Integrated Sustainability Assessment and Rehabilitation Framework for Existing Buildings

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ABSTRACT

Integrated Sustainability Assessment and Rehabilitation Framework for Existing Buildings

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Public and private sectors are concerned with controlling the undesirable environmental impact of the new construction and the renovation of buildings. The building industry accounts for 32% of global energy consumption, 19% of energy-related CO_2 emissions, 25% of global water, and 40% of global resources depletion. The operational and maintenance phase of buildings accounts for 70% to 90% of the overall impact on environment. The literature review revealed many rating systems that were developed during the last few decades to assess the sustainability of buildings based on economic, social and environmental criteria. However, they represented local industries and none of them proposed a tool to select the best economic rehabilitation alternatives to upgrade building sustainability. Therefore, the main goal of this research is to establish an integrated sustainability rating and rehabilitation selection tool for buildings to fulfil the following objectives: 1) identify and study sustainability assessment attributes, 2) develop a sustainability assessment model for buildings, 3) build a sustainability scale and 4) establish a sustainability-based rehabilitation model for existing buildings. The research utilized several modelling techniques, such as fuzzy TOPSIS technique to determine the weight of each assessment attribute, simulation to determine the energy consumption, BIM-based model to assess building sustainability and the artificial immune system (AIS) to develop the sustainability-based rehabilitation model. Several types of data were collected and used to develop the aforementioned models utilizing questionnaires, case studies and interviews with facility managers from Canada and Egypt. The results showed the significant influence of the regional variations on both the weights of the sustainability attributes and the total sustainability assessment. By using a scale from zero to one, Canada showed the highest weights in energy, indoor environmental quality (IEQ) and building management criteria with values of 0.220, 0.167, and 0.156, respectively, whereas in Egypt, energy, site and water use criteria possessed the highest weights with values 0.2, 0.191 and 0.169, respectively. The sustainability-based rehabilitation model was implemented with a case study in Canada in which the results showed the capability of the developed optimization model to determine several optimal or near optimal alternatives to upgrade the sustainability with minimal life cycle cost (LCC). The developed tool was validated by experts through an interview and questionnaires showing the potential application of the tool to existing buildings. The assessment model was also validated through a comparative analysis between the proposed model and other well-known sustainability rating tools, which showed good potential. Sensitivity analysis was conducted showing the impact of the weight variation on the sustainability assessment. The research concluded the importance of introducing a multi-level weighting scheme in the assessment to reflect regional variations. The main contribution of the present research is to provide decision-makers with a two-tier tool that 1) determines the current sustainability of buildings and highlights the weak areas that require more attention, and 2) proposes various rehabilitation alternatives that upgrades the sustainability of the building with minimal LCC utilizing multi-objective optimization. The research also contributes to the body of knowledge by developing an integrated sustainability assessment and rehabilitation framework as a step towards establishing a comprehensive global sustainability-assessment tool.

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Dedicated to

My inspiring mother "Zeinab Abd El Samie" and the soul of my Father "Ahmed Ibrahim"

My supportive, and beautiful wife "Sara Mostafa"

My kids "Ahmed, Mostafa, and Karim"

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List of Nomenclatures and Abbreviations

A_A	Area of architectural structures in the site
AB_{best}	Best Antibodies
A_{build}	Area of the Building Elevation in the direction of prevailing wind
A_f	Area of Floor
A_G	Area of open grid paving
A_H	Area of hardscape material with SRI of at least 29
ACO	Ant Colony Optimization
AHP	Analytical Hierarchy Process
AIS	Artificial Immune Systems
$A_{low\ slope}$	Low sloped Roof area
A_{ocu}	Area of occupied space in the roof
A_{plant}	Area of planted portion in the Elevation
Arc size	archive Size
A_s	Area of solar panel Units
A_{steep}	Steep Roof Area
A_T	Area of tree shading
A_w	Area of Window
BCA	Building and Construction Authority of Singapore
BEA	Building Elevation and Area Ratio
BEE	Building and Environment Efficiency
BREEAM	Building Research Establishment Environmental Assessment Methodology
BSAR	Building Sustainability Assessment Ratio
BSI	Building Sustainability Index
BSI_{max}	Maximum Building Sustainability Index
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CPSI	Life Cycle Cost Per Sustainability Index
CC	Closeness Coefficient

CFC	Cloroflurocarbons
CH_4	Methane
COV	Coefficient of Variance
CSA	Clonal Selection Algorithm
$d(M_1, M_2)$	The Euclidean distance between two fuzzy numbers
DALY	Disability Adjusted Life Years
Div	Number of divisions used to identify the borders of the hyper boxes
DV	Decision Variable
ETTV	Envelope Thermal Transfer Value
EUI	Energy Use Intensity
EIA	Environmental Impact Assessment
GAI	Green Area Index
GB	Green Building Tool
GBI	Green Building Index
gen	generation
GnP	Green Area Provision Ratio
$GtCO_2$-eq	Gega tons of Carbon dioxide equivalent of emissions
H_{build}	Height of building
HCFC	Hydro Chloroflurocarbons.
HK GBC	Hong Kong Green Building Council
HK-BEAM	Hong Kong Building Environmental Assessment Model
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
INT	Integer Value
IPCC	Intergovernmental Panel for Climate Change
IT	Information Technology
JaGBC	Japan Green Building Council
k	Number of objectives
l	length of binary string used to represent the design variable
$Lb_{k,t}$	Lower boundary of adaptive grid for objective k in generation t

LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
LLF	Light Loss Factor
LR	Building Environmental Load Reduction
MADM	Multi Attribute Decision Making
MCAT	Multi-criteria Assessment Tool
Max gen	Maximum generation
MR	Material Use Reduction
Mv_{ij}	Generalized Mean of Vector weighted fuzzy number
N_2O	Nitrogen oxide
N_c	Number of Design Variables
N_{cln}	Number of clones for antibodies
N_{dv}	Number of Design Variables
NIS	Negative Ideal Solution
PDF	Potentially Disappeared Fraction of Species
PIS	Positive Ideal Solution
PSO	Particle Swarm Optimization
Pop_size	Population Size
Q	Building Environmental Quality
$R\ c_k$	The Result of k^{th} Criterion
$R\ f_j$	The Result of j^{th} Factor
$rlb_{k,i,t}$	Lower boundary of the hyper box in the adaptive grid for objective k; coordinate I; and in generation t
RSP	Respiratory Suspended Particles
$rub_{k,i,t}$	Upper boundary of the hyper box in the adaptive grid for objective k; coordinate I; and in generation t
SC	Shading Coefficient
$SC\ c_k$	The Score of k^{th} Criterion
$SC\ f_j$	The Score of j^{th} Factor
SC total	Total Assessment Score

SRI	Solar Reflectance Index
SS	Sustainable Sites
Sub f_i	I^{th} Sub factor
TAFN	Trapezoidal Fuzzy Numbers
TBSI	Sustainability Indicators for Tall Building Projects
TFN	Triangular Fuzzy Numbers
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TSI	Total Sustainability Index
$Ub_{k,t}$	Upper boundary of adaptive grid for objective k in generation t
UNFCCC	United Nations Framework Convention on Climate Change
U_f	Thermal Transmittance of Fenestration
UF	Utilization Factor
UNEP	United Nations Environmental Programme
USGBC	United States Green Building Council
U_w	Thermal Transmittance of Wall
VLT	Visible Light Transmittance
VVVF	Variable Voltage Variable Frequency
W c_k	Weight of k^{th} Criterion
W f_j	Weight of j^{th} Factor
WFR	Wall to Floor Area Ratio
W_{site}	Width of the site
WWR	Wall to Window Ratio

CHAPTER 1: INTRODUCTION

1.1 Overview

Building accounts for 32% of global energy consumption, 19% of energy-related CO_2 emissions, 51% of global electricity consumption and 9% of global petroleum consumption (IIASA, 2012; IPCC, 2014; Mckinsey, 2009; WEC, 2013). In addition, based on UNEP (2011), the building sector is responsible for more than one-third of material global resource consumption, which contributes to the estimated 40% of global solid waste generation, as well as consuming 12% of all fresh water. Moreover, the building sector emits per electricity use 8.6 $GTCO_2$-eq., 0.4 $GTCO_2$-eq. CH_4, 0.1 $GTCO_2$- eq. N_2O, 1.5 $GTCO_2$- eq. Halocarbons (CFC and HCFC) and 35%-40% of CO_2 emissions from the use of fossil fuels (IPCC, 2007; Urge-Vorsatz et al., 2007). The estimated carbon dioxide emissions by the year 2030 considering the high economic growth scenario will be 15.6 $GTCO_2$- eq., as shown in Figure 1.1 (IPCC, 2007).

The direct impact of the building sector on the environment is the emissions of greenhouse gasses. These gasses can be classified into two groups: carbon gasses and non-carbon gasses emissions, such as halocarbons. The former arises because of the consumption of buildings to electricity, which depends on the burning of fossil fuels in its production, whereas halocarbons emissions (i.e. CFC and HCFC) arise due to utilizing different construction materials, such as paints, adhesives refrigerants, insulation materials…etc. (UNEP, 2009).

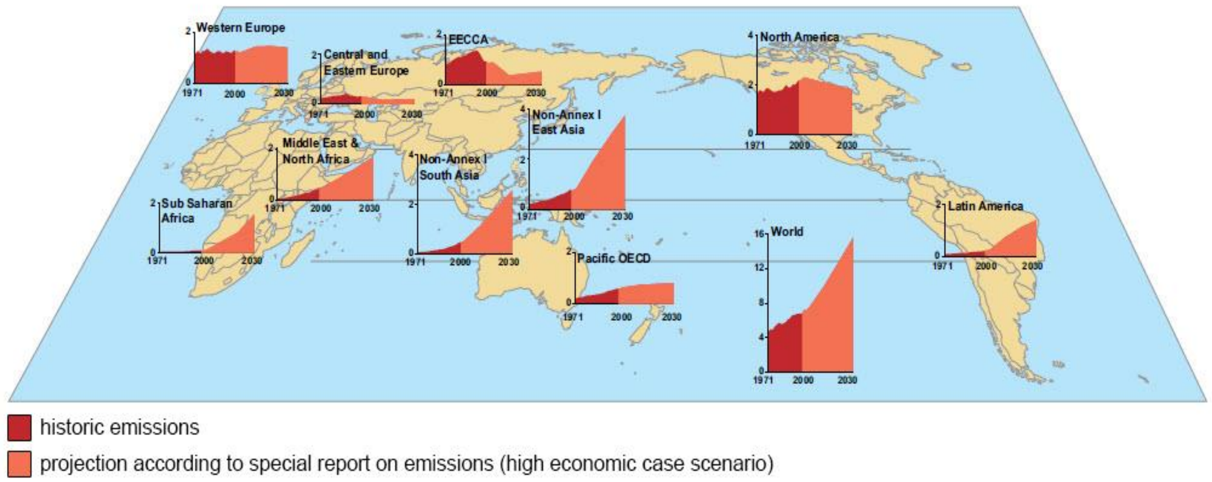


Figure 1.1 CO_2 Emissions in Building Sector from 1971 to 2030 (IPCC, 2007)

The energy consumption throughout the building phases can be divided into five main parts as shown in Figure 1.2. These phases are 1) extraction and manufacturing of materials, which possesses energy called embodied energy; 2) the transportation of materials from production to construction site called grey energy; 3) energy consumed in construction processes, which is called induced energy; 4) operational energy, the energy consumed in operation phase; and 5) energy used up in demolition and recycling phase (UNEP, 2009).

Environmental impacts are global warming potentials, including acidification, eutrophication, photochemical ozone creation potential, and human toxicity. Various studies were conducted to identify the percentage of the environmental impacts of each stage of the life cycle of buildings. The results of these studies showed that operation and maintenance phase, occupancy phase, accounts for 70%-90% of all impacts, and only 10%-20% of them attributed to the manufacturing of materials (Seppo, 2004; UNEP, 2009). Moreover, Seppo (2004) concluded that the operation phase is the main contributor to energy consumption as well as gas emissions from the building throughout its whole life cycle by utilizing North American and European case studies as shown in Figure 1.3 and Figure 1.4, respectively.

Energy consumption in the operation phase correlates with many aspects including 1) climate and location of the building; 2) supply and source of energy; 3) function of building; 4) building design, orientation, construction material and building envelope; and 5) the behaviour of occupants and the occupation period (UNEP, 2009).

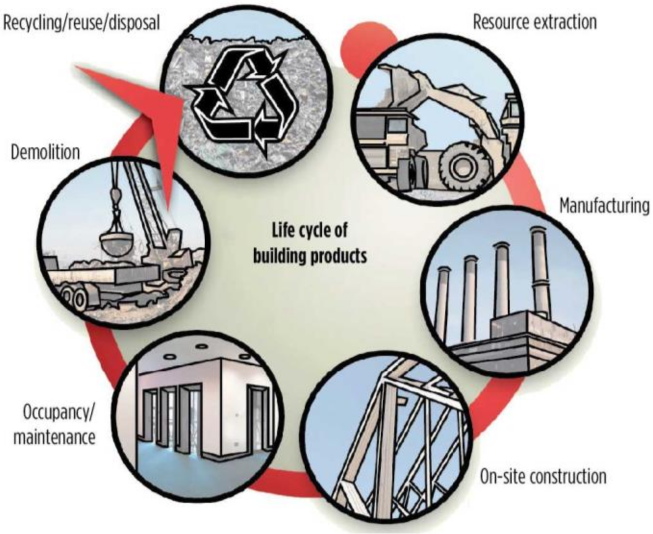


Figure 1.2: Life Cycle Stages of Building (O'Connor and Bowick, 2016)

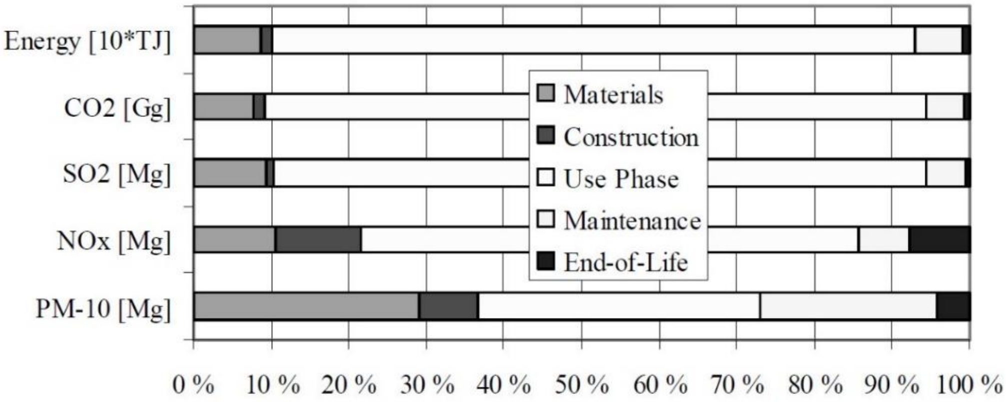


Figure 1.3 Building Emissions in Different Phases in an American Case Study (Seppo, 2004)

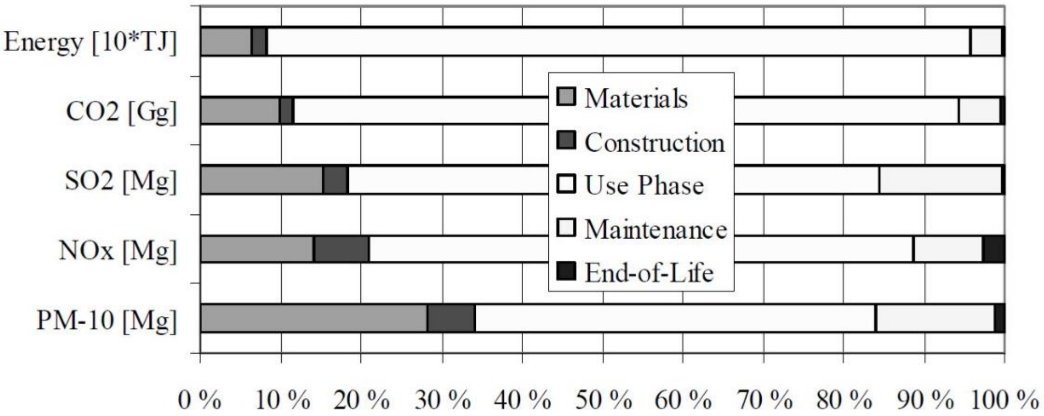


Figure 1.4: Building Emissions in Different Phases in European Case Study (Seppo, 2004)

Residential and commercial buildings are the main contributors to energy consumption in the building sector. As stated in IPCC (2014) residential and commercial building account for 24% and 8% of the total global energy use, respectively. Space heating is the main consumer of energy in both residential and commercial buildings with percentages of 32% and 33%, respectively. Cooking end use represents 29% of the total global energy consumption in residential buildings; on the other hand, IT equipment represents the second leading energy consumer with 32%. Furthermore, lighting comes in third place in importance in commercial buildings, representing 16%, whereas water heating represents 24%, which shows the third end-use energy consumer in residential buildings as depicted in Figure 1.5. Therefore, as stated in the above section, building function affects overall energy consumption and the end-use activities require fulfilling these purposes.

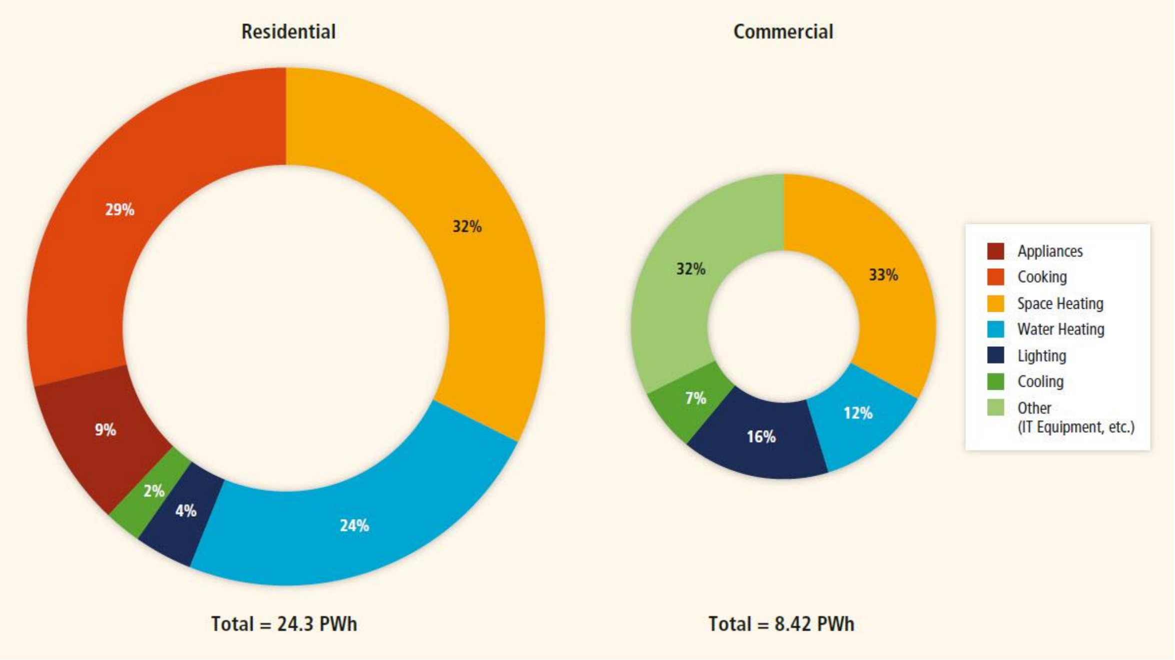


Figure 1.5: Energy Consumption by End Use of Residential and Commercial buildings (IPCC, 2014)

According to IPCC (2007), the building sector has the highest economic mitigation potential when compared with others, such as energy supply, transport, industry, agriculture, forestry and waste. For a potential mitigation cost of less than \$100 USD per ton of carbon dioxide equivalent, a building will have reduced mitigation in greenhouse gas emissions from 5.3-6.7 of Gt CO_2-eq as shown in Figure 1.6. The key mitigation technologies can be summarized in the following categories: efficient lighting and daylight; energy star rated electrical appliances, heating and cooling devices; improved cook stoves; efficient insulation; alternative refrigeration fluids; integrated meters that provide feedback and control; and integration of PV solar cells in buildings (Urge-Vorsatz et al., 2007). Moreover, the UNEP (2011) stated that relying on sustainable building standards are the most effective and efficient way to mitigate the impacts of the building sector on the environment. Although these standards require additional investments, they produce life cycle savings through a reduction in energy use, improvement in environmental health, an increase in efficiency in material use and water use and reduce risks from waste and associated hazardous substances.

Mitigation of GHG emissions accompanies several co-related benefits, such as reduced local air pollution, improved health and quality of life, improved productivity, employment creation and new business opportunities, improved social welfare and poverty alleviation and increased energy security (IPCC, 2007; UNEP, 2009).

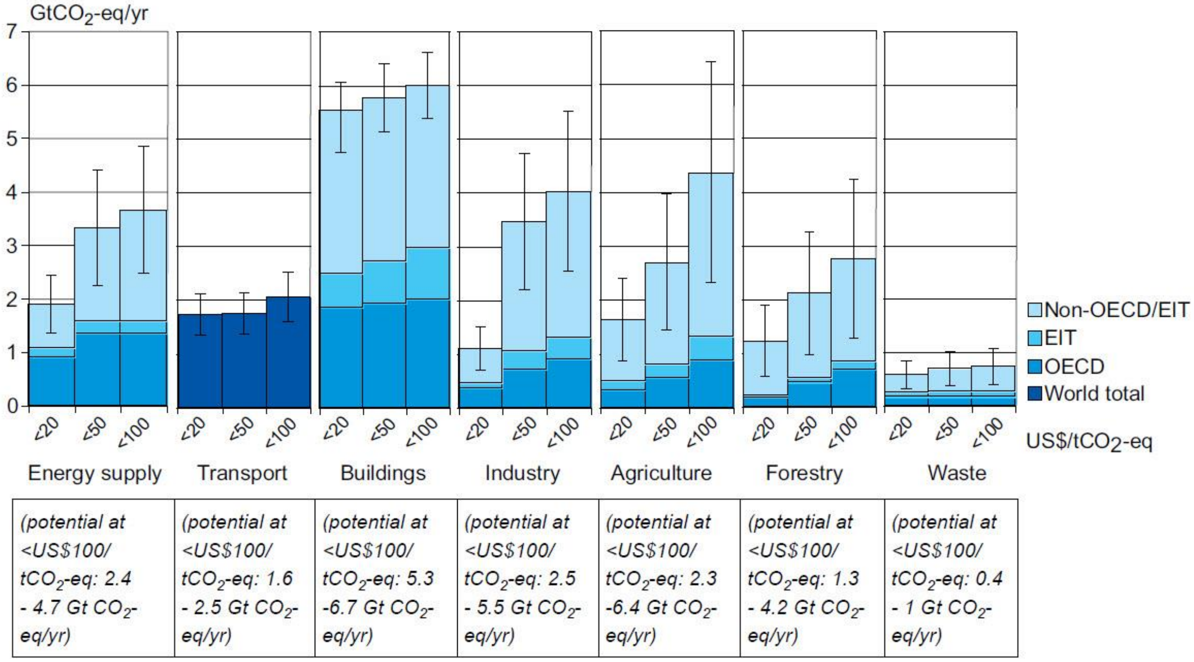


Figure 1.6: Estimated Mitigation Potential by Sector and Region Using Technologies Available in 2030 (IPCC, 2007)

1.2 Problem Statement and Research Motivation:

Based upon the previous overview, the building sector has enormous impacts on the environment and consequently on human health. However, as illustrated, it possesses a high mitigation potential when compared with other sectors. Moreover, among the various stages that a building passes through, the operation or occupational stage has the greatest amount of environmental impacts when compared with other stages. Consequently, from this point of view, existing buildings possess higher mitigation potential when they are efficiently managed.

Furthermore, the crucial aspect that should be considered when dealing with the assessment of buildings is the local context where the building exists. Profoundly, local variations severely change the building performance. Kohler (1999) described local variations as the difference in climate conditions, income level, the available building material and techniques and preservation of historical values. These variations dealing with the triple bottom-line of sustainability, which are: 1) environment, 2) society and 3) economy. Environmental variations can be briefly addressed as climate change (i.e. temperature, wind speed, rainfall frequency…etc.), location and carbon footprint. Social aspects are culture differences, working hours and vacations, which affect the building use profile. Economic aspects can be summarized as the currency value, inflation rate, interest rate, building conditions and maintenance fees, availability of ample budgets…etc. Hereafter, all the aspects mentioned above are correlated; in the same way: they differ in their importance from a local context to another. Consequently, the sustainability assessment procedure should be dynamically altered from one place to another while preserving the key assessment criteria and attributes to maintain consistency.

Based on the literature review, there is a vast number of rating systems throughout the world that aim to assess sustainability (Nguyen and Altan, 2011). However, there are noticeable variations between systems of the same grade or rating, such that BREEAM Excellent, LEED Platinum, and a 6-Star Green Star office building are not equivalent in terms of sustainability and impact on the environment. Therefore, it difficult for buildings' stakeholders, especially property investors who purchase buildings in different countries, to compare the sustainability of their buildings on a consistent basis (Dixon et al., 2008). Also, there is no unified concept or definition of sustainability assessment attributes that can be utilized to express the key aspects of sustainability and to be adopted in different regions (Baharetha et al., 2012; Banani et al., 2013; Warren et al., 2009). There is no consensus acceptance of considering a rating tool as the best globally rating tool (Reed et al., 2011). Furthermore, there is no rating system that considers the dynamism of the importance of the assessment attributes, rather, they all considered a constant weight of each assessment criterion regardless of variations according to local contexts as discussed previously. Therefore, it is urgent to introduce a dynamic weighting scheme for each attribute to express their importance according to local variation. Ding (2008) stated that there is no consensus-based approach was applied to guide the assignment of weight to the assessment criteria. The way the weight is calculated and the reason behind its assigned values in the existing systems is not explicit and clear (Berardi, 2012). Moreover, there is no rating system that provides decision-makers with a sustainability-based rehabilitation model to improve the performance of their building within an available budget. This model is important for the concept of sustainability itself because not all alternatives that can improve performance are sustainable; only those that are affordable are sustainable, as they comply with the economy. From this point of view, establishing a rating system that can provide decision-makers with a group of affordable alternatives to improve the sustainability of their buildings is the key of sustainability. Hence, the main purpose of this research is to develop an integrated sustainability rating system for existing buildings with a decision support system for sustainability-based rehabilitation for existing buildings.

1.3 Research Objectives:

The purpose of this research is to develop an integrated sustainability rating system for existing buildings that considers environmental, social and economic aspects. This rating tool will provide decision-makers with a comprehensive evaluation concerning the sustainability of their buildings. To achieve the primary objective, the following sub-objectives were developed:

1. Identify and study sustainability assessment attributes.
2. Develop a sustainability assessment model for existing buildings.
3. Build a sustainability scale.
4. Establish a sustainability-based rehabilitation model for existing buildings.

1.4 Research Methodology:

This research establishes a comprehensive sustainability-rating tool for office buildings that is connected into the local variations of economy, society and environment with respect to each country. In addition, this rating tool provides a decision-maker with a group of alternatives to upgrade the sustainability of a building within a predefined budget. In order to fulfil this goal, the following methodology was applied, which will be described in the following four steps as shown in Figure 1.7.

1.4.1 Literature Review

a. Conduct an extensive literature review to examine the existing rating system used to assess the sustainability of buildings and compare the various factors that affect the sustainability assessment of buildings.

b. Review the multi-attribute decision-making methods, especially Fuzzy TOPSIS method. This method was utilized in identifying the weight of each criterion and factor used in the sustainability assessment process.
c. Investigate the different software used for both physical model development, e.g. Revit software in addition to other software utilized to perform energy simulation, e.g. IES software. Apply energy simulation software to stand for the energy consumption of buildings based on certain inputs, such as orientation, occupancy schedules, installed HVAC systems, lighting system ...etc.
d. Explore various evolutionary multi-objective optimization algorithms. Implement the optimization algorithm for upgrading the sustainability of buildings within a tight budget.

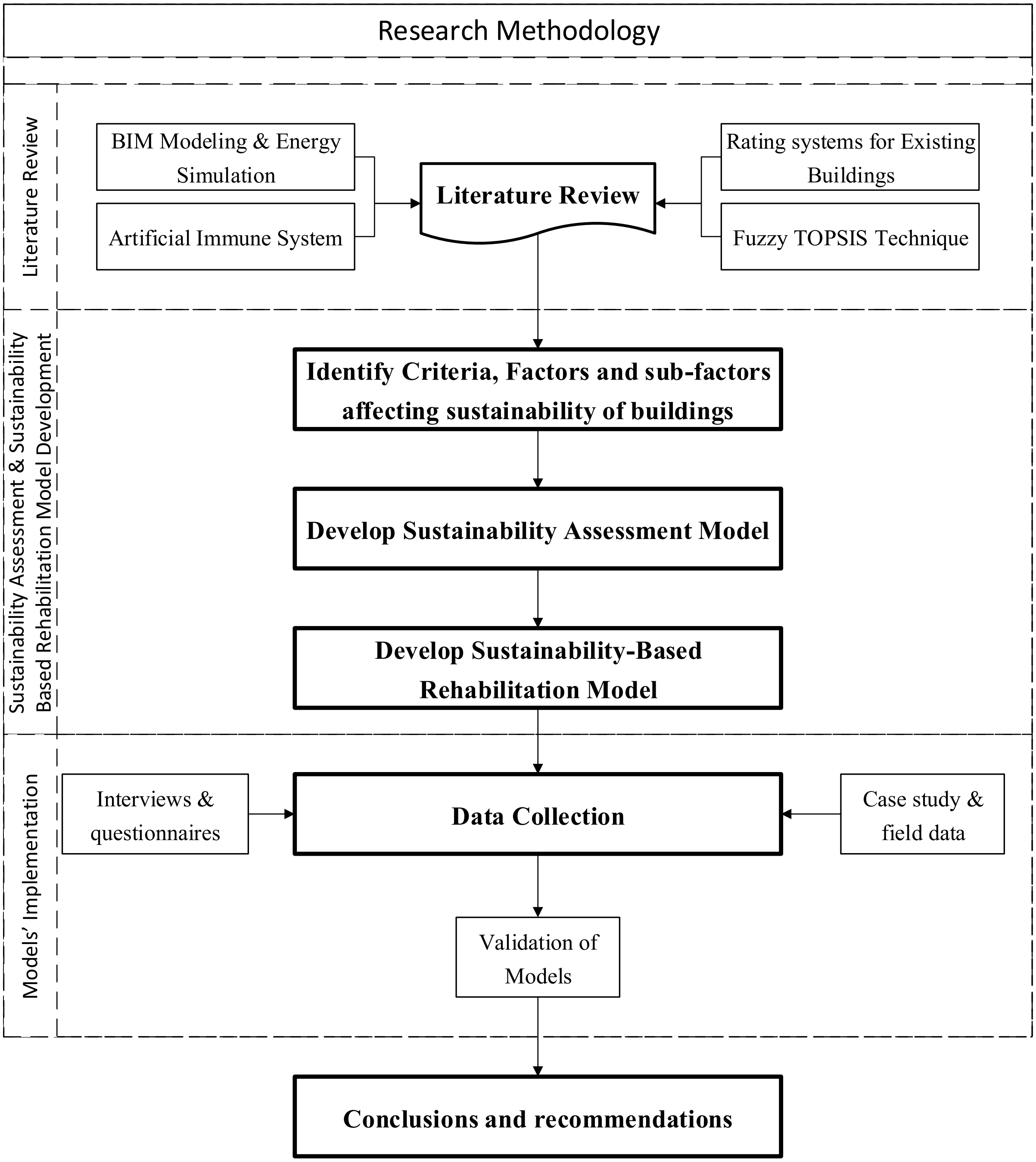


Figure 1.7: Research Methodology

1.4.2 Model Development

The model development stage is concerned with the development of two models. The first model is sustainability assessment model, which is developed to calculate the sustainability of buildings based on predefined criteria and factors based on their interchanging weights. The second model is the sustainability-based rehabilitation model that is used to provide the decision-maker with a set of alternatives to upgrade the sustainability of their buildings within a certain budget. In order to achieve these two models, this stage was subdivided into a number of small tasks as follows:

a. Identify the assessment attributes, such as criteria, factors and sub-factors that affect the sustainability of buildings based on the literature review.
b. Distribute a questionnaire among a sample of facility managers and experts to stand for the degree of importance of each criterion and factor.
c. Apply Fuzzy TOPSIS multi-attribute decision-making method to calculate the degree of importance of the criteria and factors based on the questionnaire responses.
d. Develop the sustainability assessment models based on the predefined weights of criteria and factors and according to their scores to obtain a sustainability index, which is the summation of the product of the weights and the scores of each criterion and factor.
e. Identify a group of alternatives for each sub-factor to upgrade their sustainability. This identification includes both the score in which each sub-factor can achieve by applying certain alternatives and the accompanied cost added by applying it.
f. Establish a sustainability-based rehabilitation model, which is an optimization model that allows the selection from a set of alternatives to upgrade the overall sustainability of a building. The selection process is based on the highest building sustainability assessment ratio (BSAR) and the lowest life cycle cost (LCC) resulted.

1.4.3 Implementation of the Models

This stage describes the implementation of the developed models within a case study, which was comprised of the following steps:

a. Data collection concerning the seven assessment criteria and their related factors and sub-factors. These criteria are site and ecology, transportation, water use, energy efficiency, material and waste, indoor environmental quality and building management.
b. Data collection concerning the physical data of the buildings, such as height, number of floors, area of each floor, material of the interior partitions, material of the exterior walls, CAD drawings…etc. This data is used to build up the BIM model using Revit software.
c. Constructing an energy simulation model to stand for the energy consumption of the building in the existing condition, and comparing it with the consumption after applying the selected alternatives to decrease consumption.
d. Build up and modify an automated tool that combines the whole process to make it user-friendly.
e. Implement the developed automated tool with a case study and validate it.

1.4.4 Conclusion and Recommendations

The final section presents the research conclusions, contributions to the body of knowledge and finally, research recommendations and future work.

1.5 Thesis Organization

The thesis is comprised of eight chapters. Chapter 1 includes the introduction and the building-related environmental impacts, problem statement and research motivation, research objectives, research methodology and thesis organization.

Chapter 2 covers a comprehensive literature review required for the field of research. It is comprised of six main sections as follows: 1) the evolution of the sustainability concept, 2) sustainability and buildings, 3) existing rating systems, 4) various research works concerning a sustainability rating tool for existing buildings, 5) an overview of multi-attribute decision-making to obtain the weights of criteria and factors and a discussion of the Fuzzy TOPSIS method; and 6) an overview of evolutionary optimization algorithms, especially artificial immune system optimization.

Chapter 3 describes the methodology for the developed Sustainability Assessment Model and for the Sustainability-Based Rehabilitation Model. It is divided into four main sections as follows: 1) a detailed research methodology that describes the procedures followed to achieve the objectives of the research, 2) the methodology for the development of the sustainability assessment model, 3) the methodology for the development of the sustainability-based rehabilitation model, 4) integrated sustainability assessment and rehabilitation tool methodology.

Chapter 4 describes the principle features of the optimization algorithm, which utilizes the artificial immune evolutionary algorithm (AIS). In addition, this chapter explores the various parts of the developed AIS code, beginning from data entry and ending with the development of a new generation for the following iteration.

Chapter 5 illustrates the procedures followed to collect and analyse the data. It includes three sections: 1) identification of sustainability assessment attributes; 2) comparative analysis between the proposed system and eight existing tools concerning the assessment attributes; and 3) research surveys, which includes the interviews and the questionnaire conducted for the data collection.

Chapter 6 describes the data collected from the case study to test the developed model. It is comprised of seven sections as follows: 1) weight determination and data reliability; 2) sustainability scale and threshold determination; 3) the developed BIM for the two case studies and its output data; 4) the energy simulation models for the two case studies and their output; 5) the score determination and points allocation for each sub-factor; 6) the sustainability assessment output of the two case studies; and 7) the optimization model output.

Chapter 7 demonstrates the developed automated tool under title Integrated Sustainability Assessment and Rehabilitation Tool. It illustrates the basic features of the tool, the graphical user interface (GUI) and navigating through its different windows and buttons related to sustainability assessment and optimization. Finally, Chapter 8 discusses the contributions of the research to the body of knowledge and future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview on the Sustainability Concept Development

One of the early steps towards sustainability was the conference that was held in Stockholm in 1972 which is called “United Nations on the Human Environment.” This conference set 26 principles, among these, are the following principles: 1) the natural resources of earth must be safeguarded for present and future generations, 2) the consumption of nonrenewable resources must be performed efficiently, 3) all mankind are responsible for environmental protection, 4) economic and social developments are essential, and 5) States shall co-operate to develop an international law to save environment form further damage (UN, 1982).

This concern about sustainable development and future generation was highlighted in the Brundtland Commission which is formally known as World Commission on Environment and Development report (WCED). This report introduced a commonly used definition of sustainability which is “*Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs*” (WCED, 1987). This definition was the early stage for the evolution of the concept of sustainability.

The previous efforts were elaborated in the first world summit that was held in Rio de Janeiro in 1992 in the United Nations Conference on Environment and Development this conference came up with an agreement known as United Nations Framework Convention on Climate Change (UNFCCC) (Adams, 2009; Kates et al., 2005; UN, 1992). This UNFCCC set regulations to decrease the carbon dioxide emissions within acceptable levels in which this level will save the earth’s environment from being damaged permanently. It states that “*The ultimate objective of this*

Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner"(IPCC, 2014).

Going forward after the UNFCCC, the Kyoto Protocol was an international treaty to implement the objective of UNFCCC to mitigate the global warming by decreasing greenhouse gas concentrations in the atmosphere to an acceptable level. This treaty was committed in Kyoto, Japan in December 1997. The first commitment period for this treaty started in 2008 and ended in 2012. The second commitment period started in 2012 after the amendment to the protocol, which is known as Doha Amendment to the Protocol, held in Doha, Qatar.

Further, many conferences took place from 2012 to the present date considering climate change and its mitigation strategies. One of the important conferences was held in Lima, Peru in 2014, the parties of the Kyoto Protocol made some agreements that were approved in Paris in 2015. The Paris agreement set two main goals: the first one is to reduce the global warming to 2°C less than the pre-industrial level, and the second was to decrease the greenhouse gas emissions by 40% below 2010 levels by 2050 (UN, 2015).

2.2 Sustainability and Buildings

The construction sector possesses several impacts on environment, economy, and society as discussed in the introduction. Buildings are needed to be considered in a way that can overcome or even cut down theses impacts in future. Therefore, it is important to understand the sustainability of the buildings. This stimulated the evolution of sustainability rating tools to assess the performance of buildings and to encourage the building stakeholders to improve the performance of their buildings taking into consideration economic, environmental and social aspects (Al-Waer and Sibley, 2005).

Based on the previous discussion, a principal definition was developed for employing sustainability in construction which is sustainable construction: "*a holistic thinking as regards construction and management of the built environment, taking a life cycle perspective. It implies not only new environmentally orientated construction designs, but also new environmentally friendly operation and maintenance procedures. Not only must construction materials and components be produced in a sustainable way, but their use must also answer to new requirements deriving from holistic environmental prerequisites*" (CIB & UNEP-IETC, 2002).

Two confusing terms arose when dealing with sustainability of buildings: 1) green buildings and 2) sustainable buildings. Green buildings refer to maximizing the use of renewable sources of energy, increasing daylight, encouraging natural ventilation, harvesting rain water, using waste treatment on site, and using environmentally material. In fact, all of these characteristics of green buildings introduce more technology to a conventional building which in turn incur additional building costs. Contrastingly, sustainable buildings use simple solutions to improve building performance by applying less mass and energy flow, which makes sustainable buildings more economic than the green building (Al-Waer and Sibley, 2005; UNEP, 2010)

Sustainable construction is based on three dimensions: 1) environmental, 2) social, and 3) economic. The environmental dimension can be achieved by reducing the use of non-renewable resources, limit the use of toxic material, using recycled materials, and reduce the embodied energy. The economic dimension can be achieved by analysing the life cycle cost of the project. The social dimension can be achieved by improving the aspects which are related to the user of the building (Al-Geelawe and Mohsin, 2015).

There are several classifications for the building assessment tool; some of these categorizations of the tools are based on the scope, while other are dependent on the performance. Among these trials, Crawley and Aho (1999) and Cole (2005) divided the assessment tools into Environmental Impact Assessment (EIA) and Life Cycle Assessment (LCA). The EIA assesses the impact of building according to the site location and its context, while the LCA assesses the impact regardless of its location, time or usage. Another classification divided the assessment tools into cumulative energy demand (CED), Life Cycle Analysis (LCA), and Total Quality Assessment (TQA) (Berardi, 2012; Hastings and Wall, 2007). CED focuses on energy consumption, and TQA evaluates ecological, economic and social aspects. Moreover, Fenner and Ryce (2008) categorized the assessment tools into knowledge-based tools which is comprised of manuals and information sources that can be references for designers, performance-based tools that utilize LCA, and building-rating tools that consists of check lists and credit calculators. Generally, this thesis is concerned with building rating tools which can have different nominations such as TQA or multicriteria assessment tools (MCAT).

As sustainability in construction and its performance assessment becomes vital, Fowler and Rauch (2006) defined the sustainability rating tools as "tools that examine the performance or expected performance of a ‘whole building’ and translate that examination into an overall assessment that allows for comparison against other buildings”.

Up-to-date, there are over hundreds of environmental assessment systems, ranging from single attribute assessment to MCAT. Most of MCATs comprises three main structural elements 1) local context 2) criteria or main assessment items, and 3) weighting scheme. these elements differ slightly or drastically from system to another as follows:

2.2.1 Regional Context

Every country or location has its own characteristics regarding social, environmental, and economic aspects, which are determinant of the structure of each rating system. These characteristics are 1) climate, 2) geographical features, 3) resources consumption, 4) Types of building stocks, 5) government policy and regulations, and 6) the historical features and culture value (Banani et al., 2013). These local variations hinder the direct use of the available tool in another country apart its country of origin (Alyami and Rezgui, 2012; Xiaoping et al., 2009). Moreover, the regional context influence at a great extent the importance of the assessment criteria in each rating system (Todd and Geissler, 1999). This argument leads to difference in the criteria that are included in each rating system.

2.2.2 Assessment Criteria

A sustainability rating system is a combination between quantitative and qualitative criteria in order to assess a building comprehensively. The qualitative criteria are unavoidable but require an attention and precision in the description of their assessment scale (Cole, 1999). Any sustainability rating system should incorporate environmental, social, and economic criteria to appraise the whole building performance based on the triple bottom line of sustainability (Berardi, 2012; Sev, 2009). These criteria shape the structure of the rating systems and affect their performance and evaluation scheme, in which they differ from one region to another (Ali and Al Nsairat, 2009; Cole, 2005). Therefore, every rating system adapts itself to its regional economic and social characteristics, so each system may award a building different score (Schwartz and Raslan, 2013).

