36.11	36.11
10% - 20%	10	27.77	63.88
21% - 30%	5	13.88	77.76
31% - 40%	2	5.55	83.31
41% - 50%	4	11.11	94.42
More than 50%	2	5.55	100
Total		100	

Source: Analysis of survey data 2018

The majority of projects (36%) were completed without considering sustainability as an imperative factor for building construction while implementing the sustainability activities can give a competitive advantage over the existing rival firms who are reluctant to implement those activities (Tan et al., 2011). This happened due to badly managed construction activities, and a lack of consistency and holistic methods to help to participate construction parties at different stages of building construction projects (L. Y. Shen, Li Hao, Tam, & Yao, 2007).

The participants were then asked which category of clients is well-versed in regard to sustainability and related activities to implement to their projects. The results in Table 6.17 show that public clients (27.77%) are more attuned, although their participation is low they are still better than private clients (16.66%), most of the respondents had the view that the client's affiliation does not make any difference (38.88%) while (16.66%) do not want to answer this question or do not want to disclose their main client's categories.

Table 6.17: Clients more attuned to sustainability in building construction projects

Client Types	Frequency	Percent	Valid Percent	Cumulative Percent
Private	6	16.66	16.66	16.66
Public	10	27.77	27.77	44.43
No difference	14	38.88	38.88	83.31
Cannot tell	6	16.66	16.66	100
Total		100	100	

Source: Analysis of survey data 2018

6.9.3 Sustainable construction practice overview

The data revealed that there is quite a mixed behaviour chosen by organizations for the adaptation of sustainable construction practices. By considering major sustainable construction practises available in the literature a list is developed to check whether firms have implemented those practises or not. If they have not been implemented then what are the main factors affecting their selection priorities. The data shows whether the designers have implemented sustainable construction materials selection practices or not by considering the mean and standard deviation of each practice.

Table 6.18. Descriptive statistics of variables (sustainability practices)

Practices	Variables	Mean	Std. Dev.
Having obtained ISO 14001 Certification	SCP1	2.40	1.37
Having obtained code for sustainable homes standards	SCP2	2.44	1.34
Investing resources for improving sustainable equipment and technology	SCP3	2.81	1.41
Investing resources for improving knowledge about sustainability	SCP4	2.69	1.41
Implementing a comprehensive energy-saving plan	SCP5	2.86	1.37
Implementing a comprehensive materials saving plan	SCP6	2.97	1.40
Implementing a comprehensive water-saving plan	SCP7	2.78	1.31
Implementing a comprehensive land saving plan	SCP8	2.69	1.36
Implementing a comprehensive noise controlling plan	SCP9	2.97	1.36
Implementing a comprehensive waste management plan	SCP10	3.11	1.43
Implementing a comprehensive air pollution control plan	SCP11	2.92	1.36

Source: Analysis of survey data 2018

These data represent the variation in overall results, although the major portion (66.66%) know about these sustainability practices only (11.11%) have completely implemented them, the rest have only implemented them partially depending upon satisfying clients, the requirements from regulations, and justifying the cost constraint. The data shows that the major concerns are implementing a comprehensive waste management plan (Mean 3.11, S.D 1.43), while materials saving plan and noise controlling plans are also of major concern (Mean 2.97, S.D 1.40), (Mean 2.97, S.D 1.36) respectively. The practice of least concern is getting the ISO certification as most of the organizations are of the view that it is quite a time-taking and lengthy process to manage all the requirements necessary to get the certification. In this regard, again the implementing agencies have to play a vital role to address the client's concerns by providing them with more knowledge and awareness in the easiest and cheapest way.

6.9.4 Factors affecting sustainability practice choice

The local market at least now has some information about sustainability with some big companies fully implementing these practices as a whole (11.11%) and the rest are implementing them partially. One of the main objectives of this study is to investigate the factors that compel the technical stakeholders (architects, designers, engineers, estimators and managers) to adopt sustainable construction materials selection practices. To understand the relationships among these factors a theoretical framework is developed based upon some assumptions. Fig. 6.1 shows the major driving forces and their relationships with sustainable construction practices.

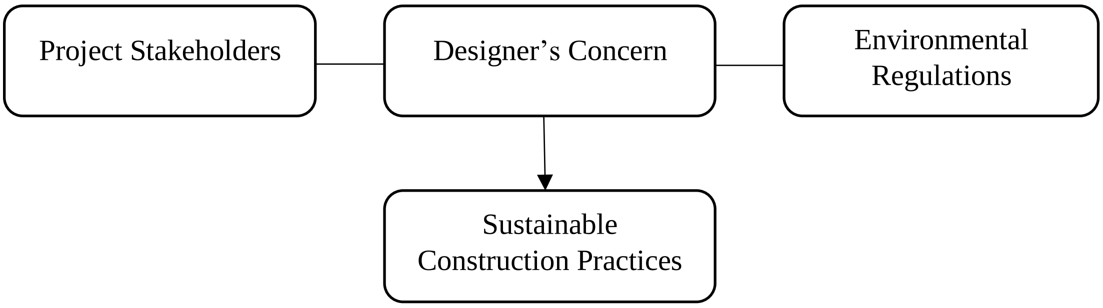

Figure 6.2: Theoretical model for sustainable construction practices

6.9.5 Assessment measures

Measurement is carried out within three major groups; pressure from stakeholders (PFS), designers environmental and design concerns (DC), the pressure imposed by environmental regulations (ER).

This relationship has also been discussed previously but in a different way, dealing with perceived stakeholder pressure, managerial environmental concerns, government environmental regulations, environmental innovation strategy and the firms' business performance (Eiadat, Kelly, Roche, & Eyadat, 2008).

On the basis of the previous literature review and the following data analysis results, the major relationships and governing factors that are developed to deal with environmental factors are:

1. Regulations for sustainable construction are stringent (RSCS).
2. Clients demand for sustainable homes is increasing to meet the regulations (RSCD)
3. Sustainable regulations have significant impacts on design practices (RIDP).
4. Regulations can deal meritoriously with sustainable construction practices (RSCP)
5. Sustainable construction laws are suitable to the Australian construction industry (RSAC)
6. Sustainable construction regulations have an impact upon materials selection (RSMS)

   According to the previous research factor (Revell & Blackburn, 2007), stakeholder pressure can affect sustainable construction practices as follows:
7. Designers face immense pressure from clients (PCL)
8. Designers face pressure from the local community (PCOM)
9. Designers face pressure from local government (PLG)
10. Designers face immense pressure from environmental non-government organizations (PEN)
11. Designers face pressure from colleagues (PC)

    Previous literature suggested that the designers' environmental concerns for implementing sustainable construction practices play an important role (Eiadat et al., 2008), (Dair & Williams, 2006);
12. Sustainable construction is an important factor for an organizational design exercise (DSDP)
13. Designers perceive sustainable construction as an effective strategy (DSCS)
14. Sustainable construction is an important factor to improve the environment (DSCE)
15. Designers pay considerable attention to sustainability in the construction process (DSCP)

6.9.6 Reliability and relationship of sustainability factors

There are thirteen main factors affecting the designer's choice of sustainability practices. The relative importance of these factors is gauged by a survey questionnaire by recording their responses on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Respondents were asked to record their relative agreement or disagreement of the significance of sustainable construction practices. Factor analysis was then performed on the data obtained from respondents. A validity test conducted on the factors was conducted using the Kaiser Method. A special value called an eigenvalue was also calculated. After passing through this scrutiny, the final factor analysis was carried out using SPSS. The results are discussed in Table 6.19.

Table 6.19 Factor analysis results

Practice Factors	Cronbach α	F1- Regulatory Pressure	F2- Stakeholders Pressure	F3- Designers' Concerns
RSCS	0.813	0.118	0.119	0.902
RSCD		0.017	-0.012	0.889
RIDP		0.119	0.107	0.772
RSCP		0.092	0.082	0.913
RSAC		0.172	0.025	0.826
RSMS		0.116	0.126	0.835
PCL	0.810	0.172	0.726	0.182
PCOM		0.276	0.732	0.179
PLG		0.119	0.702	0.220
PEN		0.162	-0.159	0.025

PC		0.177	0.125	0.074
DSDP	0.792	0.022	-0.112	0.902
DSCS		0.136	0.225	0.926
DSCE		0.270	-0.321	0.632
DSCP		0.162	0.145	0.812
KMO Value		(0.66)		

Source: Analysis of survey data 2018

The results show relative cohesion among the variables and the factors of sustainable practices. The KMO value is 0.66 which is above the recommended value of 0.5. In the result table, each practice data set has its Cronbach's α values showing the composite reliability of factors. These factors, regulator pressure (F1), stakeholders pressure (F2) and designers concern (F3) from the above analysis can be used as a multidimensional measure to represent the internal and external factors affecting the ultimate choices of the technical stakeholders for the selection of sustainable construction materials.

There is an urgent need to develop a decision support system that can help them to implement their knowledge and incorporate their experiences to make improvements to the building construction market. The organizational environmental proactivity is affected by different factors, which can be internal policies and external general environmental factors. Stakeholder pressure is the foremost factor, while the other variables work to intensify this core factor (González-Benito & González-Benito, 2006). The big contractors face more pressure from the social and economic atmosphere, as they are always on the verge of being targeted by regulatory authorities and NGOs. The main elements, including noise pollution, air pollution with reference to the dust created during the construction process were discussed (X. Li, Zhu, & Zhang, 2010). From all these results, some findings can be elaborated such that: construction firms are somewhat aware of the importance of sustainable construction materials and that they are trying to improve their selection matrices. The designer's concern is a boost to the current selection practice as they showed the knowledge and concerns towards sustainability. In summary, these results represent the local market trends, awareness and approach to the sustainable and environmentally friendly construction materials selection.

6.10 Materials Selection Practices

The selection of suitable and sustainable construction materials is considered an important and imperative variable in the construction industry, as there is always more than one material available in the market for the same purpose and function. With ever-increasing materials available in the market, engineers and manufacturers are always looking to get more modern and innovative materials. They also have to consider different attributes for the selection of materials (Rao, 2008). They have to be up-to-date and more vigilant when making their selection of materials, and they have to devise different methodologies, systems and tools for this materials selection (A Jahan, Ismail, Sapuan, & Mustapha, 2010). The latest trend tends toward composite materials, such as reinforced plastic polymer (FRP) as they have more attractive characteristics regarding weight, durability, reusability and energy efficacy (Awad, Aravinthan, Zhuge, & Gonzalez, 2012). Therefore, architects, designers and engineers have a very influential role in the selection of the materials and implementing the sustainability practices in building construction. In order to be more accurate and persuasive, they need to understand the key issues, restrictions, opportunities and latest developments to be more effective when implementing the latest and innovative enhancements into the local system. Their choice of materials selection is influenced by the following factors, diagnosed by survey data analysis.

6.10.1 Stakeholders' influence on the materials selection process

The process of building construction consists of progressions and conditions to make a finished product exactly from the provided specifications. The selection of appropriate building materials is an integral part of this process. This process is enormously affected by the stakeholders who are considered the main factor. Astoundingly little is reported on the pragmatic influence of stakeholders in the materials selection process. The instability and fragmented aggressive behaviours are the main hurdles of many stakeholders in materials and innovative energy-saving technologies. The factor of adoption of the latest energy-saving technology and materials are often expressed at the later stages of the construction process. To cope with this issue, pre-organised policies and procedures should be conveyed to stakeholders with great interest in the adoption of sustainable materials selection (Berardi, 2013). The public/private partnership was considered the best combination to make projects successful, but this combination can also fail due to stakeholder influence. Although their input is considered crucial, stakeholder opposition is the main cause of failure, most of the time this is based upon fragmented knowledge and information (El-Gohary Nora & Osman, 2006). The re-use of recycled construction materials is also considered extremely important as construction and demolition waste is the largest contributor to waste in industrialised countries. These materials are widely accepted in civil engineering but still, there are some doubts about their use in structural engineering, again stakeholder influence can also solve this issue. This concise literature review revealed the role of stakeholder's influence in the selection of construction materials. The respondents were asked to rank the level of involvement of project stakeholders on a 5 point Likert scale ranging from very low (1) to very high (5). The results show that there is a good percentage of agreement with the fact that stakeholder influence is one of the major factors in the materials selection process.

Table 6.20. Stakeholders' influence on materials selection

Stakeholders' Influence	RI	Rank
Client	0.78	1
Architects/Designers	0.73	2
Contractors	0.65	3
Project managers	0.61	4
Quantity surveyors	0.57	5
Site managers	0.58	6
Technical consultants	0.49	7
Suppliers	0.47	8
Product manufacturers	0.46	9
Kendall's W	(0.513)	

Source: Analysis of survey data 2018

The results clearly show that the main influencers are the client and its representatives, followed by architects, contractors, project and site managers, and technical consultants. A notable point is that the suppliers and product manufacturers have the smallest impact on materials selection. The lack of proper information and product knowledge is also one of the factors affecting the selection of sustainable construction materials. Clients are the most responsible as they are legally responsible for building and have to comply with all regulatory requirements as well. The client also has to arrange and manage all the finances which could be a major cause of project delays if they are not satisfied with the quality and suitability of the materials (Fugar & Agyakwah-Baah, 2010). The client is responsible for streamlining the projects and adhering to the schedule. Some of the clients are well aware of all the factors whether to include the sustainability into projects attributes or not, the client is responsible to set the priorities and evaluating the actions throughout the construction process. The client has to manage the lifecycle energy balance to make the building sustainable and to meet the building codes of local authorities (Takano et al., 2015). Some clients are so vigilant that at the starting phase they already have all the required programs, budget forecast and even the final appearance whereas others rely on their architects or third party consultants. In both cases, the inter-relationship is the key to success for every building project.

6.10.2 Materials selection information sources

An informed user always has the advantage when making correct and timely decisions regarding the selection of sustainable construction materials. Clients and their representatives/technical stakeholders need up-to-date information about the latest building materials, to be able to select the most economical and innovative building materials at the time of design. Construction innovation offers great opportunities to companies, industry and society, based upon the current management and economical strategies, including the scale, complexity and longevity of the facilities (Slaughter, 1998). The objectives of the construction industry, i.e. economic growth, social progress and protection, should consider sustainability as a main feature (Sev, 2009). This is considered a tough task in this ever-increasing market of materials where clients and their representatives have to know about the properties, performance, environmental, technical and aesthetic aspects, price and availability of materials (Tas, Yaman, & Tanacan, 2008). To investigate the source of information regarding sustainable construction materials, respondents were asked to rate their source of information using the 5-point Likert scale with 1 being lowest, and 5 being highest.

Table 6.21: Materials selection information source

Stakeholders' influence	RI	Rank
Web-based information	0.91	1
Catalogues/brochures	0.87	2
Trade journals	0.79	3
Exhibitions	0.77	4
Colleagues	0.71	5
Trade representatives	0.68	6
Kendall's W	0.492	

Source: Analysis of survey data 2018

This ranking shows that web-based information is considered the best source among the respondents. The value of Kendall's *W* shows a great conscience of all respondents as the resultant value is more than 0. It is quite obvious as everyone in this modern era has access to the Internet and manufacturer websites. An abundance of information is available on each website and interactive online chat can make it easy to solve any issues. The quality and reliability of online information are also important factors to be considered. Paper-based information is decreasing day by day due to environmental and durability issues.

6.10.3 Constraints in sustainable materials selection

The constraints of actual real-world problems faced by technical stakeholders while making a decision on the selection of sustainable construction materials and the general perception and word of mouth related to the selection of sustainable construction materials in the building construction environment. The building industry uses large quantities of raw materials and energy consumption in each stage of construction from construction to operation. This means choosing materials with high content in embodied energy involve in high energy demand at the construction stage and vice versa in the operational phase (Bribián, Capilla, & Usón, 2011).

To gauge real-life problems and obstacles faced by the technical stakeholders (architects, designers, engineers, estimators and managers) while making sustainable materials selection, respondents were asked to rank those issues on a 5 point Likert scale.

Table 6.22: Constraints in sustainable materials selection

Stakeholders' Influence	RI	Rank
Lack of information	0.73	2
Uncertainty in liability of work	0.67	7
Maintenance concern	0.73	3
Building code regulations	0.65	6
Lack of tools and data	0.70	5
Perception of the extra cost being incurred	0.76	1
Perception of extra time being incurred	0.72	5
The perception that sustainable materials are low in quality	0.45	11
Aesthetically less pleasing	0.55	10
Project will be delayed	0.67	9
Limited Suppliers	0.68	6
Low flexibility in alternatives	0.65	5
Unwilling to adopt the change	0.66	6
Kendall's W	(0.248)	

Source: Analysis of survey data 2018

The degree of agreement is calculated as Kendall's W=0.248 which shows that all the technical stakeholders are facing the same obstacles with only some exceptions.

a. The perception that sustainable materials are costly

The most important thing is that all respondents gave the same answer and showed their thoughts on the fact that an extra cost will be incurred with sustainable materials. This gap and perception can be eliminated by empowering more sustainable suppliers and providing more information to end-users and technical personnel. Even in literature, it is mentioned that sustainable materials are more costly than traditional materials (Dair & Williams, 2006). During the face to face interviews, it was determined that there is a common perception that sustainable materials are costly without any market research. As far as the local market is concerned, most of the contractors have the view that most of the work they conduct uses traditional materials as the client can be reluctant to adopt sustainable materials for their projects. The materials such as wood, aluminium, glass, concrete and ceramic tiles can save a substantial amount of energy using sustainable ones (Asif, Muneer, & Kelley, 2007). There are some other barriers in the market such as a lack of information, sustainability measures not being required by clients, stakeholders that have no powers to implement these practises, one practise is considered the alternative of other, one practise was restricted, inadequate materials availability or even unavailability, unsustainable measures were allowed by authorities etc. which propel the decision-makers to avoid the selection of sustainable materials. Some small quantities may also affect the overall strength and sustainability rating in construction materials. Manufactured nanomaterials can cause an immense effect upon the production of sustainable materials (J. Lee, Mahendra, & Alvarez, 2010). The reduction of construction waste can affect the overall cost and sustainability of the environmental factors. This can be done using prefabricated materials rather than choosing in-situ or conventional methods and materials (Jaillon, Poon, & Chiang, 2009). Literature analysis has revealed that most of the studies are related to the environmental effects rather than social and economic impacts in broader aspects. There are some exceptions who are well aware that sustainable construction can obtain excellent results by improving the overall budget cost by 1-3% (Establishment, 2005). This can be regulated by market dynamics, Government authorities and building designers (Atkinson, Jackson, & Mullings-Smith, 2009). There are some implications that sustainable materials can affect the overall project cost but only up to that extent that is being considered by local technical persons.

b. Lack of information about sustainable materials

Information about sustainable materials is not easily available and the medium of access is also difficult to use. Most of the respondents said that to get information the best available medium is the Internet. Precise information is difficult to find on one website. All of the technical stakeholders are expected to be more efficient and up to date regarding the information of sustainable materials lists, new regulations, policies and building codes. Respondents have difficulty in accessing the information source i.e. what latest materials are available, who are the main suppliers, what are most related characteristics of the materials, technical product information and price ranges. Sometimes there is not much information available for alternate materials, or information concerning the other options that are available in the market, and affordability is often the biggest hurdle considered for small to medium clients (Pitt, Tucker, Riley, & Longden, 2009). In other cases, they are unaware of the expertise and skill available to implement sustainable construction practices, so they go with the traditional products to complete the project in time (B. G. Hwang & Tan, 2012). In these kinds of situations, they normally prefer to compromise with sustainability and go with their experience and previously used products. To resolve this issue, suppliers play a vital role by organizing some information sessions and making the information available at a very basic level.

c. Lack of sustainable materials alternatives

There is a hefty and ever-increasing list of materials used in building construction as clients require more attractive, comfortable and secured buildings. The availability of alternate materials is required especially in this era of technology and innovation. Building waste is causing a great deal of environmental harm so alternate and reusable materials are necessary to replace the traditional new materials produced from natural resources (Mora, 2007). There are many tools available to categorise sustainable buildings and materials, they can be used to discuss the environmental profile of those buildings. Some of these evaluating methodologies are considered as needing comprehensiveness as far as criteria and indicators are concerned. It means that the criteria reflecting these indicators are not fully equipped with alternate choices, and do not fully compare the advantages and disadvantages of each of the materials with each other (Castro-Lacouture et al., 2009). In such cases, some important features may be missed and consequently problems can arise regarding the selection of the most relevant sustainable materials.

d. Maintenance issues

Data revealed that maintenance is also a matter of concern for the end-users. This is a special factor that needs to be addressed as most of the respondents placed this as the third most important factor overall. Most of the building stakeholders still have this notion in the back of their minds that sustainable materials require special care and a lot of maintenance (Joseph & Tretsiakova-McNally, 2010). This is the reason the clients are more conscious of and sensitive to the selection of sustainable materials. The high maintenance cost can alarm all of the building stakeholders including the client, consultants and contractors. To mitigate this issue, sustainable materials should be made available which are less expensive and easy to replace for the overall life expectancy of the building.

e. Sustainable materials are more time consuming

Time is of major concern for both parties (client and contractor). Time is considered the main performance indicator in all aspects especially with reference to cost. The time also depends upon the chosen method of construction, despite the fact that the design of a building is also an important factor. The use of the latest methodologies, like prefabricated building construction elements, is of significant importance. The selection of this method is still facing the baseless stories that sustainable materials are difficult to handle and require some special care and skills (Y. Chen, Okudan, & Riley, 2010). In the same way, sustainable materials should be available in this kind of quick installation format. The client is more concerned about the building completion date and if this type of innovative technology can be implemented with sustainable materials, it can help to improve their use. Time constraints are not only a matter of concern for the clients but also for contractors and consultants as well, as they might be incurring more project costs affecting their overall gross profit and market share. Therefore, proper project management skills are counted as a paramount factor to complete the projects in a timely and efficient manner (B.-G. Hwang & Ng, 2013). There was an increasing propensity to switch to previously used construction materials rather than spend more time searching for new and innovative sustainable construction materials.

6.10.4 Materials assessment process

The materials assessment process is also an important factor used in the materials selection process. To receive insight about this process a set of questions were asked of respondents using a 5 point Likert scale. The summary of the results is presented in the table. The degree of agreement of Kendall's W shows great confidence.

Table 6.23: Assessment tools used by building professionals

Assessment tools	RI	Rank
Building for environment and economic sustainability (BEES)	0.32	3
(BREEAM)	0.52	1
ATHENA	0.37	2
EPM	0.30	4
BEAT	0.25	7
LEED	0.27	6
BPAC	0.29	5
Kendall's W	(0.407)	

Source: Analysis of survey data 2018

The results show that most of the respondents are using BREEAM and BEES. These tools are widely used in the construction industry as they are designed to help construction industry professionals. The survey results also showed some of the respondents were unaware of these calibrating tools. The local market respondents were more concerned with the pace of work and the projects to be completed. They were of the view that most of the clients do not pay attention to the sustainability assessment and the implementation of sustainable construction materials.

6.11 Development of Sustainable Materials Selection Criteria

The main purpose of this exercise is to enhance the usage of sustainable materials in building construction, make sustainability practices common, increase the living standard of the local community, and achieve the society's environmental goals for the betterment of society, in general, and the end-user, in particular. There is a great insistence to make sustainable interventions while these buildings are being created, rather than changing things afterwards (Du Plessis, 2007). There is a gap between the understanding and practical implementation of sustainability practices, the evolution of the concept of sustainability is used as a basis for advancing understanding of sustainable construction. More precisely, and to make it easily understandable for the common man, sustainability can be sub-divided into three major factors - environment, society, and economy (*Sustainable development*, n.d.).

6.11.1 Criteria development

A comprehensive literature review revealed the paucity of lists of criteria development for sustainable construction materials selection in the building construction market. A set of sustainability criteria was developed by (Foxon et al., 2002) and they explained the use of these criteria and up to which level a developed set of criteria can deal with the problems that come under the umbrella of sustainability. Some of the most discussed research work assisted in creating a set of guidelines for the main factors that should be considered:

6.11.2 Comprehensiveness

This criterion was developed to keep in view all of the major factors that are involved in sustainability including the environmental, economic, social and technical factors. This criterion should address all of the issues that can affect the ultimate choice selection of sustainable construction materials.

6.11.3 Practicability

This is the most important factor to be considered while working to compile a set of criteria as this is a basic gauge that shows how practical and adaptable the criteria is. This includes all major factors such as tools, time constraints, resource availability and practical verification. This will give an idea of how these criteria can help to influence the decision, what medium of comparison is used and what considerations are combined to make it easy for the technical stakeholders to choose sustainable options. As discussed above in section 6.9.1. The most important factors for these criteria are environmental, socio-economical, and technical. Detailed questions were asked under the heading of resource consumption but for the purpose of clarity, this was placed under the environmental category.

On the basis of these categories, different questions were formulated and asked of the different market leader construction firms and their representatives. They were asked to rate the importance of these factors on a 5-point Likert scale that asks how they think different factors are involved and how influential they are in their sustainable materials selection process. To clarify this criterion a small description was given with each question so they could answer with a better understanding and awareness. They were also encouraged to add any other factors they thought were more important than the factors included in the questionnaire.

6.11.4 Criteria calibration

To verify the reliability and cohesiveness of the criteria results the internal cohesiveness was first examined by applying reliability analysis. The value of Cronbach's alpha is the indicator of the reliability of data. Its value ranges from 0 to 1 with a value closer to 1 meaning more consistent and reliable data is registered. To be more precise and sure of the authenticity of the data the alpha values are checked against each category and the values are recorded. The values obtained, environmental 0.799, technical 0.888 and socio-economical 0.764, are all above 0.7 which means that all of the reliability coefficients are acceptable and the internal consistency of the criteria is brilliant.

The importance of each criterion is calculated using the relative importance index which indicates the ranks of each criterion according to all respondents. The important factor is further divided into subcategories to give more precise results as:

Table 6.24: Ranking of importance factors

Description	Values
High	(1-0.8)
High to Medium	(0.8-0.6)
Medium	(0.6-0.4)
Medium to low	(0.4-0.2)
Low	(0.2-0)

The Sustainability Assessment Criteria (SAC) are also run through the factor analysis. The KMO value will assure the sampling adequacy and validity of the factor analysis. The principal value analysis is chosen to abstract the values of the latent factors which are concomitant with an eigenvalue that is greater than 1. The criteria are grouped under the different categories, environmental, technical and socio-economical, and they form the basis of the selection of building construction materials.

The ranking results for each criterion basically indicate the importance of each according to the technical stakeholders.

Five importance levels are calculated from the relative importance index values i.e. High (H) ($0.8 \leq RI \leq 1$), High to Medium (H-M) ($0.6 \leq RI \leq 0.8$), Medium (M) ($0.4 \leq RI \leq 0.6$), Medium to Low (M-L), Low (L) ($0 \leq RI \leq 0.2$). The derived SACs are likely inter-related through causal primary factors and to obtain a specific list of SACs a factor analysis can be performed. Factor analysis is the recommended technique used to describe the variability among the undescribed variables.