2.2.3 Weighting Scheme

Weighting is considered an essential part in the structure of the sustainability rating systems (Cole, 1999). Also, Lee, et al (2002) claimed that weighting is the heart of all the assessment schemes as it will dominate the overall assessment of the building. As illustrated in the regional variations, most of the rating systems are developed for local use and do not allow for regional variations; however, introducing weight can enhance the performance of these systems to be applied in different regions (Alyami and Rezgui, 2012; Ding, 2008). Additionally, Ding (2008) stated that there is no consensus-based approach that was applied to guide the assignment of weight to the assessment criteria. The importance of assigning weight is address the criteria which have the impact on the sustainability of the building (Cole, 2005; Todd and Geissler, 1999). As the weighting scheme is essential to be introduced in the sustainability rating scheme, however, the way it is calculated and the reason behind its assigned values in the existing systems is not explicit and clear (Berardi, 2012). As there is no consensus-based approach used for determining the weighting values, there are different approaches utilized for this purpose and can be classified as (Alyami and Rezgui, 2012):

- Simple additive approach; where all categories have the same weight (i.e.LEED)
- Pre-weighted credits (i.e. BREEAM)

- Weighting after score (i.e. SB TOOL)
- Multilevel weighting (i.e. CASBEE)

A lack of weighting scheme in a rating system may inherently add a sort of simplicity in assessment procedures and encourage its prevailing worldwide. This rating system may be criticized for lacking scientific evidence and environmental priorities (Alyami and Rezgui, 2012; Xiaoping et al., 2009).

2.3 Sustainability Rating Systems

As mentioned in Singh et al (2012), sustainability assessment aims to provide decision makers with a global evaluation of their properties considering environmental and social aspects in long or short-term perspectives to assist them in determining the actions that should be considered to achieve a sustainable society. In this context, the purposes of sustainability rating tools are: 1) assessing the performance of sustainable buildings, 2) guiding the sustainable construction to fulfil the three pillars of sustainability, 3) accelerating the transformation of traditional construction to sustainable one, 4) increasing the awareness of environmental issues and standards, and 5) stimulating the market for sustainable construction (Al-Waer and Sibley, 2005; Reed et al., 2009; Xiaoping et al., 2009). Moreover, Schwartz and Raslan (2013) highlighted the importance of rating systems and their influence in improving the performance of the rated buildings in which the energy consumption of LEED certifies buildings was 35% - 30% lower than the U.S national average.

Furthermore, sustainability rating systems tend to be comprehensive by including many environmental, social and economic aspects. As the number of assessment criteria increase, the complexity of these assessment methods increases as well due to the demand for a considerable amount of information to be collected and analysed. Consequently, this generalization may hinder the usefulness of the rating method. Therefore, a balance is highly recommended between completeness in the number of the assessment criteria and simplicity in maximizing the efficiency of the system (Berardi, 2012; Ding, 2008). Yet, this balance varies from one rating system to another, leading to different assessment scopes, methodology, criteria, and weighting schemes resulting in the evolution of numerous rating tools around the world ranging from single assessment criteria system to TQA tools. Consequently, Nguyen and Altan (2011) illustrated that by March 2010 there were 382 registered rating tools for evaluating energy efficiency, renewable energy, and sustainability rating tools. In the literature review, some of the widely used and well-known rating tools will be highlighted, as well as, the recently emerged research works concerning sustainability rating tools.

2.3.1 Green Building Councils' Rating Tools

The first environmental assessment method is BREEAM (Building Research Establishment's Environmental Assessment Method) rating system developed in the United Kingdom in 1990 (Ding, 2008). It covers a broad range of building types. It comprises nine assessment criteria which are *management*, *health and wellbeing*, *energy*, *transport*, *water*, *material*, *land use*, *ecology* and *pollution*. It adopts five ranking benchmarks which are unclassified, pass, good, very good, and excellent. Moreover, fixed weight for each assessment category is predefined by BRE experts to reflect the impact of each category on the final score (Banani et al., 2013; BRE, 2015). The final score is calculated using three steps: 1) calculating the ratio between the achieved points and the amount of available points in each criterion as in equation (2.1); 2) multiplying the weight of each criterion by the percentage of the achieved points as in equation (2.2); and 3) summation of the product resulted from each criterion as shown in equation (2.3) and then compare the final score to the benchmark. The benchmark is outstanding for more or equal to 85%, excellent for more or equal to 70%, very good for more or equal to 55%, good for more or equal to 45%, pass for more or equal to 30%, and unclassified for less than 30%. BREEAM overlooked some aspects such as the heat island effect in its assessment, the flexibility and adaptability, and culture and tradition aspects (Banani et al., 2013). Despite some limitations, BREEAM was adopted by other countries such as Canada, Australia, Hong Kong where they use it as prototype when establishing their own rating tools (Berardi, 2012; Ding, 2008; Fenner and Ryce, 2008; Haapio and Viitaniemi, 2008; McArthur et al., 2014).

$$Category\ Score\ percentage\ (Sc)\% = \frac{Credit\ acheive}{available\ credits} \times 100 \tag{2.1}$$

$$Total\ Category\ score\ (Sc\ total) = Category\ weight\ \times (Sc) \tag{2.2}$$

$$Total\ score\ (S\ total) = \sum Sc\ total \tag{2.3}$$

The second worldwide used rating system is LEED (Leadership in Energy and Environmental Design), which was developed in the USA in 1998 (Banani et al., 2013). There are many versions of LEED utilized to assess a diverse of types and scales of buildings (i.e. new construction, existing buildings, commercial interiors, cores and shell, homes, and neighbourhood development). It comprises six categories which are *sustainable sites*, *water efficiency*, *energy & atmosphere*, *materials and resources*, *indoor environment quality*, and *innovation and design processes*. The final score calculated by direct aggregation of the points achieved in each criterion. Then the result is compared to the benchmark to award one of the available four grades, which are platinum for

80 points and above, gold for points from 60 to 79, silver for points from 50 to 59, and certified for points from 40 to 49 (USGBC, 2009). Although LEED is widely used, it possesses some limitations such as the overlooking the assessment criteria of adaptability and flexibility in building systems, the tradition and culture aspects in its assessment framework, and the airborne emissions (Banani et al., 2013; Crawley and Aho, 1999). Also, Fenner and Ryce (2008) claimed that there is a lack of environmental customization when this system is implemented in a country with different climatic regions as Canada, which limits addressing the environmental surroundings. Although LEED is adopted in many countries due to its simplicity, a lack of weighting system is a crucial issue that hinders the tool from adequately addressing regional variations (Alyami and Rezgui, 2012; Xiaoping et al., 2009).

CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) developed in Japan in 2001. The CASBEE main frame consists of two main groups which are building environmental quality (Q) which is comprised of *indoor environmental quality*, *quality of services* and *outdoor environment on the site* while the second group is building environmental load reduction (LR) comprised of *energy*, *resources and material*, and the *off-site environment*. The final grade awarded according to *building and environment efficiency ratio* (BEE) is achieved by the applying three steps: 1) obtaining the score of each group as mentioned in equation (2.4) and equation (2.5); 2) applying equation (2.6); and 3) the final ranking obtained following the benchmark is shown in Figure 2.1 (JaGBC, 2008).

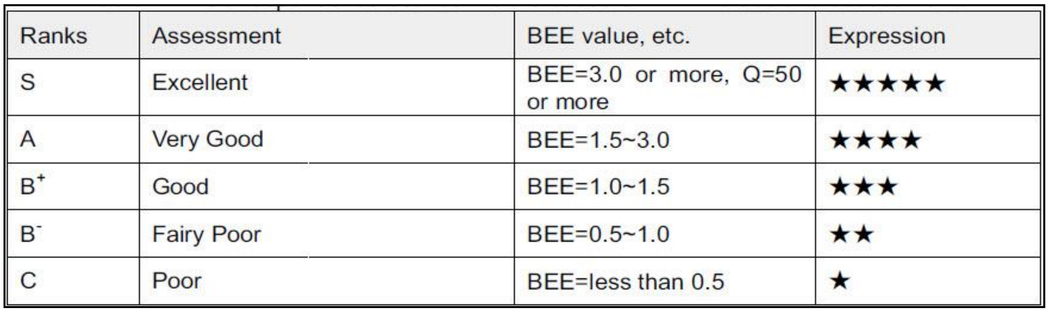
$$(SQ) = (Q1 \times 0.4) + (Q2 \times 0.3) + (Q3 \times 0.3) \tag{2.4}$$

$$(SLR) = (LR1 \times 0.4) + (LR2 \times 0.3) + (LR3 \times 0.3) \tag{2.5}$$

$$BEE = \frac{Q}{LR}, = \frac{25\ \times (SQ - 1)}{25 \times (5 - SLR)} \qquad (2.6)$$

Where:

Q = building environmental quality;
LR = building environmental load reduction;
SQ = score of building environmental quality;
SLR = score of building environmental load reduction; and
BEE = building and environment efficiency ratio.



Ranks	Assessment	BEE value, etc.	Expression
S	Excellent	BEE=3.0 or more, Q=50 or more	★★★★★
A	Very Good	BEE=1.5~3.0	★★★★
B^+	Good	BEE=1.0~1.5	★★★
B^-	Fairy Poor	BEE=0.5~1.0	★★
C	Poor	BEE=less than 0.5	★

Figure 2.1: CASBEE Ranking Benchmark (JaGBC, 2008)

BEAM (Building Environmental Assessment Method) is a voluntary private sector assessment tool for green building in Hong Kong. It was established in 1996 based on UK Building Research Establishment tool BREEAM. This rating is adopted to enhance the quality of buildings, reduce environmental impacts of buildings through their lifecycle, and evaluate their facility management practices. The assessment covers all management practices, operation, and maintenance. This tool includes seven aspects which are the *site*, *management*, *water use*, *energy*, *material and waste*, *IEQ*, and *Innovations*. It has four ratings as following: 1) Bronze (above average) for overall percentage of 40%; 2) Silver (good) for overall percentage of 55%; 3) Gold (very good) for overall percentage of 65%; and 4) Platinum (excellent) for aver all percentage of 70 (HK GBC, 2012; Kelcroft, 2016).

Malaysian Institute of Architects first introduced Green Building index in 2009. It is locally used to assess the performance of the green buildings. It comprises six assessment criteria: energy efficiency, indoor environmental quality, sustainable sites planning and management, material and resources, water efficiency, and innovation. It utilizes four classifications to express sustainability: Certified from (50) to (65); Silver from (66) to (75); Gold from (76) to (85); and Platinum from (86) to (100) (GBI, 2011; GBI, 2016).

BCA green mark was launched in 2005 to drive the construction industry towards more environmentally friendly buildings, to promote sustainability in the built environment, and to increase the awareness of developers, designers, and builders when they start their design and during construction. It embraces five assessment areas which are the *energy efficiency*, *water efficiency*, *environmental protection*, *indoor environmental quality*, and *other green features and innovations*. It uses four rating benchmark scheme such as Green Mark Certified from (50) to less than (75), Green Mark Gold from (75) to less than (85), Green Mark Gold $^{\text{Plus}}$ from (85) to (90), and Green Mark Platinum from (90) to above (BCA, 2012b; Singapore Government, 2016).

Green Building Council in Indonesia introduced Greenship rating system for new construction in 2010 and in 2011. It introduced a new rating system for existing buildings and assesses six areas such as *appropriate site development*, *energy efficiency and conservation*, *water conservation*, *material resources and cycle*, *indoor health and comfort*, *building environment management*. It comprises four ratings which are Bronze for achieving least, Silver, Gold, and Platinum for achieving most, with at least (35%), (46%), (57%), (73%) respectively (GBC Indonesia, 2011; GBC Indonesia, 2012).

BOMA stands for Building Owners and Management Association, and BESt stands for Building Environmental Standard. It is a voluntary program designed to provide building owners and builders with a framework for assessing the environmental performance and management of the existing building. It was developed in 2005 in Canada. It tackles six assessment aspects which are *energy*, *water*, *waste and site*, *emissions and effluents*, *indoor environment*, and *environmental management system*. It has five levels of certification such as certified, bronze, silver, gold and platinum which achieves at least 59%, 60-69%, 70-79%, 80-89%, and 90-100% respectively (BOMA Canada, 2013; Smiciklas, 2016).

2.3.2 Individual Sustainable Rating Tools' Frameworks

There are many individual trials to establish sustainability assessment rating tools taking into consideration specific regional contexts. These research works show how various assessment methodologies and distinct criteria can address the sustainability of buildings efficiently and adequately. This subsection will demonstrate some of these research works highlighting their methodologies, objectives, assessment criteria and frameworks, and their weighting scheme determination methodologies – if they exist.

One of the frequently cited research work when dealing with emerging rating tools is the work of Ali and Al-Nsairat (2009). Many factors encourage the development of sustainability rating tools that is based on Jordanian context, which are: poverty in energy resources, inefficient use of energy resources, limitation in water resources, trends towards modern buildings, and variety in the topography of the land. The research methodology is based on some hypothesis such as: 1) the design of a new green rating systems should be based on the most important practices had been fulfilled in the developed countries, 2) the developed system should comply with Jordan local context, 3) it should deal with residential building scope, and 4) the system should adopt life cycle approach. Further, the developed rating tool is called SABA that comprises seven categories which are *site*, *water efficiency*, *energy efficiency*, *material, indoor environmental quality*, *waste and pollution*, and *cost and economy*. The AHP method was implemented to determine the weight of each attribute according to the Jordanian context; it was found that *water efficiency* took the highest weight while the lowest was *waste and pollution*. Moreover, the assessment structure hierarchy is divided into three levels: parameters, indicators, and categories. In the parameter level, each parameter is multiplied by its corresponding weight as shown in equation (2.7). In the indicator level, each indicator score (the summation of parameters results) is multiplied by the corresponding indicator weight as shown in equation (2.8). In the category level, each category score (the summation of indicators results) is multiplied by the corresponding category weight as shown in equation (2.9). Then, finally the total score is a result of the aggregation of the category results as shown in equation (2.10). Two important aspects that were highlighted in this research work is the developed tool is used for residential building scope and it does not incorporate operation and maintenance of the projects in its assessment attributes.

$$(Rp) = Parameter\ score\ (Sp) \times Prameter\ weight \tag{2.7}$$

$$(Ri) = Indicator\ score(Si) \times Indicator\ weight \tag{2.8}$$

$$(Rc) = Category\ score(Sc) \times Category\ weight \tag{2.9}$$

$$The\ total\ score = \sum Rc \tag{2.10}$$

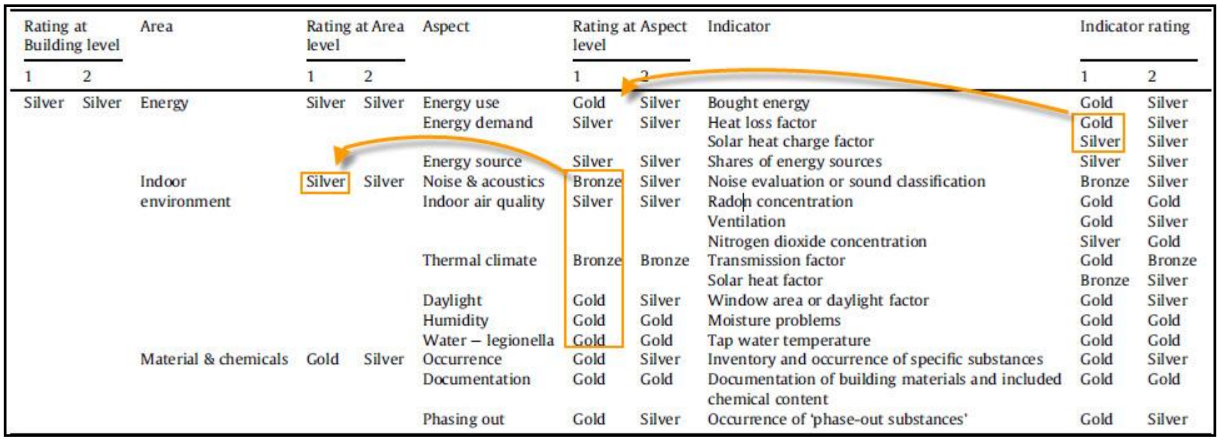
Where:

Rp = result of the parameter;

Ri = result of the indicator; and

Rc = result of the category.

The second rating tool that is proposed for discussion is the developed Sweden approach. The emerging concept of this tools was initiated in 1998 with a project named Building, Living, and Property Management aimed to stimulate the building industry towards sustainability. Its final proposal had been completed in 2008 and it is currently in use in Sweden. The project had three objectives which were: 1) set a tool for classification of buildings, 2) overcome criticism found in the popular rating tools, and 3) illustrate the importance of the role of the stakeholders in the development process. Moreover, the tool covers three assessment areas which are *energy*, *indoor environment quality*, and *material and chemicals.* Also, the rating tool consists of three hierarchy levels that are area, aspect, and indicator as shown in Figure 2.2. It has limited number of indicators when compared with the other existing rating tools because 1) it is intended to minimize the cost of the rating procedures; 2) it was developed to measure existing buildings therefore; many areas and indicators were removed. It is aimed to be a performance-based tool, so indicators that include procedures or technical solutions are excluded. The tool has four ratings, which are gold, silver, bronze, and rated. The developed rating utilizes the worst-case scenario method such that the final score at the indicator level takes the lowest rating, in turn, the same procedure is followed at the aspect level and the area level. This method guarantees if the assessed building takes a gold rating then, all the assessed items under the area level should be gold perform well as shown in Figure 2.2 (Malmqvist et al., 2011).



Rating at Building level		Area	Rating at Area level		Aspect	Rating at Aspect level		Indicator	Indicator rating	
1	2		1	2		1	2		1	2
Silver	Silver	Energy	Silver	Silver	Energy use	Gold	Silver	Bought energy	Gold	Silver
					Energy demand	Silver	Silver	Heat loss factor	Gold	Silver
								Solar heat charge factor	Silver	Silver
					Energy source	Silver	Silver	Shares of energy sources	Silver	Silver
		Indoor environment	Silver	Silver	Noise & acoustics	Bronze	Silver	Noise evaluation or sound classification	Bronze	Silver
					Indoor air quality	Silver	Silver	Radon concentration	Gold	Gold
								Ventilation	Gold	Silver
								Nitrogen dioxide concentration	Silver	Gold
					Thermal climate	Bronze	Bronze	Transmission factor	Gold	Bronze
								Solar heat factor	Bronze	Silver
					Daylight	Gold	Silver	Window area or daylight factor	Gold	Silver
					Humidity	Gold	Gold	Moisture problems	Gold	Gold
					Water – legionella	Gold	Gold	Tap water temperature	Gold	Gold
		Material & chemicals	Gold	Silver	Occurrence	Gold	Silver	Inventory and occurrence of specific substances	Gold	Silver
					Documentation	Gold	Gold	Documentation of building materials and included chemical content	Gold	Gold
					Phasing out	Gold	Silver	Occurrence of 'phase-out substances'	Gold	Silver

Figure 2.2: Worst Case Scenario Used in Sweden Rating System (Malmqvist et al., 2011)

Another sustainability rating tool is called Tall Building Sustainability Indicators (TPSI), and it was prepared by Nguyen and Altan (2011). They claimed that tall building projects have distinct characters and features, also, the existing rating systems were proved to be inadequate when applied to tall building assessment. This inadequacy appears in many fields such as construction technology and procedures, foundation construction, services of buildings, social and economic aspects, utilization of material, energy use, earthquake management, and quality of living inside the tall building. This research has three objectives which are: 1) develop an efficient design and assessment tool for buildings more than 20 floors, 2) develop a user-friendly tool, and 3) create a tool using both quantitative and qualitative criteria. The rating system comprises eight categories and another additional one which is innovation. These categories are classified into two sets which are building performance and environmental performance. Building performance comprises *project management*, *IEQ*, *building services*, and *design features*; while environmental performance comprises *resources consumption*, *material aspects*, *environmental loading*, *social and economic aspects*, and *innovations*. The TPSI's factor is calculated to stand for the balance between the building performance (B) and the environmental loading (E) by using equation (2.11) where EL is the environmental loading that is calculated using equation (2.12). TPSI possesses to methods for assessment, the first one is calculating the TPSI, while the other is a total score-based approach. The TPSI factor is determined as a ratio between building performance (B) and environmental loading (EL) as illustrated in equation (2.11), and with equation (2.12) the result is plotted on the graph as shown in Figure 2.3 wherein (EL) is on the x-axis and (E) is on the Y-axis. The total score is calculated by adopting BREEAM methodology, in which the ratio between the achieved credits and the maximum available credits is calculated, the multiplying this ratio by the corresponding weight of each category. Additionally, the final total score is the aggregation of results, obtained according to the previous step in each category. Accordingly, the TBSI factor and the total score achieved define the building's sustainability level or grade identified according to Table 2.1.

$$TBSI\ Factor = \frac{B}{EL} \tag{2.11}$$

$$EL = 100\% - the\ total\ score\ E \tag{2.12}$$

Where:

TBSI = total Project sustainability indicator;

B = the building performance; and

EL = the environmental loading.

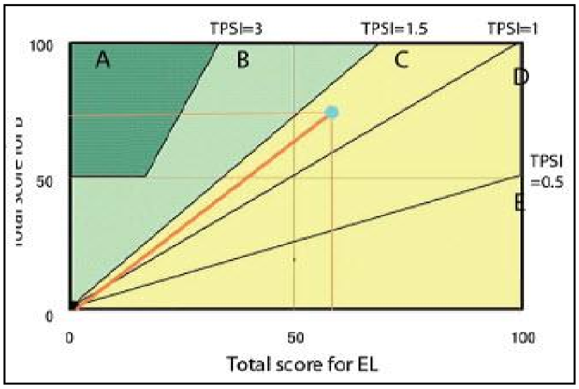


Figure 2.3: Plotting Graph for TPSI Factor (Nguyen and Altan, 2011)

Table 2.1: Ranking System Developed by TPSI

Rank	Total score	TPSI Factor	Comments
A	< 25 %	< 0.5	Unclassified
B	≥ 35 %	≥ 0.5	Pass
C	≥ 50 %	≥ 1	Good
D	≥ 75 %	≥ 1.5	Excellent
E	≥ 85 %	≥ 3.5	Outstanding

Further, Alyami and Rezgui (2012) had proposed an approach for developing a sustainability rating tool for Saudi Arabian context. The objectives of this research are: 1) identify the criteria that are suitable for the required region, 2) determine the methodology that can be utilized in weight assignment, and 3) define the methodology that was implemented to develop the rating tool. The research adopts several well-known and widely spread rating tools such as BREEAM, LEED, CASBEE, SBTool to consolidated the proposed assessment criteria. Hence, the rating tool includes ten criteria which are *management, IEQ, sustainable sites, energy, water and waste, materials, economic aspects, pollution and risk, quality of services,* and *innovations*. The score determination was not illustrated in this research. Further, the AHP method was utilized in this research to determine the weight of each criterion.

Moreover, Bragança et al (2010) proposed a sustainability rating tool for residential buildings for Portugal. The main issue that encouraged the evolution of this research was that Portuguese building technologies and the indoor environmental quality are different from most European countries. These issues were attributed to the socio-culture constraints and the mild climate. Therefore, the research main objectives were 1) mitigate the mentioned problems, and 2) construct a basis for development of sustainability rating tool for residential buildings taking into consideration Portuguese social, environmental and economic national standards. The study divided the assessment attributes into dimensions, indicators, and parameters. The dimensions are the three pillars of sustainability, which are *environmental performance*, *social performance*, and *economical performance*. The environmental indicators are *climate change*, *emissions*, *water efficiency*, and *resource depletion*. The social indicators are *hydrothermal comfort*, *indoor air quality*, *acoustic comfort*, *visual comfort*. Finally, the only economic indicator is the *life-cycle cost*. The final score is determined in four steps which are 1) parameter normalization, 2) indicator score aggregation, 3) category score aggregation, and 4) total score. The parameter normalization is utilized to transform the parameter score into unitless to avoid the confusion between 'higher is better' and 'lower is better' scores also to turn the score into a scale from zero to one as illustrated in equation (2.13). Additionally, the product sum of the parameters and their corresponding weights are determined for each indicator as showed in equation (2.14). Then, the performance of each dimension is determined as product sum of all the indicators and their corresponding weight in each dimension as demonstrated in equation (2.15). Finally, the sustainable index is the aggregation of all the product sum of all the dimensions and their corresponding weight as shown in (2.16). Moreover, the values of weights were adapted from US Environmental Protection Agency's Science Advisory Board study and a Harvard University study.

$$\overline{P_i} = \frac{P_i - P_{*_i}}{P_i^* - P_{*_i}} \tag{2.13}$$

$$I_j = \sum_{i=1}^{n} \mathrm{w}_i . \overline{P_i} \tag{2.14}$$

$$P_{env} = \sum_{i=1}^{n} \mathrm{I}_{env_i} . w_{env_i} \tag{2.15}$$

$$SS = \mathrm{P}_{env}.w_{env} + \mathrm{P}_{soc}.w_{soc} + \mathrm{P}_{Eco}.w_{Eco} \tag{2.16}$$

Where:

P_i = value of ith parameter;

P_{*_i} = best value of ith parameter;

P_i^* = standard value of ith parameter;

I_j = indicator; and

w_i = weight of parameter.

Furthermore, Gething and Bordass (2006) had developed a checklist which was intended to be used for judging the 2005 Royal Institute of British Architects (RIBA) Sustainability Award. The primary objective of this research is to identify a simple, clear, quick sustainability assessment checklist. The checklist comprises nine groups which are: *choice of site*, *use of site*; *building form*; *use of materials*; *functionality*; *indoor environment*; energy, *CO_2 and utilities*; *emission to atmosphere*; *construction and handover*; and *performance in use*. The chosen grouping was based on the order of a decision making in an architectural project as follows site context, how the land was used, the building form, of what it was made, how it was likely to work, its impact on occupants and environment, how it was built, and how it was performing in use. There are 11 levels of performance as a final result of the checklist.

Chandriatilake and Dias (2013) established a framework to develop a local rating system in Sri Lanka had two primary objectives: 1) make a weighting scheme that couples with the local context in Sri Lanka taking into account the degree of agreement among professionals on the established weights for domains and aspects; and 2) compare between the developed areas with other national existing rating systems and explain the reason for the particular discrepancies (Chandriatilake & Dias, 2013). According to the proposed weighting results, the *site*, and *energy efficiency* domains receive the highest ranking. In the second place, *water efficiency* and *material*. The lowest ranking was *waste and pollution*. To achieve the second objective, all domains from eight rating systems which illustrated in Table 2.1 were collapsed to six assessment areas such as *site*, *energy*, *water*, *material*, *IEQ*, and *waste & pollution*. A comparison is conducting between the proposed weighting scheme and the existing ones of other rating tools as illustrated in Table 2.2, the highest percentage in each domain was highlighted indicating a specific local context which requires more stress and emphasize to achieve sustainability. Consequently, the countries with significant per capita energy consumption have a high percentage in energy efficiency area. On the other hand, Middle Eastern countries in which water plays a crucial role gives water highest percentage in its system reflecting the local context of each country.

Table 2.2: Comparison of Domain Weights (Chandratilake and Dias, 2013)

System	**country**	**Site**	**Energy**	**Water**	**Material**	**IEQ**	**Waste**
LEED	USA	26	35	8.5	12	14	4.5
BREEAM	UK	15.8	29.5	6.3	25.2	11.6	11.6
SABA	Jordan	11.5	25.7	30.9	11.5	13.2	7.2
Pearl	UAE	16.6	25.5	27.4	10.2	14.6	5.7
GBI	Malaysia	15.4	32.1	12.8	7.7	26.9	5.1
Green star	Australia	22.2	27.8	11.1	11.1	22.2	5.6
Green star	New Zealand	18.8	19.6	9.8	25.9	23.2	2.7
CASBEE	Japan	20	26.7	2.7	17.3	26.7	6.6
Sri Lanka		25.7	22.2	14.4	14.5	12.3	10.9

2.4 Towards Global Rating Tools

GBTool was the first globally working rating system, which was revealed in 1995 in the Green Building Challenge (GBC) conference that was held in 1998 in Vancouver. National teams of twenty countries participated in developing a comprehensive building environmental assessment method by providing common set of assessment criteria (Cole, 1999; Seo et al., 2005). The

GBTool included six criteria and 120 sub-criteria in their assessment to incorporate many assessment aspects (Cole, 1999; Larsson and Cole, 1998). Moreover, Crawley and Aho (1999) showed that one of the limitations of this tool was its complexity of its framework.

2.5 Optimization Implementation and Sustainable Measures

As the consideration of how the building sector impacts the environment increases, the evolution of green measures and assessment tools has risen accordingly. Great attention has been drawn towards improving the sustainability of the buildings to mitigate the earlier mentioned impacts. Consequently, there are numerous of alternatives that can be applied in each sustainability aspect to improve its performance and in turn improve the overall building performance as well. However, there may be some alternatives that perform better than the others, and using trial and error is exhaustive and may lead to unreliable solutions. Hence, the optimization concept has been evolved, which has a great advantage in finding the optimal or near optimal alternatives (Wang et al., 2005). The following discussion will illustrate some of the research works that applied optimization techniques in the upgrading building performance of a single or multi-aspects.

Wang et al (2005) proposed a multi-criterion optimization algorithm utilizing the multi-objective genetic algorithm. This research aimed to provide the designers with a set of alternatives which could upgrade the building envelope performance within minimal LCC. The performance of the building envelope was determined by implementing life cycle environmental impact. The advantage of this research is utilizing the concept of LCC to determine the optimal or the near optimal upgrade alternative, but it assesses only one aspect which is the building envelope performance.

Also, Magnier and Haghighat (2010) introduced a multi-objective optimization by applying Non-Dominated Sorting Genetic Algorithm (NSGA-II). The research had two objectives 1) maximizing the thermal comfort of the building, which is translated to the Predicted Mean Vote (PMV) that was representative of what a large population would think of a thermal environment; and 2) minimizing the energy consumption of heating, cooling, and fan energy. The decision variables were related to HVAC components and building envelope elements. The limitation of this study was not integrating the economic objectives in the optimization process by considering the upgrade cost in the optimization process, because most the proposed alternatives may be inefficient in economic terms.

Bichioua and Krarti (2011) proposed a single objective optimization to minimize the LCC of the introduced HVAC and Building Envelope alternatives to achieve the required thermal comfort for a two-story residential building. This research simulated the building into five cities applying DOE-2 energy simulation software. Each of the five scenarios were introduced to three different optimization algorithms which are Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Sequential Search optimization (SS). The results revealed that evolutionary algorithms such as GA and PSO consumed less computational time than SS. The benefit of this research is utilizing the LCC approach to evaluate the proposed upgrade alternatives; however, it only considers the HVAC and building envelope decision variables.

Furthermore, Marzouk et al (2011) performed a multi-objective optimization to maximize the achieved LEED credits for new construction when using green materials, while minimizing the resulted total cost. The research applied multi-objective ant colony optimization (ACO) technique that was implemented on a residential building of two stories. The output shows the near optimal solutions that was represented through the Pareto frontier. However, this study considered only one green aspect – namely, materials – also, it considered only the total cost and overlooked the life cycle cost which may change the solution when consider time value of money.

Simmons et al (2013) introduced an optimization combinatoric model rather than the evolutionary algorithms. This idea arose from the fact the properties of the building technologies have a discrete nature and their selection nature is a combinatoric problem. The research claimed that there are 170 million unique combinations. The main objective was to explore this combinatorial space of technology alternatives and to find low cost solutions that meet the energy saving goals. Besides, this optimization algorithm aimed to minimize the sum of the premium monetary cost, which is the cost of any technology's level of achievement cost minus baseline cost. However, this study overlooked the time value of money which represented in LCC because this research aimed to meet the instantaneous energy reduction at the time of construction at minimum capital cost. Another limitation is the increased computational time load required for searching all the available combinations in which this computational loading could be decreased when applying the optimization evolutionary algorithms.

Additionally, Abdallah et al (2015; 2014) developed an optimization model that could minimize the upgrade cost of selected green measures that can achieve certain level required by LEED for existing building. The optimization model applied genetic algorithm by utilizing a single objective, which was minimizing the upgrade cost for the alternatives that are proposed to upgrade different LEED categories to a specified level. There are some limitations of the developed model which are utilizing upgrade cost rather than the LCC cost which may change the final output. Also, using a single objective optimization leads to a unique solution, while multi-objective optimization can provide the decision makers with set of different trade-offs.

In another research developed by Juan et al (2010), a hybrid decision support system was implemented using genetic algorithm and A* search techniques to get the optimal upgrade alternatives for a building sustainability with minimal upgrade cost. The research demonstrated the shortcoming of each of the utilized techniques when implemented separately, however the results of the research showed the robustness of combining the two techniques to solve large-scale zero-one programming determinate problem effectively. Despite the advantages of the proposed hybrid system, the system provided only one optimal solution in each run as it utilized a single objective optimization function that minimized the upgrade cost. Additionally, it overlooked the LCC concept in considering the renovation alternatives.

Generally, the multi objective optimization is proved to be superior than the single objective one (Wang et al., 2005). When two objectives are treated separately or combined into one meta objective the optimal solution that is obtained in a single run is only one optimal solution. Hence, the decision maker cannot learn about the impact of the change of one criterion on the other. Therefore, it is difficult to make cost effective decisions without knowing the possible tradeoffs. This dilemma is overcome in a multi-objective optimization method in which the multi- objectives are solved simultaneously resulting in a set of trade-offs.

2.6 Criticism of Some of Exiting Rating Systems

A comprehensive sustainable rating system must assess the triple bottom line of sustainability, which is social, environmental and economic aspects. An in-depth understanding of the relation between buildings and environment must be well recognized to achieve an efficient and sustainable rating tool. The majority of the existing rating tools have limitations that hinder their effectiveness and usefulness. These limitations can be found in some aspects such as the lack of the optimum selection of the assessment indicators, optimum project selection process, understanding financial issues, regional variations, the complexity of the assessment tool, weighting scheme, and measurement scales. Furthermore, many research works discussing and analysing these limitations hope to stimulate the development of more efficient rating tools (Ding, 2008).

Indoor Environmental Quality (IEQ) is one of the main LEED rating system criteria which affects the occupants of any office buildings, as they spend the majority of their time indoors. IEQ criterion directly affects social aspects as it is related to the human quality of life and health. IEQ criteria in LEED comprises six indicators which are indoor air quality, low-emitting materials, indoor chemical and pollutant source control, thermal comfort, and daylighting and views. However, there are other criteria LEED overlooked that also affect health, comfort, and productivity of office building's occupants, for example, space layout, artificial & natural lighting, acoustics and aesthetics (Lee and Guerin, 2009) .

A study was performed to select the most important criteria among the ones as mentioned above that directly affect occupant's satisfaction. Also, a post-occupancy evaluation was conducted to demonstrate the IEQ criterion in LEED certified buildings to stand for the degree of enhancement or interference of employees' satisfaction and performance. The examined IEQ measures included in the study were *office layout*, *office furnishing*, *thermal comfort*, *IAQ*, *lighting*, *acoustics*, and *cleanliness and maintenance*. The Center of Built Environment at the University of California did a survey over 200 office building including 15 LEED-certified office buildings. Each one of the examined IEQ factors contains sub-factors that will be included in the study. A scale of seven grades ranging from (+3) to (-3) used to express the degree of agreement or disagreement to the proposed survey to measure the degree of satisfaction of the IEQ criteria in the workplace. Also, a scale of seven grades ranging from (+3) to (-3), which expresses the degree of agreement or disagreement to the proposed questionnaires. Also, the same procedure was performed to measure the IEQ criteria related performance questionnaire in which (+3) stands for enhancement while (-3) stands for interference.

As shown in Figure 2.4, the results of satisfaction to the IEQ factors that all the examined got a positive score except for thermal comfort and acoustics, they got scores (-0.14) and (-0.56) respectively. On the other hand, the high scores were (1.03), (1.0) and (0.96) for cleanness and maintenance, office furnishing, and IAQ respectively. For IEQ factors' performance related results, they were all positive except for acoustics factors; it got a negative score (-0.71). The low score of acoustics factor attributed to talking in neighbouring area, co-workers overhearing private conservations and colleagues talking on a phone which got percentages (62%), (62%) and (56%) respectively. In the case of thermal comfort, in hot or warm weather almost equal number of occupants commented that their workplace is too hot or too cold. In cold weather three-quarters of occupants indicate that their workplace is too cold with percentages of (55%), (54%), and (79%). The discomfort as respondents mentioned arouses due to an uneven heating/loading distribution in different areas, remote thermostat and control of thermostat by others. The IEQ criteria are related to sustainable social aspects; therefore, the study recommended that the IEQ criterion in LEED must be enhanced to deal with social issues accurately reflecting occupants' satisfaction and performance, so some indicators should be added such as office layout, office furnishing, lighting quality and acoustic quality. As a result, to achieve an efficient rating tool for sustainable building, an explicit consideration in the selection of the assessment indicators must not be overlooked.

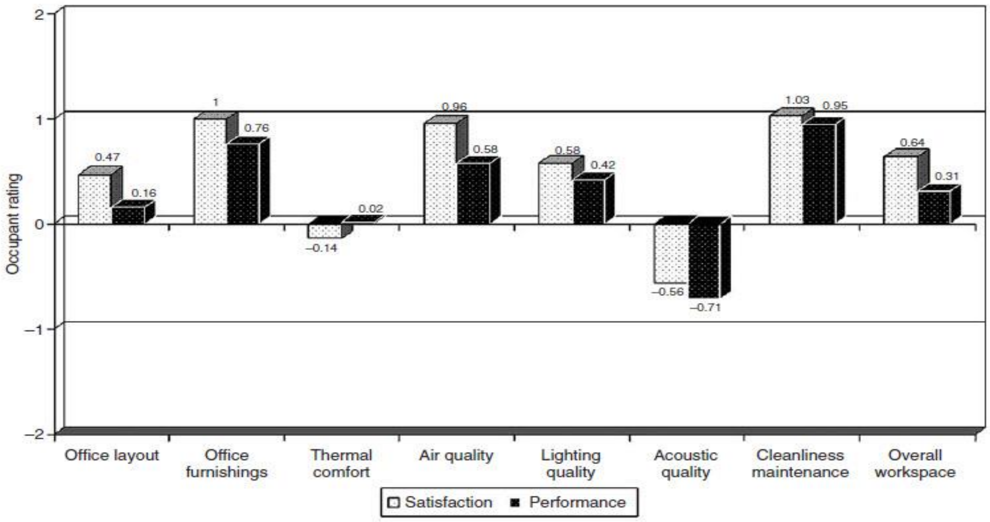


Figure 2.4: Mean Score Distribution for Occupants' Satisfaction and Performance (Lee and Guerin, 2009)

Life cycle assessment (LCA) was utilized to examine the benefits, the burdens, and to identify the critical credits of LEED rating tool. The LEED impacts were evaluated concerning four main issues which are human health, ecosystems quality, climate change, and resource consumption as shown in Figure 2.5. The analysed number of credits were 10 out of 15, 16 out of 20 credits, 14 out of 14 credits from categories sustainable sites, energy and atmosphere, and material and resources respectively. On the other hand, it was not possible to quantify credits from IEQ (Indoor Environmental Quality) as well as the credits from innovation & design process. A standard building parameter was set to compare its impacts with LEED credits to stand for the degree of benefits or burdens according to LCA. The standard building parameters were the parameters that are targeted by LEED requirements; also, the materials needed for a standard building were obtained by using data valid for an office building for approximately 500 persons. The units of damage categories, as mentioned above, were expressed respectively in disability-adjusted life years (DALY), potentially disappeared fraction of species per m² per year (PDF .m². year), the weight of equivalent emissions of carbon dioxide (kg CO2-eq) and megajoules (MJ) of primary non-renewable resources. On the other hand the results from IMPACT 2002+ software expressed in person per year (pers. yr) which corresponds respectively to 0.014DALY, 40000 PDF.m².yr, 14000 kg CO2-eq and 256000 MJ (Humbert et al., 2007).

For a standard office building and from the life cycle impacts assessment over 50 years, the results showed that the ratio of the shared operation and construction, and decommissioning were approximately (95% to 5% respectively). There is a correlation between consumption of resources and climate change. Non-renewable sources consumption increase the emissions of CO_2, resulting in climate change as shown in Figure 2.6. On the other side, ecosystem quality is small, as it is mainly affected by land use such as farming and heavy metal discharge into the soil. However, both are not the main contributor in building industry. For one-year operation analysis, it was found that commuting dominated life cycle impacts analysis in the four damage category, while electricity usage was in second place but water and waste both had a small contribution in the analysis as shown in Figure 2.7 (Humbert et al., 2007).

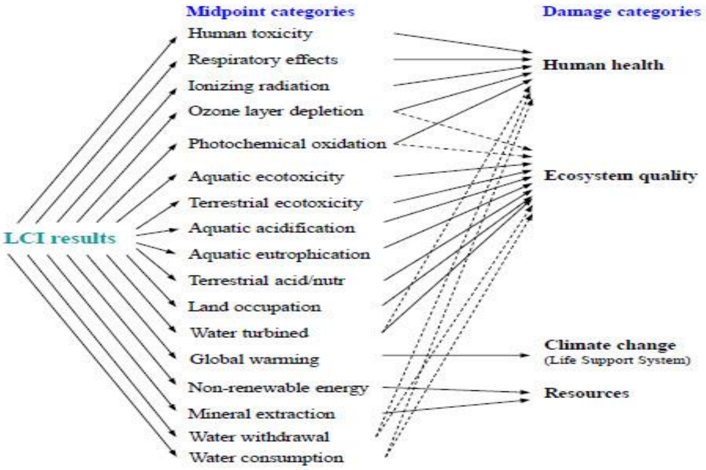


Figure 2.5: LCI Results and The Related Midpoint Categories and Damage Categories (Humbert et al., 2007)

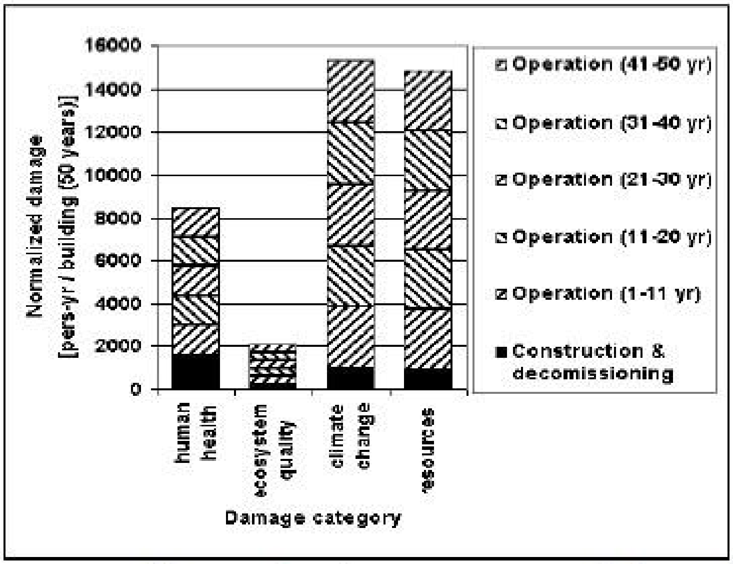


Figure 2.6: Total Impact of Standard Building Over 50 Years (Humbert et al., 2007)

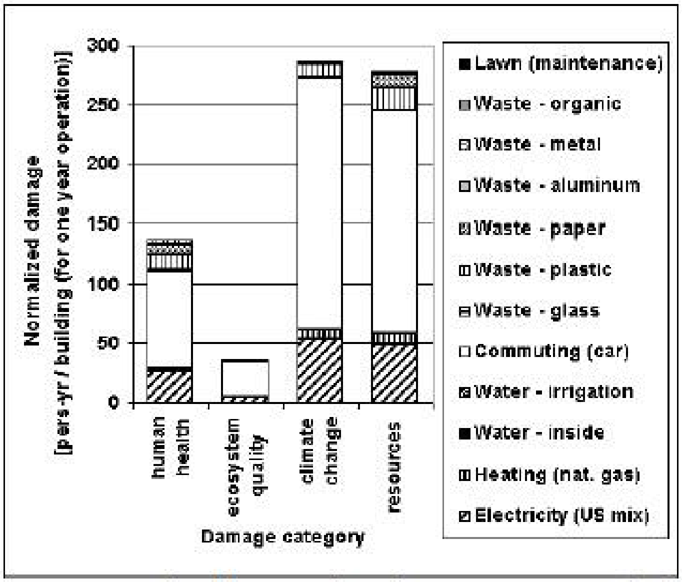


Figure 2.7: Operation Impacts for Standard Building for One Year (Humbert et al., 2007)

In the climate change damage category as shown in Figure 2.8, sustainable site (SS) and energy & atmosphere (EA) categories have high benefits resulting in a reduction in the climate change potential due to the saving in operation. The high benefit of credit EA6 estates that 50% of the demanded electricity is produced using renewable energy sources. Contrariwise, the burden of the credit SS 7.1 Alternative 2 which states that 50% of cars must be under cover (e.g. underground, under a building, a deck or a roof) as increasing structure may lead to increase in CO2 emissions during the production of the structural material mainly cement. So, this credit should be reviewed again to increase benefits. In human health damage category, the negative sign in SS 4.3 credit is due to the recommendation of use alternative fuel (bioethanol rather than gasoline) in which the former releases more air pollutants. Moreover, in the SS 7.1 Alternative 2, as discussed in the former category, increases the air pollutants through the life cycle of the building as shown in Figure 2.9. In the ecosystem quality category, as illustrated in Figure 2.10, the negative sign for credit SS 4.3 which recommends use alternative fuel which is bioethanol which affects land use as it requires more land for production. Besides, the negative sign for credit SS 7.1 Alternative two is due to the requirement of more material production and more land use to construct parking to accommodate 50% of cars. The same happen with Credit MR 6, which recommends the use of rapidly renewable material in furnishing wherein bio-based materials burdens in the ecosystem due to land use. For resources categories, all credits achieve benefits except the credit SS 7.1 alternative two as shown in Figure 2.11. As a result, and as illustrated in Figure 2.12, the credit SS 7.1 Alternative 2 demonstrates burden than benefits. On the other hand, Credit SS 4.3 using alternative fuel such as bioethanol reduces CO2 emissions but has a more hazardous effect on both human health and ecosystem quality (Humbert et al., 2007).

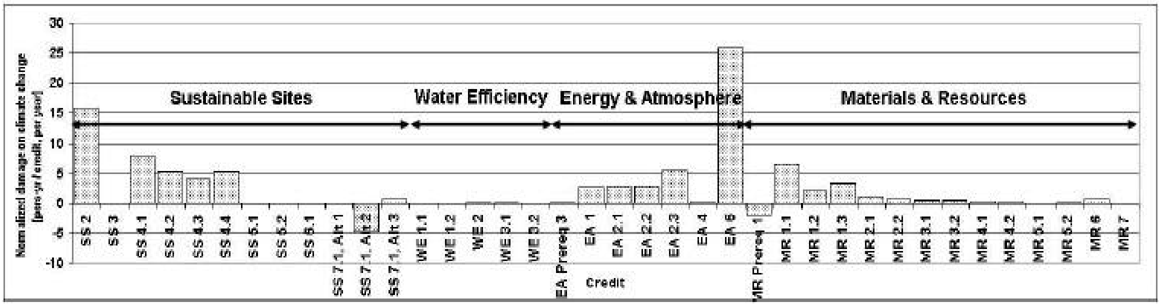


Figure 2.8: Benefits of LEED Credits on Climate Change Category of LEED Building (Humbert et al., 2007)

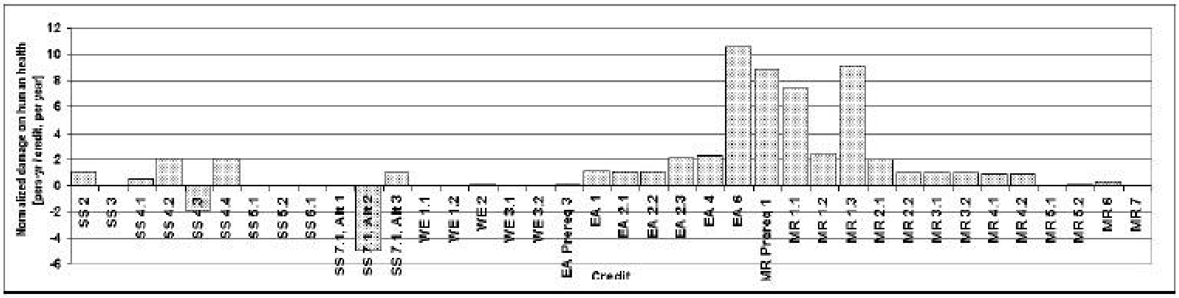


Figure 2.9: Benefits of LEED Credits on Human Health Category of LEED Building (Humbert et al., 2007)

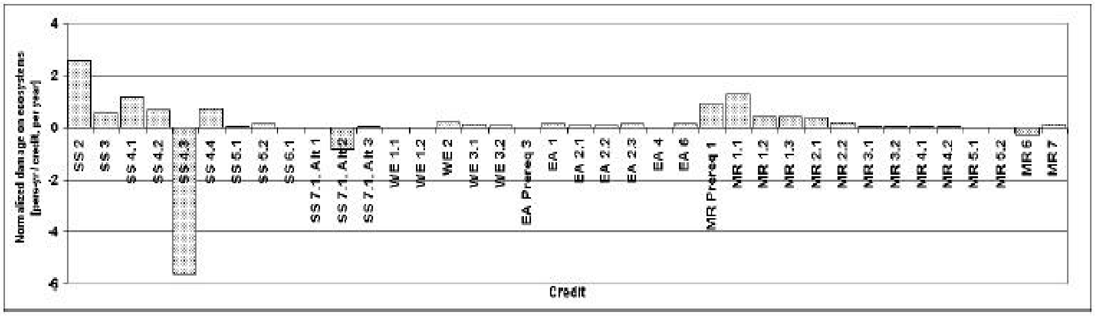


Figure 2.10: Benefits of LEED Credits on Ecosystem Quality Category of LEED Building (Humbert et al., 2007)

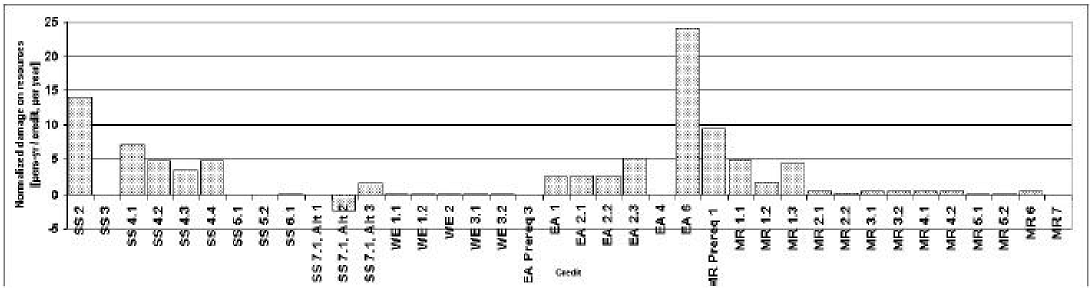


Figure 2.11: LEED Credits on Resources Quality Category of LEED Building (Humbert et al., 2007)

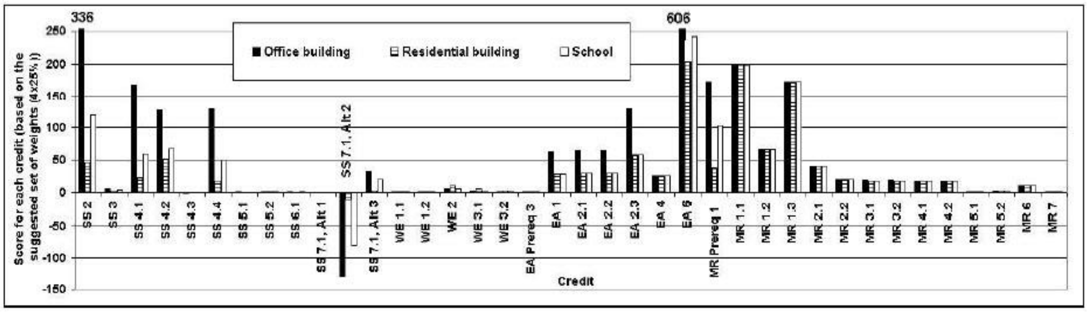


Figure 2.12: New Suggested Score Dependent on Total LCI (Humbert et al., 2007)

It is important to incorporate the assessment tools at an early stage, as in feasibility study stage before the design stage. However, the assessment is always carried out when the design process finalized (Crawley and Aho, 1999). Therefore, there must be an early intervention of the assessment tool to be useful as a design tool and to allow early collaboration between designers and the assessment team. Moreover, most of the environmental concerns are mainly considered during the design stage, but many development options and locations decided at the feasibility stage. Consequently, if a project has many development options, then selecting the one that achieves the environmental benefits and decreases its burdens will serve a major role in fulfilling the sustainability goals. Besides, later alternations may cause an excessive cost, annoyance, maximize environmental damage, maximize natural resources consumption and increase remedial costs. However, the contemporary environmental assessment tools are utilized to assess building performance late in the design stage, but it may be too late to consider many environmental issues (Ding, 2008).

Sustainability rating is a measure of the three major aspects: are economic, ecological and social aspects. Unfortunately, rating tools such as BREEAM, HK-BEAM, LEED and BEPAC do not include financial aspects in their assessment framework, despite the primary concern of any project to be financially efficient, for example, a building project may be environmentally efficient but requires a huge budget to construct. Most of the buildings' rating tools are implemented in local scale, but they are proved to be inefficient if they are applied in global scale. Because there are a lot of variations which distinguish a local context from one to another, some of these regional differences are climate conditions, building materials, buildings types, and historical considerations. Some countries adapt existing rating tools to fit their local context such as HK-BEAM of China which adapted BREEAM to suit its local context (Crawley and Aho, 1999).

2.7 Overview on Applied Research Techniques

2.7.1 Fuzzy TOPSIS

Fuzzy TOPSIS was first time introduced in 1981 (Chu and LIN, 2003; Hwang and Yoon, 1981; Kahraman et al., 2008). Fuzzy TOPSIS stands for Technique for Order Preference by Similarity to Ideal Solution, where it is one of the multi-attribute decision making (MADM) techniques. The fuzzy TOPSIS were used in this research as its capability to deal with uncertainty and it can handle both quantitative and qualitative factors. Based on (Junior et al., 2014), the fuzzy TOPSIS is superior than Fuzzy AHP in the agility in the decision process, computational time is less than fuzzy AHP when the number of alternatives increases, also, there is no limitation in the number of criteria and alternatives when considering fuzzy TOPSIS.

It is used to select an alternative or ranking a group of alternatives which have different criteria and attributes. So, the best alternative is closest to the ideal solution and farthest from the negative ideal solution. The ideal solution is the one which has the best performance values in the decision matrix, i.e. the maximum values for the benefit attributes and the minimum values in the cost attributes. Conversely, the negative ideal solution is the one which have the worst performance values in the decision matrix, i.e. the minimum values for the benefit attributes and the maximum values in the cost attributes (Byun and Lee, 2005; Ertuğrul and Karakaşoğlu, 2008; Kahraman et al., 2008; Pramanik et al., 2016; Yong, 2006).

Fuzzy TOPSIS undergoes seven steps to reach the final ranking of alternatives as following: 1) Initialize the decision matrix which is based on the ranking given by the decision makers to each attribute, where (A) is number of alternatives from 1 to m alternatives and (X) is number of decision makers from 1 to n decision makers as shown in equation (2.17), this ranking may be based on triangular fuzzy numbers (TFN) where $x_{ij}=(a_{ij}, b_{ij,} c_{ij})$ or expressed as trapezoidal fuzzy numbers (TAFN) where $x_{ij}=(a_{ij}, b_{ij,} c_{ij,} d_{ij})$; 2) initializes the normalized decision matrix as in equation (2.18). Furthermore, there are many approaches, among these approaches the one proposed by Kahraman, et al. (2008) as shown in equation (2.19), where $x_j^*=(a_j^*, b_j^*, c_j^*)$ is the highest ranking among all the attributes for one decision maker and $x_j^-=(a_j^-, b_j^-, c_j^-)$ is the lowest ranking among all the attributes for one decision maker. Another approach is illustrated in Ertugrul and Karakasoglu (2008), Pramanik, et al. (2016), and Yong (2006) and as shown in equation (2.20) where the ranking for the benefit attributes is divided by the third value of the maximum fuzzy number ranking among all attributes for single decision maker (i.e. $c_j^*= \max c_{ij}$) and the ranking for the cost attributes are divided by the first value of the minimum fuzzy number ranking among all attributes for single decision maker (i.e. $a_j^-= \min a_{ij}$). The third approach as proposed by Byun and Lee (2005) where the ranking of the benefit attributes are divided by the square root of the summation of square of the third values of all the ranking for one decision maker of all the attributes, and, conversely, the ranking of the cost attributes are divided by the square root of the summation of square of the first values of all the ranking for one decision maker of all the attributes as shown in equation (2.21); 3) Obtain the weighted normalized matrix as in equation (2.22), where the weight of each attribute is multiplied by the by all the alternatives as equation (2.23) (Byun & Lee, 2005; Ertuğrul & Karakaşoğlu, 2008; Kahraman, et al., 2008; Pramanik, et al., 2016; Yong, 2006); 4) selection of the positive ideal solutions (PIS) (A^*) and the negative ideal solutions (NIS) (A^-) as shown in equation (2.24) and equation (2.25) respectively, moreover, ranking is based on the generalized mean which is shown in equation (2.26) (Kahraman, et al., 2008); 5) calculate the distance of each alternative from PIS and NIS with respect to each criterion as it is depicted Figure 2.13 and is calculated based on the Euclidean distances as in equation (2.27) (Byun & Lee, 2005;

Ertuğrul & Karakaşoğlu, 2008; Pramanik, et al., 2016; Yong, 2006); 6) calculate the positive separation which is the summation of all distances from PIS for each alternative regarding all attributes and the negative separation which is the summation of all distances from NIS for each alternative regarding all attributes as shown in equation (2.28) and equation (2.29) respectively (Byun and Lee, 2005; Ertuğrul and Karakaşoğlu, 2008; Pramanik et al., 2016; Yong, 2006); and 7) get the closeness coefficient (CC) based on as in equation (2.30) and normalize all the CC to get the final ranking (Byun and Lee, 2005; Ertuğrul and Karakaşoğlu, 2008; Kahraman et al., 2008; Pramanik et al., 2016; Yong, 2006).

$$\widetilde{D} = \begin{array}{c} A_1 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array} \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \tag{2.17}$$

$$\tilde{R} = \begin{array}{c} A_1 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array} \begin{bmatrix} r_{11} & \cdots & r_{1j} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{i1} & \cdots & r_{ij} & \cdots & r_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mj} & \cdots & r_{mn} \end{bmatrix} \tag{2.18}$$

$$\tilde{r}_{ij} = \begin{cases} \dfrac{a_{ij}}{c_j^*}, \dfrac{b_{ij}}{b_j^*}, \dfrac{c_{ij}}{a_j^*} & (for\ benefit\ attribute) \\ \dfrac{a_j^-}{c_{ij}}, \dfrac{b_j^-}{b_{ij}}, \dfrac{c_j^-}{a_{ij}} & (for\ cost\ attribute) \end{cases} \tag{2.19}$$

$$\tilde{r}_{ij} = \begin{cases} \dfrac{a_{ij}}{c_j^*}, \dfrac{b_{ij}}{c_j^*}, \dfrac{c_{ij}}{c_j^*} & (for\ benefit\ attribute) \\ \dfrac{a_j^-}{c_{ij}}, \dfrac{a_j^-}{b_{ij}}, \dfrac{a_j^-}{c_{ij}} & (for\ cost\ attribute) \end{cases} \tag{2.20}$$

$$\tilde{r}_{ij} = \begin{cases} \dfrac{a_{ij}}{e_j^*}, \dfrac{b_{ij}}{e_j^*}, \dfrac{c_{ij}}{e_j^*} \quad , e_j^* = \sqrt{\displaystyle\sum_{i=1}^{m} c_{ij}} \quad (for\ benefit\ attribute), \\ \dfrac{e_j^-}{c_{ij}}, \dfrac{e_j^-}{b_{ij}}, \dfrac{e_j^-}{a_{ij}} \quad , e_j^- = \sqrt{\displaystyle\sum_{i=1}^{m} a_{ij}} \quad (for\ cost\ attribute) \end{cases} \tag{2.21}$$

$$\tilde{V} = \begin{array}{c} A_1 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array} \begin{bmatrix} v_{11} & \cdots & v_{1j} & \cdots & v_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ v_{i1} & \cdots & v_{ij} & \cdots & v_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ v_{m1} & \cdots & v_{mj} & \cdots & v_{mn} \end{bmatrix} \tag{2.22}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij}.\tilde{w}_j \tag{2.23}$$

$$v_j^* = \max_i v_{ij} \tag{2.24}$$

$$v_j^- = \min_i v_{ij} \tag{2.25}$$

$$M(v_{ij}) = \frac{-a_{ij}{}^2 + c_{ij}{}^2 - a_{ij}b_{ij} + a_{ij}b_{ij}}{\left[3(-a_{ij} + c_{ij})\right]} \tag{2.26}$$

$$d(\tilde{M}_1, \tilde{M}_2) = \sqrt{\frac{1}{3}\left[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2\right]} \tag{2.27}$$

$$S_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, v_j{}^*) \tag{2.28}$$

$$S_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, v_j{}^-) \tag{2.29}$$

$$CC_i = \frac{S_i^-}{S_i^- + S_i^*} \tag{2.30}$$

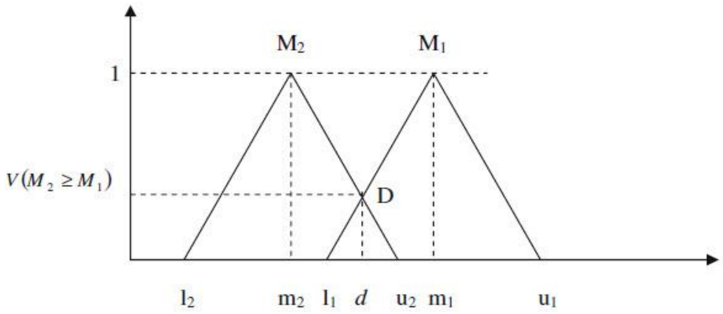


Figure 2.13: Difference between Two Fuzzy Numbers (Ertuğrul and Karakaşoğlu, 2008)

2.7.2 Artificial Immune System Optimization Technique:

Artificial immune system (AIS) was first introduced by Hunt and Cooke (1996), and it mimics the basic functions of the natural immune system in learning mechanism and memorizing frequent use information while discarding not frequently used ones. AIS is considered one of the nature-inspired meta-heuristic techniques utilized in a variety of applications, mainly, in machine learning and optimization problems (Chiong, 2009). Furthermore, AIS is applied in wide range of engineering applications. For example, economic load dispatch optimization problems are utilized to determine the suitable electric power to be generated by certain generating units while minimizing the total generation cost and satisfying the load demand simultaneously (Abdul Rahman et al., 2004; Panigrahi et al., 2007; Rao and Vaisakh, 2013; Vanaja et al., 2008); flow shop scheduling problems, which deals with optimization problem of makes pan of total weighted flow time (Vairamuthu et al., 2014); wireless sensor networks in which AIS is used to optimize the energy-aware topology control for this type of networks (Lu et al., 2008)…etc.

In general, a human immune system is such a complicated system that plays a profound and essential role in life, and it's the one which is capable of perceiving and combating different invaders to our body. These invaders may be external sourced from the so-called infectious non-self, such as bacteria, fungi, viruses, and parasites, and they may be internally source from the infectious self, such as self-malfunction cells such as cancer (Yu and Gen, 2010; De Castro and Von Zuben, 2002). All of these invaders are called pathogens, which introduces on its surface specially structured molecules named antigens. The immune system comprises two primary systems: 1) innate immune system which is general defence system not specified to a certain antigen, and 2) the adaptive immune system which response to certain antigen. Consequently, all researchers inspired by the natural immune system depend on the adaptive system while disregarding the other one.

The basic elements of the adaptive immune system are T-cells and B-cells, which act as the main soldiers in the immune system. T-cells comprises: 1) Helper-T cells (TH), their main function is to recognize the antigen and activate B-cells, other T-cells, macrophages. Natural killers cause them to proliferate; 2) Cytotoxic-T (TC) are capable of eliminating microbial, and virus invaders, as well as cancer cells by injecting noxious chemicals into the pathogen; and 3) Suppressor-T cells (TS) which are responsible for immune system maintenance in which it stops the function of other immune cells, malfunctioning in the TS cells, allergic reactions, or even immune system deficiency diseases. The main function of the B-cells is to secrete antibodies that match the required antigen to mark it for further actions (Coello and Cortes, 2005; De Castro and Von Zuben, 1999; De Castro and Von Zuben, 2002; Panigrahi et al., 2007; Vairamuthu et al., 2014).

Briefly, there are six procedures in which our immune system performs to protect our body as following and as illustrated in Figure 2.14: 1) cells called macrophages rove inside the human body digest any antigen and fragmenting it into antigenic peptides; 2) these peptides combined with other molecules called major histocompatibility complex molecules and presented on the surface of the antigen-presenting cell, which help other cells known as T cells which have receptors to recognize different peptide-MHC; 3) after this recognition T cells secretes chemical signals which stimulate other immune system cells; 4) B cells respond to these signals by its receptors, which can also recognize parts of the antigen flow in the body; 5) when the B cells are activated, it differentiate into new cells called plasma cells which secrete antibodies; and 6) when these antibodies combine with the antigen they found they can neutralize or destroy them (De Castro and Von Zuben, 1999).

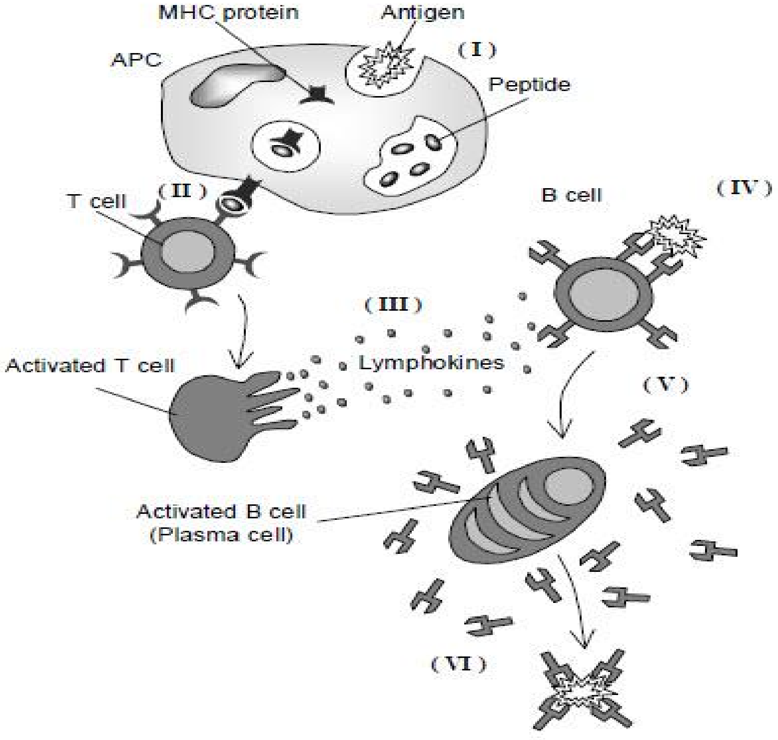


Figure 2.14: The Function of The Immune System (De Castro and Von Zuben, 1999)

i. The clonal selection algorithm principle:

The artificial immune system technique comprises various techniques adopted for optimization or machine learning problems. Each of which mimics or imitates a particular principal in the natural immune system, among these techniques: 1) clonal selection algorithm; 2) continuous and discrete immune network; and 3) negative selection (De Castro and Von Zuben, 1999; Chiong, 2009; Lu et al., 2008).This section is mainly considered clonal selection algorithm which is widely utilized, implemented and examined for robustness in different research.

De Castro and Von Zuben introduced Clonal Selection Algorithm (CSA) in 2005 (Hong and Ji, 2010). CSA depicts the basic features of the natural immune system. It adopts only the principle that those cells which recognize an antigen proliferate considering only two types of cells which are B and T cells. As illustrated in Figure 2.16, when a body is exposed to an antigen, B cells with high affinity to this antigen proliferate and produce copies of these best cells. High affinity means that its receptors recognize the antigen, and, in the case of optimization problems, high affinity means the best solution of the objective function. Furthermore, these cells differentiate into memory cells and plasma cells. Memory cells circulate in the blood, and when the body is exposed to the same antigen it quickly proliferates and excretes antibodies decrease the lag time in which the immune system consumes from antigen recognition to immune respond as shown in Figure 2.15. Plasma cells secrete antibodies which neutralize or destroy the antigen as described in section Figure 2.16 (De Castro and Von Zuben, 1999).

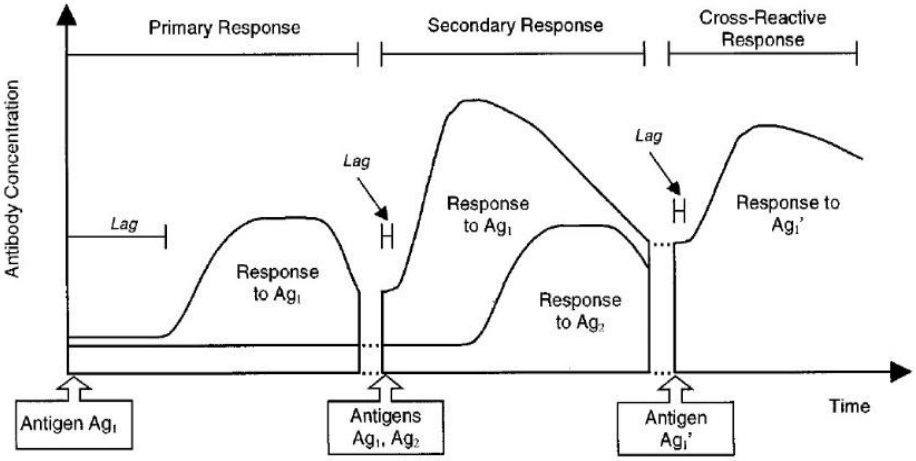


Figure 2.15: Lag Time in The Second Immune Response (De Castro and Von Zuben, 2002)

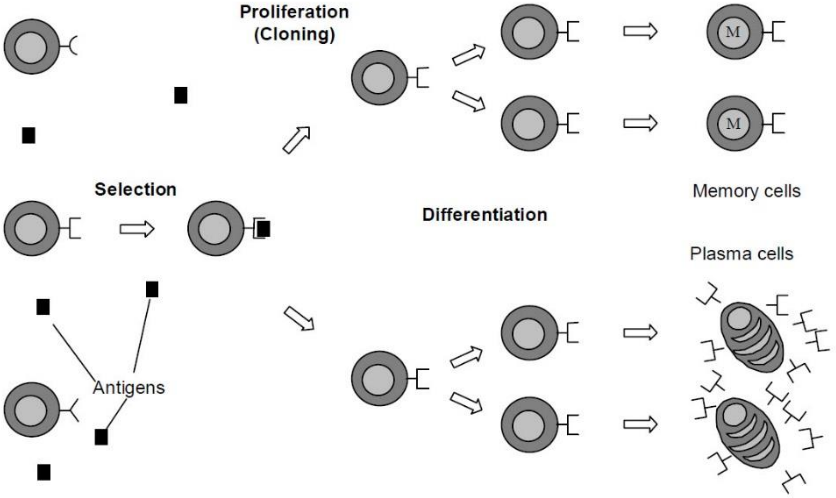


Figure 2.16: The Clonal Selection Principle (De Castro and Von Zuben, 1999)

The CSA undergoes many steps to reach the final near optimal solution, there are four main principles in this algorithm: 1) generation random population which is pool of antibodies or immune cells; 2) proliferation of best antibodies which is simply cloning or copying of parents; and 3) hyper mutation or mutation of clones (blind variation) to maintain diversity by applying random genetic changes; and 4) affinity of antigen antibody interaction which is evaluation of the objective function and elimination of low affinity antibodies (Chiong, 2009; Panigrahi et al., 2007; Yu and Gen, 2010). Affinity in AIS algorithm means the value of the objective functions after evaluation, as well as constrains satisfaction in case of constrained problems. Consequently, the best antibody (solution) or a group of variables that achieves the best objective function value will continue for more processes in the algorithm and the rest with low affinity will be removed. The clonal selection algorithm possesses three techniques to maintain diversity and therefore lead to global optimal, preventing them from being stuck into local minima: 1) hyper mutation or point mutation, 2) receptor editing that is called non-uniform mutation, 3) a fraction of new antibodies added to the solutions (De Castro and Von Zuben, 1999).

The mutation is performed to each of the selected clones with a rate based on their affinity. The antibodies with lower affinity undergo higher mutation than the high ones so hypermutation is inversely proportional to affinity (Vanaja et al., 2008). The mutation process randomly occurs through a flip of the genetic structure of each antibody, as a result, some of the mutated antibodies becomes inefficient or non-functional. In reality, they have low affinity receptors or form self-reactive cells so they must be eliminated and prohibited from being selected in the next generation (De Castro and Von Zuben, 1999).

The non-uniform mutation or receptor editing helps in maintain diversity as well as is capable of leading the antibody – antigen affinity from escaping from local minima in the affinity landscape. As shown in Figure 2.17, uniform mutation allows the antibody to conduct small local searches of antibodies with higher affinities, e.g. from point A to A’, with low ones eliminated, while receptor editing allow large search area steps, e.g. from point A’ to C, leading to reach local optimum, e.g. from point C to C’. Another technique used to maintain the diversity of the proposed solutions in each generation and to guarantee better search for global optimization is to introduce in each generation from 5-8 % new antibodies and to be replaced per each generation.

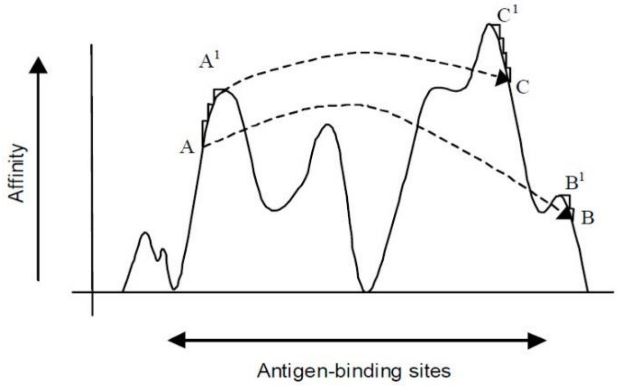


Figure 2.17: The Receptor Editing (Non-Uniform Mutation) Leads to Global Optimum (De Castro and Von Zuben, 1999)

ii. *Multi objective clonal selection algorithm:*

Coello and Cortes (2005) introduced a multi objective optimization algorithm based on clonal selection theory as shown in Figure 2.18. They encoded their antibodies into binary strings and used the archive to store non-dominated solutions found so far. They then assign ranking to each of the randomly selected individuals based on the affinity or objective function value and constrain satisfaction. The algorithm they proposed comprises four main phases comprises multiple steps that will be illustrated in the following sections.

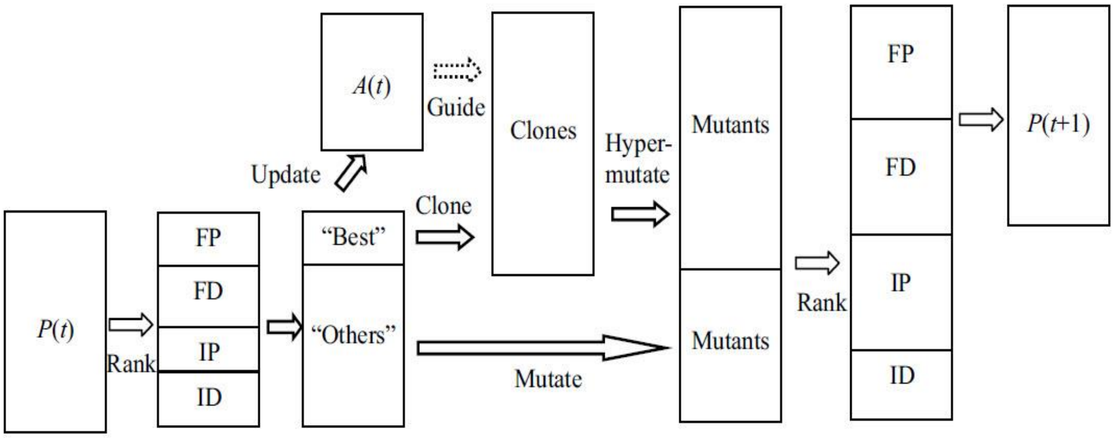


Figure 2.18: One Generation of Multi Objective Clonal Selection Algorithm (Yu and Gen, 2010)

iii. *Initialization phase:*

This phase depends on entering various data that will be used through the steps of the algorithm as follows: 1) selection of the population size (pop size), which is mainly from 5-10 times the number of the design variables; 2) the maximum generation number; 3) the archive size (arc size), which is a secondary population used to store the number of non-dominated solution found thus far based equation (2.31), where (div) is the number divisions used to identify the borders of the hyper boxes that are used to determine the crowdedness of the solutions which is regulated by equation (2.32), where (k) is the number of objectives in the problem (Knowles and Corne, 2003); and 4) the length of binary string used to represent the design variable (l), where (N_c) is maximum value available for a design variable equation (2.33).

$$arc\ size > div^k - (div - 1)^k + 2k \tag{2.31}$$

$$div > 2k \tag{2.32}$$

$$2^l > N_c \tag{2.33}$$

iv. The evolution of the first generation and ranking the random generated solutions:

All the procedures in this phase repeated until reaching the stopping criteria, which is either reaching the optimum solution or reaching the maximum predefined generation. These steps are described as following: 1) Perform a random population in binary strings for the predefined population size, each individual (chromosome) has a specific length as in equation (2.34), where (L) is the number of bits in each chromosome and (N_{dv}) is the number of the design variables in each antibody; 2) decoding the design variables of each individual based on equation (2.35), where (z) is the decoded integer value of a required string, (i) is the integer value of a certain bit which is 0 or 1, (m) is the maximum number of bits in the string, if (z) integer is larger than the maximum allowable value of the design variable (N_c) use equation (2.36) (Arora, 2012); 3) rank all the antibodies in the population size according to its objective function value and constraints satisfactions, so for the case of constrains satisfaction the antibodies are classified into feasible and non-feasible. Among each group make further discrimination for dominated and non-dominated solutions, based on these classifications feasible non dominated, feasible dominated, infeasible non-dominated and infeasible dominated are given rank 1, rank 2, rank 3 and rank 4 respectively; and 4) Select number of the best antibodies based on the equation (2.37), using rank 1 to complete the 5% if the best antibodies is not completed use rank 2 up to rank 4 respectively to fill (Ab best) (Coello and Cortes, 2005).

$$L = l \times N_{dv} \tag{2.34}$$

$$z = \sum_{i=1}^{m} ICH(i)2^{(i-1)} + 1 \tag{2.35}$$

$$j = INT\left(\frac{N_c}{2^m - N_c}\right)(z - N_c) \tag{2.36}$$

$$Ab_{best} = 0.05 \times popsize \tag{2.37}$$

v. Updating the archive size, location and shape:

An adaptive grid is one of the ways used to guarantee normal distribution of the non-dominated solutions along the Pareto front. The grid changes in size, location, and shape from one generation to the next based on the maximum and the minimum non-dominated solutions in the objective space (for each of the objective functions) found thus far as shown in Figure 2.19. The adaptive grid is applied to determine the crowdedness of the best solutions, and also helping in eliminating some of the most crowded solutions. It guarantees the diversity of solutions, thus providing the decision maker with a variety of solutions and trade-offs. This is executed based on the following steps: 1) define the range of non-dominated solutions (i.e. difference between maximum and minimum non-dominated solutions for each of the objectives according to equation (2.38), where (k) refer to objective space from 1-K, (t) is the number of generation; 2) define the upper and lower boundary of the archive in each iteration as shown Figure 2.21, where (ub) is the upper boundary of the objective (k) at generation (t) and (lb) is the lower boundary of the objective (k) at generation (t) as in equation (2.39) and equation (2.40) respectively; 3) calculate the upper (rub) and lower (rlb) boundaries of each region (i) as shown in equation (2.41) and equation (2.42) respectively; 4) determine the region in which non-dominated solution occupies, where non-dominated solution (z) of objective (k) occupies region (i) if (z) is greater than or equal the lower boundary of region (i) and smaller than of its upper boundary as well as shown in equation (2.43); and finally 5) get the average squeeze factor which is the summation of the number of the non-dominated solutions in each region divided by the total number of the regions contains the non-dominated solutions (Knowles and Corne, 2003).

$$range_{k,t} = \max_{z \in N_t} z_k - \min_{z \in N_t} z_k \tag{2.38}$$

$$ub_{k,t} = \max_{z \in N_t} z_k + \left(1/(2.div)\right)\left(range_{k,t}\right) \tag{2.39}$$

$$lb_{k,t} = \min_{z \in N_t} z_k - \left(1/(2.div)\right)\left(range_{k,t}\right) \tag{2.40}$$

$$rub_{k,i,t} = lb_{k,t} + \left(\frac{i_k}{div}\right)\left(ub_{k,t} - lb_{k,t}\right) \tag{2.41}$$

$$rlb_{k,i,t} = lb_{k,t} + \left(\frac{i_k - 1}{div}\right)\left(ub_{k,t} - lb_{k,t}\right) \tag{2.42}$$

$$z_k \geq rlb_{k,i,t} \wedge z_k < rub_{k,i,t} \tag{2.43}$$

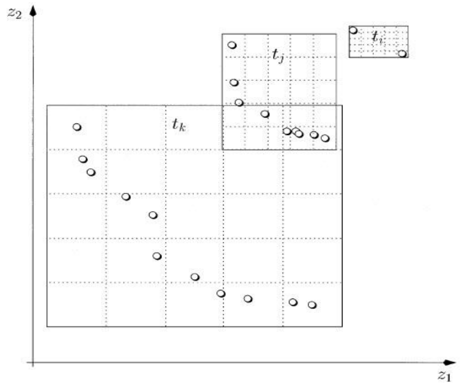


Figure 2.19: An Adaptive Grid Changes its Location and Shape in the Objective Space (Knowles and Corne, 2003)

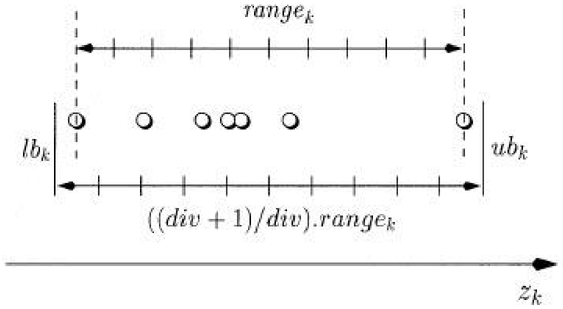


Figure 2.20: The Range of the Adaptive Grid (Knowles and Corne, 2003)

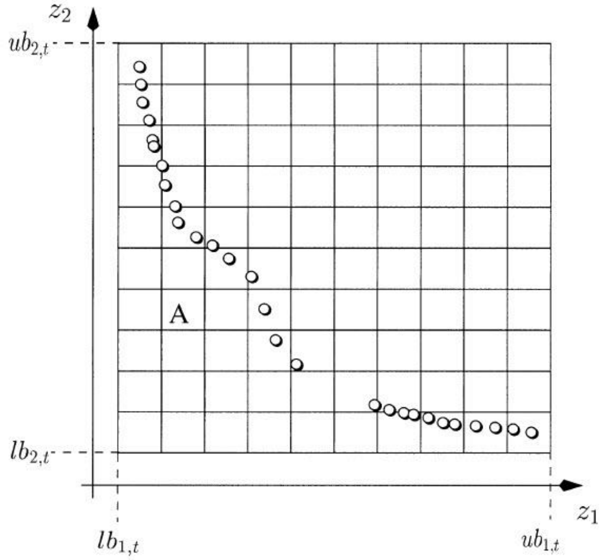


Figure 2.21: Upper and Lower Boundary of the Adaptive Grid (Knowles and Corne, 2003)

vi. Update the achieve with the best antibodies:

When copying the best antibodies to the archive, there are two scenarios: when the archive is not full, and when the archive is full. For the first case, all the non-dominated solutions or the best antibodies (according to ranking procedures as in step iv) are allowed to enter the archive. On the other hand, when the archive is full, the best antibodies which belong to the lowest crowded region are allowed to enter the archive, thus spontaneously causing a random elimination of the antibodies belong to the most crowded regions with the same rate of the newly introduced antibodies (Coello and Cortes, 2005; Yu and Gen, 2010).

vii. Cloning of the best antibodies in the archive:

The number of clones to all the antibodies are distributed equally based on the equation (2.44), but they may be decreased or increased based on the crowdedness of these antibodies and based on the archive whether it is empty or full. If the archive is not full, the total average Euclidean distance of all the antibodies is applied, and the average Euclidean distance between each antibody and the others determined as in equation (2.45). Where (D) is the Euclidean distance, (L) is the number of the objectives, (u) is the first antibody vector and (v) is the second antibody vector, if the antibody average Euclidean distance of one antibody is smaller than the total average, which means it belongs to the high crowded region so its clone number reduces by half and vice versa. If the archive is full and the best antibody belongs to the region where its squeeze factor is less than the average one, then its clone number doubles; conversely, if the best antibody belongs to region that its squeeze factor is greater than the average then its clone number is reduced by half (Coello and Cortes, 2005).

$$N_{cln} = 6 \times pop\ size \tag{2.44}$$

$$D = \sqrt{\sum_{i=1}^{L} (u_i - v_i)^2} \tag{2.45}$$

viii. Uniform and Non-Uniform Mutation:

The uniform mutation applied to the best-cloned antibodies. The number of bits to be mutated in each cloned antibody dependent on its rank as illustrated in Section iv such that: n bit flip mutations performed for rank 1 antibodies; (n+1) bit flip mutations performed for rank 2 antibodies; n+2 bit flip mutations performed for rank 3 antibodies; and n+4 bit flip mutations performed for rank 4 antibodies.