Table 6.25: Sustainable materials selection criteria for construction professionals

Environmental criteria	Socio-economic criteria	Technical Criteria
E1: Potential for reuse	S1: Disposal cost	T1: Maintainability
E2: Environmental favourable disposal options	S2: Health and safety	T2: Buildability
E3: Air quality impacts	S3: Maintenance Cost	T3: Resistance to decay
E4: Ozone depletion potential	S4: Aesthetics	T4: Fire resistance
E5: Environmental impact during manufacturing	S5: Use of local materials	T5: Life expectancy
E6: Less toxicity	S6: Capital cost	T6: Energy saving
E7: Regulatory compliance	S7: Skilled labour availability	
E8: Reduce pollution		
E9: Wastage production		
E10: Raw materials extraction process		

Source: Analysis of survey data 2018

Table 6.26: Sustainable materials selection criteria for construction professionals

Performance Criteria	Valid percentage							
	Valid percentages of scores (%)							
Environmental criteria	**1**	**2**	**3**	**4**	**5**	RI	Ranking	Importance
E1: Potential for reuse	0.0	11.1	13.9	44.4	30.6	0.79	23	M-H
E2: Environmental favourable disposal options	2.8	8.3	27.8	30.6	30.6	0.72	17	M-H
E3: Air quality impacts	2.8	8.3	33.3	33.3	22.2	0.69	18	M-H
E4: Ozone depletion potential	5.6	8.3	41.7	16.7	27.8	0.76	15	M-H
E5: Environmental impact during manufacturing	2.8	13.9	33.3	19.4	30.6	0.67	13	M-H
E6: Less toxicity	2.8	11.1	30.6	25	30.6	0.86	7	H
E7: Regulatory compliance	5.6	5.6	27.8	33.3	27.8	0.84	10	H
E8: Reduce pollution	0.0	5.6	19.4	50.0	25.0	0.85	5	H
E9:Wastage production	4.4	15.4	31.9	37.4	11.0	0.79	20	M-H
E10: Raw materials extraction process	5.6	19.8	45.1	20.9	8.8	0.77	19	M-H
Socio-economic criteria								
S1: Disposal cost	2.8	8.3	16.7	44.4	27.8	0.78	21	M-H
S2: Health and safety	0.0	8.3	27.8	33.3	30.6	0.80	9	H
S3: Maintenance Cost	0.0	5.6	22.2	38.9	33.3	0.81	8	H
S4: Aesthetics	0.0	5.6	36.1	36.1	22.2	0.88	1	H
S5: Use of local materials	0.0	8.3	33.3	41.7	16.7	0.76	16	M-H
S6: Capital cost	2.8	27.8	36.1	36.1	33.3	0.81	14	H
S7: Skilled labour availability	5.5	16.5	39.6	29.7	8.8	0.64	22	M-H

Technical Criteria								
T1: Maintainability	0.0	5.6	27.8	44.4	22.2	0.86	2	H
T2: Buildability	0.0	0.0	9.9	53.8	36.3	0.85	6	H
T3: Resistance to decay	0.0	8.3	27.8	30.6	33.3	0.79	4	M-H
T4: Fire resistance	0.0	8.3	27.8	30.6	33.3	0.84	11	H
T5: Life expectancy	0.0	5.6	25.0	30.6	38.9	0.78	12	M-H
T6: Energy saving	0.0	2.8	38.9	30.6	27.8	0.84	3	H

Source: Analysis of survey data 2018

From these results, it is quite clear that aesthetic was ranked first in the socio-economic category with RI=0.88 and has a high importance level as per the predefined importance values. All factors that have an IR value above 0.8 are considered as high importance and factors with an IR value less than 0.8 are considered to be medium to high importance values. It is quite clear that there is confusion regarding the maintenance of sustainable construction materials. Clients are also more concerned about the capital cost and they are looking to minimise this factor. Only three of the environmental criteria were ranked as high importance which means the respondents are less concerned with environmental conservation. This factor can be eliminated only by consumer awareness and proper information provided by the manufacturers and the suppliers. From Table 6.25 it is clear that most of the criteria among the environmental factors received high to medium importance factors with seven while the socio-economic having three and the technical with two. The quite interesting figures come through the data collection that off course the environmental criteria are on pages for the firms now it is not an ignored zone any more although the numbers are not so good but satisfactory factor is that it is being considered as an important factor in modern construction market now. There is a great awareness regarding the toxic construction materials for the local market as asbestos and some volatile materials are clearly banned in the West Australian market. Some special organizations and NGOs are also actively attempting to resolve this issue i.e. Asbestos Removal Contractors Association Australia (ARCA). The good and appreciable factor that also comes under consideration is that while all of the criteria are considered as important some fall under the medium to the high category rather than the high category.

The sustainable construction materials selection is now being acknowledged among the local technical stakeholders as nothing went under the list of medium to low or low importance factor categories. These results show the importance of the different criteria according to the local stakeholders. In most cases, they are rational and precisely attempt to be as close as possible to sustainability practices.

6.11.5 Factor analysis

Major criteria are recognized by using the ranking in Table 6.25 but to make a comparison and to develop an interrelationship vector of basic factors, factor analysis was also performed. For socio-economic analysis the results showed that the KMO value is 0.716 which is greater than the threshold value of 0.5, this means that this sample is acceptable to perform factor analysis. The Bartlett test value is 96.52 and the associated significance value is 0.000 showing the population correlation value was not an identity matrix value. These values are indicators that these factors could be grouped and placed in a further smaller set of factors. Two latent values with eigenvalues greater than 1.0 for the socio-economic criteria explain 52.12% of the variance.

Table 6.27: Factor loading of socio-economic criteria

Socio-economic variables	Life cycle cost	Social benefit
S3: Maintenance Cost	0.752	
S6: Capital cost	0.688	
S1: Disposal cost	0.576	
S4: Aesthetics		0.822
S5: Use of local materials		0.773
S2: Health and safety		0.575
S7: Skilled labour availability		0.553
Eigen Values	1.564	2.102
Percentage Variance	22.310	31.22
Cumulative Variance	22.310	53.53

Source: Analysis of survey data 2018

The results show the relationship and factor loadings. The higher the absolute value of the loading the more the latent factor stretches the observed variable. The main contributing latent factors were considered as the life cycle cost and the social benefits. This is the main factor analysis performed for the socio-economic criteria to find out the interrelation and interdependency of the different factors.

6.12 Chapter Summary

This chapter presents the results and outcomes of the technical stakeholders' viewpoints regarding sustainability practices and the selection of sustainable construction materials. It also highlights the main influential factors in making an ultimate choice. The respondents were mostly from medium to small firms while some bigger companies also shared their experiences to validate the overall results. Various statistical tests including the frequencies, relative index, Kendall's concordance, chi-square test and factor analysis were applied to the data. The findings were as follows:

- There are gaps in the awareness and implementation of sustainability practices and the selection of sustainable construction materials.
- A contradiction was found during this analysis about the knowledge and implication of sustainability and sustainable construction practices. For example, all of the respondents ranked environmental improvement measures as highly important but they still continue to use traditional materials that compromise these measures.
- All the stakeholders unanimously agreed that sustainability consideration should be considered at the design stage to save the environment, money, and time of construction.
- The designers' concern is a major influential factor that plays an important role in the materials selection process. In addition to the designer's concern, regulatory pressure was also ranked as a top factor to implement sustainable construction practices and the selection of sustainable construction materials.
- The clients have the most influence in the building design and materials selection process. They were the key decision-makers on whether to implement sustainable construction materials or not. This means that they must be well informed and up to date with a list of new and innovative sustainable materials.
- The major barriers to implementing sustainability practices are the perceived additional cost and the lack of pertinent and readily available information.
- Keeping in mind the global trend towards sustainability, there is an urgent need to introduce simple and adequate information to all of the decision-makers.

CHAPTER 7

SUSTAINABILITY INDEX DEVELOPMENT

This chapter covers:

- The relationship between environment and sustainable construction materials
- Importance of a sophisticated selection model
- Combination of sustainability index and decision-making model
- MCDM technique TOPSIS, fundamental to decision making

7.1 Chapter Introduction

Sustainable construction materials are of the utmost importance if we are to protect the environment and conserve natural resources. The manufacturing and use of traditional construction materials consumes a lot of energy and pollutes the environment. Increasing urbanization and the greater number of people moving to big cities is leading to rapid and haphazard development and construction. To tackle this problem, there is an urgent need to construct more energy-efficient buildings and manufacture construction materials that are cost-effective, environmentally friendly and aesthetically appealing (Madurwar, Ralegaonkar, & Mandavgane, 2013). In this work, we established the main sustainability criteria using the survey data from the local market technical stakeholders. The results (discussed in Chapter 6) show the viewpoints of stakeholders and the general practices being used by decision-makers and relevant personnel in the construction industry.

The respondents' opinions and attitudes are vital as they are hands-on practitioners and need to keep in view the social, economic and technological impacts of routine construction practice. Their viewpoints enabled us to develop a decision support model for the selection of sustainable construction materials, which will help the final decision-makers to make more appropriate and accurate choices. Their viewpoints help us to establish a sustainability index. This chapter explains the process of converting a sustainability index to a decision support system to help relevant personnel to select the most appropriate and sustainable construction materials. In this chapter, the conceptual framework is developed and discussed in detail.

7.2 Formulation of Materials Selection Criteria

The data analysis (described in Chapter 6) yields the most important and influential criteria suggested and ranked by respondents with backgrounds in architecture, engineering and construction, and from different firms. Initially, there were 24 criteria but these were reduced to six, which were considered the most significant: environmental sway, life cycle cost, waste reduction, resource knowledge expertise, social benefits and proficient performance. These criteria were based on the survey results, enriched and validated by expert opinion and represent the environmental, technical and socio-economic factors that must be considered during the sustainable building materials selection process. These criteria also strengthen the ideology of implementation of sustainable construction practices and sustainable development in the building design, construction and operational phases of a building project. These criteria were applied to develop an index grouping system to establish a decision support system. The ranking is based upon the opinions of experts in the construction industry to determine the extent to which environmental, technical and socio-economic issues are considered during the process of selecting construction materials. These refined and finalised criteria will confirm the sustainable construction practices and material selection process in building design and construction.

7.3 Fundamentals of Materials Selection Criteria

The results of data analysis showed the basics of the materials selection process, but when developing the decision model, special care was taken to remove any constraints or limitations to evaluating the alternatives to enable decision-makers to make the most relevant, appropriate and accurate decisions when choosing sustainable construction materials. This section will explain in detail the methodological framework, its practical implications for assessment, and its relevance to the sustainability index. These criteria have been considered by the experts in the relevant construction field to run the business and update the innovative face of the latest construction practices.

The major factors and enriched criteria are explained with reference to the literature and other work undertaken by researchers in the same field.

1) Environmental sway

This factor is considered the most important with respect to the modern urbanization trends and the fast-paced innovation and ongoing improvements in aesthetic appeal and comfort in modern construction. The development of sustainable construction materials and practices with reduced environmental impacts during both the manufacturing and operational phases of construction has led to interesting new trends in the building industry (Zuhua Zhang et al., 2014).

The most disturbing impacts and issues that have emerged include depletion of the ozone layer, compliance with laws and regulations, toxicity, air pollution and air quality. Construction materials have direct effects on the environment so it is important that they be chosen and used judiciously. Environmental criteria (discussed in Chapter 6) must be applied as they influence the design decisions and materials selection process. Moreover, these criteria provide a sound foundation for the development of a decision support system for the selection of sustainable construction materials for building projects.

To make further progress listed down the characteristics and range of factors affecting this list and priority is further analysed to check the influence of different factors i.e.

1) The pragmatism and cost of creating of most relevant and precise assessment as making it more difficult and lengthy will require more effort to collect the results.
2) The ability to make the assessment more reliable and easy to understand by clearing the insight in a very convincing and easy way. Its validity can be a vet by the experts as the credibility of the assessment depends upon the consistency of the results. The greater gaps in the overall responses and results represent that a large number of qualitative criteria are used. If the overall theme of the question is not clear it will give a chance to the respondent to implement personal judgement even if there is concise agreement upon the criteria i.e. some of the terminologies and aspects of the building interaction with the environment are quite common such as carbon dioxide emission and energy conservation through insulation but embodied energy is still considered a bit new for local consumers and even for technical personnel.
3) The user must be well aware of and understand the main purpose of this question. This factor can be strengthened with additional clear arguments and assessment criteria. To make it a step-by-step guide to understanding the basic theme, this will then represent the true picture of the results by respondents. This criterion has a pivotal role as it has to collaborate with other criteria to accommodate the issues and constraints of design and construction. So the comprehensive design strategies and best construction practices will formulate successful environmental principles.

   This is well defined by explaining the term "positive energy buildings" by combining the energy-saving and electricity production for a building using renewable resources such as components fabrication, construction, operation, maintenance, dismantling and waste treatment management (Thiers & Peuportier, 2012). A building and its impact on, and integration with, the external environment must be viewed as a total system and design must focus on the successful integration of the criteria and strategies rather than instituting assemblage of a series of discrete techniques for conserving or optimizing the resource use. The increasing framing of environmental issues within the wider context of building sustainability raises serious concerns upon its reconfiguration with the latest itinerary (Cole, 2005).