The non-uniform mutation is carried out on the non-best antibodies. This mutation changed from generation to generation, such that a high number of bit-flip mutations are performed for the earlier generations and the number of bit-flips decreases every generation based on equation (2.46) (Yu and Gen, 2010). Then, the final step is ranking all the obtained solutions using the same principle in section iv and select the best antibodies in a new population of size equal to the first one.

$$n = 0.6L + \frac{gen}{\max gen}\left(\frac{1}{L} - 0.6\,L\right) \tag{2.46}$$

2.8 Summary of the Limitations of the Previous Research Works

Based on the literature review of various well-known and broadly used sustainability rating tools for existing buildings, review of many individually developed research works considering the development of sustainability rating tools to fit the context of their countries, and building performance-based developed optimization algorithms, the following limitations were concluded:

- There is no unified concept to select the sustainability assessment attributes that can be utilized to express the key aspects of sustainability. Hence, the assessment of sustainability of a single building may change from one tool to another.
- There is no consensus-based approach utilized for the sustainability assessment and for score assignment for each attribute. Each rating tool has its own assessment methodology which will affect the final score.
- No unified weighting or ranking scheme can set a consensus perception of the achieved sustainability. Therefore, the existing rating systems are not equivalent such that a six star in Green Star rating system is less sustainable than the platinum in LEED and nearly equal to very good rating in BREEAM.
- Some of the rating tools such as LEED do not use a weighting scheme in its assessment, which the impact of the local context of the assessed project on the assessment attributes cannot be addressed.

- Many of the rating tools do not consider the dynamism of the importance of the assessment attributes as an example of BREEAM. Accordingly, all the assessment attributes are deemed to have a constant weight regardless the variations according to the different local contexts discussed previous
- The majority of the existing rating tools utilize a single level of weighting in the assessment attributes hierarchy, which do not reflect accurately the sustainability of the buildings.
- The weighting system is inexplicit in the most of the existing rating tools and research work, which results in a lack of transparency and consistency.
- Almost all the previous research work utilized AHP in the weight determination; however, several research studies introduced the limitations of this method. Another method needs to be investigated to overcome these limitations.
- Only, GBTool (recently named SB Tool) is considered a global rating tool, however it possesses some shortcomings as discussed. Consequently, a research needed in this area to overcome these limitations to establish a globally working rating tool.
- Some important attributes were not included in most of the existing rating tools and research work, which are disabled accessibility, risk management (i.e. natural hazard and fire), security measures, and building management.
- Most of the previous research works use a single optimization to upgrade the sustainability of the buildings, either maximizing the sustainability credits or minimizes the upgrade cost. This method results in only one optimal or near optimal solutions in a single run, which does not provide decision maker with much flexibility in the selection of the trade-offs

alternatives. Moreover, the decision maker cannot track the impact of an objective on the others.

- Most of the previous research works overlooked the LCC while emphasizing only on the upgrade or annual cost. However, the LCC is more suitable when considering upgrading the sustainability to set an accurate and long-term management plans.
- Most of the previous research work implemented genetic algorithms, while few introduced particle swarm optimization and ant colony optimization. Many other evolutionary algorithms were proved to be more robust and efficient in addressing optimization problems, especially when dealing with multi-objective optimization problems. This research area is widely demanding and another algorithm can be explored as the artificial immune optimization algorithm.
- No previously developed integrated sustainability assessment and rehabilitation framework to provide the decision makers with a two-tier tool: one for the current sustainability assessment for the project, the second tier to provide them with a group of solutions to upgrade the sustainability of their buildings within minimal LCC.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Chapter Overview

As illustrated in the previous chapter, the building industry represents a significant burden on our environment, climate and health. Moreover, the operation and maintenance stage in the building life cycle has the highest significant impact on the environment compared with the other stages of the buildings. Furthermore, the only way to mitigate these impacts is the adoption of the sustainability buildings concept. These buildings take into account many aspects that help to decrease drastically their impact by achieving healthier built environments within the local context, cutting down global environmental hazards (i.e. reducing GHG emissions, controlling pollution amounts within acceptable levels…etc.) and regulating and monitoring consumption of resources. Consequently, rating systems for sustainable buildings were developed to control and evaluate the sustainability of these buildings to achieve the before-mentioned goals. Each rating system has its advantages and limitations as well as its local context.

In that context, the main aim of this chapter is to propose a methodology to establish a rating system for sustainable existing system. In addition, this chapter will introduce: 1) the variation of local aspects between countries, which significantly affect the evaluation process; 2) the integration of the main assessment attributes that affect sustainability of buildings referring to the most globally-spread rating systems; 3) the establishment of a sustainability scale to stand for a global measurement of the sustainability of buildings; and 4) the proposal of a rehabilitation model based on sustainability to help decision-makers select the best alternative options to achieve a higher degree of sustainability within a predefined budget.

3.2 Detailed Research Methodology

The methodology for the sustainable rating system for existing buildings research is divided into five main stages as shown in Figure 3.1. The first stage is the literature review phase, which is based on gathering information from two essential sources: technical manuals for existing worldwide rating systems and review papers. The aim of this stage is to review the advantages and limitations of these existing rating systems, as well as the assessment attributes utilized to assess the sustainability of buildings and search for the contribution of the recent research in this field. Secondly, this stage will develop a sustainability assessment model comprised of two primary objectives: 1) identifying the sustainability assessment attributes (i.e. criteria, factors and sub-factors) based on the literature review and 2) establishing the sustainability assessment model. The third phase is model validation based on the implementation of the developed model on a selected case study using the real performance field data and a questionnaire. That data will compare the model output with some of the existing rating tools. If the model is valid, the methodology will continue, if it is not, the model will be rectified and adjusted. The fourth stage is the development of a sustainability-based rehabilitation model, which is an optimization model adopting the artificial immune system optimization algorithm. This model aimed to be an assistant tool to the facility decision-makers to select the best alternatives that can upgrade their sustainability ranking within an available budget. Finally, the fifth stage is validating the rehabilitation model through testing by experts where, if it is valid, the conclusion of the research will be addressed expressing the contribution of the research that is added to the body of knowledge, as well as the limitations of this study.

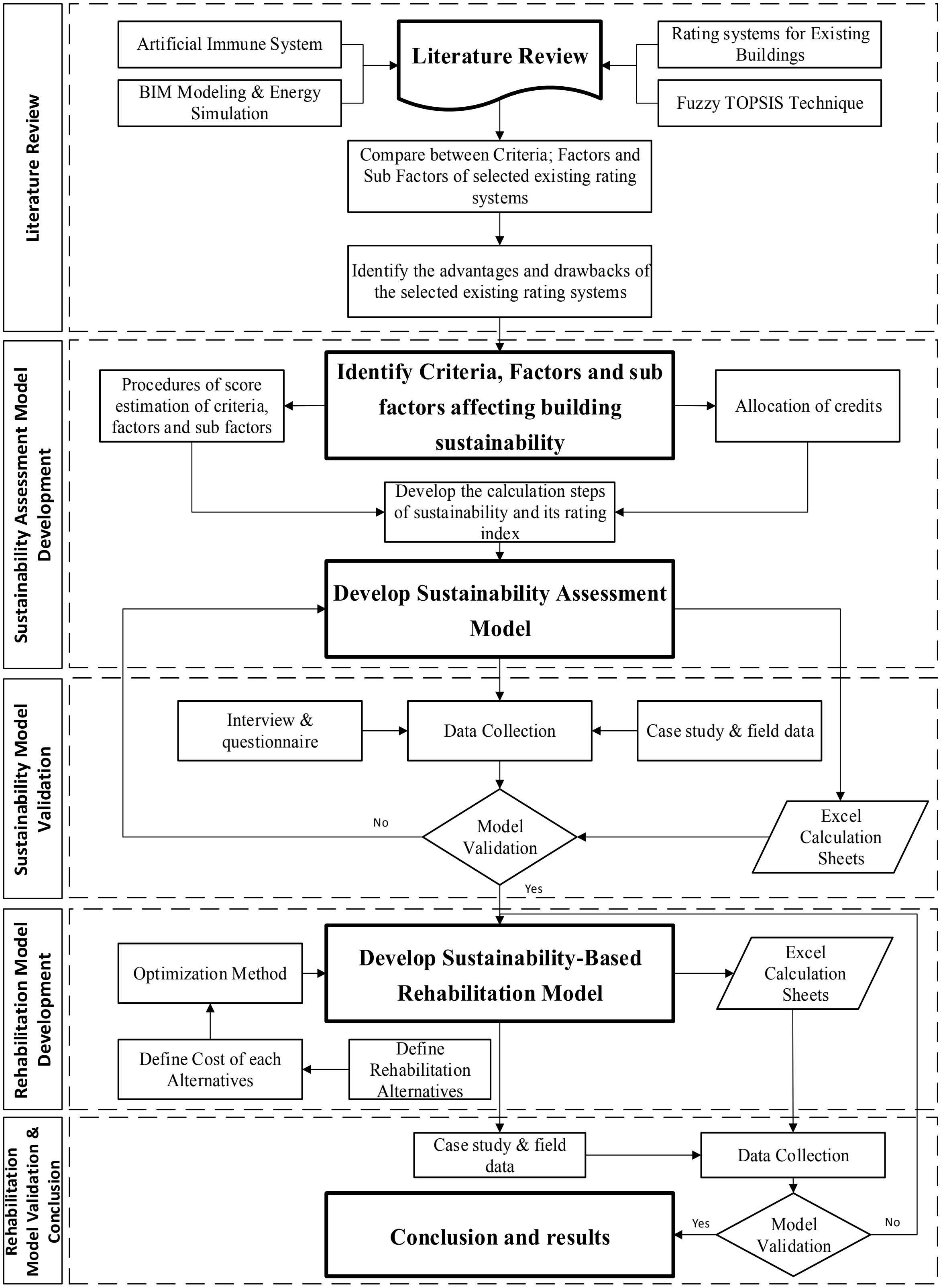


Figure 3.1: Research Methodology for Sustainable Rating System for Existing Buildings

3.2.1 Literature Review

The literature review explored eight rating systems and their manuals were utilized as a reference: 1) LEED-Operation and Maintenance; 2) BREEAM-In-Use; 3) BEAM Plus for Existing Buildings; 4) CASBEE for New Construction; 5) Green Building Index for Existing Buildings; 6) Green Ship for Existing Buildings; 7) Green Mark for Non-Residential Existing Buildings; and 8) Green Globes. The selection preference of these rating systems was based on three criteria: 1) the World Green Building Council list of existing building rating systems; 2) the broad range of their implementations around the globe; and 3) the availability of data and technical guidelines. Through the sets of data mentioned above, an analysis was performed concerning: 1) identification of the assessment attributes affecting the sustainability evaluation of buildings; 2) a distinction of the various advantages and limitations of the existing rating systems; and 3) investigation of the different models utilized for the sustainability evaluation of buildings.

3.3 The Sustainability Assessment Model Development Methodology:

Developing the assessment model occurred through six steps as shown in Figure 3.2. The first step identified the sustainability assessment attributes, such as criteria, factors and sub-factors. The second determined the weights for the criteria and the global weights (W_g) for factors applying a fuzzy multi-atribute decision-making technique. The third step evaluated the scores for sub-factors (SC_{subf}) and factors (SC). The fourth step determined the sustainability index of each factor. The fifth step determined the building sustainability index (BSI) and the building sustainability assessment ratio (BSAR). Finally, the last step established the ranking scheme for the sustainability assessment tool.

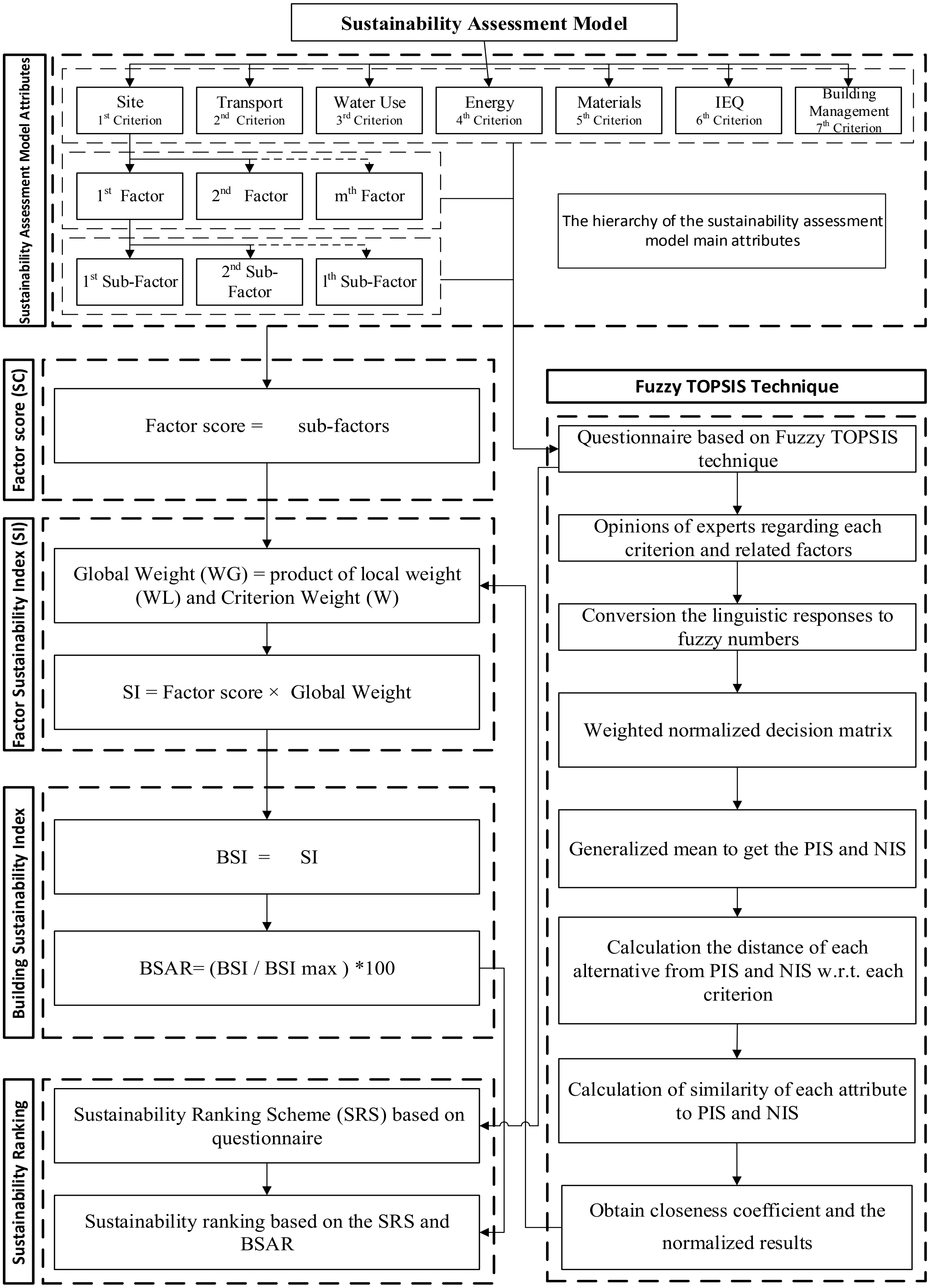


Figure 3.2: Sustainability Assessment Model Development Methodology

3.3.1 Identification of Sustainability Assessment Attributes

Comparisons and integrations were performed based on the literature review resulting in seven criteria as will be illustrated in CHAPTER 5. These criteria will be considered the primary attributes that have a considerable influence on the sustainability of buildings. These criteria are 1) site and ecology, 2) transportation, 3) energy efficiency, 4) water use, 5) material and waste reduction, 6) indoor environmental quality (IEQ) and 7) building management. Each criterion is comprised of factors and sub-factors used to subdivide and assess each criterion.

3.3.2 Weight Evaluation of Criteria and Factors (WL)

The weight of each criterion and factor has been evaluated by applying the fuzzy TOPSIS technique by implementing the procedures discussed in the previous chapter in Section 2.7.1. The input data required to begin the evaluation process is dependent on information collected from the responses of experts through their responds to a questionnaire to stand for the degree of importance of each criterion and factor to the sustainability of buildings. Moreover, the global weight (WG) is the product of the local weight (WL) of the factor and the weight of the related criterion as illustrated in equation (3.1).

$$WG_j = W_k \times WL_j \tag{3.1}$$

Where:

WG_j = corresponding global weight of the jth factor;

W_k = corresponding weight of the kth criterion; and

WL_j = corresponding local weight of the jth factor.

3.3.3 Score Determination of Factors and Sub-Factors

As mentioned previously, each criterion is comprised of a number of factors and sub-factors, each of which has certain available points to be achieved. Consequently, the score of each factor is a simple aggregation of points of its related sub-factors as shown in equation (3.2). The score of each sub-factor is determined based on the equations that will be illustrated in the following section:

$$SC_j = \sum_{i=1}^{l} SC_{subf_i} \tag{3.2}$$

Where:

SC_j = score of the jth factor in each criterion; and

$Sub\ f_i$ = score of the ith sub-factor in each factor.

3.3.4 Determination of Factors' and Buildings' Sustainability Indices (SI), (BSI):

The sustainability index of each factor (SI) is the product of the factor score (SC) and its corresponding global weight (WG) as shown in equation (3.3). Further, the building sustainability index (BSI) is the summation of all the sustainability indices of all the factors.

$$SI_j = SC_j \times WG_j \tag{3.3}$$

$$BSI = \sum_{j=1}^{m} SCf_j \times W_{g_j} = \sum_{j=1}^{m} SI_j \tag{3.4}$$

Where:

SI_j = sustainability index of jth factor; and

BSI = building sustainability index.

3.3.5 Determination of the Building Sustainability Assessment Ratio (BSAR)

The building sustainability assessment ratio (BSAR) is the percentage between the BSI and the maximum BSI; such that the maximum BSI is determined utilizing the previous steps in the factor score determination, but the maximum available score for each sub-factor is used. The BSAR can be expressed either by equation (3.6) or in the general form as in equation (3.5).

$$BSAR = \frac{\sum_{j=1}^{m} SC_j \times WG_j}{\sum_{j=1}^{m} (\mathrm{SC}_j)_{max} \times WG_j} \times 100 \tag{3.5}$$

$$BSAR = \frac{BSI}{\mathrm{BSI}_{max}} \times 100 \tag{3.6}$$

3.4 Sustainability Scale Determination:

The sustainability scale determination is based on two main strategies: 1) the responses of respondents to the proposed questionnaire, 2) studying the differences between the various rating systems. In the first strategy, the respondents are requested to provide their opinion about the proper scale to be applied to represent each degree of sustainability of buildings (i.e. outstanding, excellent, very good, good, pass and fail). In addition, they are asked to select the threshold for each criterion to achieve a particular rating. In the second strategy, a comparison is conducted between eight rating systems (i.e. LEED, BREEAM, HK-BEAM, GBI Indonesia, Green Mark Singapore, Green Ship Malaysia, Green Globes, CASBEE Japan) to stand for the differences in their sustainability scales as illustrated in the next chapter.

3.5 Sub-Factors Score Determination

As discussed, each criterion has (*m*) factors and (*l*) sub-factors. Sub-factors are the primary attributes of the sustainability assessment. Each one has a maximum of available credits (points) to be achieved. If the building fulfils the requirements of a particular sub-factor, it will gain the maximum points; if not, the building will score some or no credits according to the degree of its fulfilment. Mainly, the sub-factors have two main types: quantitative and qualitative. Qualitative sub-factors deal with long-term plans, policies and procedure-based aspects, in which a building is scored based on the degree of its fulfilment of them. Quantitative sub-factors are design-based, and deal with the fulfilment of the design requirements and thresholds based on equations and quantity constraints. Accordingly, the following subsections will distinguish between these two types and shed light on the design-based sub-factors and their procedures of calculations.

3.5.1 Site and Ecology Criterion

Site and ecology criterion are comprised of four factors and thirteen sub-factors. The sub-factors of *site selection* and *site management* factors are qualitative sub-factors. The sub-factors of *reduce heat island effect* and *site emission* factors are quantitative sub-factors, as well, the sub-factor *light pollution reduction* under the factor of *site emissions* is also qualitative. The sub-factor *heat island reduction in non-roof area* is utilized to mitigate the effect of heat that arises from the solar emissivity of the materials of the non-roofed landscape of the project. The points are awarded if the qualified non-roof area is greater than or equal to 50% of the total non-roofed area as in equation (3.8) and equation (3.7) (USGBC, 2009).

$$Q = A_S + A_T + A_H + A_A + A_G \tag{3.7}$$

$$Q \geq \frac{Nonroofed\ area}{2} \tag{3.8}$$

Where:

Q = qualified non-roofed area;
A_S = area of installed solar panel;
A_T = shaded area of trees;
A_H = material of hardscape of at least SRI of 29;

A_A = architectural structures used for shading of at least SRI 29; and
A_G = area of the open grid space, the voids are more than 50%.

The *heat island reduction in roof area* is utilized to drop off the effect of the dark materials that are used in roof finishing, as these materials absorb the sun heat and emit it back to the surroundings, resulting in an increase in the cooling loads and electricity consumption, which consequently increases GHG emissions. The summation of the weighted average SRI roof area that is greater than 75% of the roof area, and the planted area, which is more than 50% of the roof area, must be more than or equal to the net roof area as shown in equation (3.9) (USGBC, 2009).

$$\left(\left(\frac{A_{low\ slope}}{78 \times \left(\frac{0.75}{SRI}\right)}\right) + \left(\frac{A_{steep}}{29 \times \left(\frac{0.75}{SRI}\right)}\right) + \left(\frac{planted\ area}{0.5}\right)\right) \geq (A_{total} - A_{ocu.}) \tag{3.9}$$

Where:

$A_{\text{low slope}}$ = area of roof with low slope;
A_{steep} = area of roof with steep slope;
A_{total} = total roof area; and
$A_{\text{ocu.}}$ = roof.

The *exterior walls finishing and planting* sub-factor is applied to increase the efficiency of the materials of the building envelope to decrease its solar gain by utilizing materials with high SRI or through benefits of the planting surfaces applying the efficient material ratio. The efficient material ratio is the ratio between the summation of the planted area and the high SRI material installed on the building envelope to the total exterior wall area as in equation (3.10) (JaGBC, 2008).

$$M_{ratio} = \frac{\mathrm{A}_{plant} + \mathrm{A}_{SRI}}{\text{Exterior wall area}} \times 100\% \tag{3.10}$$

Where:

$\mathrm{M_{ratio}}$ = area of roof with low slope;
$\mathrm{A_{plant}}$ = exterior wall planted area; and
$\mathrm{A_{SRI}}$ = exterior walls with high solar reflection index material.

Consideration of *wind movement* and *building exterior design* sub-factors encourage the design efficiency for the building exterior shape to allow prevailing wind flow within the site. This wind flow helps lessen the effect of the heat islands that arise from the built environment. The building elevation design efficiency is calculated as shown in equation (3.11). The elevation building area ratio is the ratio between the area of the building from the direction of the prevailing wind to the product of the width of the site from the direction of the prevailing wind and the height of the building as shown in Figure 3.3 (JaGBC, 2008).

$$BEA = \frac{\mathrm{A}_{build}}{\mathrm{W}_{site}\ \mathrm{x}\ \mathrm{H}_{build}} \times 100\% \tag{3.11}$$

Where:

BEA = efficient building elevation area;
$\mathrm{A_{build}}$ = area of the building from the direction of the prevailing wind;
$\mathrm{W_{site}}$ = width of the site; and
$\mathrm{H_{build}}$ = height of the building.

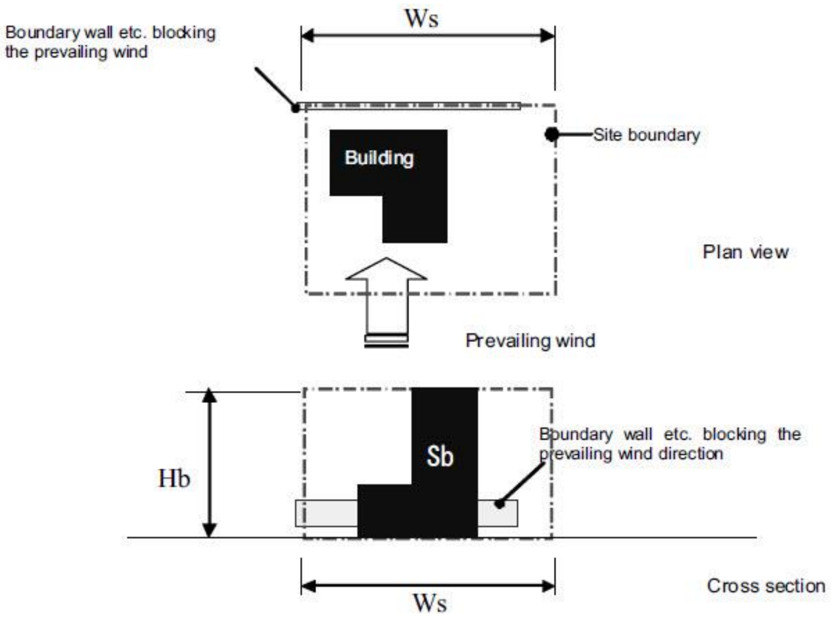


Figure 3.3: Calculation Procedures for the Building Elevation Area Ratio (JaGBC, 2008)

The *greenery provision and ecological features* sub-factor is calculated to mitigate the heat island effect by encouraging the increase of the green area spot in the project applying equation (3.12) (BCA, 2012b). Furthermore, the noise from building equipment and the amount of noise emitted from the building to the nearest receiver based on measurements and analysis must be taken into consideration, where the noise at the receiver must be 5db or as stated in other standards according to each country (HK GBC, 2012).

$$\mathrm{GnP} = \frac{\text{Quantity of green elements or Area} \times \text{Canopy Area} \times \text{radius}^2 \times \mathrm{GAI}}{\text{Site Area}} \tag{3.12}$$

Where:

GnP = green area provision ratio; and
GAI = green area index.

3.5.2 Transportation Criterion

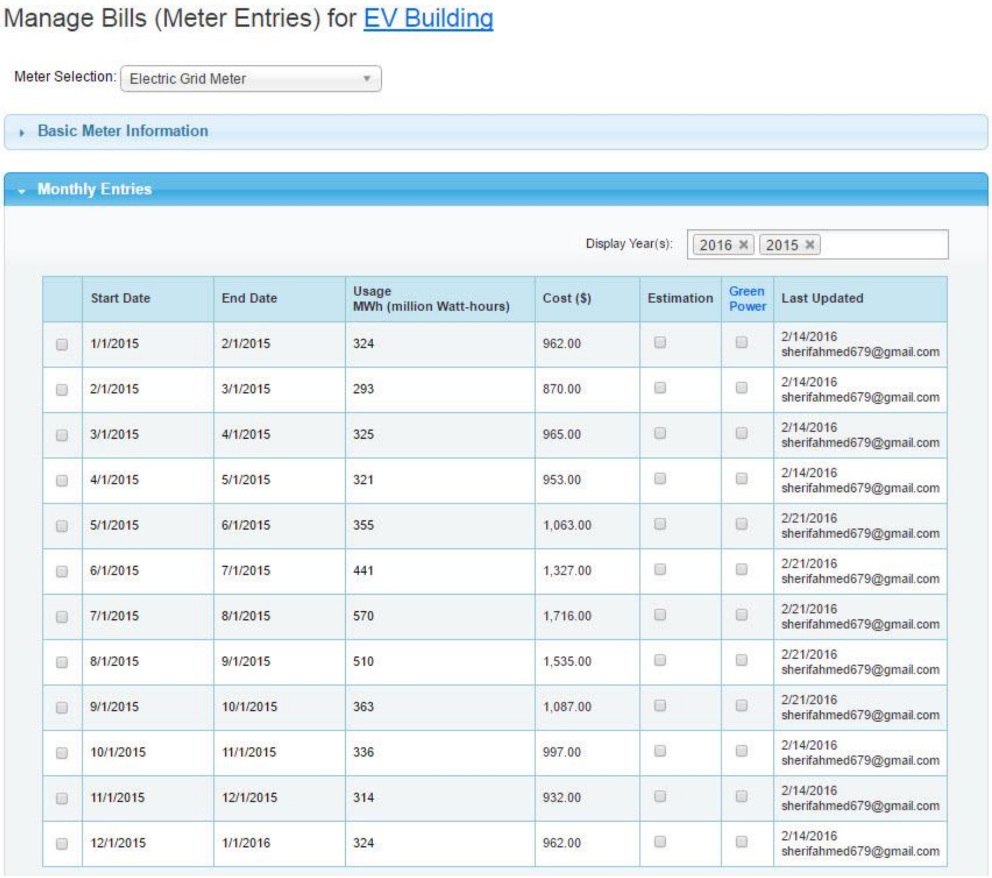
The transportation criterion is comprised of four factors and five sub-factors. The *cyclist facilities* and *carpooling* are qualitative sub-factors, which are located under *cyclist facilities and alternative methods of transport* factor. The factors *public transport accessibility and community accessibility*, *provision of maximum car parking capacity* and *provision of low-emitting and fuel-efficient vehicles* are all qualitative. Alternately, the reduction in *conventional commuting trips* sub-factor under *cyclist facilities and alternative methods of transport* is a quantitative factor. It uses a random sample of regular occupants as in equation (3.13). Furthermore, there is difference between those who use conventional single occupancy vehicles and the others who uses alternative means of transportation for commuting. The ratio between individuals who use alternative means of transportation for commuting to the whole sample size represents the reduction in conventional commuting (Reduction $_{\text{conventional}}$), then the points are achieved according to the reduction percentage as shown in equation (3.14).

$$Required\ sample\ size = \frac{number\ of\ reqular\ occupants\ \times 752}{number\ of\ reqular\ occupants + 752} \tag{3.13}$$

$$Reduction_{conventional} = \left(\frac{no.of\ respondents\ uses\ alternative\ commuting}{total\ sample\ size}\right) \times 100 \tag{3.14}$$

3.5.3 Energy Criterion

Energy criterion is composed of four factors and fourteen sub-factors. The factor *provision of energy management* and all its related sub-factors, the *energy efficient circulation systems* sub-factor and the *high-efficiency boilers and hot water systems* sub-factor are all qualitative. In contrast, the *minimum energy performance* sub-factor is quantitative. It requires the historical data for energy consumption or simulation data. It includes four steps to obtain the final score: 1) data entry for the energy (electricity and natural gas consumption) in the Energy Star portfolio manager as shown in Figure 3.4 and Figure 3.5; 2) obtain the energy use intensity from Portfolio Manager as in Figure 3.6; 3) enter the EUI into the offline LEED calculator; and 4) obtain the percentage less than national average consumption to select the corresponding points (USGBC, 2009).



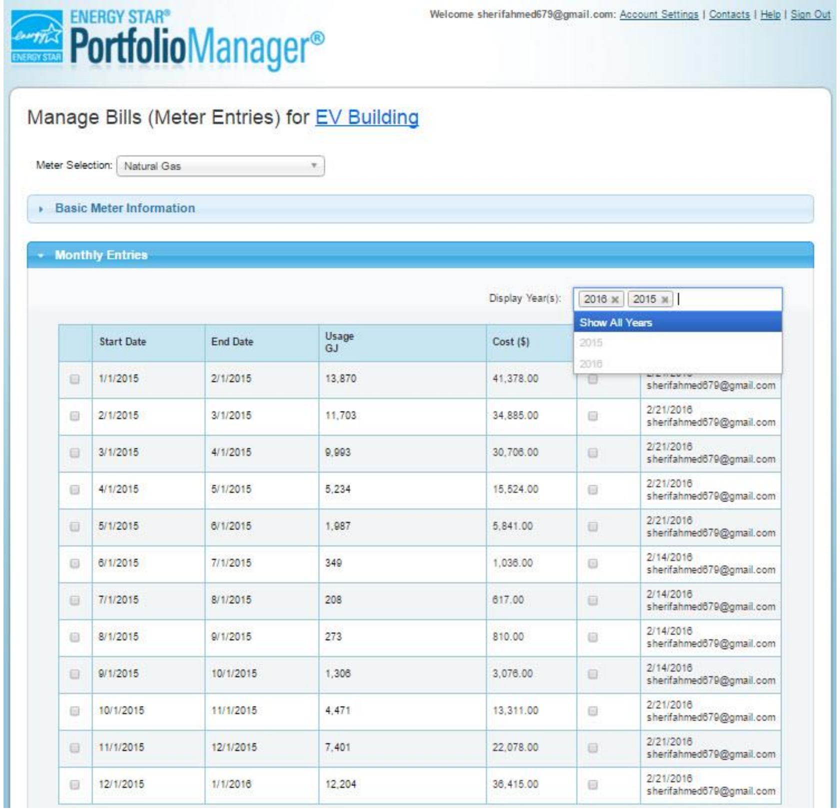
Manage Bills (Meter Entries) for EV Building

Meter Selection: Electric Grid Meter

Display Year(s): 2016 2015

	Start Date	End Date	Usage MWh (million Watt-hours)	Cost ($)	Estimation	Green Power	Last Updated
☐	1/1/2015	2/1/2015	324	962.00	☐	☐	2/14/2016 sherifahmed679@gmail.com
☐	2/1/2015	3/1/2015	293	870.00	☐	☐	2/14/2016 sherifahmed679@gmail.com
☐	3/1/2015	4/1/2015	325	965.00	☐	☐	2/14/2016 sherifahmed679@gmail.com
☐	4/1/2015	5/1/2015	321	953.00	☐	☐	2/14/2016 sherifahmed679@gmail.com
☐	5/1/2015	6/1/2015	355	1,063.00	☐	☐	2/21/2016 sherifahmed679@gmail.com
☐	6/1/2015	7/1/2015	441	1,327.00	☐	☐	2/21/2016 sherifahmed679@gmail.com
☐	7/1/2015	8/1/2015	570	1,716.00	☐	☐	2/21/2016 sherifahmed679@gmail.com
☐	8/1/2015	9/1/2015	510	1,535.00	☐	☐	2/21/2016 sherifahmed679@gmail.com
☐	9/1/2015	10/1/2015	363	1,087.00	☐	☐	2/21/2016 sherifahmed679@gmail.com
☐	10/1/2015	11/1/2015	336	997.00	☐	☐	2/14/2016 sherifahmed679@gmail.com
☐	11/1/2015	12/1/2015	314	932.00	☐	☐	2/14/2016 sherifahmed679@gmail.com
☐	12/1/2015	1/1/2016	324	962.00	☐	☐	2/14/2016 sherifahmed679@gmail.com

Figure 3.4: Electricity Data Entry in Portfolio Manager



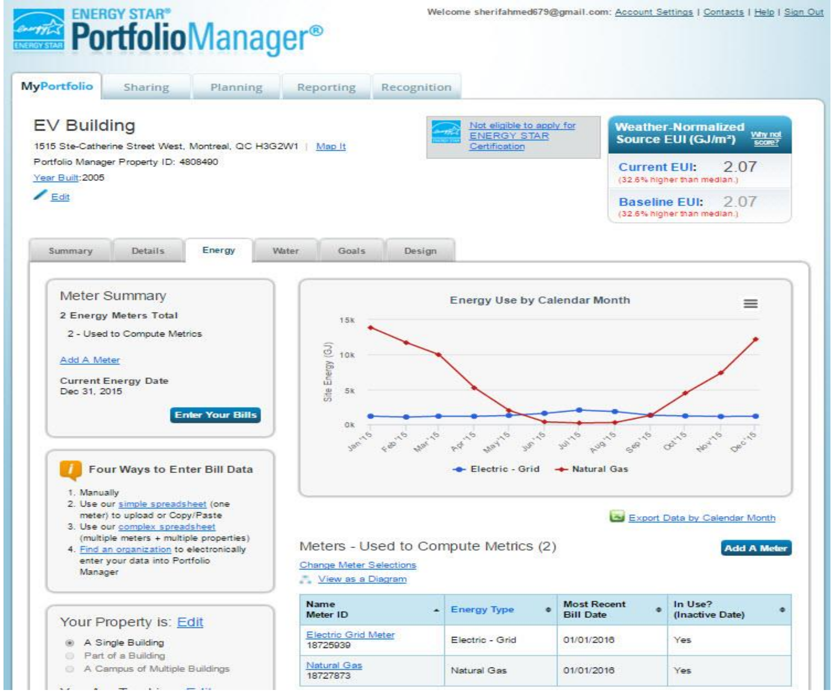
Manage Bills (Meter Entries) for EV Building

Meter Selection: Natural Gas

Display Year(s): 2016 × 2015 ×

	Start Date	End Date	Usage GJ	Cost ($)		
☐	1/1/2015	2/1/2015	13,870	41,378.00	☐	sherifahmed679@gmail.com
☐	2/1/2015	3/1/2015	11,703	34,885.00	☐	2/21/2016 sherifahmed679@gmail.com
☐	3/1/2015	4/1/2015	9,993	30,706.00	☐	2/21/2016 sherifahmed679@gmail.com
☐	4/1/2015	5/1/2015	5,234	15,524.00	☐	2/21/2016 sherifahmed679@gmail.com
☐	5/1/2015	6/1/2015	1,987	5,841.00	☐	2/21/2016 sherifahmed679@gmail.com
☐	6/1/2015	7/1/2015	349	1,036.00	☐	2/14/2016 sherifahmed679@gmail.com
☐	7/1/2015	8/1/2015	208	617.00	☐	2/14/2016 sherifahmed679@gmail.com
☐	8/1/2015	9/1/2015	273	810.00	☐	2/14/2016 sherifahmed679@gmail.com
☐	9/1/2015	10/1/2015	1,306	3,076.00	☐	2/14/2016 sherifahmed679@gmail.com
☐	10/1/2015	11/1/2015	4,471	13,311.00	☐	2/21/2016 sherifahmed679@gmail.com
☐	11/1/2015	12/1/2015	7,401	22,078.00	☐	2/21/2016 sherifahmed679@gmail.com
☐	12/1/2015	1/1/2016	12,204	36,415.00	☐	2/21/2016 sherifahmed679@gmail.com

Figure 3.5: Natural Gas Data Entry in Portfolio Manager



EV Building

1515 Ste-Catherine Street West, Montreal, QC H3G2W1

Portfolio Manager Property ID: 4808490

Year Built:2005

Weather-Normalized Source EUI (GJ/m²)

Current EUI: 2.07
(32.6% higher than median.)

Baseline EUI: 2.07
(32.6% higher than median.)

Meter Summary

2 Energy Meters Total

2 - Used to Compute Metrics

Current Energy Date
Dec 31, 2015

Four Ways to Enter Bill Data

1. Manually
2. Use our simple spreadsheet (one meter) to upload or Copy/Paste
3. Use our complex spreadsheet (multiple meters + multiple properties)
4. Find an organization to electronically enter your data into Portfolio Manager

Your Property is: Edit

● A Single Building
○ Part of a Building
○ A Campus of Multiple Buildings

Meters - Used to Compute Metrics (2)

Name Meter ID	Energy Type	Most Recent Bill Date	In Use? (Inactive Date)
Electric Grid Meter 18725939	Electric - Grid	01/01/2016	Yes
Natural Gas 18727873	Natural Gas	01/01/2016	Yes

Figure 3.6: Energy Use Intensity (EUI)

The *evaluation of thermal performance reduction of building envelope* sub-factor is used to enhance the overall performance of the building envelope to minimize solar heat gain and in turn, decrease the cooling load for the building. It is calculated as in equation (3.15) and equation (3.16) (BCA, 2004).

$$ETTV = 12(1 - WWR)U_w + 3.4(WWR)U_f + 211(WWR)(CF)(SC) \tag{3.15}$$

$$ETTV = \frac{A_1 \times ETTV_1 + A_2 \times ETTV_2 + \cdots + A_n \times ETTV_n}{A_1 + A_1 + \cdots + A_n} \tag{3.16}$$

Where:

ETTV = envelope thermal transfer value;
WWR = wall to window ratio;
$\mathrm{U_w}$ = thermal transmittance of opaque wall;
$\mathrm{U_f}$ = thermal transmittance of fenestration;
CF = correction factor for solar heat gain through fenestration;
SC = shading coefficients of fenestration;
$\mathrm{A_n}$ = area of envelope in direction n; and
$\mathrm{ETTV_n}$ = envelope thermal transfer value in direction n.

The *lighting efficiency and interior zoning control* sub-factor is applied to encourage the use of efficient lighting while maintaining the same lighting quality (BCA, 2012b) by utilizing equation (3.17) (Chan, 2008). Furthermore, the following sub-factors are dependent on the degree of improvement to achieve points: *renewable energy systems*, *energy efficient appliances and cloth drying facilities* and *energy-efficient AC equipment*.

$$E = \frac{n \times N \times F \times UF \times LLF}{A} \tag{3.17}$$

Where:

E = lighting efficiency;
n = number of lamps in each luminaire;
F = lumens per lamp;
UF = utilization factor;
LLF = light loss factor; and
A = area of the horizontal working plane.

3.5.4 Water Use Criterion

Water use criterion includes three factors and eleven sub-factors. The *water-tap efficiency in public* sub-factor areas is qualitative, in addition to all the sub-factors related to the *water management* factor. Contrariwise, the other sub-factors are quantitative. The *minimum indoor plumbing fixtures* and *additional indoor plumbing fixtures* sub-factors utilize the LEED water use calculator to calculate the percentage of water reduction over the baseline by entering the required data, such as the number of occupants, type of fixtures used and their water consumption (flush rate or flow rate) (USGBC, 2009). The *water recycling & rainwater harvesting* sub-factor is applied to encourage a reduction in the use of potable water and the use of either grey water or other water harvested from rain (BRE, 2015; GBC Indonesia, 2011; GBI, 2011; HK GBC, 2012; JaGBC, 2008).

3.5.5 Indoor Environment Quality Criterion:

This criterion is composed of six factors and twenty-five sub-factors. All the sub-factors are qualitative except the following: 1) *natural lighting and external views*; 2) *minimum IAQ* *performance*; 3) *increased ventilation performance*; and 4) *localized ventilation & ventilation in common areas*. The *natural lighting and external views* sub-factors possesses two methods of calculation: 1) using simulation and proving that 50% of the regularly occupied areas have illumination of a minimum of 25 foot candles (269.1 lumen/m^2) and a maximum of 500 foot candles (5381.9 lumen/m^2); 2) using the calculation of product of visible light transmittance (VLT) and wall floor area ratio as (WFR) as shown in equation (3.18) and equation (3.19), where (WA) is the window area and (FA) is the floor area (USGBC, 2009).

$$0.150 < (VLT) \times (WFR) < 0.180 \tag{3.18}$$

$$WFR = WA/FA \tag{3.19}$$

Where:

VLT = visible light transmittance;
WFR = number of lamps in each luminaire;
WA = window area; and
FA = floor area.

Minimum IAQ performance and *increased ventilation performance* sub-factors are applied to improve the air quality in buildings; hence, preserving the health and wellbeing of the occupants. It is governed by equations (3.20) and (3.21). Then, points are awarded according to the ratio between the calculated required outdoor airflow and the required by the standard (ASHRAE, 2007; USGBC, 2009).

$$Vbz = R_p \times P_z + R_a \times A_z \tag{3.20}$$

$$Aoz = \frac{Vbz}{E_z} \tag{3.21}$$

Where:

Vbz = lighting efficiency;

R_p = outdoor air rate required per person;

P_z = zone population;

R_a = outdoor air rate required to ventilate area;

A_z = floor area of the zone;

Aoz = zone outdoor air flow; and

E_z = outdoor air rate required per person.

The first section in *purchase sustainable cleaning products and materials* sub-factor in *green cleaning* factor is based on the ratio between the amount of sustainable cleaning products and/or materials used during the performance period to the total the amount of cleaning products and/or materials utilized in the same period ($R_{\text{sustainable cleaning}}$), and points are scored based on equation (3.22) (USGBC, 2009).

$$R_{sustainable\ cleaning} = \frac{Sustainable\ cleaning\ products}{total\ cleaning\ products} \times 100 \geq 30\% \qquad (3.22)$$

3.5.6 Building Management Criterion

This criterion is composed of seven factors and nine sub-factors all of which are qualitative as they are considering plans, procedures and policies to fulfil the required objectives and achieve points.

3.6 Sustainability-Based Rehabilitation Optimization Model

The sustainability assessment rehabilitation model is an optimization model. It aims to provide the decision-makers and building stakeholders with a robust tool to help them upgrade the sustainability of their buildings within a predefined available budget. Unfortunately, this budget is usually tight and consequently requires compromises and trade-offs among various alternatives. The model is comprised of four phases as shown in Figure 3.1: 1) current sustainability assessment phase; 2) constraint identification and input data phase; 3) model development phase; and 4) output phase.

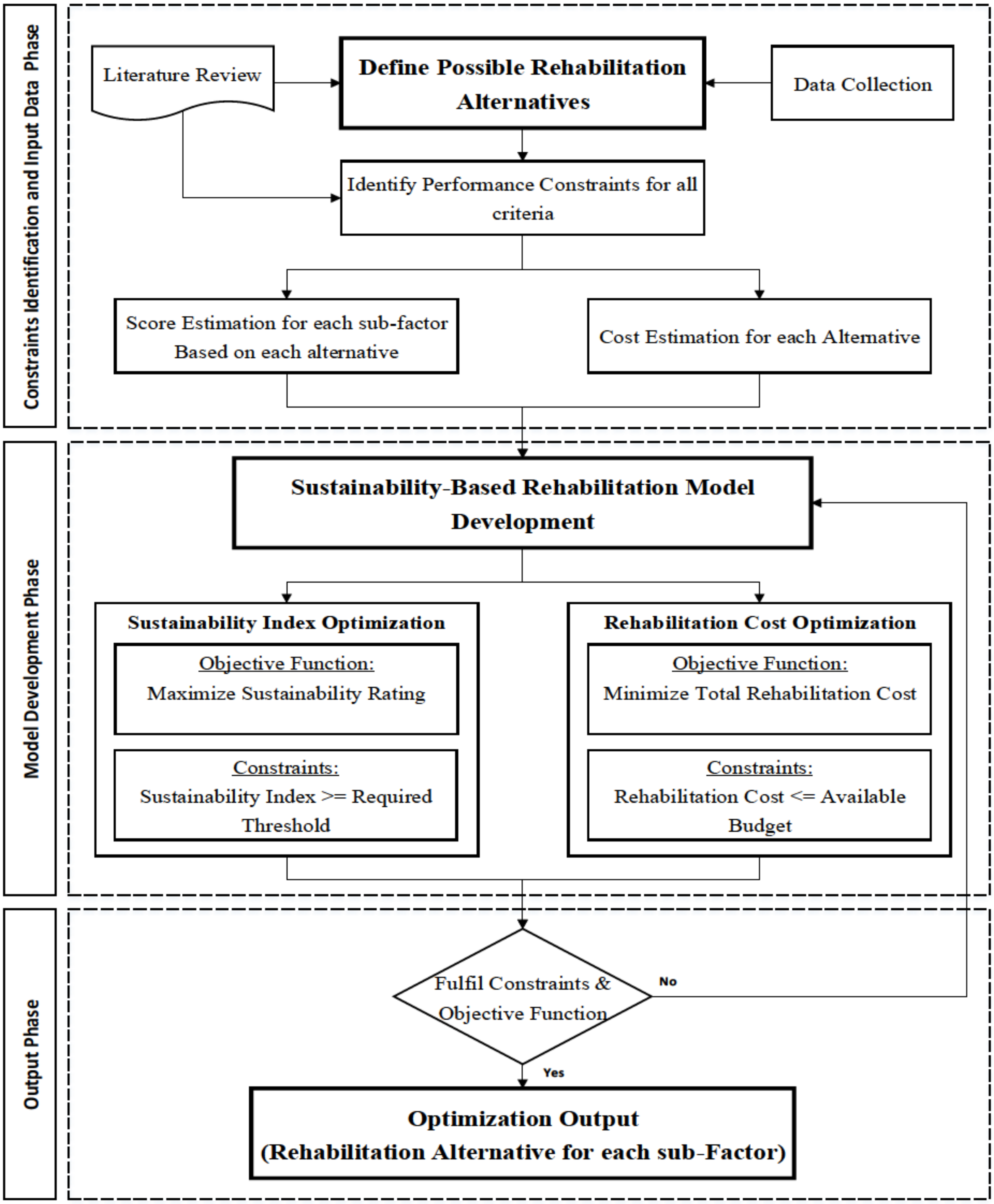
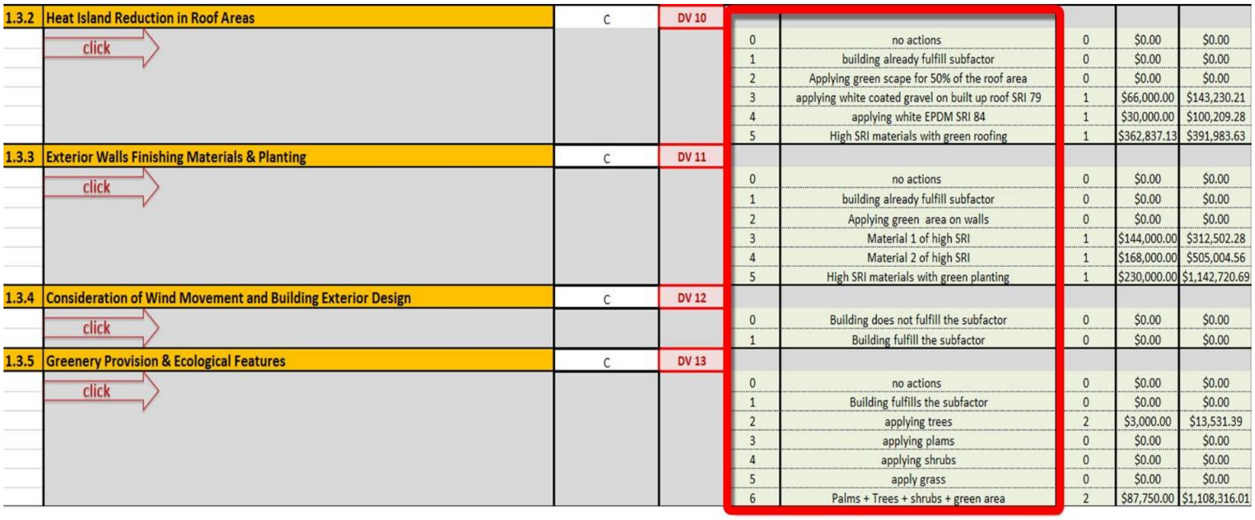


Figure 3.7: Sustainability-Based Rehabilitation Model Development Methodology

3.6.1 *Current Sustainability Assessment Phase*

In this phase, the current sustainability status of a building is calculated through four steps: 1) a Revit model of the building is built utilizing the available cad drawings of the entire floor of the building; 2) the developed model is exported to IES VE software to stand for the energy performance of the building by performing simulations in the software, as well as the daylighting intensity in the perimeter zones of the building exposed to daylight; 3) the BIM data from Revit and the energy and daylight simulation data is compiled and entered into the previously developed sustainability assessment model to begin the evaluation procedures and obtain the degree of sustainability of the building as previously described; and 4) possible available rehabilitation alternatives are estimated and introduced in the Excel calculation sheet as shown in Figure 3.8.



1.3.2	Heat Island Reduction in Roof Areas	C	DV 10					
	click			0	no actions	0	$0.00	$0.00
				1	building already fulfill subfactor	0	$0.00	$0.00
				2	Applying green scape for 50% of the roof area	0	$0.00	$0.00
				3	applying white coated gravel on built up roof SRI 79	1	$66,000.00	$143,230.21
				4	applying white EPDM SRI 84	1	$30,000.00	$100,209.28
				5	High SRI materials with green roofing	1	$362,837.13	$391,983.63
1.3.3	Exterior Walls Finishing Materials & Planting	C	DV 11					
	click			0	no actions	0	$0.00	$0.00
				1	building already fulfill subfactor	0	$0.00	$0.00
				2	Applying green area on walls	0	$0.00	$0.00
				3	Material 1 of high SRI	1	$144,000.00	$312,502.28
				4	Material 2 of high SRI	1	$168,000.00	$505,004.56
				5	High SRI materials with green planting	1	$230,000.00	$1,142,720.69
1.3.4	Consideration of Wind Movement and Building Exterior Design	C	DV 12					
	click			0	Building does not fulfill the subfactor	0	$0.00	$0.00
				1	Building fulfill the subfactor	0	$0.00	$0.00
1.3.5	Greenery Provision & Ecological Features	C	DV 13					
	click			0	no actions	0	$0.00	$0.00
				1	Building fulfills the subfactor	0	$0.00	$0.00
				2	applying trees	2	$3,000.00	$13,531.39
				3	applying plams	0	$0.00	$0.00
				4	applying shrubs	0	$0.00	$0.00
				5	apply grass	0	$0.00	$0.00
				6	Palms + Trees + shrubs + green area	2	$87,750.00	$1,108,316.01

Figure 3.8: Example of the Introduced Alternatives in Excel Calculation Sheet

3.6.2 *Constraints Identification and Input Data Phase*

All the equations that are illustrated in Section 3.5 and its related subsections represent the performance constraints. These equations estimate the performance of each factor based on the thresholds introduced in these formulas and identify whether these thresholds are satisfied or not.

Consequently, each sub-factor score within the sustainability assessment model is calculated for each of the introduced alternatives as shown in the fifth column in Figure 3.8. Moreover, the unit cost and the total LCC for each of the alternatives is determined as shown in the seventh and eighth columns, respectively, in the above-mentioned figure. The scores and the cost of each alternative represent the input data to the sustainability-based rehabilitation model.

3.6.3 Model Development Phase

The model development phase is the core of the optimization process in which a multi-objective optimization algorithm has been developed using Matlab software. As shown in Figure 3.9, the multi-objective optimization algorithm is comprised of two main objectives: maximizing the BSAR using equation (3.23) and minimizing the total life cycle cost of the rehabilitation alternatives as shown in equation (3.24), which is dependent on interest rate and the inflation rate as illustrated in equation (3.25). Hence, after the optimization process, the model is subjected to three groups of constraints: 1) performance; 2) boundary; and 3) score. These constraints are explained as follows:

i. Performance Constraints

The performance constraints are utilized to confirm that the alternatives of the decision variables (DV) achieved the required performance. If an alternative does not meet the required performance threshold (constraints), this alternative will have no effect on the upgrade score or life cycle cost (LCC) as will be illustrated in the score constraints. Each performance constraint is related to a specific decision variable in a criterion. In the site and ecology criterion, there are four performance constraints. The first constraint is the heat island effect for non-roofed areas, which is related to ninth decision variable (DV9) as shown in equation (3.26). The second constraint is the heat island for roofed areas is related to DV10 to measure if the total weighted areas for introduced alternatives is greater than or equal to the net roof area as shown in equation (3.27). The third constraint in this criterion is for DV11, which detects if the ratio between the planted area and the material with high albedo to the total exterior area is greater than 20%, if so, the alternative fulfils the constraint as illustrated in equation (3.28). The fourth constraint is the greenery provision constraint as illustrated in equation (3.29), such that the greenery provision ratio must be greater than zero and is related to DV13.

Moreover, in the transportation criterion, there is one constraint related to the reduction in conventional commuting methods, such that this ratio is greater than or equal to 10%, which is related to DV18. In the energy criterion, there are three constraints. The first one is related to DV24, which examines if the energy use intensity of the building is greater than 19% of the energy use intensity of the median in the same country as shown in equation (3.31). The second constraint detects if the thermal performance of the building is greater than 45% as shown in equation (3.32). The third constraint is the energy efficiency of lighting, which must be greater than or equal to 250 W/m^2 as shown in equation (3.33) and is related to DV38.

The water criterion is comprised of two constraints. The first constraint is the water tap efficiency for the public areas, which must be greater than or equal to 50% as shown in equation (3.34), and is related to DV52. The second constraint is related to DV56, where the isolation valve ratio must be greater than or equal to 25% as demonstrated in equation (3.35).

ii. Boundary Constraints

There are 134 decision variables; each one is comprised of a number of alternatives that range from two as a minimum and twenty-nine as maximum. Each alternative is given a number range from zero, which represents the first alternative, to the upper bound (Ub), which represents the maximum number of alternatives from one to twenty-eight, in the case of two alternatives or twenty-nine alternatives, respectively. Each alternative defines two values, which are the score it achieves and its life cycle cost if applied. Therefore, the selected alternative number in each decision variable in the population should be within the bounds of the decision variable, as each alternative possesses distinct characteristics as illustrated. Hence, there are 134 boundary constraints within the optimization process and it is governed by equation (3.36) for the minimum bound and equation (3.37) for the maximum bound.

iii. Decision Variable Score Constraints

Each alternative achieves a number of points (score) according to its percentage of fulfilment of the constraints in the case of quantitative attributes, or its degree of fulfilment of the qualitative requirements in the case of qualitative attributes as illustrated in detail in Chapter 6. Some of the alternatives in a decision variable may not fulfil the requirements and, in turn, score zero points or some of these alternatives may score fewer points than the already achieved points in this sub-factor. Consequently, a constraint is set to use the score of the alternative if it is not included in the two cases just mentioned. If not, the alternative is automatically given the score of the corresponding achieved sub-factor, and in turn, it will have no effect on the upgrade of the sustainability and its life cycle will be zero.

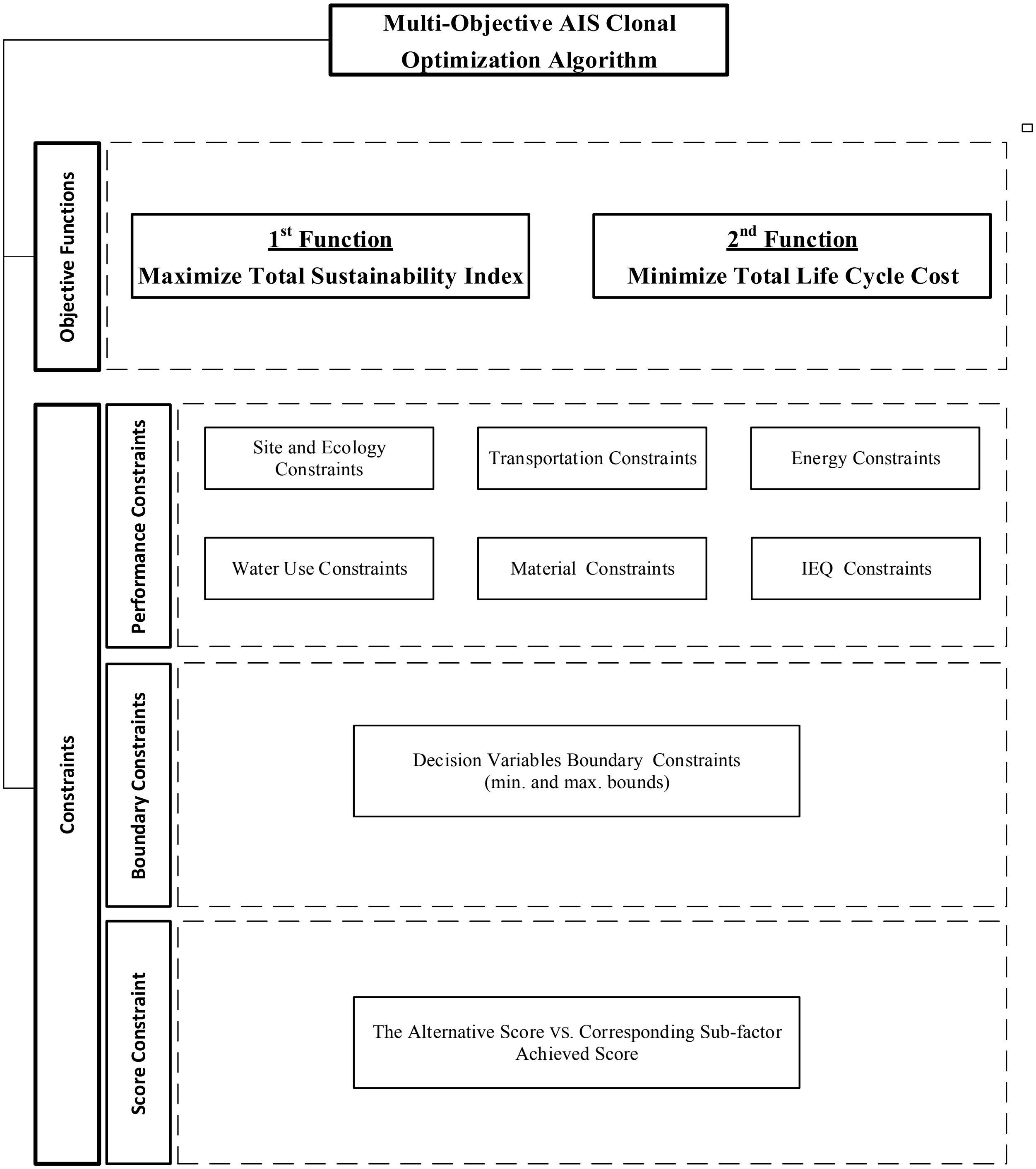


Figure 3.9 : Optimization Objective Functions and Constraints

$$Maximize\ F_1 = \max(BSAR) = \max\left(\frac{\sum_{j=1}^{m} SC_j \times WG_j}{\sum_{j=1}^{m} (\mathrm{SC}_j)_{max} \times WG_j} \times 100\right) \tag{3.23}$$

$$Minimize\ F_2 = LCC = \sum_{k=1}^{n}\sum_{j=1}^{m}\sum_{i=1}^{l}\sum_{x=1}^{y} CC_i + \frac{RC_i}{(1+r)^x} \tag{3.24}$$

$$\mathrm{r} = \frac{(1+i)}{(1+f)} - 1 \tag{3.25}$$

Where:

LCC = life cycle cost;

$\mathrm{CC_i}$ = capital cost for ith sub-factor;

$\mathrm{RC_i}$ = recurring cost for ith sub-factor;

r = real interest rate;

i = interest rate;

f = inflation rate;

n = total number of criteria; and

m = total number of factors.

Subject to:

$$Q \geq \frac{Nonroofed\ area}{2} \tag{3.26}$$

$$SRI_{roof\ area} \geq (A_{total} - A_{ocu.}) \tag{3.27}$$

$$M_{ratio} \geq 20\ \% \tag{3.28}$$

$$\mathrm{GnP} > 0 \tag{3.29}$$

$$Reduction_{conventional} \geq 10\% \tag{3.30}$$

$$EUI_b \geq 0.81\ EUI_m \tag{3.31}$$

$$ETTV \geq 45\ \% \tag{3.32}$$

$$E_l \geq 250\ W/m^2 \tag{3.33}$$

$$E_{tab} \geq 50\ \% \tag{3.34}$$

$$I_{valve} \geq 25\ \% \tag{3.35}$$

$$DV_i \geq 0 \qquad , i = 1,2, \ldots \ldots ,134 \tag{3.36}$$

$$DV_i \leq Ub_i \qquad , i = 1,2, \ldots \ldots ,134 \tag{3.37}$$

$$SC\ DV_i > SC_{subf_i} \qquad , i = 1,2, \ldots \ldots ,134 \tag{3.38}$$

Where:

Q = qualified site area;

$SRI_{roof\ area}$ = weighted average roof area occupied with high albedo;

M_{ratio} = area of roof with low slope;

GnP = greenery provision;

$R_{conventional}$ = reduction in conventional commuting trips;

EUI_b = energy use intensity;

$ETTV$ = envelope thermal transmittance value;

E_l = lighting efficiency;

E_{tab} = public tab efficiency;

I_{valve} = isolation valves efficiency;

DV_i = index of the i^th decision variable;

Ub_i = upper boundary (maximum value for i^th decision variable);

$SC\ DV_i$ = score of the i^th decision variable; and

SC_{subf_i} = score of the i^th sub-factor.

3.6.4 Output Phase:

In the final stage, a list of solutions is developed, such that its size depends on the archive size discussed in Section 2.7.2. These solutions satisfy all the identified constraints (i.e. performance, sustainability rating and budget). Moreover, each single solution contains a list of decision variables, which include 134 decision variables mentioned earlier. Each decision variable corresponds to an alternative that satisfies the required constraints.

3.7 Integrated Sustainability Assessment Tool

The proposed sustainability assessment tool is an integration of a group of software and developed models as shown in Figure 3.10. The whole process is comprised of five phases, which will be explained in the following subsections. The main aim of this integrated process is to provide decision-makers with a comprehensive view concerning the sustainability of their building. This overview includes both the current sustainability rating of their building and the optimal rehabilitation alternatives required to upgrade the sustainability rating of their building within the available budget. It will be illustrated as follows:

3.7.1 Data Input Phase

This phase depends on the data collected from a case study. These data are necessary for the assessment of each criterion as described in the above sections, in addition to the CAD drawings of the case study building.

3.7.2 BIM Modelling & Energy Simulation Phase

All the drawings collected from the first stage are used to execute the BIM modelling in the Revit software. Besides, the data obtained previously will be utilized in the modelling data entry, such as the type of walls, type of curtain wall glazing, the floor height, the building orientation, the type of the interior partitions, type of floor and ceiling layers. After the building model is completed in the Revit software, it is exported to the energy simulation software, Integrated Environmental Solutions Software (IES). Afterward, the model is imported into the IES and then checked for any unenclosed space to be ready for simulation. Another group of data is then required to perform the simulation: 1) the operation schedule of the building; 2) the main holidays of the country; 3) the type of HVAC system; 4) lighting fixture type and intensity; and 5) the total energy load of the other appliances installed in the building.

3.7.3 Calculation Sheet Preparation Phase

Data is collected from different sources and include the following: 1) the primary data gathered from the first phase; 2) data from Revit model such as the number of floors, the area of exterior glazing, the area of each floor, the types of finishing materials…etc.; 3) data from IES model, which include the total annual energy consumption, annual electricity consumption, annual natural gas consumption, carbon dioxide equivalent produced as a result of energy consumption, the monthly and daily energy consumption, the maximum energy peak demand; and 4) the weight of each criterion and factor obtained from Fuzzy TOPSIS model.

3.7.4 The Sustainability Assessment Model Phase

This phase concerns the calculation of the current sustainability rating based on the collected data and the Excel calculation sheet prepared in the previous step. The model calculates the score of each of the sustainability assessment attributes (i.e. criteria, factors and sub-factors). In addition, it calculates the score and LCC of the selected rehabilitation alternatives based on the performance constraint related to each assessment attribute.

3.7.5 The Sustainability Based Rehabilitation Model Phase

In this phase, the sustainability-based rehabilitation model aims to provide the decision-makers with optimal rehabilitation alternatives required to upgrade the sustainability rating of their building within the available budget. The input of this model is comprised of four main groups: 1) score of each rehabilitation alternative based on the performance constraints fulfilment; 2) cost of each rehabilitation alternative; 3) the available budget constraint; and 4) the range of the required sustainability index constraint. The output of this model is a number of sets of optimal rehabilitation alternatives needed to upgrade the sustainability of the building within the available budget.

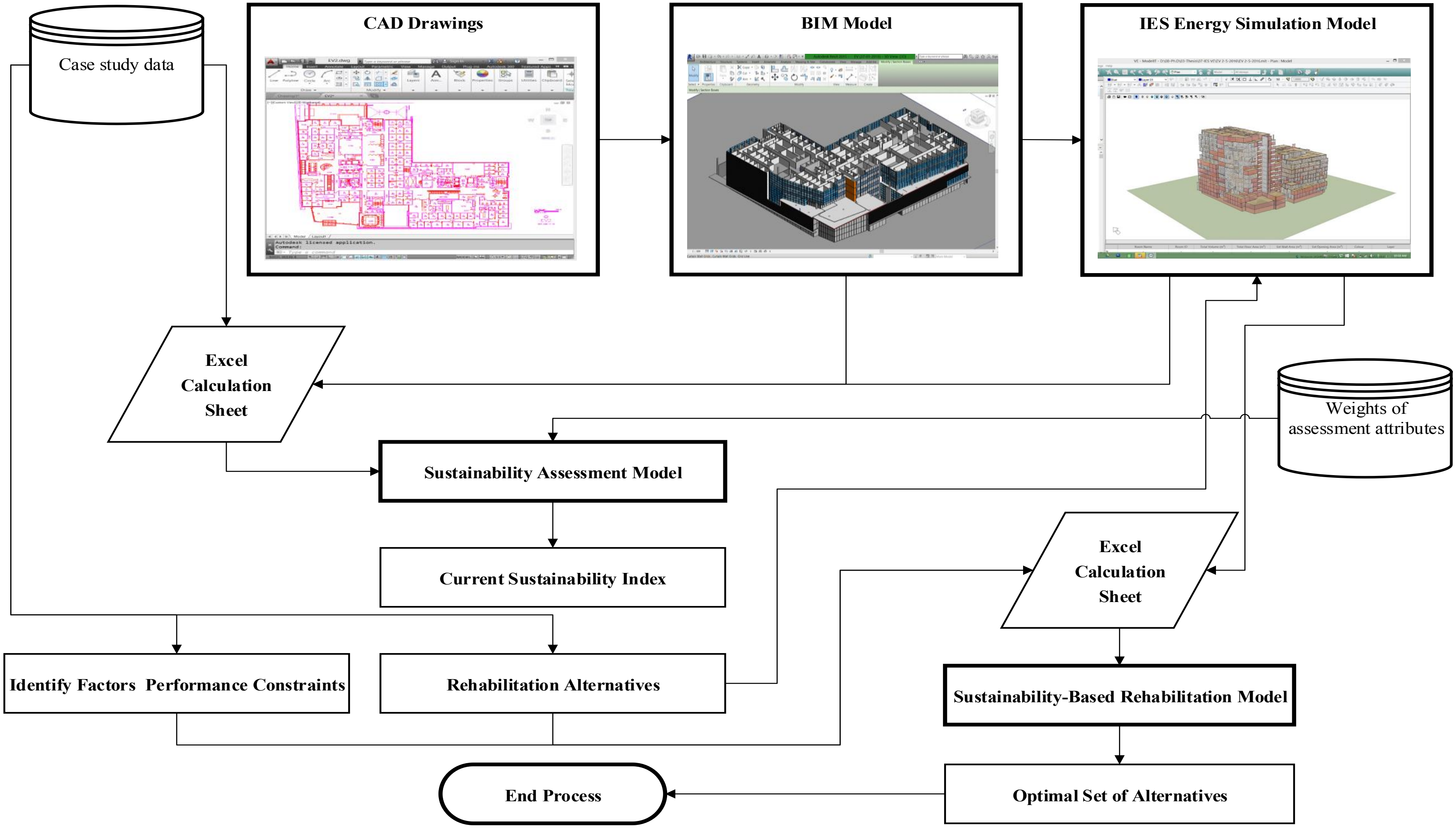


Figure 3.10 An Integrated Sustainability Assessment Tool

3.8 Summary

This chapter introduced the research methodologies implemented to conduct this research. The first research methodology is the generic one, which describes the procedures that have been followed starting from the literature review, passing through the developing methodologies of the sustainability assessment model and the rehabilitation-based optimization model up to reaching the conclusion and recommendation chapter. In addition, a detailed methodology of the development of the sustainability assessment model was introduced in this chapter. This methodology illustrates the steps followed to determine the weights that are assigned for each assessment attribute and the score determination procedures until determination of the BSAR, which is the result of the assessment. The methodology of the development of the sustainability-based rehabilitation model has been introduced. This methodology illustrated the different phases of the model development starting from defining the decision variables and alternatives followed by the model development phase that addresses the constraints and the objective functions and ending with the output phase. The last methodology illustrated in this chapter was the integrated sustainability assessment and rehabilitation tool development. It demonstrates the different steps of the tools to determine the sustainability of the building and its optimized upgrade alternatives. Finally, the following chapters will demonstrate each methodology in detail starting with the following chapter, which describes the development of the optimization model.

CHAPTER 4: MULTI-OBJECTIVE OPTIMIZATION MODEL DEVELOPMENT

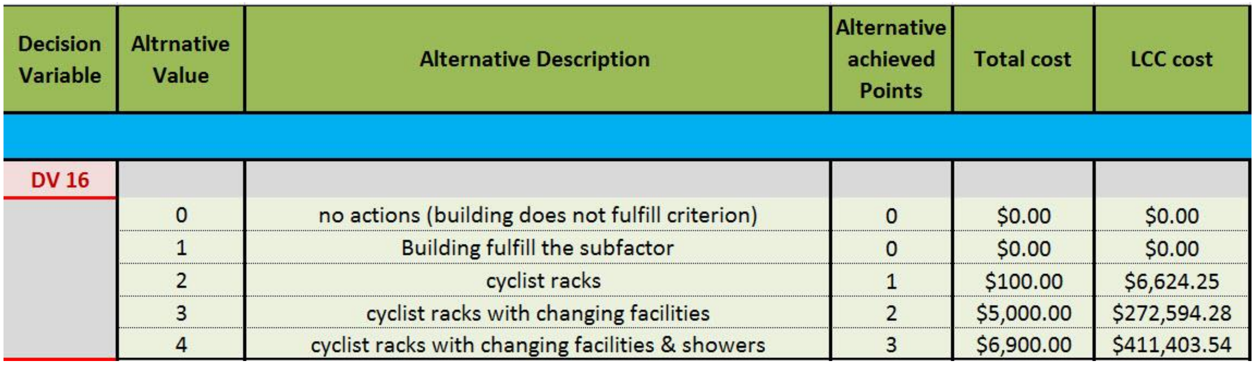
4.1 Chapter Overview

This chapter illustrates in detail the main features of the artificial immune optimization method (AIS) which is applied for the sustainability-based rehabilitation optimization model. Moreover, this chapter demonstrates the developed Matlab code to run the optimization algorithms. Mainly, the chapter comprises three sections, which are the optimization algorithm basic features, the model development, and the summary of the chapter. The optimization algorithm basic features tackle several topics such as the representation of the decision variables, the antibody-chromosome representation, the affinity evaluation and ranking of antibodies, dominated and non-dominated solutions distinction, the archive size and the adaptive archive, the crossover, somatic mutation and hyper mutation. Furthermore, the model development demonstrates the main concept of the algorithm, the code input boundaries, the objective functions evaluations and solution ranking, the archive and the adaptive grid, and the generation evolution. Finally, this chapter ends with a brief summary pinpointing the main purpose of developing this optimization algorithm and the benefits of utilizing AIS optimization method.

4.2 AIS Basic Features

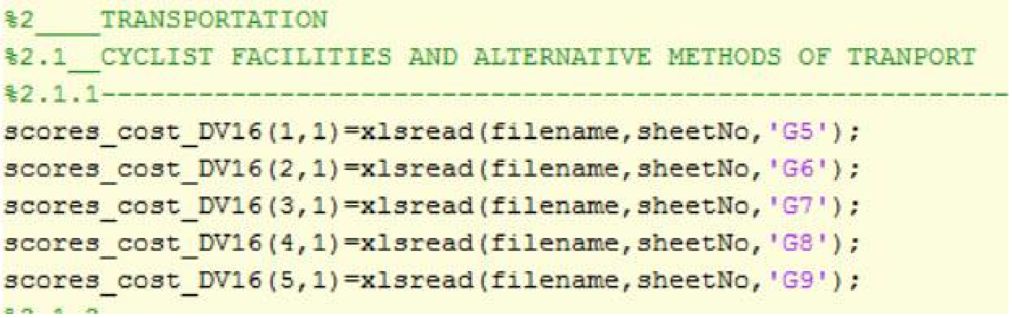
4.2.1 Representation of Decision Variables

As illustrated in the previous chapters, the assessment of sustainability deals with seven criteria which comprises factors and sub-factors. Each sub-factor represented in the optimization process was an individual decision variable. Each decision variable embodies four different types of information which are the number of the alternatives, the sustainability score that can be achieved, the total cost, and the life cycle cost as shown in Figure 4.1. Additionally, The Matlab software reads this information and stores it as a data base in a matrix called (scores_cost_DV), which is recalled in the optimization process as shown in Figure 4.2. The number of alternatives varies from one decision variables to another ranging from two as minimum and twenty-eight as maximum. The optimization process selects the sets of best alternatives, which fulfils the optimization objective functions. The whole sustainability assessment comprises one hundred and thirty-four decision variables distributed among the seven criteria.



Decision Variable	Altrnative Value	Alternative Description	Alternative achieved Points	Total cost	LCC cost
DV 16					
	0	no actions (building does not fulfill criterion)	0	$0.00	$0.00
	1	Building fulfill the subfactor	0	$0.00	$0.00
	2	cyclist racks	1	$100.00	$6,624.25
	3	cyclist racks with changing facilities	2	$5,000.00	$272,594.28
	4	cyclist racks with changing facilities & showers	3	$6,900.00	$411,403.54

Figure 4.1: Types of Information for Each Decision Variables



```
%2____TRANSPORTATION
%2.1__CYCLIST FACILITIES AND ALTERNATIVE METHODS OF TRANPORT
%2.1.1--------------------------------------------------
scores_cost_DV16(1,1)=xlsread(filename,sheetNo,'G5');
scores_cost_DV16(2,1)=xlsread(filename,sheetNo,'G6');
scores_cost_DV16(3,1)=xlsread(filename,sheetNo,'G7');
scores_cost_DV16(4,1)=xlsread(filename,sheetNo,'G8');
scores_cost_DV16(5,1)=xlsread(filename,sheetNo,'G9');
```

Figure 4.2: The Reading of Decision Variables information in Matlab

4.2.2 Antibody Chromosomal Representation

Each generation in the optimization consists a population with predefined size. Each population comprises number of solutions which are called antibodies in the AIS algorithm. An antibody contains a combination of alternatives of the total number of the decision variables.

In order to perform the AIS mutations, each decision variable is represented as a binary string with a number of bits based on the number of alternatives it possesses and is governed by equation (4.1). In this research, the length of a single string is five, because the maximum number of alternatives in a single decision variable is 28. Each antibody contains a group of strings called chromosome. Accordingly, by utilizing a group of 134 strings of a length of five we get the total length of a single chromosome as illustrated in Figure 4.3.

$$2^{l} \geq N_c \tag{4.1}$$

Where:

N_c = maximum number of alternatives in each decision variable; and

l = number of bits in a single string.

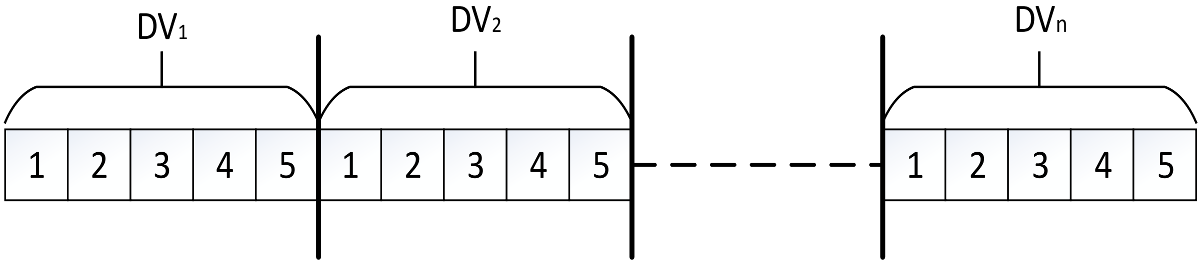
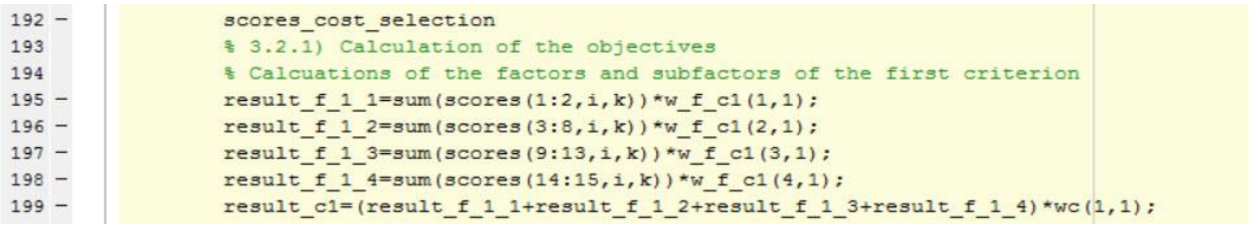


Figure 4.3: Antibody-Chromosomal Representation

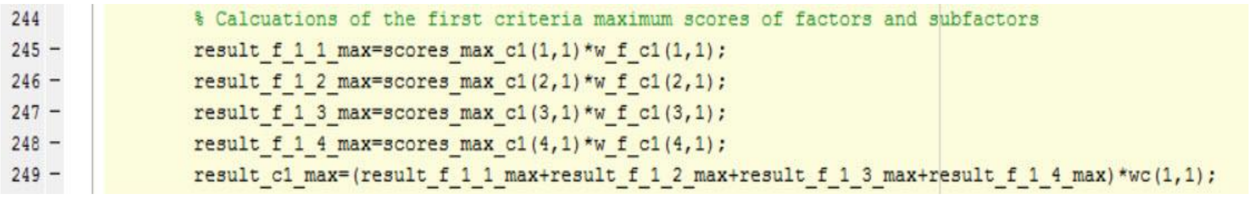
4.2.3 Affinity Evaluation

Affinity evaluation in the AIS optimization algorithm means the calculation of the objective functions for the existing population in each generation. Each antibody will have different value than the others according to its individual decision variables. Consequently, each antibody achieves the objective functions with a different extent, in which one gives better results than the others. In the optimization process, the antibodies of the best results and higher affinity are more vulnerable to be selected as the best antibody for the following generations until another one is found to achieve better values for the objective functions. In the case of this research, measuring the affinity is based on two objective functions as illustrated in the previous chapter. Moreover, calculating the BSAR, the first objective, is based on the determination of the criteria results (sustainability indices of criteria) for the achieved points and the maximum available criteria result as described in the code as shown in Figure 4.4 and Figure 4.5. Accordingly, the BSAR is the percentage between the criteria result of the achieved points and the maximum available criteria result. The total life cycle cost (LCC) calculation, the second objective, is the summation of all the determined LCCs of all the sub-factors as shown in Figure 4.6.