2) Life-cycle cost

This is considered one of the most relevant and startling criteria as it contains the "cost" means the capital cost (initial cost), construction cost, maintenance cost and ultimately disposal cost. The client is always looking for a lucrative building with minimum cost and less lead time. Oberg says "building represent a large and long-lasting investment in financial terms as well in other resources" (DESIGN)(1). The perception of property as a commodity is changing and the worth of a building is assessed by its characteristics and performance determinants. Environmental and social considerations are more closely aligned with investment and economic return. In particular, the rationale and initial considerations are explored for incorporation of environmental and social issues into valuation (Lützkendorf & Lorenz, 2005). A huge concern is being observed by the financial institutions that initial cost and the overall project viability and operational cost should be in benefit vector.

Previously there was an imbalance between sustainability measures and the project budget but now this is a prime priority to overcome the huge pressure on the industry for the rate of return and social benefits as well. Therefore the ultimate decision-makers are under immense pressure to procure the ingredients of the sustainable project by having a deep insight into the universal market and latest trends to speed up the construction process with minimal waste generation. That is why the role of life cycle cost analysis (LCCA) is playing a pivot role to bring harmony among the project cost and sustainability factors (Goh & Yang, 2009). Sustainability and the life cycle cost have a very close rapport in modern construction practice.

There are no doubts to accept the importance of sustainability for the construction projects but the respondents gave a noticeable value to the cost as well which includes the huge capital investment and protracted operational cost of the construction projects. During the data analysis phase, one strong point emerges as a selection of low initial capital costs cannot guarantee the overall cost-efficient option for the building project. In this scenario, the LCCA can give us the most appropriate analysis results and economic assessment which can predict on safe mode the initial, operational and maintenance cost of a sustainable building project.

The estimation of energy requirements and entire data management for the efficient buildings is determined by using a large data set of simulation and prototype buildings. Simulated energy consumption and building cost database are used to determine the effectiveness of (LCCA) and carbon emission safe design. The pronounced results showed that around 40% of the energy consumption can be saved just by selecting the appropriate buildings type and locations by managing the energy cost at negative life cycle cost due to smaller and cheaper HVAC equipment installation. This can save time, cost and especially the carbon footprints of a building by a margin of 16% which is huge (Kneifel, 2010). The LCA is the best suitable technique to compare the results of cost and social benefits using a simple traditional construction material with eco-materials.

This study can scoop out the knowledge of energy and environmental specifications of building materials, possibilities to improve the selection habit for the new construction and renovation or rehabilitation of existing buildings. This can be achieved by promoting the use of the best techniques and eco-innovative construction materials. This would generate a sense of competition among the local traders to bring more sustainable construction products and implement sustainable construction practices at the local level (Bribián et al., 2011). Thus the operation cost is sometimes greater than the initial cost of the building and the decision made merely upon the selection criteria of minimum initial cost can often misguide to realise the long term cost implications of sustainable developments in building construction projects.

3) Waste reduction

Waste reduction has a very vast domain including the availability of sustainable materials, comprehensive disposal plan and impending for recycling and reuse. This factor is important not only for efficiency improvement but also to tackle the most concerning environmental issues i.e. air, water and land pollution. This is considered to be an uphill task to reuse and separate those composite materials which are used in building construction. Such the concrete used is a complex concoction of fine and coarse sand, cement, steel and water.

Some chemical reactions are also involved which are irreversible. The space allocation and the reuse of that land are also big question marks in this regard. Some of the small countries are suffering more adversely. The dumping is casing the barren land and burning is causing severe air pollution and health issues. The immense use of these natural resources also ringing the danger bells for future generations as there are chances of the scarcity of these resources for them. Construction and demolition waste management are some of the leading subjects to be studied in recent years.

There are many techniques and methodologies are devised to quantify the C & D waste i.e. site visit method, waste generation rate method, lifetime analysis (LCA) method, classification on the basis of waste accumulation method, variables modelling methods etc. so quantification of C & D waste is considered one of the preconditions in the implementation of the successful waste management system(Z. Wu, Ann, Shen, & Liu, 2014). The construction and demolition waste is increasing exponentially i.e. smaller amount of waste is generated at the start of the building construction project but as the project goes on the quantity of the waste increases rapidly which could be as high as 0.2 m^3 per m^2 of the finished floor area (Katz & Baum, 2011). This value impends the value of waste to be generated in the coming days as the building construction is increasing and approaching the next level of innovation and modernism.

The construction industry has become well aware of the importance of waste management in time. The implementation of effective construction and demolition management is requisite to the accomplishment of a sustainable construction process. The social and environmental aspects are also considered imperative to achieve and promote an effective construction and demolition management system (Yuan, 2013). It is quite evident that the mass of construction waste is released in the atmosphere as a molecular form which has already increased than the waste generated by the per capita in the industrialised countries. This consideration of waste management of building materials not only reduces the danger of environmental pollution but also nurtures the cognizance and cause behavioural change among the major industrial giants.

This includes the change at an individual level by providing proper and readily available information regarding the sustainability in design, construction and operational phases of building construction. In accordance with commercial and financial issues, waste reduction and waste avoidance at all stages of the construction process has long term insinuations in terms of all aspects of building construction and operation.

This more serious concern in the modern and so-called more sophisticated developed construction countries the waste has reached an alarming range for example the annual construction waste in the UK is around 120 million tons while 13 million tons is wasted unused (Osmani, 2012). Europe is struggling in the same manner (del Río Merino et al., 2010). The Australian construction industry is behind these countries but still is in a race to achieve these figures in near future.

4) Resource adeptness

The survey results concluded this factor as one of the most imperative by focusing on methods of raw materials extraction, environmental impact during the fruitage, amount of likely wastage in use of materials and embodied energy in a nut shell means to get big results using a lesser amount of resources. This trend is growing rapidly especially in developed countries to achieve maximum resource efficiency by improving the materials selection processes and implementation of sustainable construction practices. It means that certain stock of construction materials is decreasing considerably while the other amply available should be used cautiously. Comparing carbon emission and embodied energy is the latest trend but the emphasis is on using alternative materials to give some relief to the scarcity of some materials (Monahan & Powell, 2011).

Many information sessions and symposiums are conducted to outspread awareness about the resource efficiency and usage of alternate materials. There is a gap between information availability and practical usage and implementation. The stride towards sustainability implications depends majorly upon the availability of information and awareness of the consequences of individual actions (Abidin, 2010). The construction industry is the major consumer of energy and resources therefore many of the ecological factors are considered to make buildings more sustainable and green. The efficiency of resources can be well preserved using a complete array of sustainable and green building materials (P. Graham, 2009). One of the major factors which are studied extensively in recent times is a passive design which aims to reduce the usage of non-renewable resources, consumption of energy production, life cycle design for construction and operation of a building.

The main concern is about minimizing the materials used with extra wastage and providing opportunities for resource consumption efficiency. In the modern world, many efforts have been made to the implementation of solar passive design strategy especially in residential buildings by changing the planning and building regulations. The most driving dynamism is the demand for more energy-efficient buildings for residence.

In this case, good gains can be achieved by changing the orientation of the building and developing the sense of design adaptability. The sizes of the building and overall energy demand are also important factors to be considered. The results show a very impressive approach that to implement the higher standards are easy to apply on the smaller buildings and cost-effective as well. The most profiling feature is that this approach can easily be adapted at the design stage of the building (Morrissey et al., 2011).

5) Social benefits

The social benefits include attractive building features as they are mostly of concern to the end-user and ultimately have impacts on the community in terms of aesthetics, local materials consumption, availability of skilled labour, health and safety etc. The promotion of a green strategy in the housing industry has a momentous impact on the implementation of sustainability. The social aspect is included as a further component in a sustainable environment as it is directly related to the employment opportunities and permanent source of satisfaction for its inmates. The usage of local materials all over the world can generate a big wave of good remuneration and cost-effectiveness with respect to savage in the transportation and haulage cost. The housing developing personals and authorities can implement the different green strategies such as solar energy systems and home thermal envelop package improvement. They can contribute to reputation gaining, reduction in design, construction and operational cost, predicting the favourable land cost and availability of more channels for financing a building project (X. Zhang, Shen, & Wu, 2011).

This effort can raise the overall standard of living and portray a positive image of developing society. Building aesthetics are also an important factor to consider because the degree of satisfying the needs of diverse stakeholders is highly significant in achieving the social sustainability performance of building construction projects (Almahmoud & Doloi, 2015). The aesthetic aspect should be an important part of building and should not be compromised for greater productive capacity and adaptability. This can help a construction firm in improving its image on the commercial forefront and developing its thorough professional prestige among the local competitors. Although some social issues arose as well due to non-addressing the customer intellect and need such as lack of understanding of the basic needs of the customer, purchasing intention, social needs, public attitudes and behaviours, rebound effect and social acceptance.

There is a need to implement this green theory covering these factors as well and should make it possible to convey to the client that green building sustainable concept has immense influence over the customer's decision making sense, a comprehensive plan to be implanted to give a piece of handful information about the sustainability to the general public, sustainability should not be restrained to energy-oriented building only (D.-X. Zhao, He, Johnson, & Mou, 2015). The next most important factor is to be considered is health and safety. The safety and removal of hazardous materials from the construction materials list and construction site as well. The construction industry is attached and termed the circular economy.

Therefore the usage of refurbished or reusable materials is considered as the most favourable and attractive means for the financial stakeholders the only concern is considered to be safe and free from any hazardous traces. This change requires the altogether transformation in value chain model, product design and new business design and market. This can be achieved by converting the waste into a resource. For instance, the sludge waste is fired and converted to ash. These renewable materials are effectively used in the manufacturing of earth bricks, tiles, cement raw materials and rich sources of aggregate (Smol, Kulczycka, Henclik, Gorazda, & Wzorek, 2015). In the last two decades, the use of terahertz technology in construction materials imaging and sensing systems has emerged as a well known and innovative system. The (THz) spectroscopy has great potential to change the forefront of the construction industry related to materials manufacturing and selection (Abina, Puc, Jeglič, & Zidanšek, 2015).

One latest trend is to use the low emissivity materials in the opaque or transparent parts of buildings as they emit lesser energy and require lesser energy to maintain the overall thermal envelop of the building. It avoids the loss of energy by thermal transfusion. These (low-e) materials also save the daylight and total solar radiation by placing them in windows (Jelle, Kalnæs, & Gao, 2015). There are a lot more techniques and materials which are used to manage sustainability in construction. The main challenge for new sustainability studies is to create harmony among these techniques and a list of sustainable construction materials list.

6) Performance proficiency

This is considered as a detailed study about the materials anatomy i.e. resistance to decay, fire resistance, energy-saving and thermal insulation, the durability of materials, workability and maintainability. Each characteristic is marked as a trademark of construction materials. The basic ingredients of buildings are like the microorganisms of anybody. They make the building serve the basic objective to find out the trade-offs that gratify a multitude of performance matrices. Performance achievement means to serve the basic objective throughout the building life right from design, construction, performance and demolition.

The occupants may feel highly satisfied, comfortable, healthy and financially strong enough to save their money and they enjoy the actual spirit of quality of life. The buildings should be safe enough that do not catch fire easily if there is any danger of fire on the contrary do not leak during the rains and are structurally stable during the winds and earthquakes. Especially do not have any signs of sick building syndrome. To avoid this issue the nano-metal treatment is applied to improve the fungal growth resistance. This treatment is applied on those building materials which are considered more prone to fungal attack i.e. wooden flooring, green wooden flooring, gypsum boards, calcium silicate, mineral fibre ceiling. Nano-zinc and nano-silver are considered as most successful materials for this treatment especially on wood (Huang, Lin, & Hsu, 2015). Pollutants and micro-ingredients which are emitted during the performance stage of the buildings are considered more dangerous for human health.

The use phase affects more due to longer stay and larger exposure to the different chemicals and minerals. This is measured by comparing the human pollutant intake fraction and health impacts in terms of human carcinogenic potential (HCP) (Park, Ji, & Hong, 2016). If the building malfunction has prevailed it will affect the business operations of occupants, creates physical and mental health issues. The remedial cost creates a financial imbalance. This may affect the interest and confidence in the building that is why the design stage analysis is considered the best among all (design, construction, and operational analysis).

Good insulation and proper orientation can save a lot during the construction and especially for the whole operational life. Indoor environmental quality (IEQ) is the latest emerging trend that can be tailored by imposing the natural ventilation and usage of solar energy by proper orientation. The microclimates in urban buildings are written off as low wind speed, high surface temperature difference especially in summers, high pollutant concentration and high noise levels. Reasonable building planning and careful building energy envelop design can solve this problem up to a maximum extent (Ai & Mak, 2015).

All these issues need to be addressed at the design and construction phase in order to avoid long hauled life-cost. Therefore it is a long term task for the technical stakeholders to provide steadfast means and tools by considering the performance criteria in the sustainable building materials selection process.

7.4 Development of Conceptual Framework for Materials Selection

The economic consideration is the main criteria that dominate in most cases for materials selection rather than sustainability or suitability. The client is always interested to use materials that can fulfil the required function at the lowest cost. The environmental consideration normally appears when there is a legal binding to obey the rules and regulations. But this dilemma is no longer to survive anymore due to increasing awareness and more concerns are shown by local people and community overall (Giesekam, Barrett, & Taylor, 2016).

For long term stability and growth in social health, it is evident to alleviate the overall balance of the natural resources and ambience. At length, these issues were ignored but the increasing concerns of modern society and the key role of non-profit organizations have put this topic under shear light. This credit is also shared with the media due to repetitive highlighting of these issues on almost all fronts. When the analysis is concluded that building is the main cause of environmental inequality and loss of biodiversity, it means there is a need to take some practical steps to save nature. In such cases, it is a bit difficult to describe all these scenarios with a single variable that can define a single valid indicator.