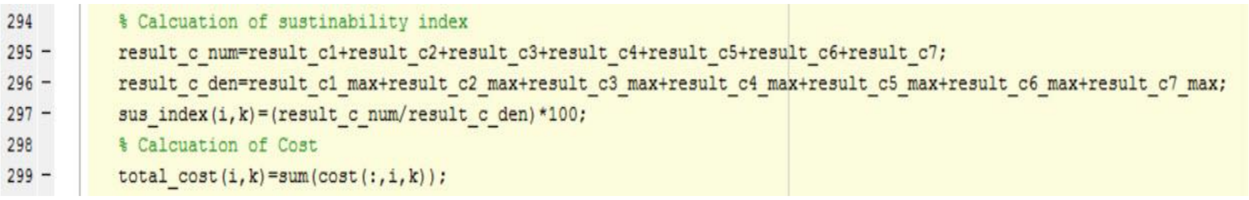
```
scores_cost_selection
% 3.2.1) Calculation of the objectives
% Calcuations of the factors and subfactors of the first criterion
result_f_1_1=sum(scores(1:2,i,k))*w_f_c1(1,1);
result_f_1_2=sum(scores(3:8,i,k))*w_f_c1(2,1);
result_f_1_3=sum(scores(9:13,i,k))*w_f_c1(3,1);
result_f_1_4=sum(scores(14:15,i,k))*w_f_c1(4,1);
result_c1=(result_f_1_1+result_f_1_2+result_f_1_3+result_f_1_4)*wc(1,1);
```

Figure 4.4: The Calculation Code for a Criterion sustainability index



```
% Calcuations of the first criteria maximum scores of factors and subfactors
result_f_1_1_max=scores_max_c1(1,1)*w_f_c1(1,1);
result_f_1_2_max=scores_max_c1(2,1)*w_f_c1(2,1);
result_f_1_3_max=scores_max_c1(3,1)*w_f_c1(3,1);
result_f_1_4_max=scores_max_c1(4,1)*w_f_c1(4,1);
result_c1_max=(result_f_1_1_max+result_f_1_2_max+result_f_1_3_max+result_f_1_4_max)*wc(1,1);
```

Figure 4.5: The Calculation Code for a Criterion Maximum sustainability index

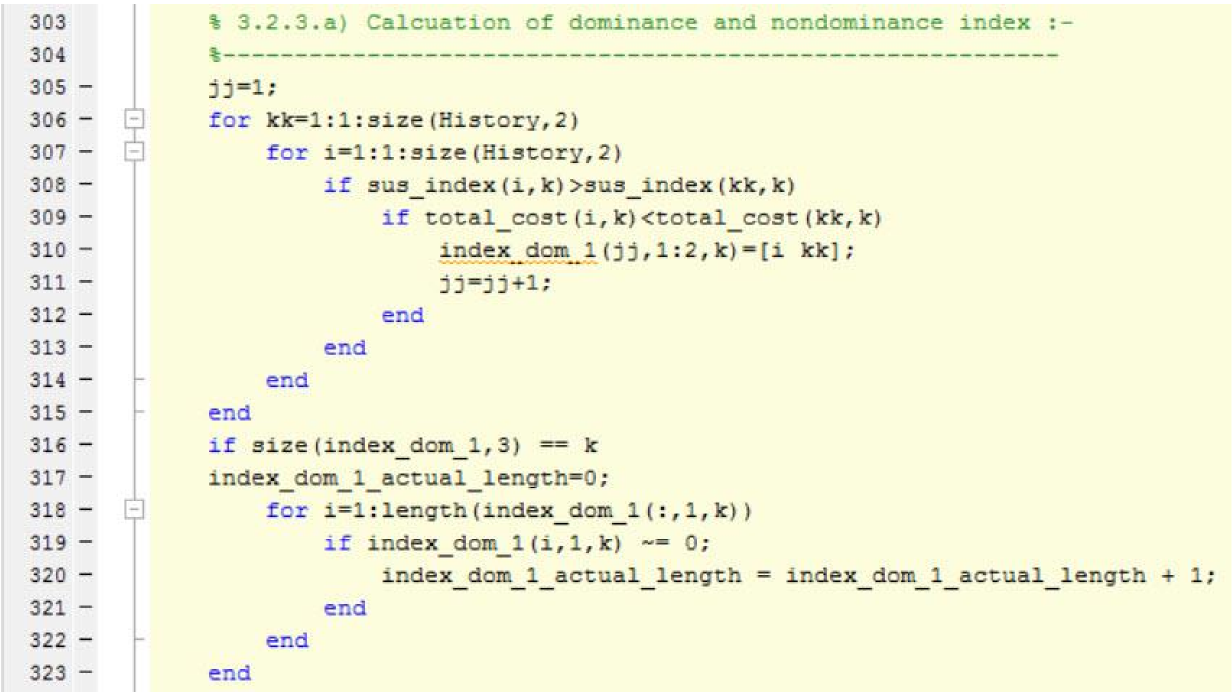


```
% Calcuation of sustinability index
result_c_num=result_c1+result_c2+result_c3+result_c4+result_c5+result_c6+result_c7;
result_c_den=result_c1_max+result_c2_max+result_c3_max+result_c4_max+result_c5_max+result_c6_max+result_c7_max;
sus_index(i,k)=(result_c_num/result_c_den)*100;
% Calcuation of Cost
total_cost(i,k)=sum(cost(:,i,k));
```

Figure 4.6: The Code for the Determination of BSAR and total LCC

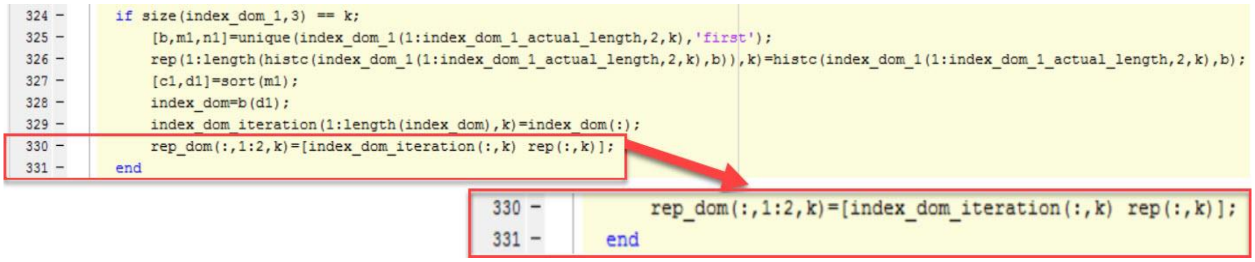
4.2.4 *Dominated Antibodies and Non-Dominated Antibodies*

Sorting of the antibodies according to their affinity requires comparing the affinity of all the antibodies in a population of a single generation with each other. The result of the comparison determines the non-dominated and the dominated antibodies. A non-dominated antibody is the superior one among all the other antibodies in a single generation, such that no other antibody capable to achieve higher affinity to this one in all the objectives. In this research, for example, the antibody (A) dominates antibody (B) if and only if (A) achieves higher sustainability index and lower LCC than (B) so the antibody (A) is called non-dominated and (B) is called dominated. As shown in Figure 4.7 the line number 308 and 309 in the Matlab Code checks the dominance and the non-dominance of the antibodies according to the affinity (the sustainability index and the LCC cost) of each other. The line 310 indicates the indices (i.e. position of antibodies in a population) of the dominated and non-dominated antibodies of all the antibodies in each generation. In addition, line 330 demonstrates the index of the dominated antibody and how many times it is dominated preparing for the ranking process.



```
% 3.2.3.a) Calcuation of dominance and nondominance index :-
%-----------------------------------------------------------
jj=1;
for kk=1:1:size(History,2)
    for i=1:1:size(History,2)
        if sus_index(i,k)>sus_index(kk,k)
            if total_cost(i,k)<total_cost(kk,k)
                index_dom_1(jj,1:2,k)=[i kk];
                jj=jj+1;
            end
        end
    end
end
if size(index_dom_1,3) == k
index_dom_1_actual_length=0;
    for i=1:length(index_dom_1(:,1,k))
        if index_dom_1(i,1,k) ~= 0;
            index_dom_1_actual_length = index_dom_1_actual_length + 1;
        end
    end
end
```

Figure 4.7: The Code for the Affinity Comparison among the Antibodies



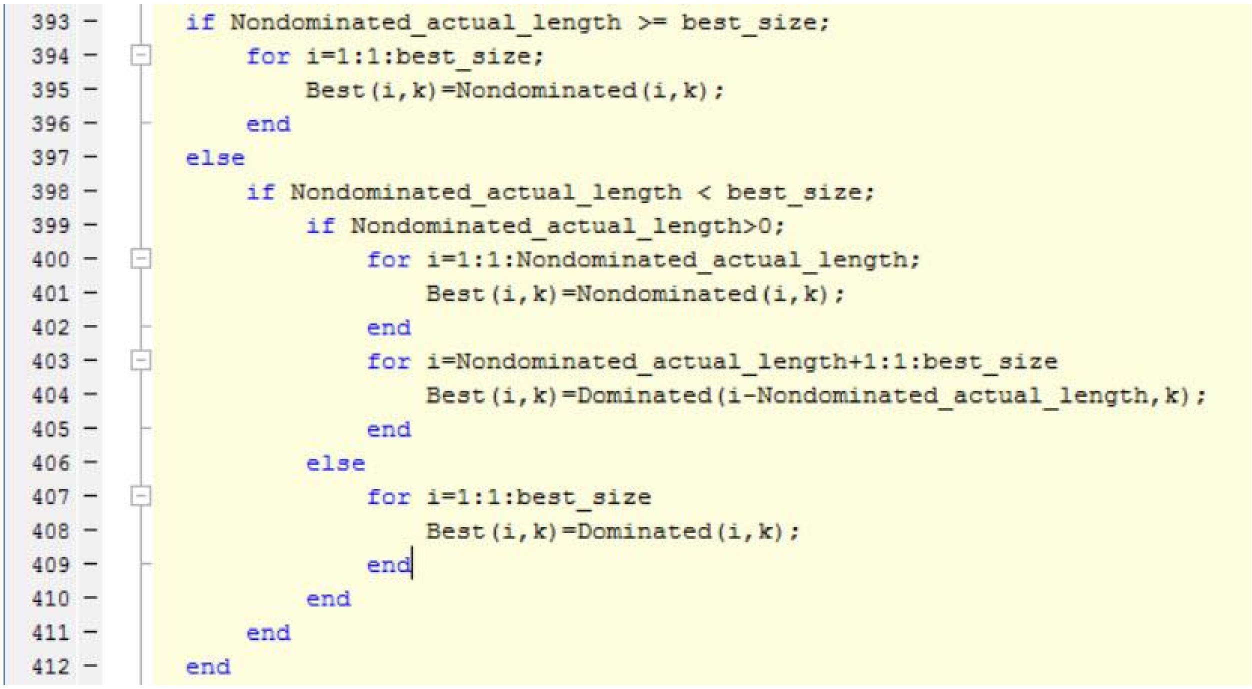
```
if size(index_dom_1,3) == k;
    [b,m1,n1]=unique(index_dom_1(1:index_dom_1_actual_length,2,k),'first');
    rep(1:length(histc(index_dom_1(1:index_dom_1_actual_length,2,k),b)),k)=histc(index_dom_1(1:index_dom_1_actual_length,2,k),b);
    [c1,d1]=sort(m1);
    index_dom=b(d1);
    index_dom_iteration(1:length(index_dom),k)=index_dom(:);
    rep_dom(:,1:2,k)=[index_dom_iteration(:,k) rep(:,k)];
end
```

```
    rep_dom(:,1:2,k)=[index_dom_iteration(:,k) rep(:,k)];
end
```

Figure 4.8: The Determination of the Repetition Frequency of the Dominated Antibodies

4.2.5 Selection of Best Antibodies in a Generation

Following the AIS cloning concept, the best antibodies are selected and cloned to assure and increases the tendency towards the optimal solution. Consequently, a number of non-dominated antibodies are selected as the best antibodies according to the predefined length of the best antibodies matrix. If the number of non-dominated antibodies could not complete the predefined number of best antibodies or if the non-dominated antibodies do not exist, the dominated antibodies are selected based on the least number of dominance by other antibodies as shown in Figure 4.9.



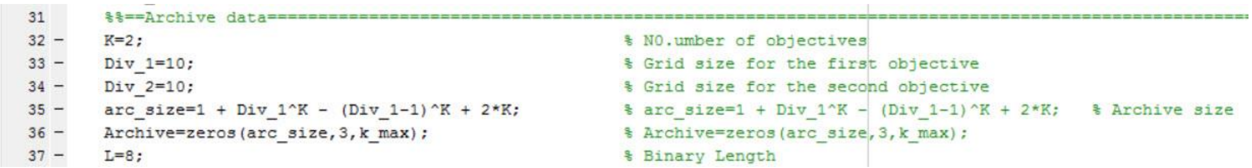
```
if Nondominated_actual_length >= best_size;
    for i=1:1:best_size;
        Best(i,k)=Nondominated(i,k);
    end
else
    if Nondominated_actual_length < best_size;
        if Nondominated_actual_length>0;
            for i=1:1:Nondominated_actual_length;
                Best(i,k)=Nondominated(i,k);
            end
            for i=Nondominated_actual_length+1:1:best_size
                Best(i,k)=Dominated(i-Nondominated_actual_length,k);
            end
        else
            for i=1:1:best_size
                Best(i,k)=Dominated(i,k);
            end
        end
    end
end
```

Figure 4.9: Selection of the Best Antibodies from Non-dominated and Dominated Antibodies

4.2.6 Archive size and Adaptation

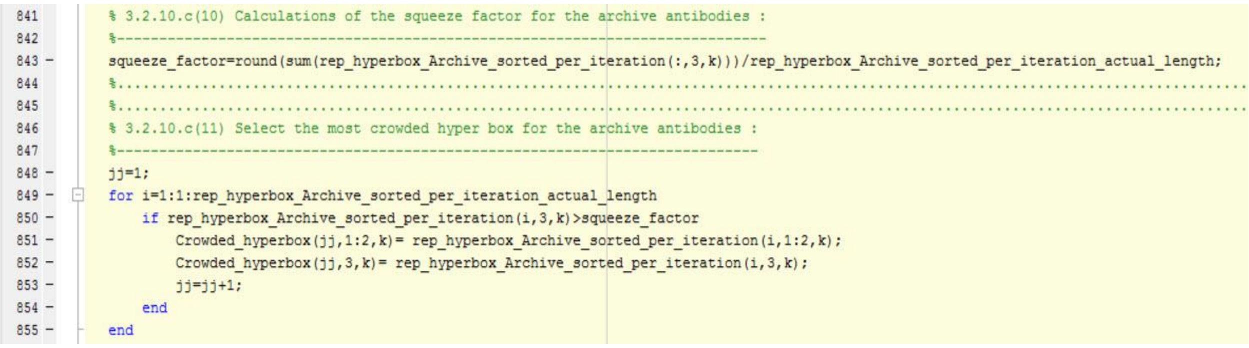
An archive in the AIS multi-objective optimization is utilized to store the elected best antibodies in each generation. Basically, the archive is divided into grid, which is called adaptive grid as discussed in the literature review chapter. Each of the objective search spaces (i.e., sustainability index and total cost) is divided into predefined number of horizontal and vertical lines which are named in the code as *Div_1* and *Div_2* as shown in Figure 4.10. The archive size (*arc_size*) is determined according to *Div_1, Div_2,* and the number of objectives *K* as shown in equation (2.31) in CHAPTER 2 and in the code line 35 as shown in Figure 4.10. In this study, the archive size is selected to be 24.

The archive will be filled with the best non-dominated antibodies to the archive obtained in each generation until it is full. Consequently, there is no place to add the newly generated best antibodies into the archive, so some antibodies should be removed from the archive to accept the new developed antibodies. As mentioned previously, the archive is divided into grid, each antibody in the archive contained in a specific square of the grid. A square may contain more than one antibody, therefore, according to the number of antibodies included in each square of the grid, an average is calculated called a squeeze factor. The squeeze factor defines the average number of antibodies that should exist in one square of the grid. Hence, the square which contains number of antibodies greater than the squeeze factor is called *crowded hyper box* as illustrated in the code from line 841 to line 855 as shown in Figure 4.11. Therefore, a number of antibodies in the archive contained in crowded hyper boxes will be replaced by new best non-dominated generated antibodies, then the adaptive grid and the squeeze factors are calculated again and the process is repeated. This process allows a diversity and uniform distribution of solutions in the archive.



```
%%==Archive data====================================================================================================
K=2;                                        % NO.umber of objectives
Div_1=10;                                   % Grid size for the first objective
Div_2=10;                                   % Grid size for the second objective
arc_size=1 + Div_1^K - (Div_1-1)^K + 2*K;   % arc_size=1 + Div_1^K - (Div_1-1)^K + 2*K;    % Archive size
Archive=zeros(arc_size,3,k_max);            % Archive=zeros(arc_size,3,k_max);
L=8;                                        % Binary Length
```

Figure 4.10: Archive Size and Adaptive Grid Divisions Data Entry



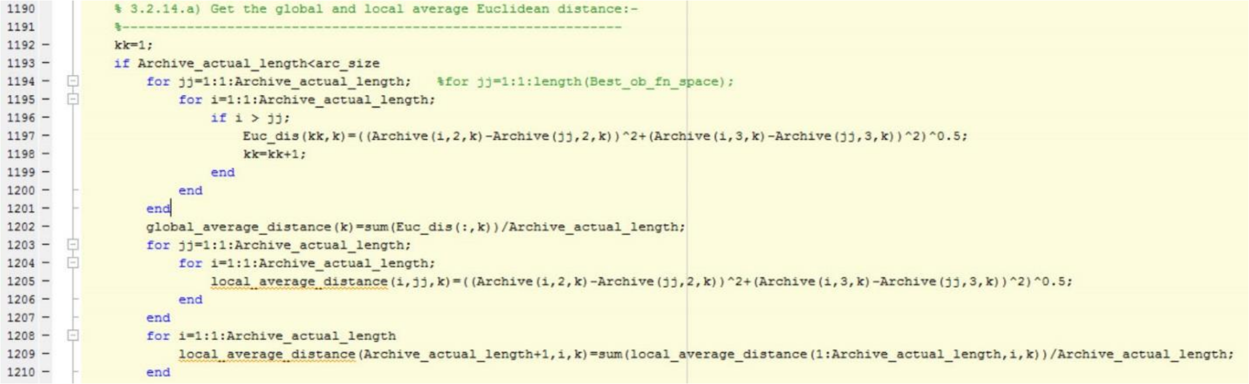
```
841      % 3.2.10.c(10) Calculations of the squeeze factor for the archive antibodies :
842      %----------------------------------------------------------------------------
843 -    squeeze_factor=round(sum(rep_hyperbox_Archive_sorted_per_iteration(:,3,k)))/rep_hyperbox_Archive_sorted_per_iteration_actual_length;
844      %............................................................................................................................
845      %............................................................................................................................
846      % 3.2.10.c(11) Select the most crowded hyper box for the archive antibodies :
847      %---------------------------------------------------------------------------
848 -    jj=1;
849 -    for i=1:1:rep_hyperbox_Archive_sorted_per_iteration_actual_length
850 -        if rep_hyperbox_Archive_sorted_per_iteration(i,3,k)>squeeze_factor
851 -            Crowded_hyperbox(jj,1:2,k)= rep_hyperbox_Archive_sorted_per_iteration(i,1:2,k);
852 -            Crowded_hyperbox(jj,3,k)= rep_hyperbox_Archive_sorted_per_iteration(i,3,k);
853 -            jj=jj+1;
854 -        end
855 -    end
```

Figure 4.11: Squeeze Factor and Crowded Hyper Boxes Determination

4.2.7 Cloning, Uniform Mutation, and Non-Uniform Mutation

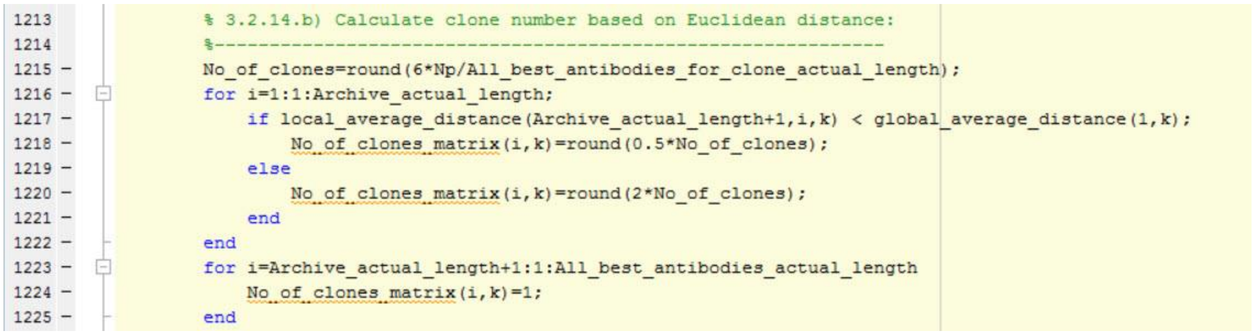
The AIS optimization utilizes cloning action to increase the tendency to find the best solutions and in turn speeding up the convergence towards the near optimum solutions. The best antibodies are subjected to higher cloning frequency than the non-best antibodies. There are two scenarios to select the number of clones. The first scenario when the archive is not full, the detection of the number of clones depends on the crowdedness of the antibodies in the archive; the more the crowded antibodies the less the number of clones and vice versa. In this scenario, calculation of the crowdedness relies on the *global average distance* and *local average distance*. The global average distance is the summation of all the Euclidian distances between all the antibodies divided by the number of antibodies existing in the archive, while the local average distance is the distance between each antibody and the rest of antibodies in the archive divided by the number of antibodies in the archive as shown in Figure 4.12. Furthermore, if the local average distance of an antibody is smaller than the global average distance, this means that the antibody is in a crowded region, so the number of clones are reduced by half, if else, the number of clones are doubled as illustrated in Figure 4.13. The second scenario when the archive full, the number of clones depends on the comparison between the crowdedness and the squeeze factor. When an antibody belongs to a hyper-box in which its crowdedness is greater than the squeeze factor, this means that the antibody belongs to a crowded hyper-box, hence its clone number is reduced by half. If the antibody belongs to a less crowded hyper-box whose crowdedness is lower than the squeeze factor, its clone number is doubled as illustrated in Figure 4.14.

The mutation is used to explore wide range of search space and avoid trapping into local minima. There are two types of mutations are performed in AIS optimization which are uniform mutation for best antibodies and non-uniform mutations for the non-best antibodies. Mutations are bit flips performed on the antibody chromosome if a certain bit to be mutated is *zero* it is flipped to one and vice versa. Therefore, all the antibodies should be changed from real number to a binary system of a length of five bits for each decision variable as illustrated in Figure 4.15 and Figure 4.16. The uniform mutation performs one hundred and thirty-five different bit flips on all the best antibodies, this type of mutation is fixed in each generation in which the number of bit flips required do not change through the whole process. The non-uniform mutation performed on the non-best antibodies. The number of bit flips is dependent on the number of the generation where the mutation is performed. The earlier generations are subjected to higher number of bit flips than the latest ones, it is governed by equation (2.46) in CHAPTER 2 and as demonstrated in Figure 4.17.



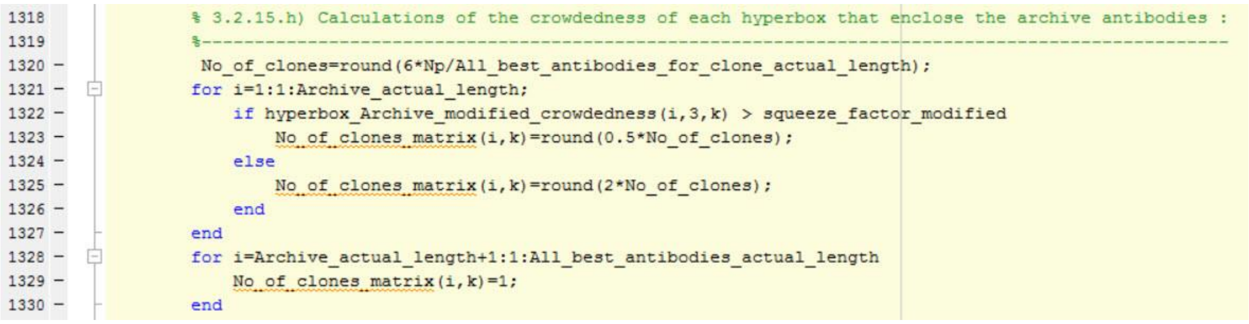
```
% 3.2.14.a) Get the global and local average Euclidean distance:-
%-------------------------------------------------------------
kk=1;
if Archive_actual_length<arc_size
    for jj=1:1:Archive_actual_length;   %for jj=1:1:length(Best_ob_fn_space);
        for i=1:1:Archive_actual_length;
            if i > jj;
                Euc_dis(kk,k)=((Archive(i,2,k)-Archive(jj,2,k))^2+(Archive(i,3,k)-Archive(jj,3,k))^2)^0.5;
                kk=kk+1;
            end
        end
    end
    global_average_distance(k)=sum(Euc_dis(:,k))/Archive_actual_length;
    for jj=1:1:Archive_actual_length;
        for i=1:1:Archive_actual_length;
            local_average_distance(i,jj,k)=((Archive(i,2,k)-Archive(jj,2,k))^2+(Archive(i,3,k)-Archive(jj,3,k))^2)^0.5;
        end
    end
    for i=1:1:Archive_actual_length
        local_average_distance(Archive_actual_length+1,i,k)=sum(local_average_distance(1:Archive_actual_length,i,k))/Archive_actual_length;
    end
```

Figure 4.12: Determination of Global and Local Average Distances



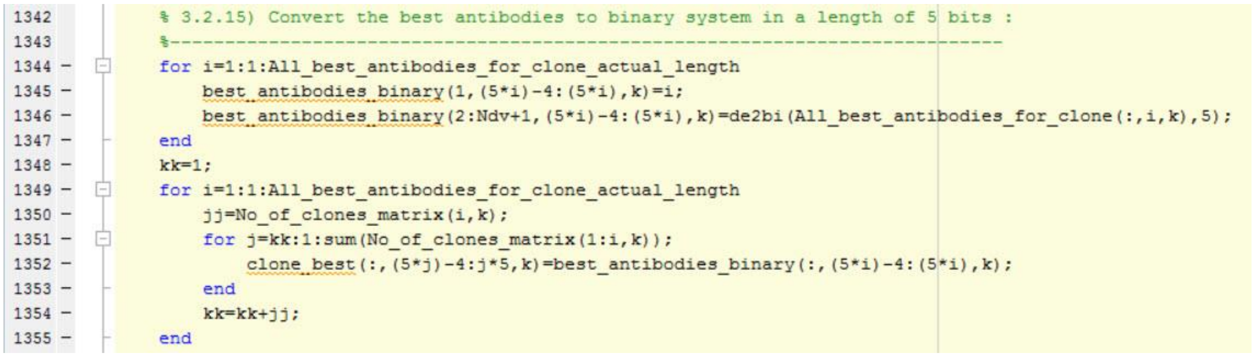
```
        % 3.2.14.b) Calculate clone number based on Euclidean distance:
        %-------------------------------------------------------------
        No_of_clones=round(6*Np/All_best_antibodies_for_clone_actual_length);
        for i=1:1:Archive_actual_length;
            if local_average_distance(Archive_actual_length+1,i,k) < global_average_distance(1,k);
                No_of_clones_matrix(i,k)=round(0.5*No_of_clones);
            else
                No_of_clones_matrix(i,k)=round(2*No_of_clones);
            end
        end
        for i=Archive_actual_length+1:1:All_best_antibodies_actual_length
            No_of_clones_matrix(i,k)=1;
        end
```

Figure 4.13: Determination of Number of Clones Based on Average Distances



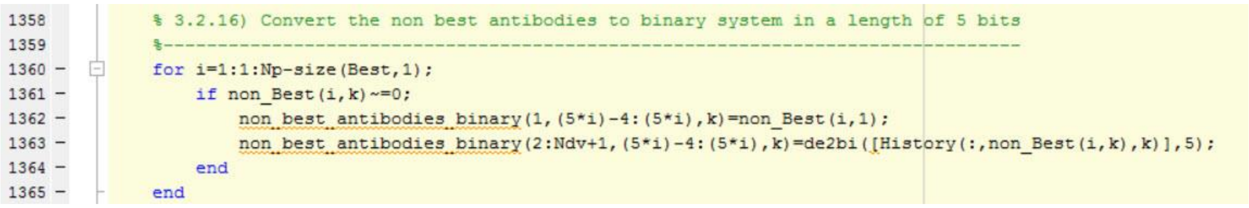
```
        % 3.2.15.h) Calculations of the crowdedness of each hyperbox that enclose the archive antibodies :
        %-------------------------------------------------------------------------------------------------
         No_of_clones=round(6*Np/All_best_antibodies_for_clone_actual_length);
        for i=1:1:Archive_actual_length;
            if hyperbox_Archive_modified_crowdedness(i,3,k) > squeeze_factor_modified
                No_of_clones_matrix(i,k)=round(0.5*No_of_clones);
            else
                No_of_clones_matrix(i,k)=round(2*No_of_clones);
            end
        end
        for i=Archive_actual_length+1:1:All_best_antibodies_actual_length
            No_of_clones_matrix(i,k)=1;
        end
```

Figure 4.14: Determination of Number of Clones Based on Squeeze Factor



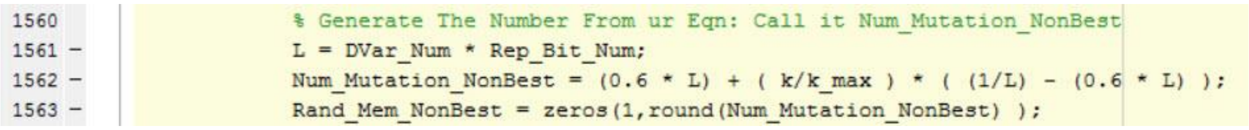
```
    % 3.2.15) Convert the best antibodies to binary system in a length of 5 bits :
    %---------------------------------------------------------------------------
    for i=1:1:All_best_antibodies_for_clone_actual_length
        best_antibodies_binary(1,(5*i)-4:(5*i),k)=i;
        best_antibodies_binary(2:Ndv+1,(5*i)-4:(5*i),k)=de2bi(All_best_antibodies_for_clone(:,i,k),5);
    end
    kk=1;
    for i=1:1:All_best_antibodies_for_clone_actual_length
        jj=No_of_clones_matrix(i,k);
        for j=kk:1:sum(No_of_clones_matrix(1:i,k));
            clone_best(:,(5*j)-4:j*5,k)=best_antibodies_binary(:,(5*i)-4:(5*i),k);
        end
        kk=kk+jj;
    end
```

Figure 4.15: Conversion of Best Antibodies from Real Numbers into Binary System



```
    % 3.2.16) Convert the non best antibodies to binary system in a length of 5 bits
    %-----------------------------------------------------------------------------
    for i=1:1:Np-size(Best,1);
        if non_Best(i,k)~=0;
            non_best_antibodies_binary(1,(5*i)-4:(5*i),k)=non_Best(i,1);
            non_best_antibodies_binary(2:Ndv+1,(5*i)-4:(5*i),k)=de2bi([History(:,non_Best(i,k),k)],5);
        end
    end
```

Figure 4.16: Conversion of Non-Best Antibodies from Real Numbers into Binary System



```
                % Generate The Number From ur Eqn: Call it Num_Mutation_NonBest
                L = DVar_Num * Rep_Bit_Num;
                Num_Mutation_NonBest = (0.6 * L) + ( k/k_max ) * ( (1/L) - (0.6 * L) );
                Rand_Mem_NonBest = zeros(1,round(Num_Mutation_NonBest) );
```

Figure 4.17: Mutation for Non-Best Antibodies

4.3 The Developed AIS Optimization Algorithm

The proposed AIS algorithm comprises various steps to achieve the optimal solution which fulfils the objective functions and satisfies the constraints. As shown in Figure 4.18, the algorithm starts with data entry followed by development of initial generation. Moreover, affinity is checked for each antibody, and dominance is distinguished. Furthermore, best and non-best antibodies and best are added to archive. Additionally, cloning and mutation are performed. Finally, the dominance of the final results is checked, then a new generation is developed that will be illustrated as follows:

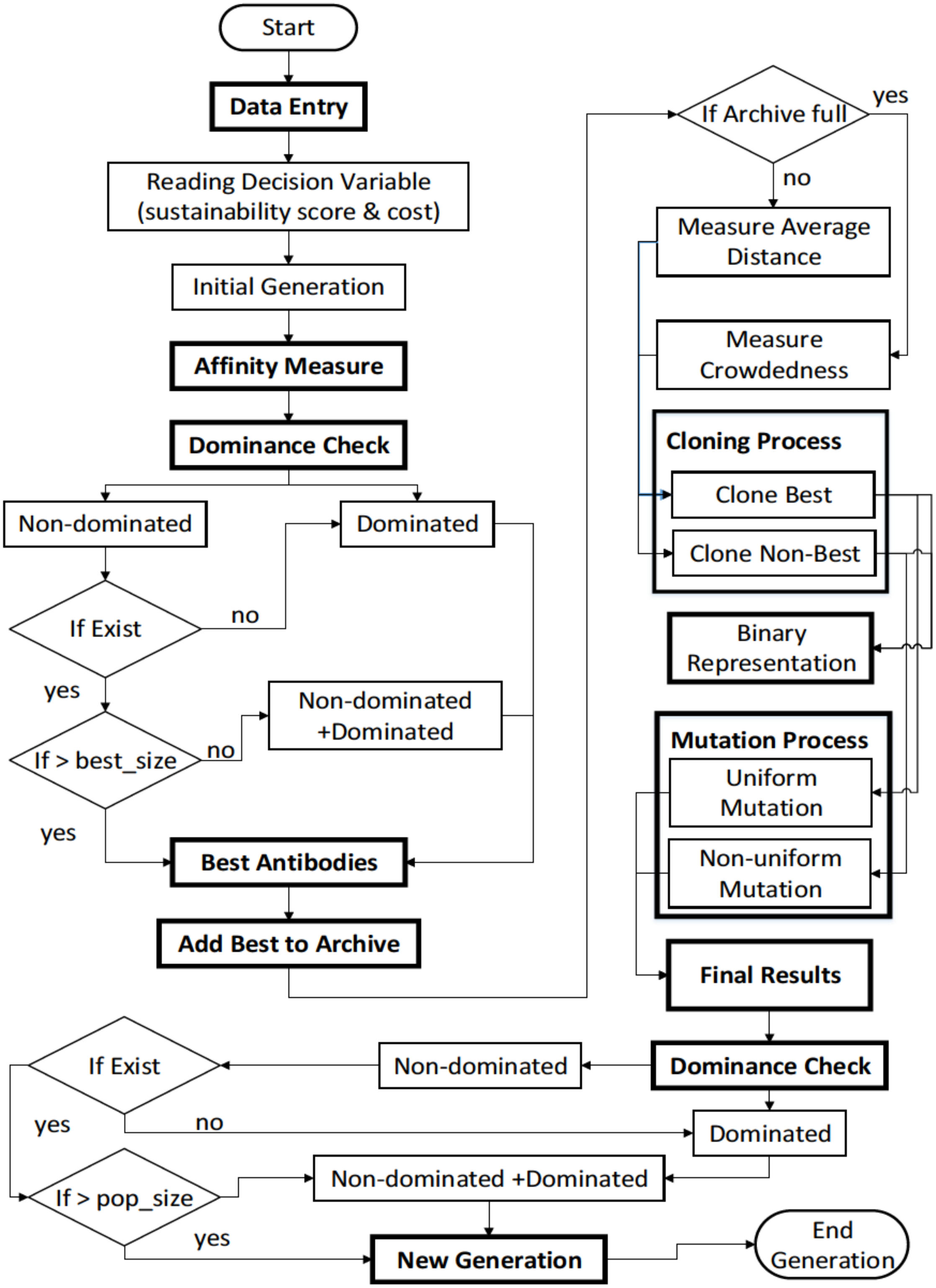
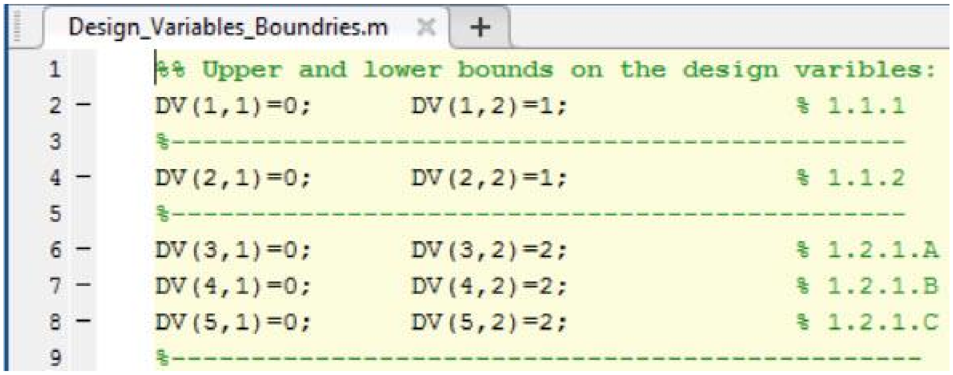


Figure 4.18: The Developed AIS Optimization Algorithm

4.3.1 Data Entry

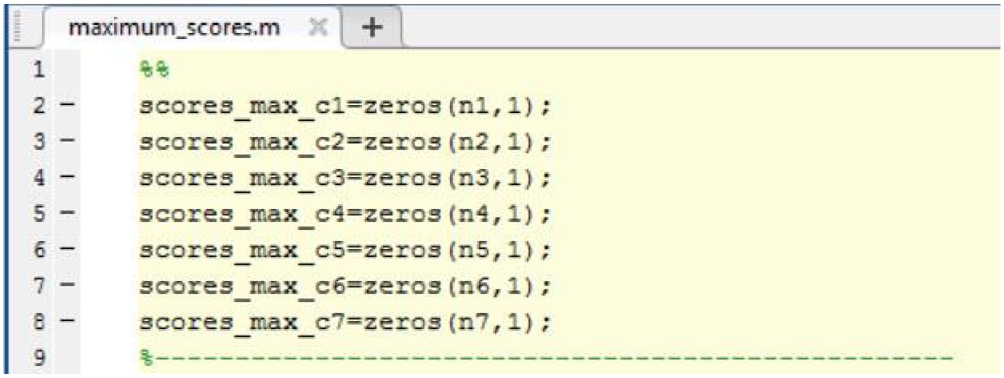
The Data entry starts with defining the main structure of the algorithm such as the population size (*pop_size*), which is calculated as 2-3 multiplied by the number of decision variable, it is determined to be 300 antibodies in a single population. Furthermore, the number of divisions of the adaptive grid Div_1 and Div_2 which are defined as ten divisions, also the archive size which is calculated as illustrated in the previous section based on the number of objectives and the number of divisions. Another aspect, which is the number of best antibodies selected in each generation to enter the archive, is determined as 5% the number of the decision variable. Moreover, the determination of the stopping criteria is the maximum number of generations that the algorithm will develop or the maximum number of generations the algorithm will stop if no new solutions are produced.

In addition, another sort of data entry is the data imported from the Excel spread sheets such as the upper and lower boundaries of each decision variable; the maximum score of each decision variable; the scores, total cost, and LCC of each decision variable; and finally, the weight of each criteria and its related factors. The upper and lower boundaries are the upper and lower indices of the alternatives in each decision variable, which are stored in the code in file called *Design_ Variables_ Boundaries*, which stores the upper and lower values in matrix called *DV* as shown in Figure 4.19. The maximum score of each criterion and its related factors is recalled in the file *maximum_scores* and stored in a matrix called *scores_max* as shown in Figure 4.20, which is the maximum scores used to calculate the sustainability index of each antibody in the population. The scores and LCC of each alternative is stored in a file named *scores_and_cost* and the data of each alternative is stored in the matrix *scores_cost_DV* as shown in Figure 4.21, in which the data stored is used to determine the affinity evaluation for each decision variable. Additionally, the weight for criteria and factors are stored imported by in the file *weights_factors_criteria* and stored in a matrix *wc* to store criteria weight and matrix *w_f_c* to store factors weight as shown in Figure 4.22.



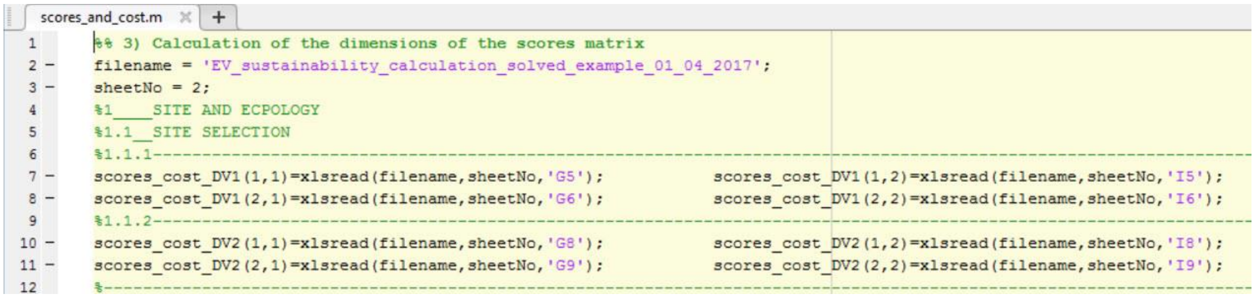
```
%% Upper and lower bounds on the design varibles:
DV(1,1)=0;      DV(1,2)=1;              % 1.1.1
%---------------------------------------------
DV(2,1)=0;      DV(2,2)=1;              % 1.1.2
%---------------------------------------------
DV(3,1)=0;      DV(3,2)=2;              % 1.2.1.A
DV(4,1)=0;      DV(4,2)=2;              % 1.2.1.B
DV(5,1)=0;      DV(5,2)=2;              % 1.2.1.C
%----------------------------------------------
```

Figure 4.19: The Upper and Lower Boundaries of Decision Variables in Matlab



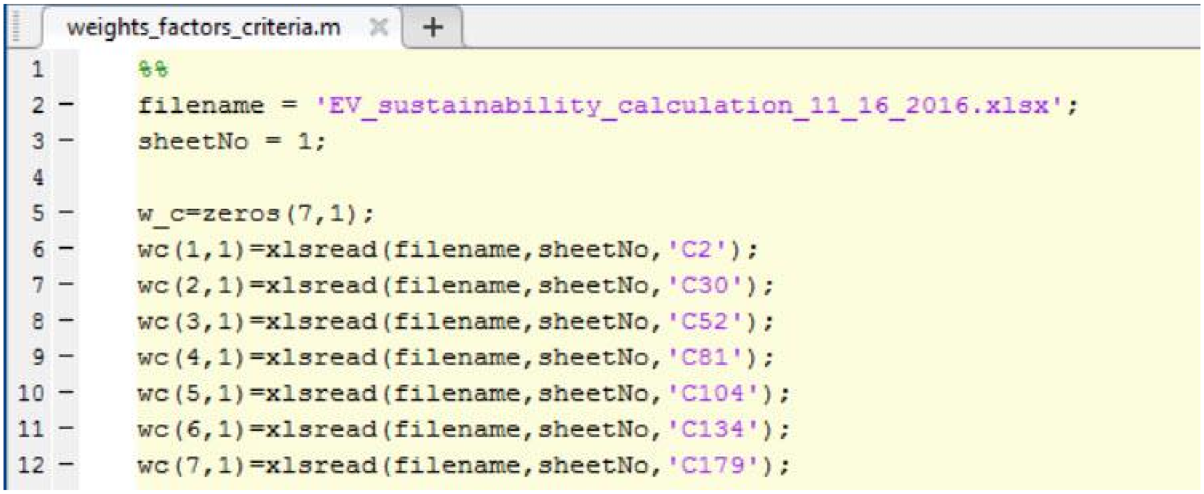
```
%%
scores_max_c1=zeros(n1,1);
scores_max_c2=zeros(n2,1);
scores_max_c3=zeros(n3,1);
scores_max_c4=zeros(n4,1);
scores_max_c5=zeros(n5,1);
scores_max_c6=zeros(n6,1);
scores_max_c7=zeros(n7,1);
%----------------------------------------------
```

Figure 4.20: The Maximum Scores for Each Criterion and Factor in Matlab



```
%% 3) Calculation of the dimensions of the scores matrix
filename = 'EV_sustainability_calculation_solved_example_01_04_2017';
sheetNo = 2;
%1____SITE AND ECPOLOGY
%1.1__SITE SELECTION
%1.1.1-------------------------------------------------------------------------------------------------------------
scores_cost_DV1(1,1)=xlsread(filename,sheetNo,'G5');         scores_cost_DV1(1,2)=xlsread(filename,sheetNo,'I5');
scores_cost_DV1(2,1)=xlsread(filename,sheetNo,'G6');         scores_cost_DV1(2,2)=xlsread(filename,sheetNo,'I6');
%1.1.2-------------------------------------------------------------------------------------------------------------
scores_cost_DV2(1,1)=xlsread(filename,sheetNo,'G8');         scores_cost_DV2(1,2)=xlsread(filename,sheetNo,'I8');
scores_cost_DV2(2,1)=xlsread(filename,sheetNo,'G9');         scores_cost_DV2(2,2)=xlsread(filename,sheetNo,'I9');
%-----------------------------------------------------------------------------------------------------------------
```

Figure 4.21: The Score and Cost for each Decision Variable in Matlab



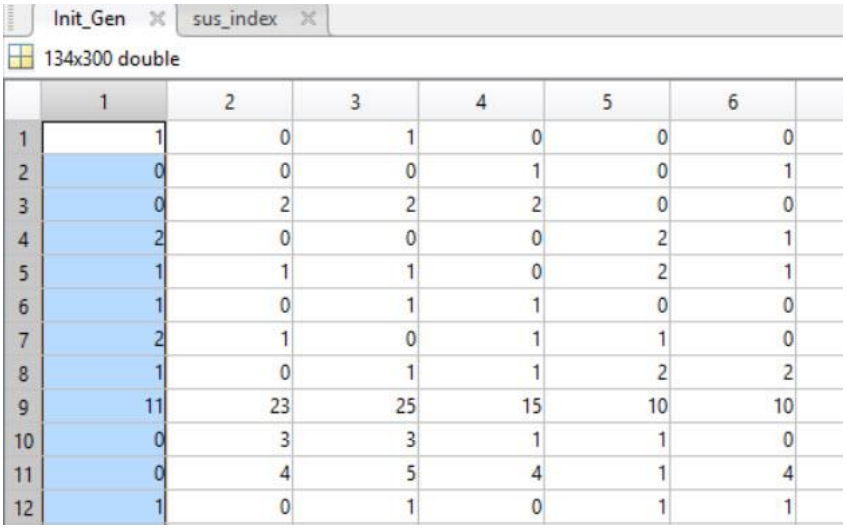
```
%%
filename = 'EV_sustainability_calculation_11_16_2016.xlsx';
sheetNo = 1;

w_c=zeros(7,1);
wc(1,1)=xlsread(filename,sheetNo,'C2');
wc(2,1)=xlsread(filename,sheetNo,'C30');
wc(3,1)=xlsread(filename,sheetNo,'C52');
wc(4,1)=xlsread(filename,sheetNo,'C81');
wc(5,1)=xlsread(filename,sheetNo,'C104');
wc(6,1)=xlsread(filename,sheetNo,'C134');
wc(7,1)=xlsread(filename,sheetNo,'C179');
```

Figure 4.22: The Weight of Criteria and Factors Matlab File

4.3.2 Initial Generation and Affinity Measure

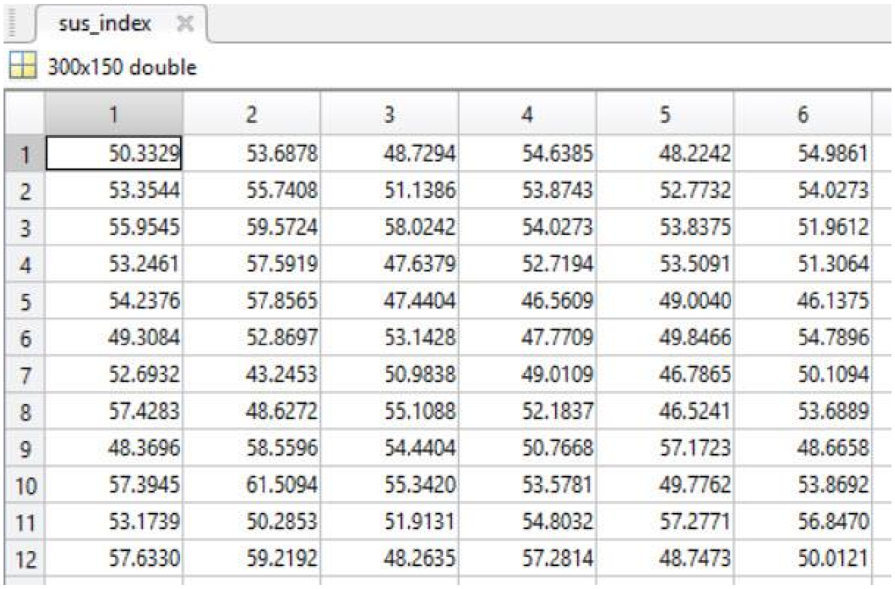
The optimization process starts with a random initial generation with a population size equal to 300 antibodies. Each antibody contains random indices of the 134 decision variables. The random selection of the indices of the decision variable lies between zero which is the minimum boundary and the maximum available boundary as predefined for each decision variable. As shown in Figure 4.23, the columns of the initial generation matrix define the number of the antibodies and the rows defines the random indices of each decision variable contained in each antibody. Each index of an antibody indicates a certain sustainability score and LCC used in the affinity measure.

The affinity measure is the evaluation of each antibody according to the sustainability scores and the LCCs of its included antibodies as illustrated in section 4.2.3. The affinity measure is the determination of the total sustainability index and the total LCC of all the antibodies in the population according to the randomly generated decision variables contained within these antibodies. The BSAR values for each antibody in a single generation is stored in the matrix *sus_index* as shown in Figure 4.24, such that the columns represent the generation number and the rows represent the index (number) of the antibody generated in each generation. The total LCC values for each antibody are stored in a matrix *total_cost* as shown in Figure 4.25, in which the columns represent the generation number and the rows represent the index (number) of the antibody generated in each generation.



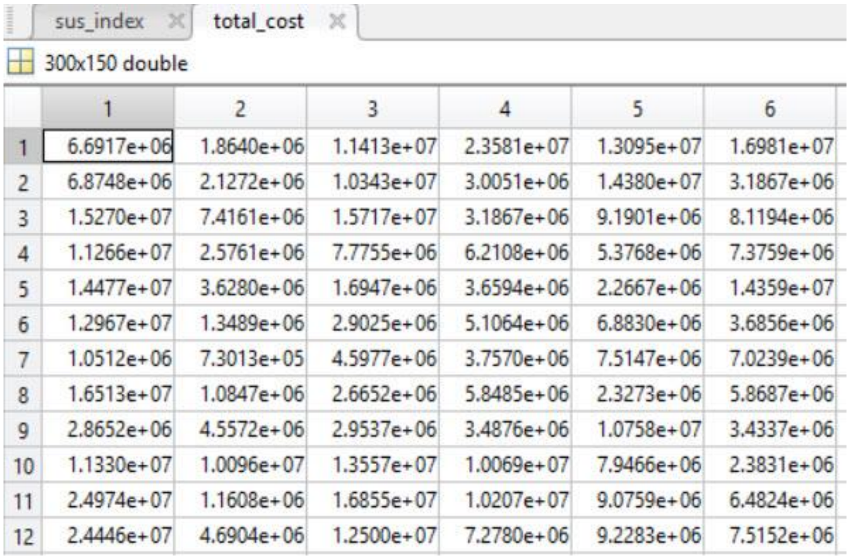
	1	2	3	4	5	6
1	1	0	1	0	0	0
2	0	0	0	1	0	1
3	0	2	2	2	0	0
4	2	0	0	0	2	1
5	1	1	1	0	2	1
6	1	0	1	1	0	0
7	2	1	0	1	1	0
8	1	0	1	1	2	2
9	11	23	25	15	10	10
10	0	3	3	1	1	0
11	0	4	5	4	1	4
12	1	0	1	0	1	1

Figure 4.23: A Part of the Random Generation of Each Decision Variable



	1	2	3	4	5	6
1	50.3329	53.6878	48.7294	54.6385	48.2242	54.9861
2	53.3544	55.7408	51.1386	53.8743	52.7732	54.0273
3	55.9545	59.5724	58.0242	54.0273	53.8375	51.9612
4	53.2461	57.5919	47.6379	52.7194	53.5091	51.3064
5	54.2376	57.8565	47.4404	46.5609	49.0040	46.1375
6	49.3084	52.8697	53.1428	47.7709	49.8466	54.7896
7	52.6932	43.2453	50.9838	49.0109	46.7865	50.1094
8	57.4283	48.6272	55.1088	52.1837	46.5241	53.6889
9	48.3696	58.5596	54.4404	50.7668	57.1723	48.6658
10	57.3945	61.5094	55.3420	53.5781	49.7762	53.8692
11	53.1739	50.2853	51.9131	54.8032	57.2771	56.8470
12	57.6330	59.2192	48.2635	57.2814	48.7473	50.0121

Figure 4.24: A Part of the Sustainability Index Matrix in Matlab



	1	2	3	4	5	6
1	6.6917e+06	1.8640e+06	1.1413e+07	2.3581e+07	1.3095e+07	1.6981e+07
2	6.8748e+06	2.1272e+06	1.0343e+07	3.0051e+06	1.4380e+07	3.1867e+06
3	1.5270e+07	7.4161e+06	1.5717e+07	3.1867e+06	9.1901e+06	8.1194e+06
4	1.1266e+07	2.5761e+06	7.7755e+06	6.2108e+06	5.3768e+06	7.3759e+06
5	1.4477e+07	3.6280e+06	1.6947e+06	3.6594e+06	2.2667e+06	1.4359e+07
6	1.2967e+07	1.3489e+06	2.9025e+06	5.1064e+06	6.8830e+06	3.6856e+06
7	1.0512e+06	7.3013e+05	4.5977e+06	3.7570e+06	7.5147e+06	7.0239e+06
8	1.6513e+07	1.0847e+06	2.6652e+06	5.8485e+06	2.3273e+06	5.8687e+06
9	2.8652e+06	4.5572e+06	2.9537e+06	3.4876e+06	1.0758e+07	3.4337e+06
10	1.1330e+07	1.0096e+07	1.3557e+07	1.0069e+07	7.9466e+06	2.3831e+06
11	2.4974e+07	1.1608e+06	1.6855e+07	1.0207e+07	9.0759e+06	6.4824e+06
12	2.4446e+07	4.6904e+06	1.2500e+07	7.2780e+06	9.2283e+06	7.5152e+06

Figure 4.25: A Part of the Total LCC Matrix in MATLAB

4.3.3 The Dominance Check and best antibody selection

The dominance is determined based on the affinity measure (i.e. the sustainability index and the total LCC). A comparison is conducted among all the generated antibodies in the population of each generation to check the whether the antibody is dominated or non-dominated as discussed in section 4.2.4. Furthermore, after dominated and non-dominated antibodies are determined, the best antibodies are selected based on three scenarios as depicted in Figure 4.18. If the number of the non-dominated antibodies are greater than the number of the best antibodies required, then all the best antibodies are selected from the non-dominated antibodies. The second scenario, if the number of the non-dominated antibodies is lower than the number of the best antibodies, then all the non-dominated antibodies are selected and the rest of the best antibodies are selected from the dominated antibodies. Moreover, if there are no non-dominated antibodies, then all the best antibodies are selected from the dominated ones, as the dominated antibodies by fewer number on antibodies are selected first until the best is completed.

4.3.4 Add the Best Antibodies to the Archive

According to the size of the archive, the best antibodies are inserted in every generation until the archive is full. If the archive is full, then the dominance of the best antibodies is checked with respect to the other antibodies in the archive. The non-dominated best antibodies to the archive are the only ones which capable to replace other antibodies in the complete archive. In other words, the best antibodies that can enter a full archive must be superior to the antibodies of the archive and have high affinity (i.e. achieve higher sustainability index than the antibodies of the archive, or achieve lower LCC than the antibodies of the archive, or achieve both previously mentioned conditions).

Another challenge is to select the antibodies that should be removed from the archive. The crowdedness of the antibodies of the archive should be calculated based on the squeeze factor, as explained in section 4.2.7. Hence, a number of antibodies in the archive that belongs to the most crowded hyper boxes will be removed based on the number of the non-dominated best antibodies that will enter the archive.

4.3.5 Cloning, Binary Representation, and Mutation

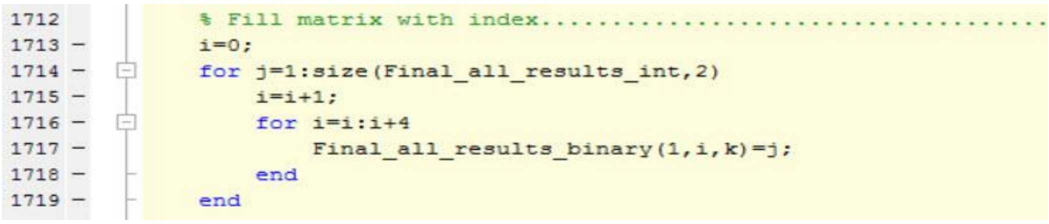
Cloning is an important stage to increase the tendency towards exploring the best solutions. The best antibodies are cloned with a predefined rate which is six times the number of population divided by the number of best antibodies. The best antibodies that are selected for cloning are the antibodies included in the archive, and the best antibodies that are not selected for the archive because they are dominated with respect to the archive. The number of clones is determined based on the crowdedness of the antibodies in the archive as shown in Figure 4.12 and Figure 4.13.

Each antibody (solution) is represented as a chromosomal binary string as shown in Figure 4.3. The string length is 670 bits that represent the 134 decision variables in each antibody. The rationale for using the binary coding is allowing the random mutation process to take place. The mutation is based on changing a specific number of bits from zero to one or vice versa as illustrated previously. After the binary representation of all the antibodies in a single generation, uniform mutation is performed on the cloned best antibodies and the non- uniform mutation is conducted on the non-best antibodies to increase the probability of finding more best antibodies.

4.3.6 Final Results, Dominance Check, and Next Generation

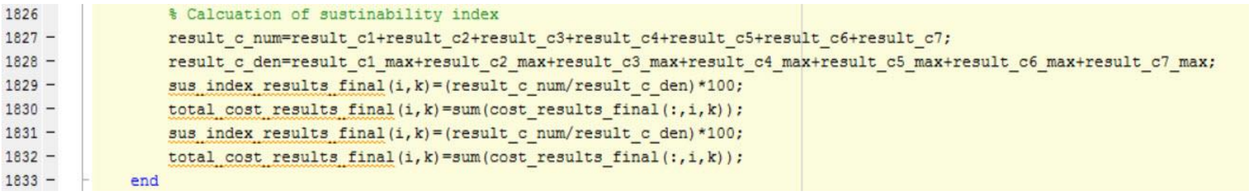
The final antibodies that are resulted from the cloning and the mutation processes are gathered and decoded from binary to real numbers, then are stored in a matrix *final_all_results_int* as shown in Figure 4.26. Furthermore, the BSAR and the total LCC of all the final antibodies are determined to check their dominance and non-dominance. The dominance check is performed as illustrated in the sub-section 4.2.4.

In order to select the new generation from the developed antibodies there are three scenarios: 1) the non-dominated antibodies are larger than or equal the initial population size; 2) dominated antibodies only exists; and 3) the number of the non-dominated antibodies is smaller than the initial generation. If the first scenario exists, all the population size of the next generation is selected from the non-dominated antibodies. For the second scenario, the size of the next generation is completed from the dominated antibodies. If the third scenario exists, all the non-dominated antibodies are selected, then the rest of the size of the next generation is completed from the dominated antibodies as illustrated in Figure 5.3.



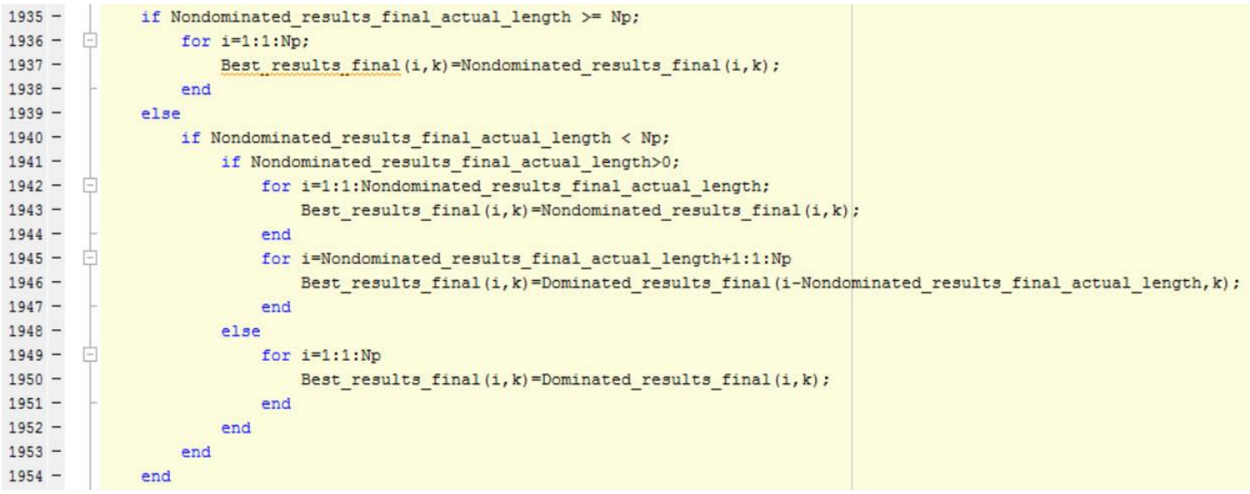
```
% Fill matrix with index.....................................
i=0;
for j=1:size(Final_all_results_int,2)
    i=i+1;
    for i=i:i+4
        Final_all_results_binary(1,i,k)=j;
    end
end
```

Figure 4.26: Gathering of Antibodies after Mutation Process



```
    % Calcuation of sustinability index
    result_c_num=result_c1+result_c2+result_c3+result_c4+result_c5+result_c6+result_c7;
    result_c_den=result_c1_max+result_c2_max+result_c3_max+result_c4_max+result_c5_max+result_c6_max+result_c7_max;
    sus_index_results_final(i,k)=(result_c_num/result_c_den)*100;
    total_cost_results_final(i,k)=sum(cost_results_final(:,i,k));
    sus_index_results_final(i,k)=(result_c_num/result_c_den)*100;
    total_cost_results_final(i,k)=sum(cost_results_final(:,i,k));
end
```

Figure 4.27: Determination of the BSAR and the Total LCC of the Final Antibodies



```
if Nondominated_results_final_actual_length >= Np;
    for i=1:1:Np;
        Best_results_final(i,k)=Nondominated_results_final(i,k);
    end
else
    if Nondominated_results_final_actual_length < Np;
        if Nondominated_results_final_actual_length>0;
            for i=1:1:Nondominated_results_final_actual_length;
                Best_results_final(i,k)=Nondominated_results_final(i,k);
            end
            for i=Nondominated_results_final_actual_length+1:1:Np
                Best_results_final(i,k)=Dominated_results_final(i-Nondominated_results_final_actual_length,k);
            end
        else
            for i=1:1:Np
                Best_results_final(i,k)=Dominated_results_final(i,k);
            end
        end
    end
end
```

Figure 4.28: Selection of the Best Antibodies for the Next Generation

4.4 Summary

This chapter describes in detail the development of the optimization model using artificial immune system (AIS) utilizing clonal selection algorithm. Also, this chapter shows the main parts of the developed optimization code that has been conducted in Matlab, describing the code main features. Moreover, this chapter addresses the principal features of the AIS as follows:

- decision variables representation;
- antibodies chromosomal representation;
- affinity evaluation;
- dominance and non-dominance of antibodies;
- selection of best antibodies;
- archive size and adaptation; and
- cloning and mutation.

Further, this chapter illustrates the developed algorithm and its steps starting from the data entry, followed by the initialization by introducing the initial generation and evaluating its affinity going through dominance checking of the best antibodies, then adding these antibodies to the archive, followed by cloning and binary representation and mutation. Finally, the algorithm ends with the final results obtained from cloning and mutation, then selecting the new generation, after checking dominance, to start the following iteration.

CHAPTER 5: DATA COLLECTION AND ANALYSIS

5.1 Chapter Overview

This chapter will address the procedures followed to select the assessment attributes based on the literature review. An illustration will be introduced to every criterion and its related factors and sub-factor mentioning the aim of each. Moreover, this chapter gives a detailed description of the questionnaire employed to gather information related to the importance of each attribute, in turn, this information is used to estimate their weight. Also, an illustration of the strategies applied to establish the sustainability assessment scale to measure the degree of the sustainability of the buildings.

5.2 Identification of Sustainability Assessment Attributes:

The identification of the sustainability assessment attributes (criteria, factors, and sub-factors) was based on the reviewing many of the pioneer rating tools such as BREEAM, LEED, HK-BEAM, GreemMark, Green Ship, Green Building index, CASBEE, BOMA BESt and Green Globes as illustrated in the literature review chapter. Moreover, different studies, which were concerned with developing sustainability rating tools based on various regional contexts, were examined. As a result, some limitations and advantages were concluded. Based on these limitations and lacking some important attributes, a list of attributes was addressed that were considered to have a significant impact on the sustainability of buildings and to be used to assess the sustainability comprehensively based on the three pillars of sustainability. Furthermore, different interviews and questionnaires were conducted based on the developed list of attributes and their hierarchy to make the final modifications; as a result, the final list of the attributes was selected.

A comparison was conducted between eight rating systems selected from the World Green Building Council member list, the selection based on the membership level which is the already established green building council tool (Worldgbc, 2016). This comparison performed to spotlight on the overlooked attributes and the most crucial ones that affect the total sustainability of existing buildings and should be integrated into the developed rating tool as shown in Table 5.1, Table 5.2, and Table 5.3. Seven criteria are concluded to have the primary effect on the sustainability of buildings which are: 1) site and ecology, 2) transportation, 3) energy efficiency, 4) water use, 5) material and waste reduction, 6) indoor environmental quality (IEQ), and 7) building management as shown in Figure 5.1.

5.2.1 Site and Ecology Criterion:

Site and Ecology criterion deals with the site and all its related aspects which expressed in four factors as shown in Figure 5.2. These factors are: 1) site selection indicates whether the building was certified previously in any rating system in design and construction phase, as well as, the conservation of the historical or culture interest of the site after construction; 2) site management evaluates the existence of an environmental policy and/or a purchasing plan, the purchasing practices of all the required materials on the site, as well as, the green cleaning goods, operation and maintenance of the site and the building exterior, and the pest management and landscape management; 3) reduce the heat island effect evaluates the practices utilized to minimize the impact of heat arises from the building materials and in turn increase the temperature of the surroundings; and 4) site emissions assesses the procedures utilized to lessen the pollution impact of the existence of buildings on the surroundings such as noise and light pollution.

5.2.2 Transportation Criterion:

It encourages utilizing of efficient means of transportation, and urge using public means of transportation rather than private ones in commuting. It comprises four factors as shown in Figure 5.3 and as follows: 1) cyclist facilities and public means of transport are provisioned with suitable facilities encouraging building's occupants to use efficient means of transport that will reduce the polluting emissions; 2) public transport accessibility and community accessibility emphasize the importance of existence of public means of transport or safe ways nearby the building ; 3) provision of maximum parking capacity ensures reduction of use private cars in commuting; 4) green vehicle priority offers a preferred parking priority to green fuelled vehicles.

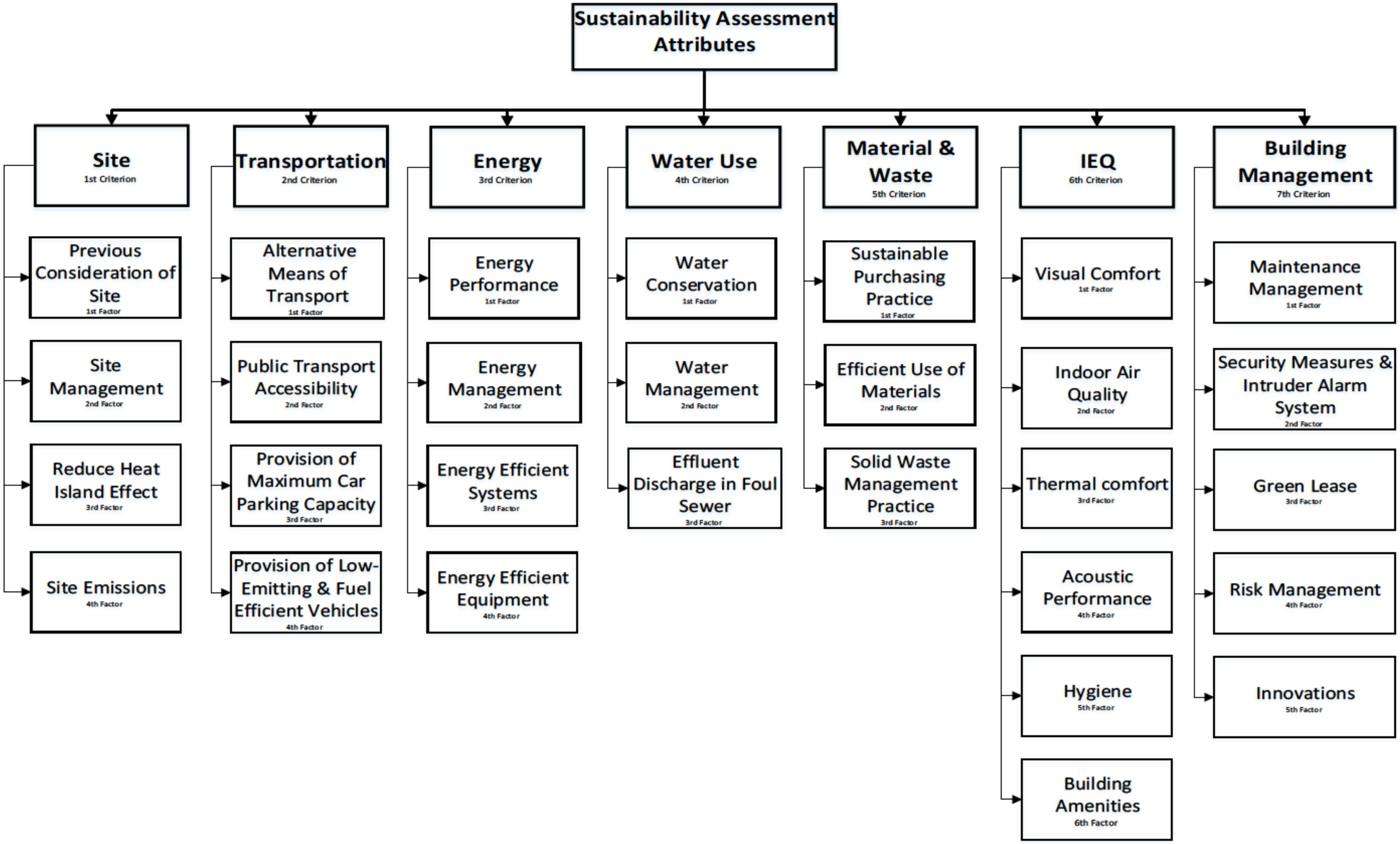


Figure 5.1: Sustainability Assessment Attributes (Criteria and Factors)

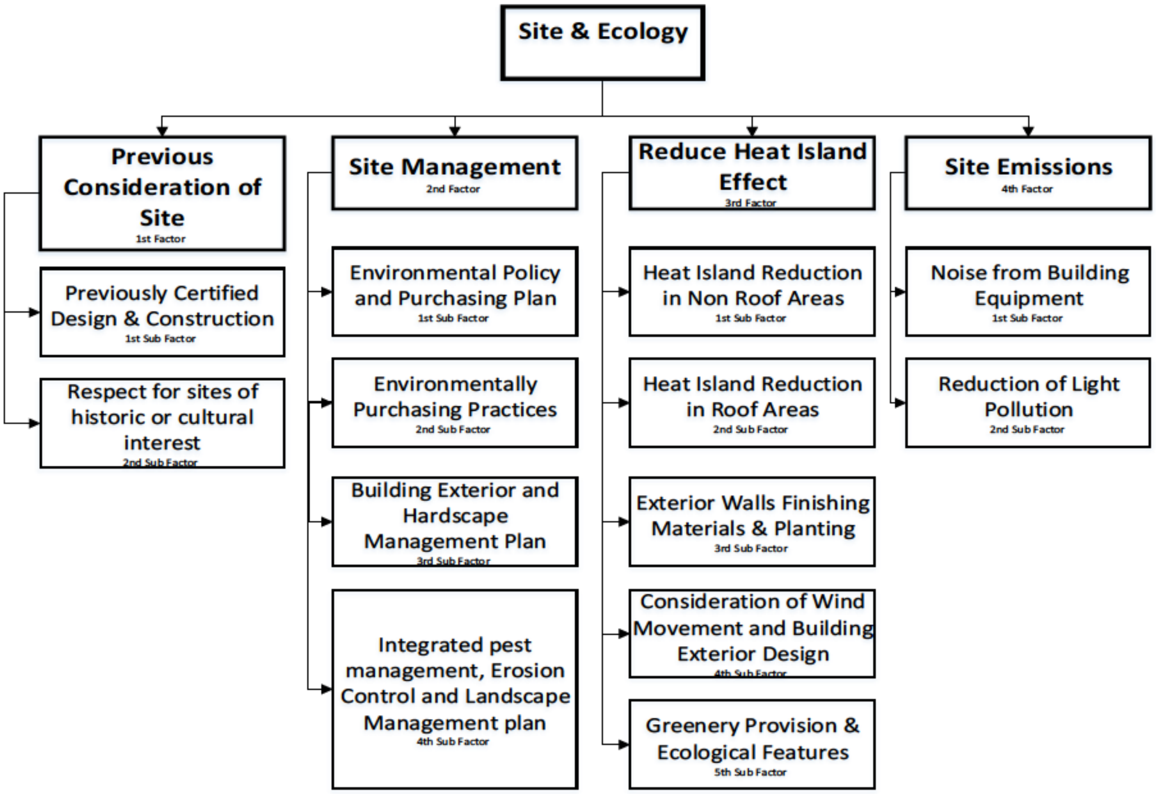


Figure 5.2: Site and Ecology Criterion and Its Related Factors and Sub-Factors

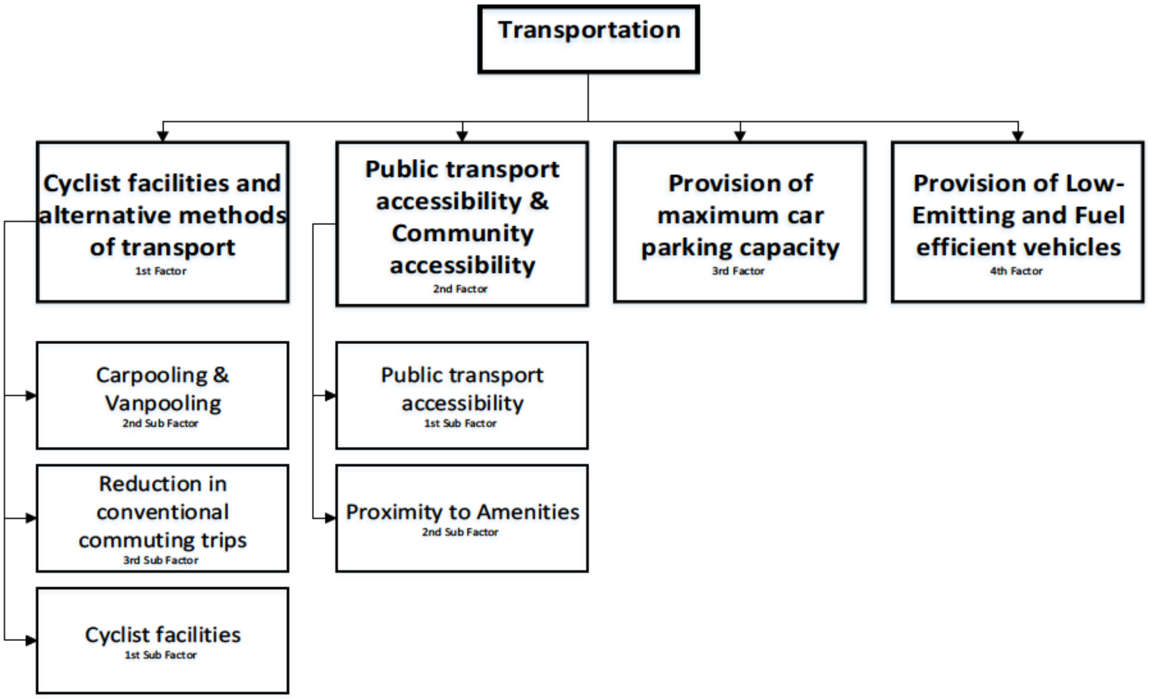


Figure 5.3: Transportation Criterion and Its Related Factors and Sub-Factors

5.2.3 Energy Criterion:

It is one of the primary targets of sustainability assessment aims to the reduction in energy consumption and the unwanted life cycle buildings' impacts. It includes four factors as depicted in Figure 5.4 and as the following: 1) energy performance measures percentage of reduction in energy use through the minimum required energy performance, and optimizing energy performance; 2) energy management systems reveal the existence of energy operating plan for the building, energy audit, energy monitoring and metering for the operated equipment to stand for their energy consumption, commissioning and testing for analysing energy demand and end-uses and to provide an ongoing commissioning, building automated system which monitors and controls all the building systems, emissions reduction then reporting them to identify building performance parameters which reduce conventional energy consumption and quantify these reductions, and finally, sustainable maintenance to ensure that all the systems will perform in an efficient way according to the designed building maintenance; 3) energy efficient systems reduce energy consumption such as: interior lighting and zone control, renewable energy systems, energy efficient circulation system and efficient ventilation in car parks; and finally 4) energy efficient equipment assess the amount of utilizing energy-efficient appliances and cloth drying facilities, energy-efficient AC equipment and high-efficiency equipment.

5.2.4 Water Use Criterion:

It assesses the practices used to conserve water and decrease water consumption by employing efficient and innovative practices. It is composed of three factors as illustrated in Figure 5.5 and explained as follows: 1) water use evaluates the minimum indoor plumbing fixtures and fittings' efficiency, the additional indoor plumbing fixtures efficiency, water recycling and rainwater harvesting, the water efficient landscaping and irrigation, and water tab efficiency in public areas; 2) water management appraises the various procedures applied to control and reduce water demand such as setting a water conservation plan, illustrates the regular procedures taken for checking and fixing leaks, perform water quality and quantity survey, water performance monitoring, cooling tower water management, and storm water quantity control and surface water runoff; and finally 3) effluent estimates the percentage of reduction of water discharged into foul sewer.

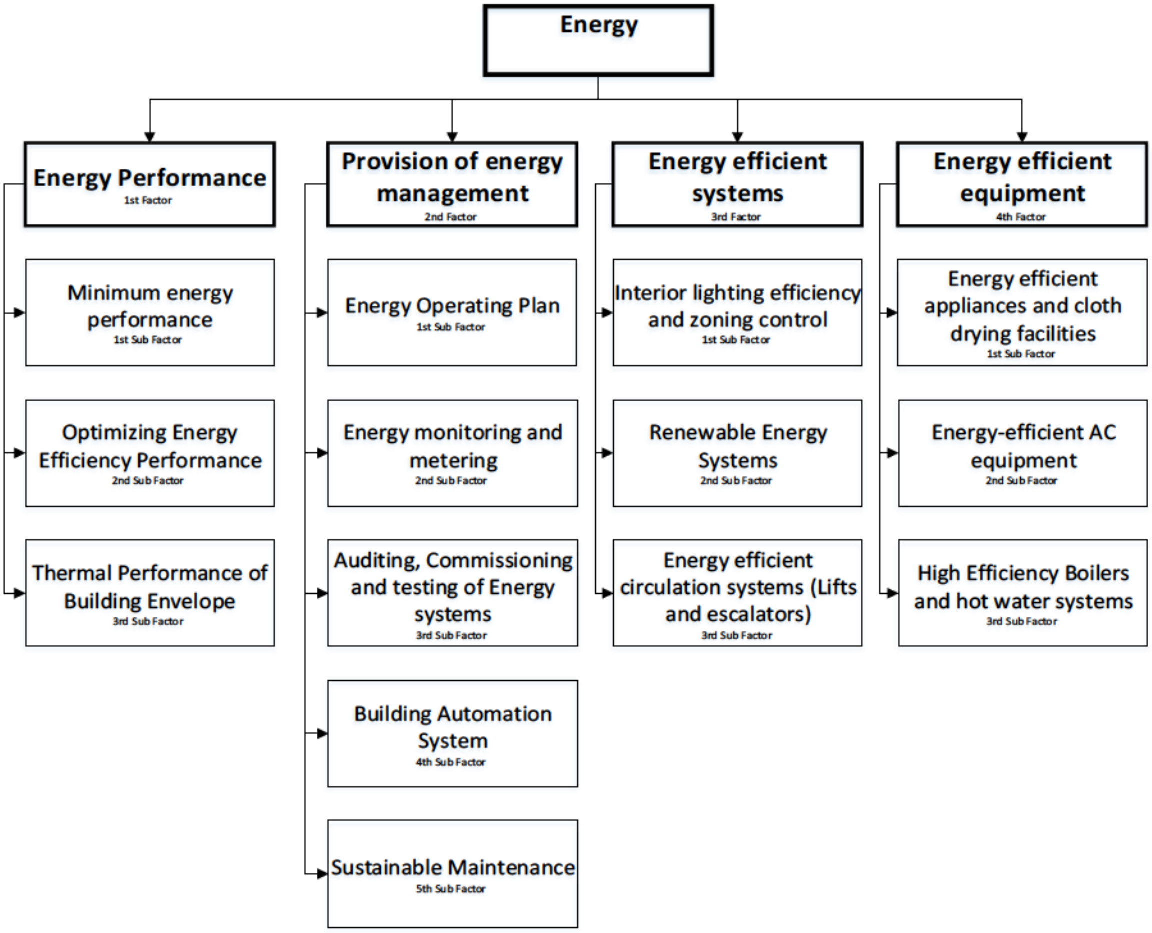


Figure 5.4: Energy Criterion and Its Related Factors and Sub-Factors

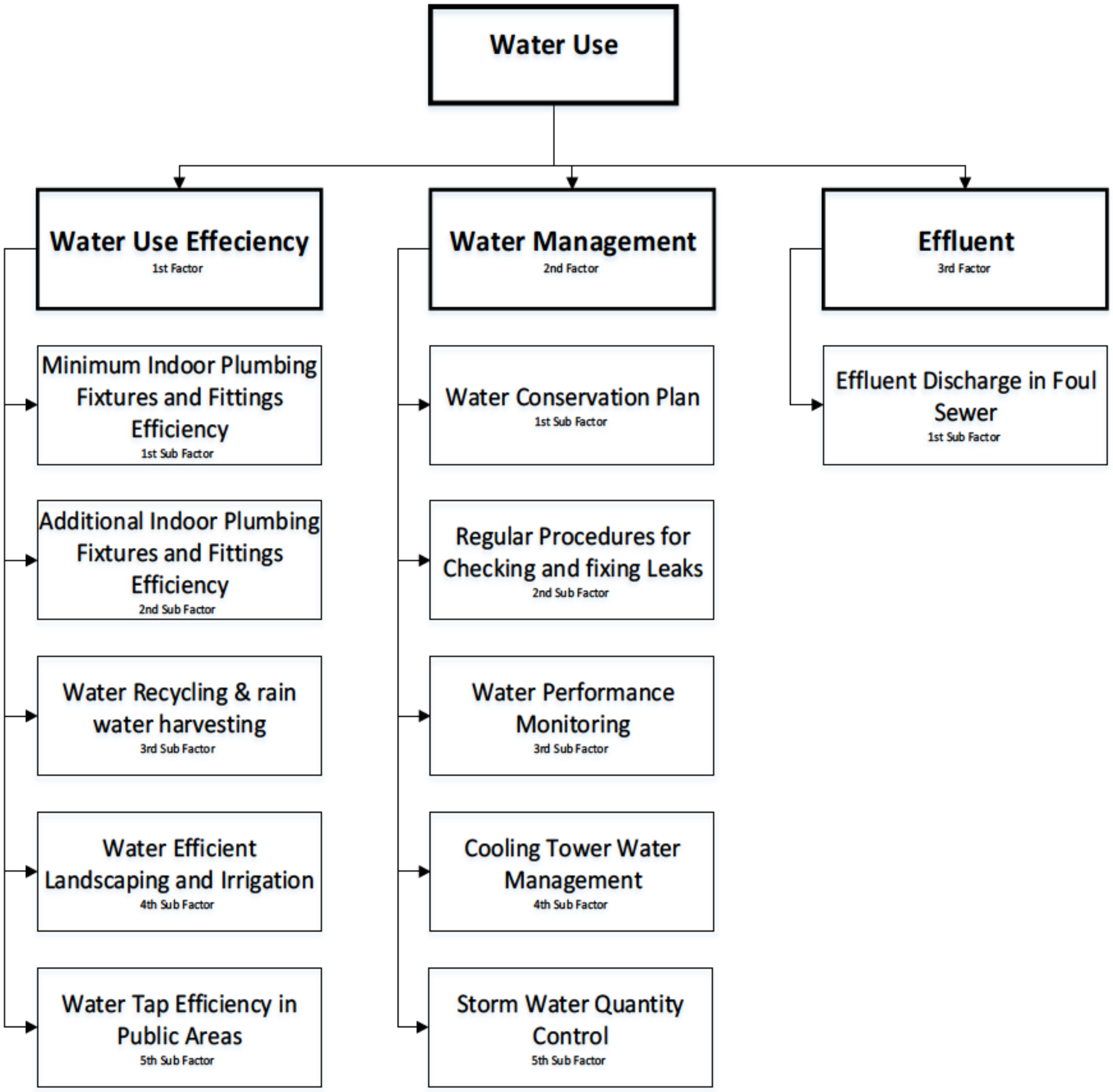


Figure 5.5: Water Use Criterion and Its Related Factors and Sub-Factors

5.2.5 Material and Waste Reduction Criterion:

This criterion evaluates the efficient use of materials and assesses the practices utilized to manage the solid waste efficiently, safely and environment-friendly. It comprises five factors as shown in Figure 5.6 and as described: 1) material management ensures the existence of sustainable purchasing policy for all materials consumed in the building; 2) sustainable purchasing practice for all materials whether they are ongoing goods or durable ones, the sustainable practices applied in dealing with facility alternations and additions, purchasing lamps of low mercury content, apply rapidly renewable materials, saving ecology and environment by using sustainable forest goods, and encourage using regional materials to reduce the environmental impacts that are resulted from transportation; 3) environmentally friendly materials assesses the amount of used non-ozone depleting materials and substances, also, monitoring and controlling leak of refrigerants; 4) efficient use of materials estimates the content of major building elements reuse, encourage modular and standard design, considering adaptability and deconstruction in design, and considering robustness for the asset and landscape; and 4) solid waste management evaluates the existence of solid waste management policy, hazardous waste management, waste stream audit, also how to address the waste of consumables goods and durable ones, as well as, how to treat the waste resulted from facility alternation and addition, also, it evaluates the existence of collection, storage and disposal of recyclables, and finally, provision of installed equipment for waste reduction such as compaction or composting.

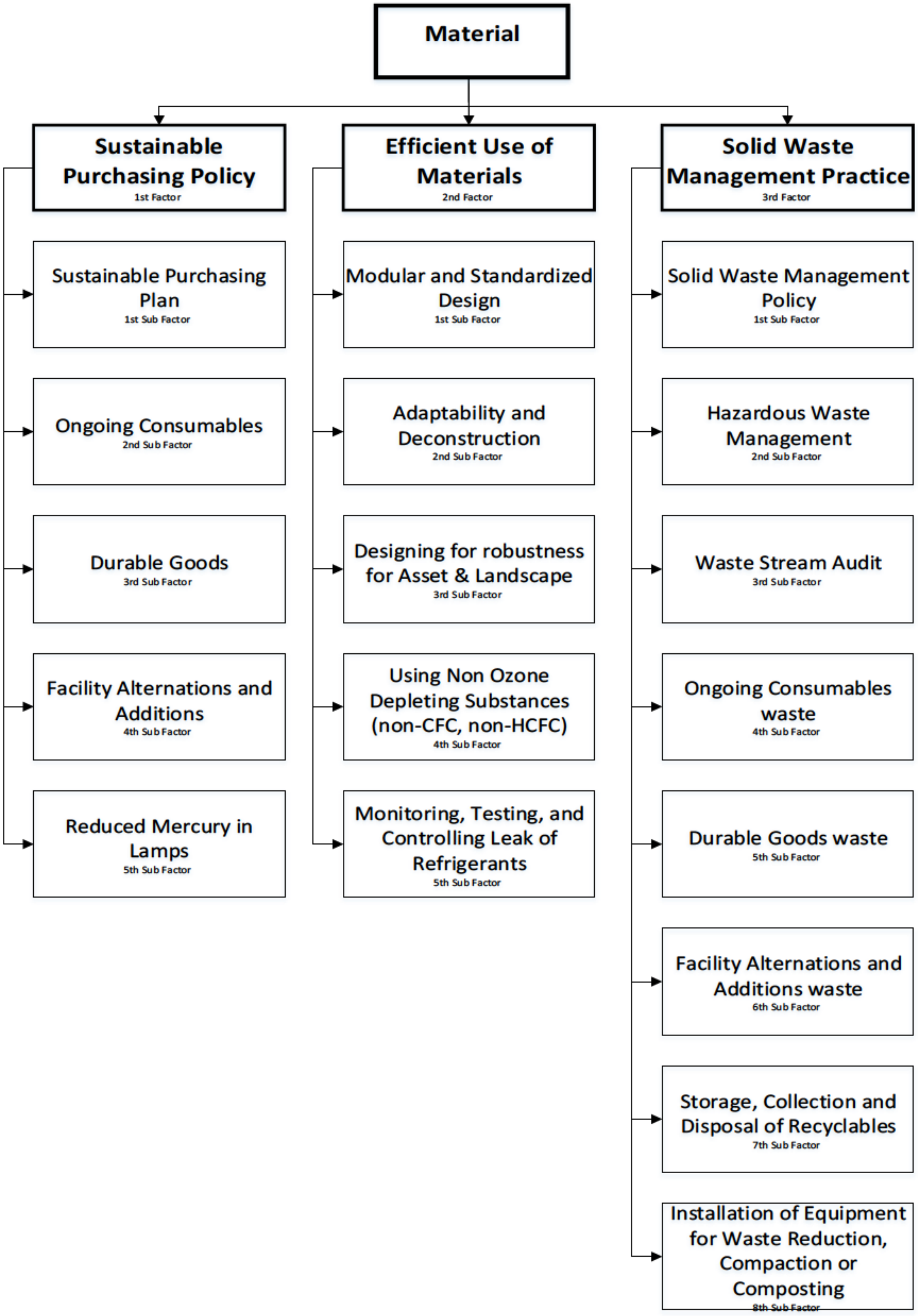


Figure 5.6: Material and Waste Reduction Criterion and Its Related Factors and Sub-Factors

5.2.6 Indoor Environmental Quality:

It encourages the use of adequate and efficient practices to help in improving the indoor environmental quality, improve occupants' comfort, and decrease environmental hazards. It embraces eight factors as demonstrated in Figure 5.7 as follows: 1) visual comfort assesses the amount of natural lighting and glare, the practices used to reduce and control glare, the adequacy of interior lighting distribution in normally and non-normally occupied areas, the systems installed to control artificial lighting, and encourage the use of high frequency ballasts in lighting; 2) indoor air quality evaluates the required minimum indoor air quality, the environmental tobacco smoke control, the indoor air quality performance and management that addresses (auditing, construction management, management plan and monitoring of CO2, CO, NO2 and RSP), indoor air quality pollution monitoring, and green cleaning policy assesses the maintenance and cleaning practices and procedures; 3) ventilation represents the minimum ventilation performance, the increased ventilation performance to meet the increasing number of occupants, as well as the efficiency of the localized ventilation and the ventilation in the common areas; 4) thermal comfort evaluates the design for thermal loads and its mitigation, monitoring and testing the air speed and radiant temperature for analysing and system development, the existence of temperature controlling, and the degree of thermal comfort in both naturally and mechanically ventilated areas; 5) acoustic performance assesses all related aspects to room acoustics, noise isolation efficiency, and background noise; 6) hygiene represents plumbing and drainage system to ensure that it is contaminant free, minimize impacts of chemical leakage in storage, reduce and control the biological contamination such as Legionellosis, and finally provision of deodorizing system in all refuse collection room; 6) building amenities consider the provision of amenities for disabled persons, as well as, the percentage of the amenity features that are provided within the building to increase functionality of the building; 7) and the last factor is verification such as conducting an occupant comfort survey.