The requirement for integrating conservational issues into the building design and materials selection process becomes more and more important and wider as well. Alternatives have been found to replace the traditional market approach with different techniques which are independent of the environmental issues which are almost impossible to assess them a). Environmental impact assessment (EIA) (Mok, Shen, & Yang, 2015) and cost-effectiveness analysis (CEA) (Ferrara, Monetti, & Fabrizio, 2018).

This work is a starting point for developing the sustainability criteria. These criteria pertain to materials selection during the design and construction phases of a building. During the analysis of building materials functions, it is important to check the suitability of the materials aligned with key sustainability criteria for the decision-making process. This is managed by amassing sustainability criteria into a combined index that can define and satisfy the sustainability of building materials based upon major four characteristics based upon our questionnaire (data analysed in chapter 6) i.e. technical, environmental, economic and social.

7.5 Sustainability Index

A sustainability index is established to model and rank the most important criteria in the construction decision-making process. It deals with the tedious ecosystem issue but remains simple to be used keeping the other variables intact. This is independent of the method of construction to be used either modular or conventional (Kamali & Hewage, 2017). Sustainable decision making in building technology is extensively supported by the multi-criteria decision-making techniques (MCDM) (E. Zavadskas, Antucheviciene, Vilutiene, & Adeli, 2018).

The expansion of the sustainability index includes the dispassionate factors such as life cycle cost (LCC) and the practical and slanted objectives such as resource efficacy, performance advantage, waste reduction, environmental improvement factors and ultimately the social gains. Sustainability index formation is basically a replication of the sustainable construction concept by ranking the sustainable construction materials based upon the traits, characteristics and their impact on the environment. Another use of the sustainability index is it can suggest alternate materials if that does not align with the required sustainability criteria means this would be a tool to carry out the relative performance in a single framework. The third and most important use of this sustainability index is that it guarantees the matchup most important factors affecting the ecosystem and is easily approachable by the public. All the criteria i.e. life cycle cost, resource efficiency, waste reduction, performance benefit, social benefit and last but not least environmental impact have much more important now because of extensive usage and the danger of scarcity of natural resources.

These criteria are combined to develop an algorithm to rank the construction materials based upon their contribution to achieving maximum sustainability in building construction projects. Each criterion is measured under the MCDM technique and given index score, the higher the score means more close to achieving sustainability.

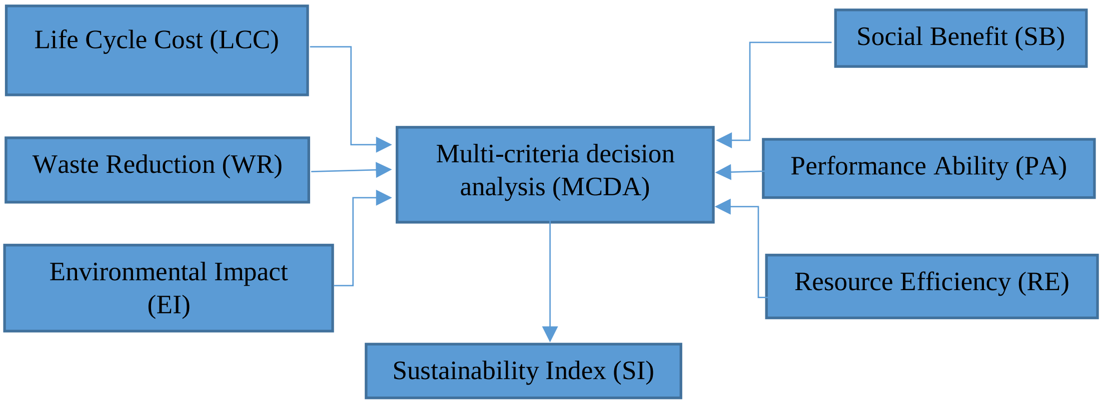

Figure 7.1: Sustainability Index chart

7.6 Multi-Criteria Decision Models

Many multi-criteria decision models are discussed in the literature. These models are intended to represent the empirical conclusions drawn by researchers in ways that can be easily understood by the addressees without creating any ambiguity or difficulty, enabling them to use those findings to solve professional problems. The reason for sustainability measurement is described by Ness et al. (2007)" The purpose of sustainability measurement is to provide the decision-makers with an evaluation of global to local integrated nature-society systems, in short, a long term perspective in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable" (R. K. Singh, Murty, Gupta, & Dikshit, 2012).

The decision-makers are always sandwiched between two major factors they have to tick one choice among the economic factor and environmental impacts. Although it is quite difficult to mark each without affecting one now they have a vast list of alternate materials so they can juggle with those. In a composite index approach, incongruent variables are combined together.

Sustainability is discussed under different MCDM techniques the common factor included in these techniques is substituting the maximization of a function compromising the preference of decision-makers, as a utility function the same process was carried out previously in optimization of the distance existing between an alternative and the reference point or points enjoying good preferential properties (Diaz-Balteiro, González-Pachón, & Romero, 2017). There is a criticism that MCA and MCDM methods lack complete and absolute objectivity and leave the problem with no defined mathematical solution.

Therefore normally a hybrid method is used to resolve this issue. Especially with the green building materials (GBM) because the impact of building materials is different from each stage of its life cycle production to decay. The selection of GBM has to clear performance criteria such as indoor ambience, quality, performance, aesthetics, and energy cost (Büyüközkan & Karabulut, 2017).

However, these MCA and MCDM techniques are still suitable solutions as a theoretical framework for the construction of composite criteria vectors. Those must allow the weighted aggression of quantitative individual indicators. There are many techniques used in the literature to make multi-criteria decision making although there no uniform agreed methodology exists for aggregation of composite criteria for sustainability evaluation (Zhou, Ang, & Zhou, 2010) while weighs heavily influence the set of criteria, some are discussed and a comparative analysis will be given showing the reason of selection of TOPSIS among others.

1) Multi-Attribute Utility Theory (MAUT)

This technique uses the utility to enumerate the subjective components of the attributes. This means it refers to measure the cachet or gratification of an attribute of the substitute under consideration. Breaking down the problem into their appropriate hierarchies is the most fascinating fact about MAUT.

The problem is broken down by separating the main goal (highest hierarchy) from the criterion (second level hierarchy), the criterion is further broken down into sub-criterion (third level hierarchy). At the very bottom of the hierarchy, there are alternatives. The elements together form a complex problem (Pohekar & Ramachandran, 2004). The utility values can be considered with weights W_i to give more accurate and steadfast results. The expression is calculated by following a simple equation.

$$S_j = \sum_{i=1}^{n} W_i U_{ij} \qquad 7.1$$

2) Multiple Regression Technique (MRT)

This statistical technique is basically used to make a prediction and observe the effect of independent variables upon a dependant variable. In recent times simple linear regression and multiple linear regression are widely used in engineering and science (L. Sharma & Singh, 2018). In the mathematical form, we can simply draw it in the form of an equation.

$$Y= a + b_1(X_1) + b_2(X_2) + b_3(X_3) + \ldots.b_n(X_n) \qquad .7.2$$

Where *Y* is the final product *a* is the function of independent variables and *b1, b2, b3, …bn* are the partial regression coefficient demonstrating the number of independent variables. This can help to deal overtly with the interdependency of initial information (E. K. Zavadskas, Bausys, Juodagalviene, & Garnyte-Sapranaviciene, 2017).

In the practical application of MRM, the various attributes or criteria will be signifying the dependent variables and independent overall scores. R^2 is the coefficient of determination showing the results of the percentage of variance in the dependent variable by all independent variables. The higher the value means the more accurate result prediction values. The difference between the actual value and predictive value is called the residuals.

3) Cluster Analysis Technique (CAT)

This technique is used to group the objects having the same characteristics into similar categories. This algorithm starts with the *k* factor means centroid. Different values are implemented on this until the assigned values and *k* values are the same. This tool is widely used in the classification of problems in the decision-making process (Gaitani, Lehmann, Santamouris, Mihalakakou, & Patargias, 2010).

Its functioning is quite simple and properly administered i.e. group the given numbers of alternatives in *n* of clusters in such a way that the clusters in the same category should be alike to each other and unlike others clusters of different alternatives. In this way, all the similar clusters can be placed as subsets up to an adaptable manner. Those clusters can be analysed separately to get the best-suited results.

4) Linear Programming Technique (LPT)

It is an augmenting technique to identify the maximum and minimum value of a linear function, i.e. $f(x_1, x_2, x_3, \ldots x_n)$ called an objective function to a number of linear constraints. Mathematically can be expressed as;

$$A_x + B_y + C_z + \ldots \geq N \tag{7.3}$$

The largest and smallest value of the objective function is called the optimal value and the sequence of collection of optimal values is called optimal solution and the variables are called the resultant variables.

5) Weighted sum method (WSM)

This method is also called as decision metrics approach. It is also called simple additive weighted (SAW). In this method, each alternative is evaluated with respect to each criterion. This gives a ranking scale with a particular alternative. This is considered the simplest and classic MCDM method. Its work is based on the overall performance rating of an alternative (Stanujkic & Zavadskas, 2015).

$$S_i = \sum_{j=1}^{n} W_j r_{ij} \tag{7.4}$$

Where S_j is the overall performance rating of alternative i, w_j is the overall weight of criterion j, r_{ij} is the normalized performance rating of alternative i with respect to criterion j. It can be performed with the different normalization techniques i.e. Vector normalization, Max normalization, Max-Min normalizations. The alternatives used with one or more preference ratings better than the preferred performance rating could recompense for the impact of their shoddier performance ratings acquired with respect to the remaining criteria.

6) Analytical Hierarchical Process (AHP)

The analytical hierarchical process (AHP) is commonly used for the prioritization of decision alternatives. This method was devised by Thomas Saaty in 1971 (Wind & Saaty, 1980). The analytical hierarchical process has gained importance for giving the solution of complex problems in the construction method (Darko et al., 2019). The method is very effective as it bifurcates the complex problem into judicious hierarchy keeping the objective at the top and criterion and sub-criterion at the further down the hierarchy placing the alternative at the bottom of the hierarchy. Its main feature which makes it more simple and effective is the pairwise comparison of the elements.

This method calculates and aggregates the eigenvectors till the composite final vector of weight coefficient for alternatives is achieved. This method is used in combination with other techniques as well. For the criteria selection, Delphi can also be used which gives the priority to the group knowledge upon the individual one.

This method is combined with the fuzzy method for supplier selection in the construction method as well (Plebankiewicz & Kubek, 2015). This method calculates the inconsistency index as the ratio of a decision-maker's inconsistency. The higher value of the inconsistency index has required a re-evaluation of pairwise comparison but the decision obtained in some cases can also be treated as the best optional solution.

7.7 Technique Selected for Development of Sustainability Index

Urbanization and living comfort have revolutionized the construction industry. Many techniques and strategies have been proposed to improve overall efficiency and reduce waste during and after construction. Some are cost-effective, some are not. To a certain extent, the sustainable construction strategy has tackled these issues but the selection of sustainable construction materials is the most effective, and cost and environment saving.

Being the basic ingredient of building and overall construction the sustainable construction materials selection has gained vital importance (Govindan et al., 2016). There are many ways to carry out this practice but using MCDM techniques have already given an edge to decision-makers to choose the best ranked sustainable construction materials. We have selected the TOPSIS among the many other techniques. This is because of its diversity and collaborative physiognomies.

TOPSIS stands for **T**echnique for **O**rder of **P**references by **S**imilarity to **I**deal **S**olution. This method can address the treacherous and tedious question of decision-making problems which was actually developed by Hwang and Yoon in 1981 (C.-L. Hwang & Yoon, 1981) to choose the best alternative with a finite number of criteria. This method selects the alternative with the shortest distance to the ideal solution and the farthest distance from the negative ideal solution. TOPSIS makes full use of attribute information, provides cardinal ranking alternatives and does not require the attribute preferences to be independent (K. P. Yoon & Hwang, 1995).

At times, it can solve the decision-making problems by itself: at other times, a hybrid technique is developed with other MCDM techniques (E. K. Zavadskas, Mardani, Turskis, Jusoh, & Nor, 2016). The analogy with this technique is that scores are assigned to correlated criteria with a threshold set, below which the sustainability test if failed.

Using a square of closeness coefficient these results are matched to relative comparison score to track down sustainability over time (Afful-Dadzie, Afful-Dadzie, & Turkson, 2016). A decision model will facilitate the technical stakeholders to exercise a wide range of options either classical or innovative. This method utilises the sustainability criteria for computational analysis to formulate the best possible combination of alternate materials.

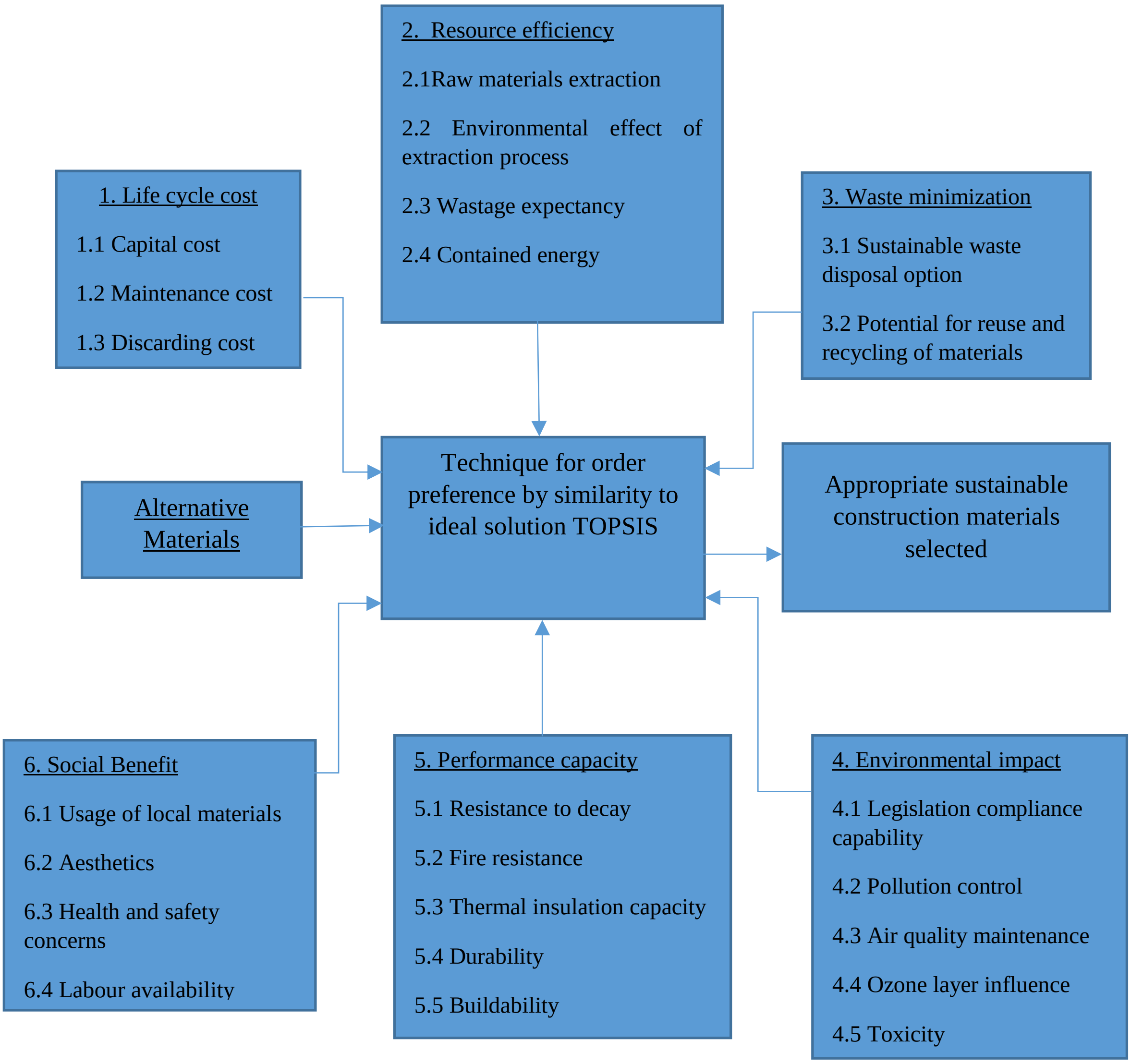

Figure 7.2: Conceptual framework for sustainable materials selection

The six main criteria are further divided into sub-criteria. The total numbers of 23 sub-criteria are shown in Table 7.1 below.

Table 7.1: Criteria and sub-criteria grouping with type

Criteria	Sub Criteria	Description	Criteria & Type
1. Life-cycle cost	1.1 Capital cost	The initial purchasing cost of materials	$-C_1$
	1.2 Maintenance cost	Total repair cost during life whole cycle of materials	$-C_2$
	1.3 Discarding cost	The demolition and disposal cost of materials	$-C_3$
2. Resource efficiency	2.1 Raw materials extraction	The source of getting the raw materials	$-C_4$
	2.2 Environmental effect of the extraction process	The quantitative detrimental effects during the extraction	$-C_5$
	2.3 Wastage expectancy	Probability of wastage during extraction	$+C_6$
	2.4 Contained energy	The total amount of energy dedicated to providing the sustainable, renewable energy	$+C_7$
3. Waste minimization	3.1 Sustainable disposal option	How favourable to create sustainable disposal options i.e. carbon burial, incineration etc.	$+C_8$
	3.2 Potential of reuse and recycling of materials	Capacity to be reused and amount of total wastage during recycling	$+C_9$
4. Environmental impact	4.1 Legislation compliance capability	What percentage of the capability to comply with the local and international legislation	$+C_{10}$
	4.2 Pollution control	The level of overall ability to contribute to pollution control	$+C_{11}$
	4.3 Air quality maintenance	The level of maintaining the air quality using potential materials	$+C_{12}$
	4.4 Ozone layer influence	The level of impact to protect the ozone layer	$+C_{13}$
	4.5 Toxicity	The level of generating the toxic materials, such as asbestos etc.	$-C_{14}$
5. Performance capacity	5.1 Resistance to decay	The level of durability and sustainable age	$+C_{15}$
	5.2 Fire resistance	The level of resistance against fire-related damages	$+C_{16}$

	5.3 Thermal insulation capacity	The level of maintaining an inner temperature of residential building	$+C_{17}$
	5.4 Durability	The level of reliability and effective resistance again deterioration	$+C_{18}$
	5.5 Buildability	The level of easiness of use and execution	$+C_{19}$
6. Social Benefit	6.1 Usage of local materials	The level of local materials usage saving the transportation and utilising the local workforce	$+C_{20}$
	6.2 Aesthetics	The level of visual and usage comfort	$+C_{21}$
	6.3 Health and safety concerns	The level of internal environmental and air pollution control	$+C_{22}$
	6.4 Labour availability	The level of local skilled workforce	$+C_{23}$

The sustainable criteria related to construction structural materials comprise three components.

1) Materials total life thinking
2) Sustainable factors
3) Materials sustainable measurement scale, adopted from

The relationships between the sustainable factors and the criteria are shown below in Table 7.2.

Table 7.2: Relationship between sustainable factors and criteria current work derivation

No.	Sustainable criteria	Environmental	Economic	Social	Technological
1	Life cycle cost		√		
2	Waste minimization	√			√
3	Resource efficiency	√			
4	Environmental impact	√	√	√	√

5	Performance capacity	√	√		
6	Social benefit	√		√	
Total of sustainable criteria		5	3	2	2

This table indicates the effectiveness of the sustainability index criteria and effects on different sustainable factors. Its appropriateness depends upon the sustainability factor effectiveness which is calibrated using the score systems.

TOPSIS-based approach for prioritized aggregation

The aggregation MCDM environment involves combining the values of a set of attributes to arrive at a single value for an entire set of attributes. A significant amount of effort is required to establish prioritization in aggregation using TOPSIS. The derivation of the MCDM model using this prioritization approach is done using the following methodology.

The development of a sustainability index framework basically helps the decision-makers to integrate the issues of suitability when selecting construction materials. The environmental building assessment method helps the decision-maker to validate the whole design rather than to comment on only part of it. These are the guidelines during the design development and solutions.

The selection of sustainable construction materials from a pool of alternative sustainable materials can be a time-consuming and treacherous practice. The selection of alternatives with conflicting criteria by using the MCDM approach is somewhat challenging. The integration of objective and subjective weights of different criteria when choosing the best-suited sustainable alternative materials can be best accomplished with the MCDM technique.

The first step is to determine the most suitable aggregation method. Normally, there are two types of aggregation: crisp aggregation is used to aggregate the real values, and fuzzy aggregation is used to aggregate the linguistic labels (Xu & Yager, 2006).

The second and most important step is to define the boundary condition.

The boundary condition drives the result of an aggregation function $f(x)$. The limit can be defined when we obtain the minimal and maximal boundaries of possible output.

$$f(0, \ldots 0) = 0 \text{ and } f(1,\ldots,1) = 1, \text{ where } x \epsilon [0.1] \quad (1)$$

The commutativity property means that the ordering/ranking of arguments does not matter when each criterion is of equal importance, or when there is no relationship between them.

$$f(x_1,x_2,\ldots x_n) = f(x_2,x_1\ldots,x_n) = f(x_n,x_2,x_1\ldots,), x\epsilon S \quad (2)$$

The continuity condition ensures that the aggregation function will not produce drastic results if small changes are made to the attributes considered for aggregation.

$$U_{x\epsilon S}[0,1]^x \rightarrow [0,1] \text{ is a continuous aggregation function if } f(x)\text{: } [0,1]^x \rightarrow [0,1] \quad (3)$$

The monotonicity condition implies that the aggregation function shows a 'non-decreasing relationship between the criteria and the aggregation manoeuvre.

$$x_i' > x_i, \text{ then } f(x_i') > f(x_i) \text{ where } x\epsilon S \quad (4)$$

Idem-potence condition is an algebraic property of a binary operation which shows the relationship if:

$$f(x,x,\ldots,x)=x \text{ where } x\epsilon S \quad (5)$$

The associativity condition is the ability of the aggregation function to object to the choice of the group, but should not influence the overall result of the aggregation process (Omar & Fayek, 2016):

$$f(f(x_1,x_2,\ldots),x_n) = f(f(x_1,x_2)\ldots.,x_n), x\epsilon S \quad (6)$$

Many applications require the evaluation of a set of criteria with a prioritised relationship between them to reach a final conclusion. (X. Zhao, Lin, & Wei, 2013), (Yager, Gumrah, & Reformat, 2011), (L. Chen & Xu, 2014). Yager comprehensively determined the prioritized aggregation using the prioritized scoring operator, stating that the application of a prioritized scoring operator allows the poor satisfaction of any higher-priority criteria to reduce the ability of compensation by lower priority criteria.

TOPSIS is an approach that originates from the geometric concept of displaced ideal point, which deals with the criterion under investigation that needs to be situated between the positive (most favourable) and negative (least favourable) locations (Chu, 2002).

Determining the weights and criteria ranking

Many methods for criteria ranking and weights determination were discussed in previous research work (Lootsma, 2000), (Yager, 2009), (Bisdorff, Meyer, & Veneziano, 2014) and include the following common methods:

Direct choice of weights: This method deals with direct weight assignments based upon the opinion and consensus of a group of experts.

Weights determination from data: This method is based upon the derivation of the weights of criteria from the data available in the same domain for aggregation purposes.

Selection of notable type of aggregation: This method works using simple operators, i.e., t-norms and s-co-norms

Maximum entropy: This method was devised by O Hagan (O'Hagan, 1990) using an offline, nonlinear, geometric program to develop weights by means of a mathematical algorithm using the coefficient α introduced by the decision-makers.

Linguistic functional specification: Yagar (Yager, 1996) introduced this method using the basic monotonic functions; it is basically a type of mapping the criteria for aggregation. The prioritised aggregation method is explained using the MCDM technique of TOPSIS using the set of criteria.

Application and validation of sustainability model

The main objective of this research work, as mentioned in chapter 1, is to develop a model for the selection of sustainable construction materials. This section demonstrates the practical application of the model developed on the basis of a case study and input data collected about the local roofing alternative materials. The best way to test the developed model is by using an example to validate the results and show how the sustainability model works in practice to rank the sustainable construction materials.

Given the complexity of the data collection process and research output, we undertook an empirical inquiry into the real-life practical scenario. The data from the model’s six basic recommended criteria and sub-criteria (mentioned above sections) were computed and analysed to assess the validity and effectiveness of the developed model. The data collected concerns roofing materials specifically for residential buildings in Australia, supplied by two major roof tile companies. This validation involved the application and evaluation of two different suppliers with six alternative tile options. The scenario is hypothetical but validates the practicality of the proposed model.

This hypothetical case study involves roofing tiles from different suppliers and different alternative options depending upon the type of materials selected for a test run and the type of structure being built. This is for a single residential dwelling requiring the most enviro-friendly materials for roof construction. The cost is one of the factors to be considered; however, the most important considerations are the criteria and related sub-criteria as shown in Table 7.1. The details and physical characteristics of the materials are presented in Table 7.3.

This model will analyse and rank the most sustainable through the use of mathematical implications through the use of the multi-criteria decision model discussed in previous chapters. The data collected for this example was collected by means of the questionnaire. The experts ranked the different alternatives based upon the criteria and sub-criteria specified in the questionnaire. These values were tabulated in Excel and analysed using the TOPSIS model.

Being a multi-climatic country, Australia boasts a topography that consists of plain deserts, dense rainforests, and vast coastal areas. This geographic diversity requires different types of roof constructions and different types of roofing materials. The main factors that drive the selection of roofing materials are:

1. compliance with Australian building codes and local estate building codes;
2. house type, orientation and building construction;
3. local council requirements; and
4. Energy management, insulation and the overall anatomy of the roof.

The most commonly-used roof types are generally known as hipped or skillion, hip and valley, gable, cross-gable, mansard, pyramid hip, cross-hipped, saltbox, gambrel, flat, bonnet and shed.

These roofs have different pitches depending upon the type of building, the style of the house, and the use of sarking. The most common pitch is 18 to 20 degrees, depending upon the materials used for roofing in Australia. The major reason for the selection of roofing materials is that they can be tailored at the design stage, providing an ideal foundation for analysis and comparison.

Table 7.3: Roofing options with different types of roof tiles

	Roof type	Building	Structural location	Roof tile size	Roof pitch
Option 1 with two Alternatives, from two different suppliers	Timber truss pitched roof	Residential	Treated timber trussed roof with anti-con underlay, batts insulation with concrete interlocking tiles	418mm x 260 mm	18 to 20 degrees
Option 2 with two Alternatives, from two different suppliers	Timber truss pitched roof	Residential	Treated timber trussed roof with anti-con underlay, batts insulation with clay terracotta tiles	418mm x 260 mm	18 to 20 degrees
Option 3 with two Alternatives, from two different suppliers	Timber truss pitched roof	Residential	Structurally insulated roofing panels with anti-con underlay, with designer ceramic tiles	418mm x 260 mm	18 to 20 degrees

These three options are tested against six alternatives offered by the two major suppliers of tiles in the Australian construction industry; these options have competitive advantages over each other. This will give a practical demonstration of the multi-criteria decision model and how it works when applied to the selection of the most suitable and sustainable construction materials. These competitive advantages are discussed below.

Tiles were tested according to the Australian Standard AS2049. Both the suppliers have had their products approved as they meet the minimum criteria for products to be used as roofing materials. The dimensional tolerance is tested according to the Australian

Standard AS4046.2. The tolerance is set ± 2% in both directions i.e. width and length. The permeability is tested according to the Australian Standard AS4046.5 which states that no drop of water should form on the underside of any test specimen after two hours of soakage. Water absorption was tested according to the Australian Standard AS4046.4 which regulates that water absorption shall not exceed 10%.

The transverse breaking load is tested according to the Australian Standard AS4046.3 which specify that it shall not be 4N per millimetre of exposed width of all test tile samples. The resistance to salt attack is tested according to Australian Standard AS4046.7 and this must be less than 0.4 g of loss in 40 cycles. These exposed tiles should withstand the severe coastal weather as much of Australia is exposed to the coastal climate. The most important factor is fire resistance due to recent bushfire tragedies. These tiles were tested according to Australian Standard AS3959-2009. These samples were ranked against the experts' opinions using a seven-point Likert scale of assessment anchored by strongly agree (1) to strongly disagree (7).

Table 7.4. Expert opinion rating values

Agreement/Disagreement	Strength
Strongly disagree	1
Disagree	2
Somewhat disagree	3
Neither agree nor disagree	4
Somewhat agree	5
Agree	6
Strongly agree	7

The tabulated values in the Excel sheet contain the sub-criteria with positive or negative signs. The criteria which show an inverse relationship with sustainability are marked as negative while the values of criteria that support sustainability are marked as positive. These six alternatives were tested against twenty-three criteria and sub-criteria. The MCDM technique, TOPSIS, gives a final ranking based upon these criteria and sub-criteria derived from experts' opinions (Çalışkan, Kurşuncu, Kurbanoğlu, & Güven, 2013).

Yoon and Hwang introduced the TOPSIS method which is based upon the idea that the best alternative should be the shortest distance from the ideal solution (K. Yoon, 1980) (B. G. Hwang & Tan, 2012). The attribute which is considered in favour of the alternative materials is the 'best attribute' and the other with the worst-case scenario is called the 'worst attribute'. The goal of this approach is to find the Euclidean space from the ideal solution (Tzeng, Lin, & Opricovic, 2005). The TOPSIS method has the ability to deal with an unlimited range of materials properties, and performance attributes can be included as well. In the materials selection process, each attribute cannot be treated in isolation but must always be considered as a trade-off with respect to the other attributes. TOPSIS enables explicit trade-offs and collaborations among attributes.

TOPSIS is based upon the six major steps which are described below and applied to our hypothetical problem of roofing materials (roof tiles) from two major roof tiling companies.

Step 1: Calculate the normalised matrix

The normalization is calculated using equation 1 (Ali Shanian & Oumarou Savadogo, 2006);

$$\overline{X\imath\jmath} = Xij/\sqrt{\sum_{j=1}^{n} X_{\imath j}^{2}} \quad (1)$$

Where i = 1, 2 …n *and* j = 1, 2 …m

In a matrix, the *i and j* belong to the first row and first column values.

Step 2: Calculate the weighted normalised matrix

The normalized matrix is then multiplied with the weighted value using equation 2 (P. K. Sharma, Aggarwal, & Gupta, 1993) (Tzeng et al., 2005):

$$V_{ij} = \overline{X\imath\jmath} \ x \ W_j \quad (2)$$

Step 3: Calculate the ideal best and ideal worst value

This step is used for the calculation of the value ideal best; this is the value that suits the criteria; the maximum value is the ideal best, while the value against the agreement of criteria is considered ideal negative best which will be the minimum value.

Step 4: Calculate the Euclidean distance from the ideal best value

This value will be the closest value to the ideal best value, using equation 3:

$$S^{+}_{i} = [\sum_{j=1}^{n}(V_{ij-}V_{J^{+}})^{2}]^{0.5} \quad (3)$$

Step 5: Calculate the Euclidean distance from an ideal value

This value will be the closest value from the ideal worst value, equation 4:

(Chatterjee, Athawale, & Chakraborty, 2010):

$$S^{+}_{i} = [\sum_{j=1}^{n}(V_{ij-}V_{J^{-}})^{2}]^{0.5} \quad (4)$$

Step 6: Calculate the relative closeness to the ideal solution

The relative closeness to the ideal solution is calculated using equation 5

$$C_i = S^{-}_{i}/S_i^{+} + S_{i^{-}} \quad (5)$$

These values will help to rank the best alternatives. The MADM can be used to solve the materials selection problem where an indefinite number of alternatives are involved. This technique uses the discrete number variables with pre-defined alternatives as they do not require an explicit relationship between input and output variables (Zanakis, Solomon, Wishart, & Dublish, 1998). In this technique, the decision matrix comprises 1) criteria, 2) alternatives, 3) weight and decision. All the elements in the decision matrix are normalised to enable a comparison to be made (Opricovic & Tzeng, 2004). This TOPSIS method has good potential to solve the materials selection problem with great ease and accuracy (Tzeng et al., 2005).

We used Excel to solve the equations in the TOPSIS method and implemented it on the input data. The calculated values are shown in the tables below. Table 7.6 shows the strengths of responses obtained from the experts, and Table 7.7 contains the criteria and nominations for purposes of analysis. The data input table, Table 7.5, contains the data obtained from the experts' opinions through the questionnaire. The next step is to normalize the decision matrix which is carried out in Table 7.8 using equation 7. The next step is to multiply the normalised matrix with relative accumulated weights which are carried out using equation 8 and shown in Table 7.9. The next step is to find out the ideal and nadir ideal solution values, mentioned as V^+ and V^- presented in Table 7.10. The Euclidean distances S_i^+ and S_i^- are calculated with equations 9 and 10 shown in Table

7.11. In the same table, the closeness to an ideal solution is calculated by using equation 11; the greater the closeness, the higher is the rank.

Table 7.5: Data input

Data Input table				Capital cost	Maintenance cost	Discarding cost	Raw material extraction	Environmental effect of extraction process	Wastage expectancy	Contained energy	Sustainable disposal option	Potential of reuse and recycling of material	Legislation compliance capability	Pollution control	Air quality maintenance	Ozone layer influence	Toxicity	Resistance to decay	Fire resistance	Thermal insulation capacity	Durability	Buildability	Usage of local material	Aesthetics	Health and safety concerns	Labour availability
			Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
Supplier	Name for reference	Alternatives																								
	Terracotta range	A1		7	6	6	7	6	6	4	7	7	7	7	6	4	6	3	5	4	3	5	7	6	5	4
	Designer ceramic range	A2		4	2	4	6	4	4	5	5	5	6	5	5	5	2	5	7	6	5	6	4	7	7	5
S1	Concrete range	A3		3	1	4	6	3	2	6	4	4	6	6	4	5	3	6	6	5	7	7	5	6	6	7
	Terracotta range	A4		6	6	6	7	6	5	4	7	6	7	7	6	4	6	3	4	3	4	6	6	6	6	5
	Designer ceramic range	A5		5	2	4	6	4	4	6	5	5	6	5	4	5	4	4	6	5	5	5	5	5	5	6
S2	Concrete range	A6		4	1	4	6	2	2	7	4	4	6	6	4	4	3	5	7	4	6	4	4	6	6	5
		Criteria Sign Range		-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	1	1	1	1	1	1	1	1	1
		W(Lambda)		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 7.6. Likert scale for responses by experts

Agreement/Disagreement	Strength
Strongly disagree	1
Disagree	2
Somewhat disagree	3
Neither agree nor disagree	4
Somewhat agree	5
Agree	6
Strongly agree	7

Table 7.7. List of criteria

List of Criteria	
C1	Capital cost
C2	Maintenance cost
C3	Discarding cost
C4	Raw materials extraction
C5	Environmental effect of the extraction process
C6	Wastage expectancy
C7	Contained energy
C8	Sustainable disposal option
C9	Potential of reuse and recycling of materials
C10	Legislation compliance capability
C11	Pollution control
C12	Air quality maintenance
C13	Ozone layer influence
C14	Toxicity
C15	Resistance to decay
C16	Fire resistance
C17	Thermal insulation capacity
C18	Durability
C19	Buildability
C20	Usage of local materials
C21	Aesthetics
C22	Health and safety concerns
C23	Labour availability

Table 7.8. Normalised values table

Normalization = N	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
A1	0.5697	0.6626	0.5145	0.4500	0.5547	0.5970	0.2998	0.5217	0.5417	0.4500	0.4719	0.4983	0.3607	0.5721	0.2739	0.3442	0.3549	0.2372	0.3656	0.5417	0.4064	0.3475	0.3015
A2	0.3255	0.2209	0.3430	0.3857	0.3698	0.3980	0.3748	0.3727	0.3869	0.3857	0.3371	0.4152	0.4508	0.1907	0.4564	0.4819	0.5324	0.3953	0.4388	0.3095	0.4741	0.4865	0.3769
A3	0.2441	0.1104	0.3430	0.3857	0.2774	0.1990	0.4497	0.2981	0.3095	0.3857	0.4045	0.3322	0.4508	0.2860	0.5477	0.4131	0.4437	0.5534	0.5119	0.3869	0.4064	0.4170	0.5276
A4	0.4883	0.6626	0.5145	0.4500	0.5547	0.4975	0.2998	0.5217	0.4643	0.4500	0.4719	0.4983	0.3607	0.5721	0.2739	0.2754	0.2662	0.3162	0.4388	0.4643	0.4064	0.4170	0.3769
A5	0.4069	0.2209	0.3430	0.3857	0.3698	0.3980	0.4497	0.3727	0.3869	0.3857	0.3371	0.3322	0.4508	0.3814	0.3651	0.4131	0.4437	0.3953	0.3656	0.3869	0.3386	0.3475	0.4523
A6	0.3255	0.1104	0.3430	0.3857	0.1849	0.1990	0.5247	0.2981	0.3095	0.3857	0.4045	0.3322	0.3607	0.2860	0.4564	0.4819	0.3549	0.4743	0.2925	0.3095	0.4064	0.4170	0.3769

Table 7.9: Table of weighted normalised values

Weighted Normalization = V	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
A1	0.0239	0.0172	0.0206	0.0247	0.0200	0.0197	0.0138	0.0240	0.0244	0.0247	0.0245	0.0209	0.0141	0.0200	0.0104	0.0172	0.0138	0.0102	0.0176	0.0244	0.0211	0.0174	0.0139
A2	0.0137	0.0057	0.0137	0.0212	0.0133	0.0131	0.0172	0.0171	0.0174	0.0212	0.0175	0.0174	0.0176	0.0067	0.0173	0.0241	0.0208	0.0170	0.0211	0.0139	0.0247	0.0243	0.0173
A3	0.0103	0.0029	0.0137	0.0212	0.0100	0.0066	0.0207	0.0137	0.0139	0.0212	0.0210	0.0140	0.0176	0.0100	0.0208	0.0207	0.0173	0.0238	0.0246	0.0174	0.0211	0.0209	0.0243
A4	0.0205	0.0172	0.0206	0.0247	0.0200	0.0164	0.0138	0.0240	0.0209	0.0247	0.0245	0.0209	0.0141	0.0200	0.0104	0.0138	0.0104	0.0136	0.0211	0.0209	0.0211	0.0209	0.0173
A5	0.0171	0.0057	0.0137	0.0212	0.0133	0.0131	0.0207	0.0171	0.0174	0.0212	0.0175	0.0140	0.0176	0.0133	0.0139	0.0207	0.0173	0.0170	0.0176	0.0174	0.0176	0.0174	0.0208
A6	0.0137	0.0029	0.0137	0.0212	0.0067	0.0066	0.0241	0.0137	0.0139	0.0212	0.0210	0.0140	0.0141	0.0100	0.0173	0.0241	0.0138	0.0204	0.0140	0.0139	0.0211	0.0209	0.0173

Table 7.10: Ideal best and worst values table

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
V+	0.0239	0.0172	0.0206	0.0247	0.0200	0.0197	0.0241	0.0240	0.0244	0.0247	0.0245	0.0209	0.0176	0.0200	0.0208	0.0241	0.0208	0.0238	0.0246	0.0244	0.0247	0.0243	0.0243
V-	0.0103	0.0029	0.0137	0.0212	0.0067	0.0066	0.0138	0.0137	0.0139	0.0212	0.0175	0.0140	0.0141	0.0067	0.0104	0.0138	0.0104	0.0102	0.0140	0.0139	0.0176	0.0174	0.0139

Table 7.11: Relative closeness and final ranking table

Si+	Si-	Ci	Rank
0.0269	0.0372	0.5801	1
0.0325	0.0252	0.4372	3
0.0364	0.0272	0.4272	4
0.0260	0.0343	0.5686	2
0.0310	0.0215	0.4095	5
0.0399	0.0209	0.3440	6

The weighted values show the best or worst alternative. The obtained results show a good agreement with the TOPSIS ranking technique. Alternative 1 is ranked in the first position indicating that this is the best alternative available according to all the twenty-three criteria suggested by the experts. The remaining alternatives are ranked accordingly against other criteria.

7.8 Chapter Summary

This chapter described the development and use of a materials selection model to rank the various alternatives, making sustainability considerations the top priority. The middle section describes the importance and the development process of the model using the TOPSIS technique, by using a hypothetical case study based on the original values validated by experts. The last section discusses the application of the technique and the step-wise application of the model to the real values obtained from top roofing materials suppliers in Australia. The results are totally aligned with the data validated by the experts, which confirms the accuracy, completeness and comprehensiveness of the model and its suitability for the selection of sustainable construction materials for building construction projects.

CHAPTER 8

CONCLUSION, RECOMMENDATIONS AND FUTURE WORK

This chapter contains:

- Summary of the study
- Outcomes from literature review
- Research findings and conclusion
- Recommendations for future work

8.1 Chapter Introduction

This chapter presents the research outcomes and summarises the research work. The findings from the literature review and the analysis of data obtained through the survey questionnaire and face-to-face interviews pertain to environmental awareness and sustainable practices carried out by the building practitioners. A multi-criteria selection model was devised to assess the sustainability of construction materials during the decision-making process. The research findings lead to conclusions that can point to future research directions. This research work critically scrutinizes and categorizes the environmental problems and issues generated by construction activities, especially the construction of buildings. The implementation of sustainability practices in design, and during and after construction is analysed in terms of the selection of construction materials. This thesis investigates the building assessment methods used currently in the construction industry and their shortcomings as a tool to develop a materials selection model.

8.2 Factor Analysis

The major factor affecting the materials selection and sustainability practices is the economic factor which is analysed and critically examined during the data analysis stage. The environment is being considered as the most important factor emerging in the building construction industry, and sustainable practices concern all stages of the construction process. Further, the research findings and their relevance to the aims and objectives are discussed. At the start of this section, the aims and objectives of this research are reiterated.

8.3 Aims and Objectives Appraisal

This study has achieved the aims and objectives introduced at the beginning of this thesis. It discussed six sustainable development criteria including the triple bottom (economic, environmental and social) and developed a model for aggregating the suitability index for materials selection using the MCDM technique. The sustainability index counts the vital variables adding the technical aspect to the triple bottom when choosing the best alternative sustainable construction materials.

Materials selection flaring issue

The selection of materials is one of the basic constituents of building construction as it has very long-lasting impacts upon the environment as the end product (the building) is a major user of energy. The development is directly related to the economic development of any country but not at the cost of the natural environment and resources. The current situation and upcoming challenges together with modern developments are discussed in detail in chapter 2 as is the damaging impact of construction on the environment. It is evident from the literature that the increasing consumption of energy by the construction industry is producing different types of pollution and environmental distress. However, the realisation and increasing awareness of sustainability and sustainable construction practices should be right from the start at the design stage through to the tangible on-ground construction. The best way is to consider sustainable construction practices and sustainable construction materials from the outset. The selection process requires a modern, more vigilant, vibrant and integrated decision-making model.

Better decision-making tool

The literature also reported the current practices regarding materials selection and suggests techniques for developing an improved version of the materials selection model. The literature clearly states that the traditional economic approach of life cycle cost assessment (LCC) has some serious shortcomings which can lead to environmental degradation by not showing the true prices during the decision-making process. Hence, if environmental principles are not considered during the life cycle cost analysis process, the ultimate selection will be wrong, causing irreparable loss to the decision-making model. The literature also revealed that most of the decision models are unidimensional and therefore cannot accommodate complex environmental values. The latest environmental assessment models were discussed and investigated, revealing that these methods are unable to integrate sustainability in the decision-making process because most of them take a unidimensional approach when basic or simple environmental issues. A multidimensional assessment model is required to help decision-makers to make better and more appropriate decisions when selecting sustainable construction materials, taking into account all the available alternatives. This study will help the managers to make an appropriate, quick and accurate decision while making a choice of the most sustainable construction materials for a building project. The managers will have a tabular and ranked form of data depending upon the sustainability.

Sustainability: the prime concern

One of the main objectives of this study was to gauge the environmental and sustainability awareness of local construction practitioners and the role of sustainable construction materials in the construction industry. The findings from the data analysis reported in chapter 6 show that there is now a greater awareness of sustainability in the construction industry, but there is still a discrepancy between awareness and knowledge, and actual application. Numerous companies are adopting sustainability, given the competitiveness among construction firms and the need to comply with building laws and regulations. The main issue they are facing at the moment is the availability of skilled labour and the availability of alternative sustainable materials. The gap between the awareness and implementation causing hindrance in the application of sustainable construction practice and enviro-friendly construction materials. The cost issue also played a vital role in the selection of sustainable construction materials. The importance of the decision support system was explained in detail in previous chapters, bearing the cost factor in mind. The managers will be among the direct beneficiaries of this ranking model by having a handful of information on readily available sustainable construction materials in the local market. They can make appropriate decisions for materials selection keeping in mind sustainability the major point of concern.

Identification of sustainability criteria and development of an assessment model

The next major objective was to identify the sustainability criteria and to develop an evaluation model to refine the modelling of a decision support system to help decision-makers to make informed and appropriate decisions when selecting sustainable construction materials for a building project. A multi-dimensional approach was adopted, unlike the uni-directional approach taken by most researchers in the reviewed literature. Hence, a multidimensional evaluation model was developed in chapter 7 using the MCDM technique, TOPSIS. The six criteria were derived from the literature review and the data from the survey, questionnaire and face to face interviews with experts to develop a sustainability index.

These six criteria pertain to these areas:

- Life-cycle cost
- Resource efficiency
- Environmental impact
- Waste minimization
- Social benefits and performance capability

8.4 Main Contributions

The aim of this thesis was to develop a decision support model to help technical stakeholders to select the most suitable sustainable construction materials for building construction projects. This thesis:

1. successfully evaluated the relationship between the building construction and environmental degradation;
2. successfully gauged the environmental and sustainability awareness among Australian technical stakeholders;
3. investigated the extent of implementation of sustainable construction practices and the obstacles to the selection of sustainable construction materials;
4. developed several sustainable assessment criteria to facilitate the materials selection process associated with a building construction project; and
5. Developed a sustainability index to assist with the selection and evaluation of sustainable construction materials.

Sustainability is the concern of the modern era, and efforts are being made to mitigate the environmental issues and address the scarcity of natural resources. Thus, the selection of alternative sustainable construction materials can play a vital role in promoting sustainability. This thesis makes a small contribution to these efforts.

8.5 Chapter Summary

In brief, the basic purpose of this research was to discover current practices in the local construction market when selecting construction materials and to determine the main factors/criteria that construction personnel consider when making their final decisions about materials and their usage. Described the drivers and retarders in the implementation of sustainable construction practices right from the sustainable design through the different phases of building construction.

The recommended model integrated the sustainability features into a decision-making practice to promote the selection of sustainable materials and to implement sustainable construction practices. The degradation of the environment due to construction-related activities has been more obvious in recent times in the construction industry which is one of the largest users of natural resources and has a great negative impact on the environment. The economic factor is an obstacle to the implementation of sustainable construction practice in the real world, so the best solution is to include it for a comprehensive assessment.

The recommended sustainability index can assess the environmental performance of a building using the main factors/criteria related to the environment. This work involved ascertaining the sustainable development criteria, inspecting the methods of taxonomy, and developing a decision model to integrate the criteria into a single decision-making system.

A sustainability index is a decision-making tool used to combine composite indices to rank the different construction materials available for building construction projects. This helps decision-makers to make choices that take into account the attributes of materials in terms of their enviro-friendliness and practicality. This model helps to optimize the cost-effectiveness, minimize resource consumption, maximize the re-use of alternate materials and minimize the destructive effects on the environment.

This research journey had three major elements: a comprehensive literature review to discover environmental footprints; a questionnaire-based survey to determine the extent of local Australian construction practitioners' environmental awareness and practical implementation of sustainability, and the development of a sustainability index to assist the technical stakeholders with the selection of sustainable construction materials.

In this work, we critically examine the current unit-directional building sustainability evaluation methods in order to determine the sustainable performance of building materials used. Following this evaluation, we developed a sustainability-related questionnaire to obtain the opinions of experts, and determine their level of awareness of sustainability practices.

The literature review and expert opinions from the industry provided the foundation for a multi-criteria decision model for materials selection. This decision model used the MCDM technique, TOPSIS, to develop a sustainability index for materials selection. The main criteria for materials selection were: life cycle cost, resource efficiency, environmental impact, waste minimization, social benefits and performance capability.

The ultimate goal of this research work was to develop a decision model to aggregate the sustainability criteria into a sustainability index to assess the sustainability performance of the construction materials used in building projects. The sustainability index developed is basically a multi-criteria approach for materials selection, aligning economic considerations with environmental features and other imperceptible criteria within the assessment framework.

8.6 Final Deductions

The primary goal of this research work was to develop a sustainability index, which has been accomplished. The mathematical model using the TOPSIS was presented in chapter 7. This sustainability index is a composite index that accommodates the triple bottom i.e. economic, environmental, social and technical criteria to rank the building materials keeping in view the sustainability.

The general drift in environmental assessment away from the usually qualitative descriptions of environmental practices towards a comprehensive, quantitative construal is made more effective by using the MCDM. This research work is carried out using TOPSIS to develop the sustainability index as a tool for construction materials selection and evaluation. This sustainability index addresses the current demand for a combination of environmental and economic considerations.

This sustainability index enables the measurement of sustainability issues that cannot be measured effectively by sustainability assessment methods such as BREEAM and BEEPAC in which the scores obtained for ranking purposes depend on certain environmental and sustainability features. This research work resolves this issue by using the proposed composite sustainability index. A multidimensional approach for decision making is provided using this sustainability index. This method assesses the building materials based upon the economic values in conjunction with environmental issues. This work also gives technical stakeholders, as experts in the field, to have an equal voice in the final decisions.

This can be used as a yardstick for the selection of building materials, enabling decision-makers to make environmentally-friendly decisions to improve the quality of life in communities and in the built environments overall. This SI helps decision-makers to make better choices based on environmental issues. This will help to make decision-makers tasks easier and encourage them to put more effort into introducing and implementing sustainable construction practices from the initial design phase through to construction and operation.

8.6.1 Implementation of green policy

There is an urgent need to consider construction activities that exploit natural resources and are responsible for a major part of global energy consumption. The development of this sustainability index indicates the importance of establishing and applying a sustainability policy that can bridge the gap between the awareness and implementation of sustainability in the true spirit of collaboration. This will ensure that all the required parameters are checked and evaluated to ensure that sustainability is the first and foremost consideration in a built environment.

More attention must be given to long-term sustainability strategies starting from the feasibility stage and through to the construction phase, by making sustainability the first priority. The cost factor cannot be the main determinant when selecting materials for a building construction project. Sustainability can be achieved only through the combined efforts of technical stakeholders, the final decision-makers, and the construction industry itself.

This means by making the benefits widely known and establishing a cooperative approach towards sustainable construction practices, we can promote this idea in building design and the whole construction process. This research work demonstrates the importance of considering sustainability when choosing construction materials, and this can be done by meeting the selection criteria proposed in this study. This will be the only way to save the environment and conserve natural resources.

8.7 Limitations and Future Prospects

The main objectives and aims of this research work were achieved with the development of a sustainability index as a decision support tool that can assist technical stakeholders to make appropriate decisions when selecting sustainable construction materials. However, one limitation is that this study was carried out in the Australian context and therefore the findings indicate the attitudes and opinions of people who work in the building industry in Australia building experts of Australia.

The findings predominantly can help them deal with problems in a particular scenario. However, it is acknowledged that there were some deficiencies in the data collected from leading construction firms. Therefore, a research sample should include other trades as well rather than being limited to specific professionals. These discrepancies should not compromise the overall importance value of previous research; rather, they can be considered as challenges prompting future research undertakings in a broader range of areas.

This research work is carried out for the purpose of facilitating the selection of sustainable construction materials for building projects. We also identified six major sustainability criteria, encompassing the triple bottom that can improve the sustainability of building construction practices. Several areas can provide the impetus for future research work as they can be applied to different physical infrastructures in a built environment, and even in the manufacturing industry. Future research could extend the scope and applicability of our findings.

More work could be carried out to further investigate and change the perception of the technical stakeholders that environmental considerations or sustainability means higher cost and more time. These were the major notions found among the industry experts. Hence, there is a great need to change this perception that ‘environmentally friendly’ means more expensive construction materials.

It was found that a significant number of architects, designers and contractors were reluctant to use innovative and sustainable construction materials. The data analysis results (see chapter 6) clearly indicate that when the technical stakeholders were given a choice between environment and cost, most of them chose cost. Therefore, it is recommended that research work be undertaken to investigate and recommend a number of measures to change this traditional mindset among the construction practitioners and final decision-makers.

This research work focused on developing a sustainability index comprising a set of actions that meet six criteria. However, further research can be undertaken to investigate the performance of construction materials based upon additional criteria. It is important that this type of research be carried out for different construction materials and construction methods in more diversified areas of built environments.

This research work has collected data only from technical experts in the building construction industry, as the findings can be applied to other large construction projects such as roads, bridges and dams. Future research can validate these criteria or even introduce more elaborate criteria that can help to implement sustainable practices in a large-scale construction environment, because the built environment, especially in big infrastructure projects, is largely responsible for environmental degradation.

This thesis focused on developing a sustainability index that can be used for the ranking of sustainable construction materials in order to provide a list of the best available alternative materials. This research has opened up new avenues for future researchers who may wish to extend our findings to other construction fields to improve sustainability awareness and promote the implementation of sustainable construction practices in built environments.

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