5.2.7 Building Management Criterion:

It is the seventh and the last criterion that comprises five factors as presented in Figure 5.8 as following: 1) *maintenance management* assesses condition survey, the staffing quality of the maintenance stakeholders and the resources required to perform efficiently such as drawing plans, material used, maintenance requirements,…etc., also, evaluates the existence of building's user manual and information, maintenance policy, and operation and maintenance procedures; 2) *security measures and intruder alarm* to prevent any damage to the asset and in turn save excess use of materials; 3) *green lease* encourages lease agreements that engage tenants in considering energy, water and waste efficient practices; 4) *risk management* related to fire risk management and natural hazard risk management; and 5) *innovations* assesses the innovative techniques that are utilized and the extent of the performance enhancement.

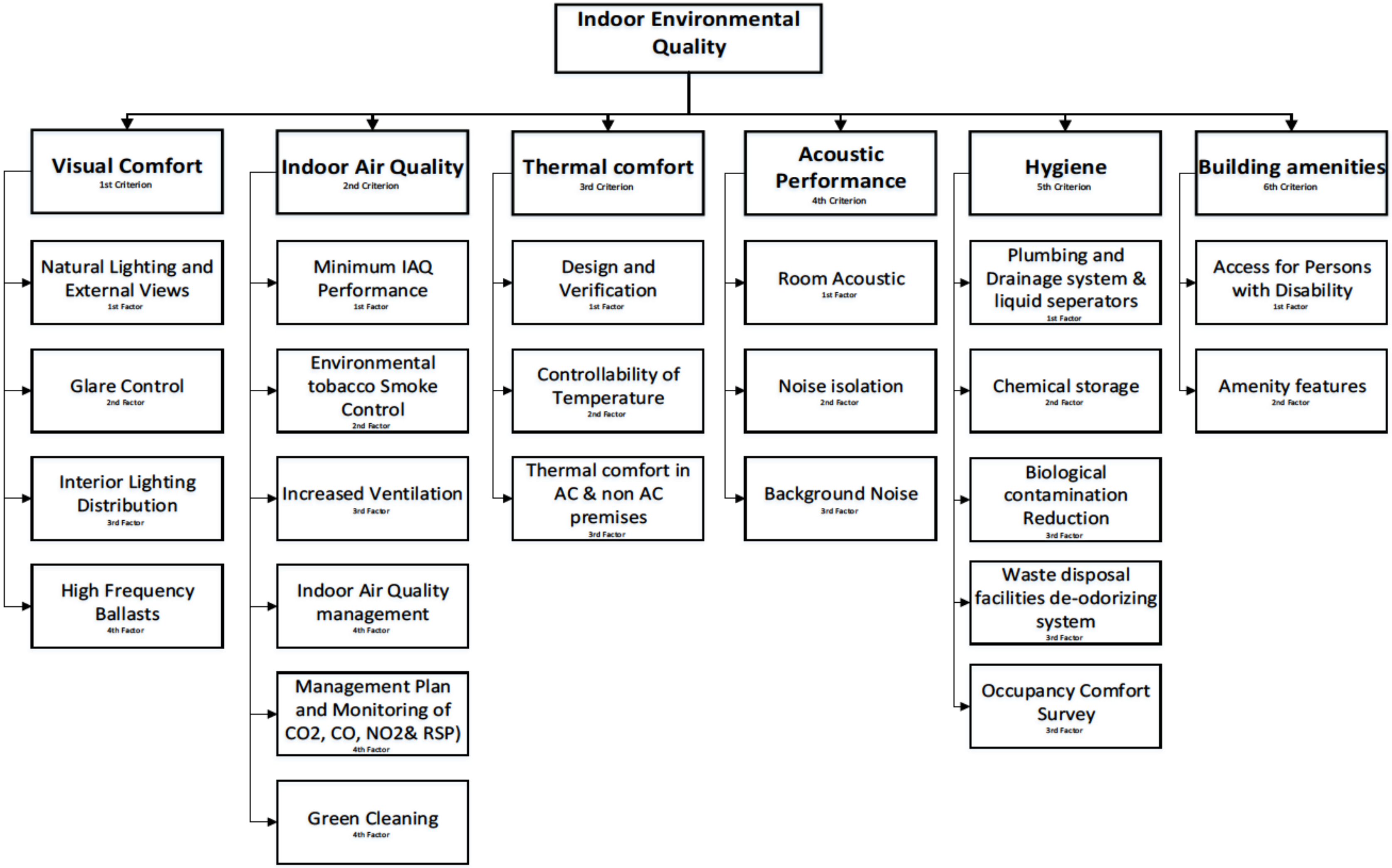


Figure 5.7: IEQ Criterion and Its Related Factors and Sub-Factors

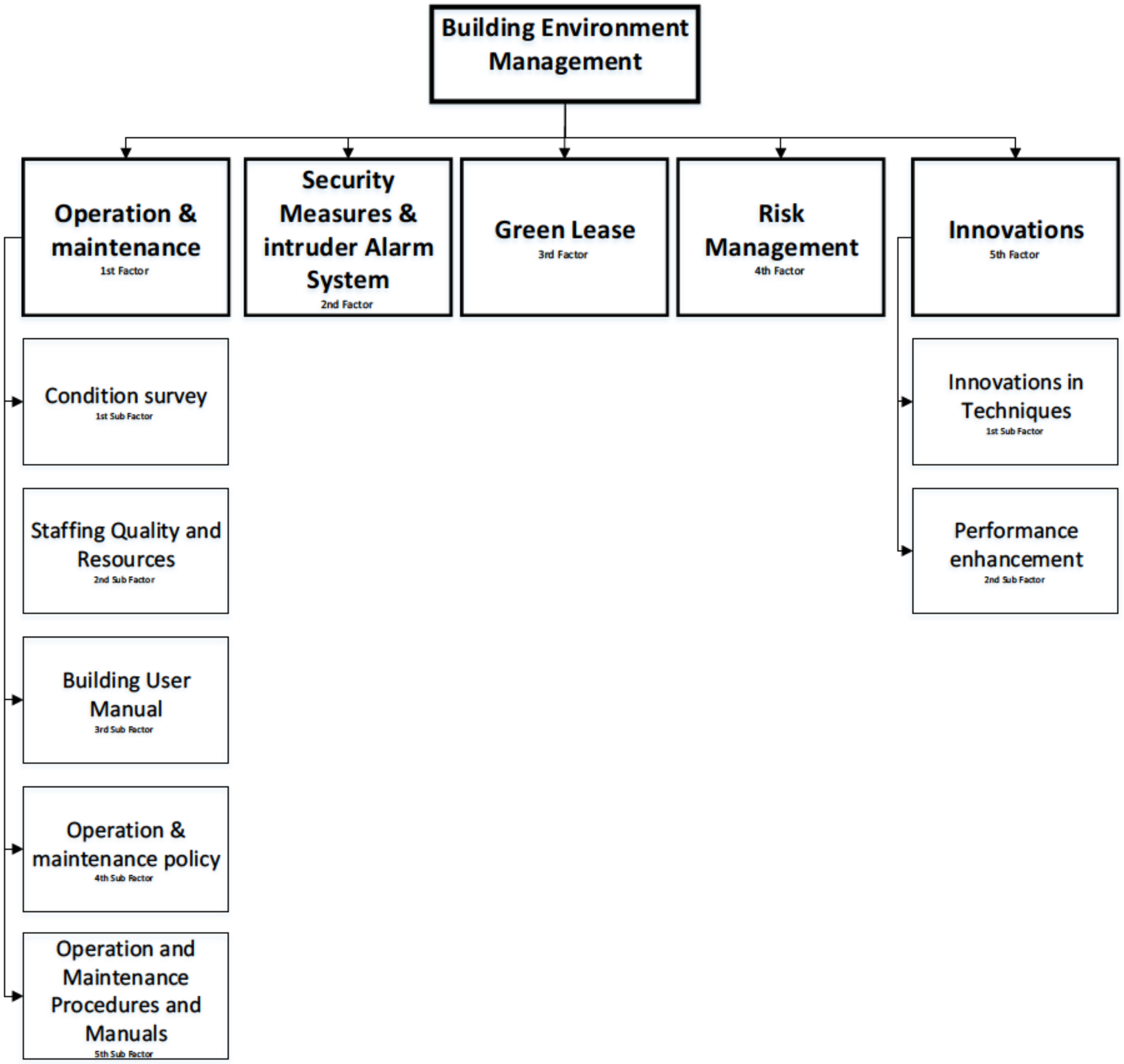


Figure 5.8: Building Management Criterion and Its Related Factors and Sub-Factors

5.3 Comparative Analysis of the Selected Sustainability Assessment Attributes

Based on the literature review, seven criteria have been addressed to have the primary effect on the sustainability of buildings. These criteria are site and ecology, transportation, energy efficiency, water use, material and waste reduction, indoor environmental quality (IEQ), and building management as shown Table 5.1, Table 5.2, and Table 5.3. A comparison is conducted between eight rating systems selected from the World Green Building Council member list (Worldgbc, 2016). The already established green building tool is the key selection criteria of these eight rating tools. The eight rating tools are LEED, BREEAM, HK-BEAM, BCA green mark, Greenship, Green Building Index, BOMA BESt, and CASBEE as shown in Table 5.1, Table 5.2, and Table 5.3. The comparison aims to spotlight on the fundamental attributes and the overlooked ones that affect the sustainability of existing buildings and should be integrated into the developed rating tool.

Table 5.1 shows a comparison between the selected rating systems concerning *site*, *transportation*, and *energy use* criteria. For *Site and ecology* criterion, all the selected rating tools consider *reduce heat island effect* factor, while *site selection* and *site emissions* factors have the lowest concern. *Transportation* criterion has the least consideration in the sustainability framework of the rating tools. Moreover, for *energy* criterion, all the tools include the *provision of energy management* and *energy efficient systems* factors in their assessment framework, contrarily, *energy efficient equipment* has the lowest share.

Additionally, Table 5.2 demonstrates the comparison that is related to *water use*, and *material and waste reduction* criteria. *Water conservation* and *water management* factors have the highest consideration, while *efficient discharge in foul sewer* factor has the lowest importance among the rating systems. Furthermore, the BCA green mark rating system of Singapore do not consider this criterion in its sustainability assessment. In addition, all the factors of the *material and waste reduction* criterion are considered in all the selected rating tools, expressing the importance of this criterion.

The final comparison deals with the *indoor environmental quality* and *building management* criteria as illustrated in Table 5.3. For the *indoor environmental quality* criterion, the percentage of rating tools' consideration for the factors are 100%, 87.5%, 75%, 62.5%, 50%, and 25% for the *indoor air quality, visual comfort*, *thermal comfort*, *acoustic performance*, *hygiene*, and *building amenities* respectively. Likewise, for the factors of the *building management* criterion, the percentages are 62.5%, 37.5%, 37.5%, and 12.5% for *operation and maintenance management*, *security measurement*, *innovations*, and *risk management respectively*.

Table 5.1: Site, Transportation, and Energy Use Criteria Comparison among Eight Rating Tools

Criteria factors and sub factors of the proposed System	**LEED V.3.0**	**BREEAM 2015**	**Green Mark V.4.1**	**HK BEAM V.1.2**	**GBI V.1.05**	**BOMA Ed.2013**	**Green ship V.1.0**	**CASBEE Ed.2008**
Site & Ecology Criterion								
Site Selection Factor	●			●	●		●	●
Previously Certified Design & Construction	●			●	●			
Respect for Sites of Historic or Cultural Interest							●	●
Site Management Factor	●	●	●	●	●	●	●	●
Environmentally Purchasing Plan			●	●				
Environmentally Purchasing Practices & Green Cleaning			●	●				
Building Exterior and Hardscape Management Plan	●			●	●		●	●
Integrated Pest Management, Erosion Control and Landscape Management	●				●	●	●	
Reduction of Heat Island Effect Factor	●	●	●	●	●			●
Heat Island Reduction in Not Roofed Areas	●				●			●
Heat Island Reduction in Roof Areas	●		●		●			●
Exterior Walls Finishing Materials & Planting			●					●
Consideration of Wind Movement and Building Exterior Design								●
Greenery Provision & Ecological Features		●	●					●
Site Emissions Factor	●			●		●		●
Noise from Building Equipment				●				
Light Pollution Reduction	●			●				●
Boiler Emissions						●		
Asbestos Management Plan						●		
Transportation Criterion								
Cyclist Facilities & Alternative Methods of Transport Factor	●	●	●				●	
Cyclist Facilities		●	●				●	
Carpooling & Vanpooling							●	
Rreduction in Conventional Commuting Trips	●							
Public Transport Accessibility & Community Accessibility Factor		●	●				●	
Public Transport Accessibility		●	●					
Proximity to Amenities		●					●	
Provision of maximum Car Parking Capacity Factor					●			
Provision of Low-Emitting & Fuel-Efficient Vehicles Factor			●		●			
Energy Criterion								
Energy Performance Factor	●	●	●	●	●	●	●	
Minimum Energy Performance	●			●	●		●	
Optimizing Energy Efficiency Performance & Reduction of CO2 emissions	●	●		●	●	●	●	
Evaluation of Thermal Performance Reduction of Building Envelope			●			●		
Provision of Energy Management Factor	●	●	●	●	●	●	●	●
Energy Operating Plan	●		●	●		●	●	
Energy Monitoring and Metering	●			●	●	●	●	●
Commissioning and Testing Energy Systems	●	●		●	●	●	●	
Building Automation System, or Energy Management System (EMS)	●				●			
Emissions Reduction Reporting	●						●	
Sustainable Maintenance					●		●	
Energy Efficient Systems Factor	●	●	●	●	●	●	●	●
Interior Lighting Efficiency and Zoning Control.	●	●	●	●	●		●	
Renewable Energy Systems	●	●	●	●	●	●	●	●
Energy Efficient Circulation Systems (Lifts and escalators)			●					
Efficient Ventilation System in Car Parks and Common Areas.			●	●				
Energy Efficient Equipment Factor		●	●	●		●	●	●
Energy Efficient Appliances and Cloth Drying Facilities				●				
Energy Efficient AC Equipment		●	●	●			●	●
High Efficiency Boilers		●				●		

Table 5.2: Water Use, Material, and Waste Reduction Criteria Comparison among Eight Rating Tools

Criteria factors and sub factors of the proposed System	**LEED V.3.0**	**BREEAM 2015**	**Green Mark V.4.1**	**HK BEAM V.1.2**	**GBI V.1.05**	**BOMA Ed.2013**	**Green ship V.1.0**	**CASBEE Ed.2008**
Water Use Criterion								
Water Conservation Factor	●	●		●	●	●	●	●
Minimum Indoor Plumbing Fixtures and Fittings Efficiency	●	●		●		●	●	
Additional Indoor Plumbing Fixtures and Fittings Efficiency	●	●		●	●	●	●	●
Water Recycling & Rain Water Harvesting		●		●	●	●	●	●
Water Efficient Landscaping and Irrigation	●			●	●	●		
Water Tap Efficiency in Public Areas							●	
Water Management Factor	●	●		●	●	●	●	
Water Conservation Plan				●		●	●	
Regular Procedures for Checking and fixing Leaks		●				●	●	
Water Performance monitoring	●	●		●	●	●	●	
Cooling Tower Water Management	●					●		
Storm Water Quantity Control & Surface Water run off	●	●				●	●	
Effluent Discharge in Foul Sewer Factor				●		●		
Material & Waste Reduction Criterion								
Sustainable Purchasing Practice Factor	●	●	●	●	●	●	●	●
Sustainable Purchasing Policy	●				●		●	
Ongoing Consumables	●		●					●
Durable Goods & Sustainable Forest Products	●	●	●	●	●		●	●
Facility Alternations and Additions & reuse	●		●	●	●		●	●
Reduced Mercury in Lamps	●						●	●
Efficient Use & Selection of Materials Factor	●	●	●	●	●	●	●	●
Modular and Standardized Design				●				
Adaptability and Deconstruction		●		●				
Designing for robustness for Asset & Landscape		●						
Using Non-Ozone Depleting Substances (non-CFC, non-HCFC)	●	●	●	●	●	●	●	
Monitoring, Testing, and Controlling Leak of Refrigerants		●				●		
Solid Waste Management Practice Factor	●	●	●	●	●	●	●	●
Solid Waste Management Policy	●			●		●	●	
Hazardous Waste Management						●	●	
Waste Stream Audit	●		●	●		●		●
Ongoing Consumables	●							
Durable Goods	●							
Facility Alternations and Additions	●							
Storage, Collection and Disposal of Recyclables among tenants		●	●	●	●	●		●
Installation of Equipment for Waste Reduction, Compaction or Composting						●		●

Table 5.3: IEQ and Building Management Criteria Comparison among Eight Rating Tools

Criteria factors and sub factors	**LEED V.3.0**	**BREEAM 2015**	**Green Mark V.4.1**	**HK BEAM V.1.2**	**GBI V.1.05**	**BOMA Ed.2013**	**Green ship V.1.0**	**CASBEE Ed.2008**
Indoor Environment Quality Criterion								
Visual Comfort Factor	●	●	●	●	●		●	●
Natural Lighting and External Views	●	●		●	●			●
Glare Control		●			●			
Interior Lighting Distribution in Normally and Non-Normally Occupied		●	●	●	●			●
Controllability of Lighting System	●	●	●					●
High Frequency Ballasts		●			●		●	
Indoor Air Quality Factor	●	●	●	●	●	●…	●	●
Minimum IAQ Performance	●				●			
Environmental tobacco Smoke Control	●			●	●		●	●
Increased Ventilation Performance, Localized Ventilation& Ventilation	●	●		●				●
Indoor Air Quality Performance & management (audit, Construction	●	●	●	●	●	●	●	●
Indoor Air Quality Pollutant monitoring (chemical, physical and	●	●	●	●	●		●	●
Green Cleaning Policy	●	●	●	●				
IAQ Verification Before/ During Occupancy					●			
Thermal Comfort Factor	●	●	●	●	●			●
Design, Verification and	●				●			●
Controllability of Temperature		●	●		●			
Thermal Comfort in Air-Conditioned Premises and in Naturally			●	●				●
Acoustic Performance Factor			●	●	●		●	●
Room Acoustic				●	●		●	
Noise isolation				●			●	●
Background Noise			●	●	●		●	●
Hygiene Factor	●	●		●	●			
Plumbing and Drainage				●				
Chemical storage		●						
Biological contamination Reduction		●		●				
Waste disposal facilities de-odorizing system				●				
Occupancy Comfort Survey	●				●			
Building Amenities Factor		●		●				
Access for Persons with Disability		●		●				
Amenity features				●				
Building Management Criterion								
Operation and Maintenance Management Factor		●	●	●	●		●	
Condition Survey		●						
Staffing Quality and Resources			●	●				
Building User Manual and Information		●	●	●	●			
Operation & Maintenance Policy		●					●	
Operation & Maintenance Procedures and Manuals		●					●	
Security Measures & Intruder Alarm System Factor		●	●				●	
Green Lease Factor		●	●				●	
Risk Management Factor		●						
Fire Risk Assessment; Fire Risk Manager		●						
Natural Hazards		●						
Innovations Factor		●		●			●	
Innovations in Techniques		●		●			●	
Performance enhancement		●		●			●	

5.4 Research Surveys

The research utilizes two types of surveys to gather the required data to develop and implement the sustainability assessment model and the sustainability based rehabilitation models: 1) interviews, and 2) questionnaires. These types of surveys are performed over two years of research.

5.4.1 Interviews

The interviews were conducted with a number of experts to grasp the different aspects that were applied to assess the sustainability of buildings and to identify the research problems and objectives. These interviews are divided into non-structured and structured ones. The non-structured interviews were undertaken with facility managers and building sustainability experts at the early stages of the research to define the main issues that affect the sustainability of buildings. Hence, this type of interview was utilized to identify the research problems and objectives. The structured interviews are questions based to identify the importance of the developed sustainability assessment attributes. These structured interviews are held with facility manager experts, mechanical engineers that have experience in the sustainability of buildings, civil engineers, and architects.

5.4.2 Questionnaire

The questionnaire underwent many modifications to be in the final form to adjust the time taken to respond the questionnaire which is limited to be taken in 10 to 15 minutes. Also, the way the questions were proposed in the questionnaire were adjusted several times to achieve clarity, directness, and reliability. Two hundred experts in the building, construction, and sustainability fields were contacted by email and requested to fill the questionnaire. This number of questionnaires was divided into two equal groups: one was sent to Egyptian experts and the other was sent to Canadian experts.

There is a substantial number of experts in sustainability field in Canada and Egypt. However, the exact number of the population of those experts is hard to be estimated. So, when the sample size is to be selected, two elements should be taken into consideration which is degree of confidence and margin of error. The degree of confidence represents the percentage of correct results will be obtained out of the questionnaire that will be the same. If the degree of confidence is 90%, this means that the true results out of different samples in the same population will get true result that matches the confidence level. The margin of error represents the allowable error that can be obtained out of the sample results, so, the greater the margin of error the less confidence is the experiment or the results out of the sample. The sample size can be determined by using Figure 5.9, by knowing the population size, the confidence level, and the margin of error (Research Advisors, 2006). Therefore, the population size of experts was assumed to be 150, so based on the previous figure the sample size was selected to be 100. The value in Figure 5.9 is based on equation (5.1) (Krejcie and Morgan, 1970).

$$n = \frac{X^2 NP(1-P)}{d^2(N-1) + X^2 P(1-P)} \tag{5.1}$$

Where:

n = required sample size;

X^2 = table value of chi-square for one degree of freedom at desired confidence level (3.841);

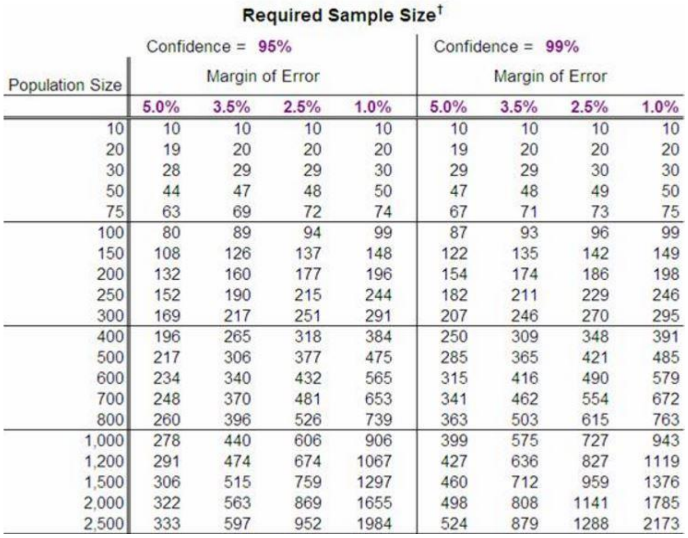
N = population size;

P = population proportion (assumed 0.5); and

d =degree of accuracy (0.05).

Moreover, forty respondents from Egypt answer the questionnaire and 25 respondents from Canada answer the questionnaire with percentages 40% and 25% respectively. There is a diversity of respondents' professions in the Canadian and the Egyptian samples. The Canadian respondents includes civil engineers, mechanical/electrical engineers, sustainability experts, facility managers, and architects, while the Egyptian samples consisted of architects, civil engineers, and sustainability experts as shown in Figure 5.10.

The rationale for selecting Canada and Egypt to determine the weights of each attribute was attributed to the apparent variation between the two countries in the following aspects: climate; resources; consideration of environmental protection; cultural and traditional values; and abundance of water resources. These aspects and their variation in the importance to the sustainability according to the two selected countries (Canada and Egypt) would have a distinct effect on the weights of each attribute and in turn, will differ from country to another. Furthermore, this variation will illustrate the importance of introducing weights in the sustainability assessment process that will demonstrate the impact of regional variation on the sustainability assessment.



Required Sample Size[†]

Population Size	Confidence = 95%				Confidence = 99%			
	Margin of Error				Margin of Error			
	5.0%	3.5%	2.5%	1.0%	5.0%	3.5%	2.5%	1.0%
10	10	10	10	10	10	10	10	10
20	19	20	20	20	19	20	20	20
30	28	29	29	30	29	29	30	30
50	44	47	48	50	47	48	49	50
75	63	69	72	74	67	71	73	75
100	80	89	94	99	87	93	96	99
150	108	126	137	148	122	135	142	149
200	132	160	177	196	154	174	186	198
250	152	190	215	244	182	211	229	246
300	169	217	251	291	207	246	270	295
400	196	265	318	384	250	309	348	391
500	217	306	377	475	285	365	421	485
600	234	340	432	565	315	416	490	579
700	248	370	481	653	341	462	554	672
800	260	396	526	739	363	503	615	763
1,000	278	440	606	906	399	575	727	943
1,200	291	474	674	1067	427	636	827	1119
1,500	306	515	759	1297	460	712	959	1376
2,000	322	563	869	1655	498	808	1141	1785
2,500	333	597	952	1984	524	879	1288	2173

Figure 5.9: Sample Size Determination (Research Advisors, 2006)

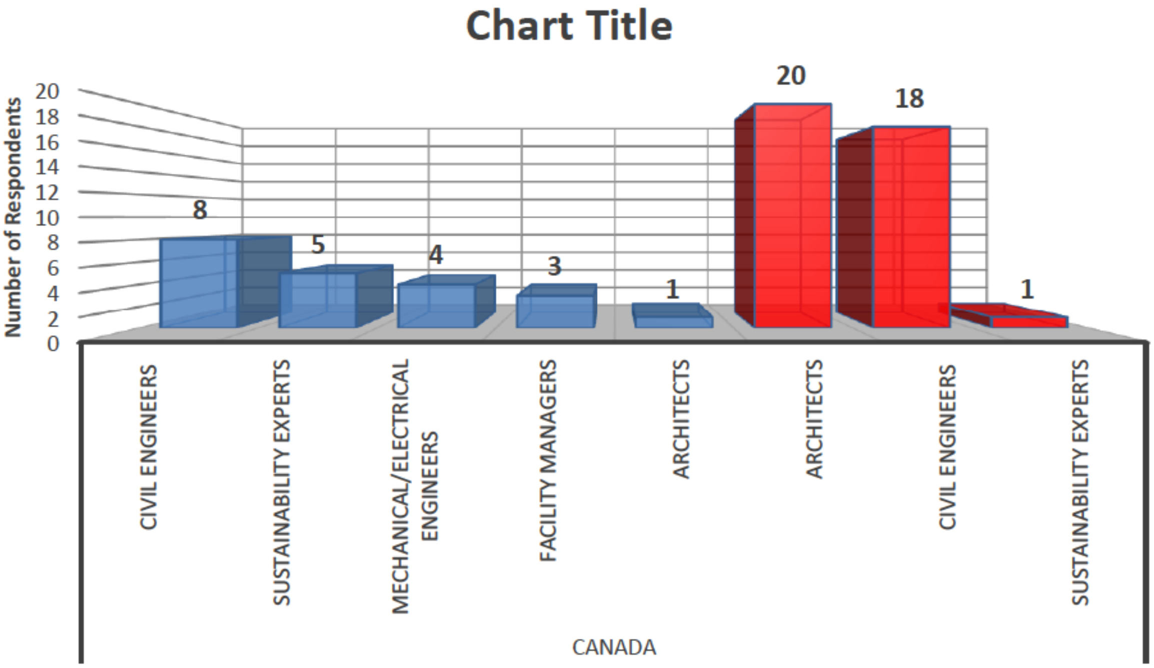


Figure 5.10: Respondent Fields of Expertise

5.5 List of Questionnaire Sections

The questionnaire was comprised of several sections aiming to achieve reliability and consistency among all the responses. Further, the main objectives of the questionnaire: 1) identify the importance of the sustainability criteria and factors, 2) establish a sustainability assessment scale, and 3) establish a minimum required threshold for each criterion for each assessment rank. The questionnaire sections are introduction, respondent self-data and general information, degree of importance of sustainability assessment criteria, degree of importance of sustainability assessment factors, sustainability assessment scheme, and sustainability criteria thresholds.

5.5.1 Introduction and Respondent-self Information

This part of the questionnaire introduces the main sustainability assessment attributes and their hierarchy as developed in section of identification of sustainability assessment attributes. Figure

5.11 shows the seven assessment criteria and their related factors, as well as how it distinguishes the factors that can be improved in the rehabilitation. Moreover, the first part of the questionnaire includes the respondent-self information which is required to express the reliability of the responses. The respondent is asked to enter general information that expresses his/her profession and years of experience as shown in Figure 5.12. Hence, the years of experience for each respondent will be expressed as weight which will be given to introduce the reliability of the responses in the calculations as will be discussed in the following chapter.

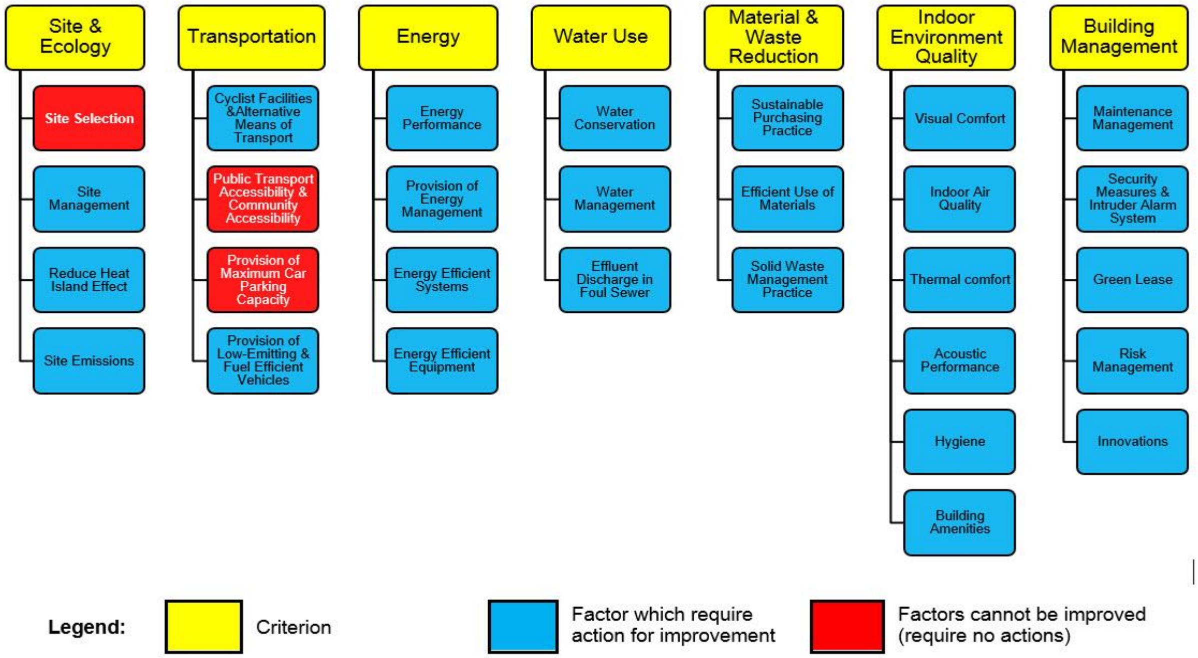


Figure 5.11: Questionnaire Introduction Section and the Sustainability Assessment Attributes

PART (1): GENERAL INFORMATION

1) How do you describe your occupation?

☐ Civil Engineer ☐ Architect
☐ Mechanical/Electrical Engineer ☐ Others ________________

2) Which best describes your working experience?

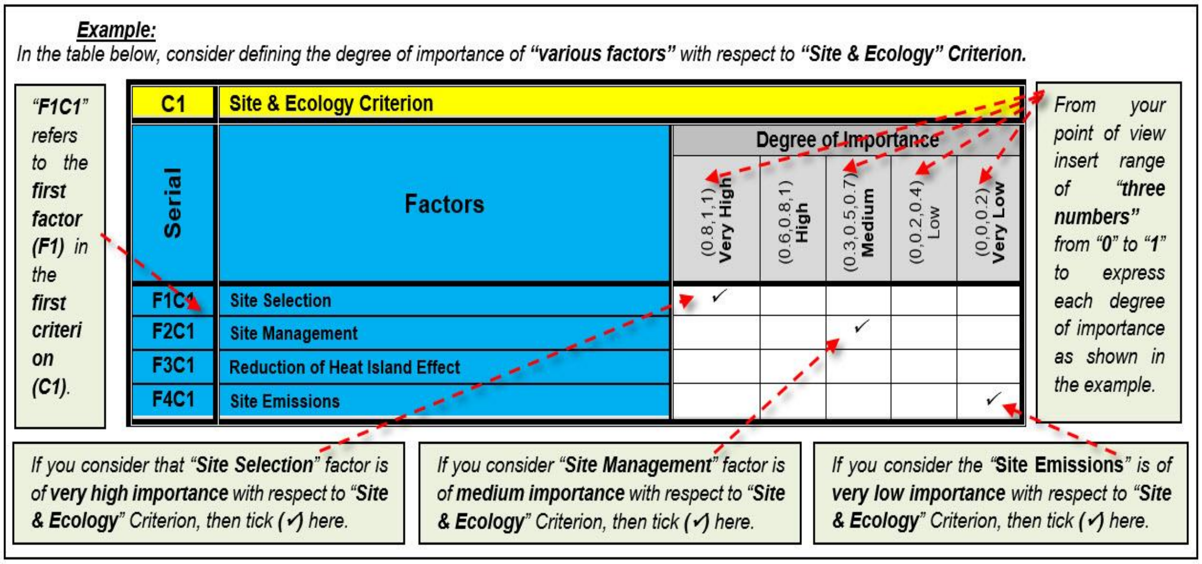
☐ Less than 5 years ☐ 6 -10 years
☐ 11 – 15 years ☐ 16 – 20 years
☐ More than 20 years

Figure 5.12: Respondent self-information

5.5.2 Criteria and Factors Degree of Importance

The aim of this part of the questionnaire to identify the importance of each criterion and factor that will affect the total sustainability assessment. The importance will differ according to the regional location of the building. Accordingly, the questionnaire was sent to experts in two different regions (i.e. Egypt and Canada) to stand for variations of the importance consideration of the assessment attributes among the experts of the two countries.

The respondents are requested to enter range of three numbers to express a five-linguistic scale: very high, high, medium, low, and very low which will be utilized in a fuzzy method to fuzzify these linguistic variables for further calculations as illustrated in Figure 5.13. Furthermore, respondents are asked to insert the degree of importance of each criterion of the seven criteria with respect to the overall assessment of the sustainability of buildings as shown in Figure 5.14. Additionally, the respondents are also requested to enter the degree of importance of each factor concerning the criterion it represents, based on their experience in the field as shown in Figure 5.15. The questionnaire is designed to use responses collected from the respondent data and apply fuzzy TOPSIS method to determine the weight of each criterion and factor according to regional variations as will be illustrated in the following chapter.



Example:

*In the table below, consider defining the degree of importance of **"various factors"** with respect to **"Site & Ecology" Criterion.***

*"**F1C1**" refers to the **first factor (F1)** in the **first criterion (C1)**.*

C1	**Site & Ecology Criterion**					
Serial	**Factors**	**Degree of Importance**				
		(0.8,1,1) **Very High**	(0.6,0.8,1) **High**	(0.3,0.5,0.7) **Medium**	(0,0.2,0.4) Low	(0,0,0.2) **Very Low**
F1C1	**Site Selection**	✓				
F2C1	**Site Management**			✓		
F3C1	**Reduction of Heat Island Effect**					
F4C1	**Site Emissions**					✓

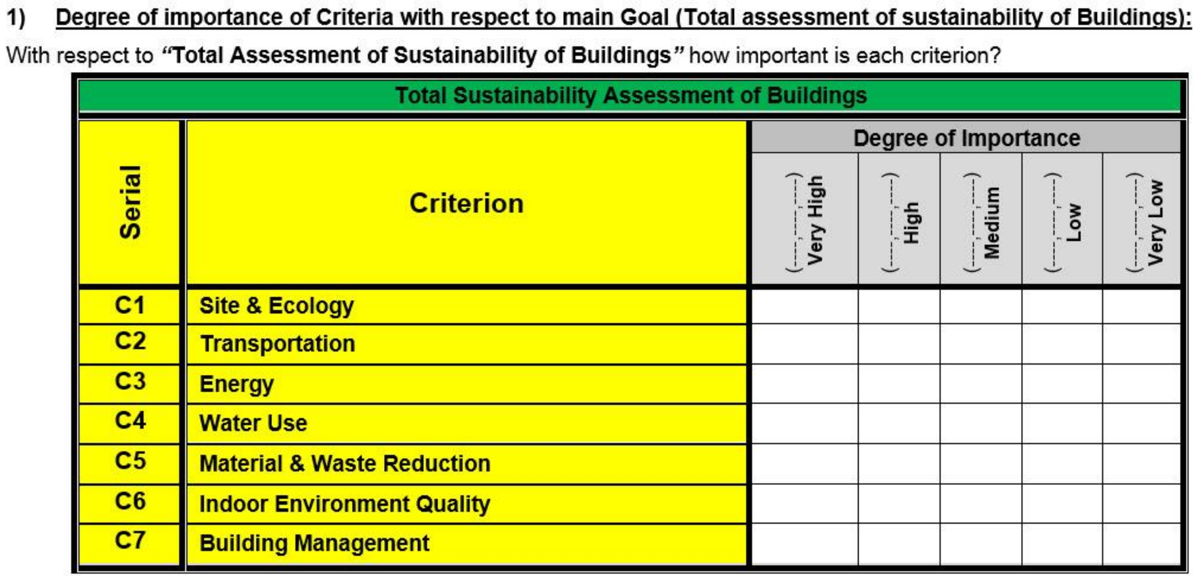
*From your point of view insert range of **"three numbers"** from **"0"** to **"1"** to express each degree of importance as shown in the example.*

*If you consider that "**Site Selection**" factor is of **very high importance** with respect to "**Site & Ecology**" Criterion, then tick (✓) here.*

*If you consider "**Site Management**" factor is of **medium importance** with respect to "**Site & Ecology**" Criterion, then tick (✓) here.*

*If you consider the "**Site Emissions**" is of **very low importance** with respect to "**Site & Ecology**" Criterion, then tick (✓) here.*

Figure 5.13: Expressing Linguistic Scale into Triangular Fuzzy Numbers

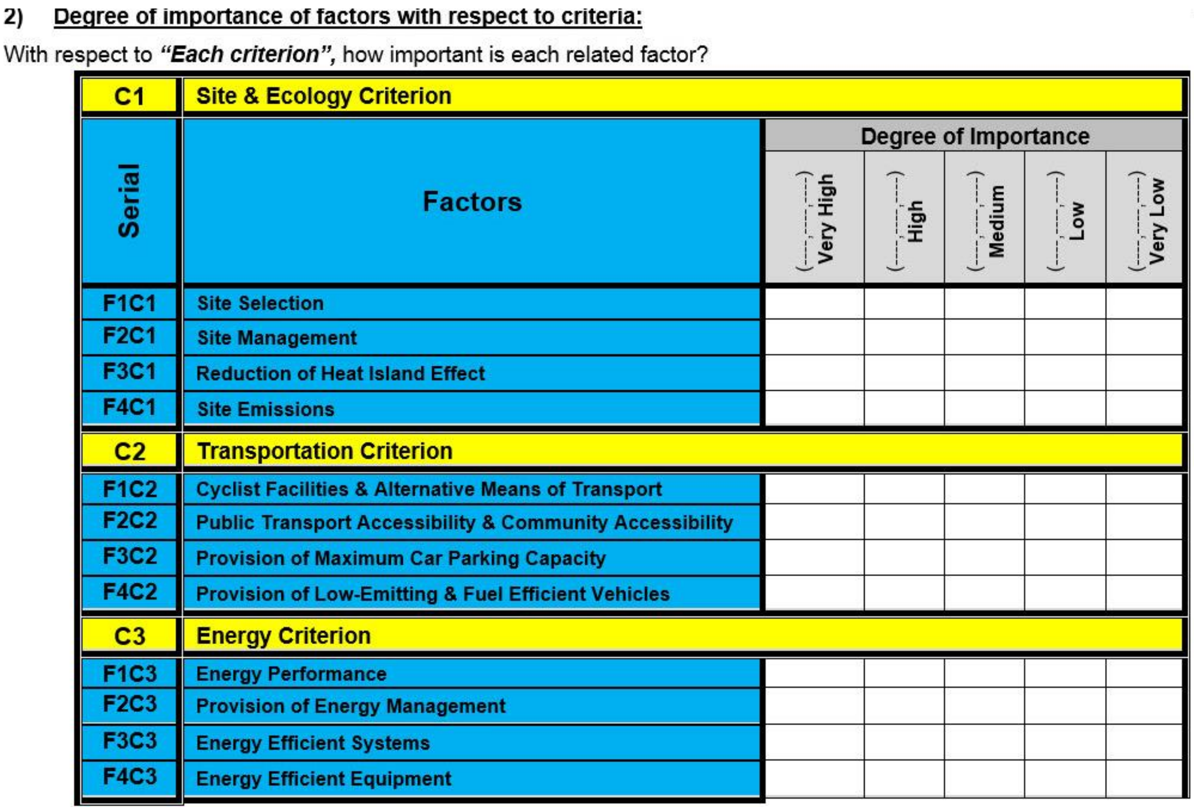


1) Degree of importance of Criteria with respect to main Goal (Total assessment of sustainability of Buildings):

With respect to ***"Total Assessment of Sustainability of Buildings"*** how important is each criterion?

Total Sustainability Assessment of Buildings						
Serial	**Criterion**	**Degree of Importance**				
		(---,---,---) **Very High**	(---,---,---) **High**	(---,---,---) **Medium**	(---,---,---) **Low**	(---,---,---) **Very Low**
C1	**Site & Ecology**					
C2	**Transportation**					
C3	**Energy**					
C4	**Water Use**					
C5	**Material & Waste Reduction**					
C6	**Indoor Environment Quality**					
C7	**Building Management**					

Figure 5.14: Degree of Importance of Each Criterion



2) Degree of importance of factors with respect to criteria:

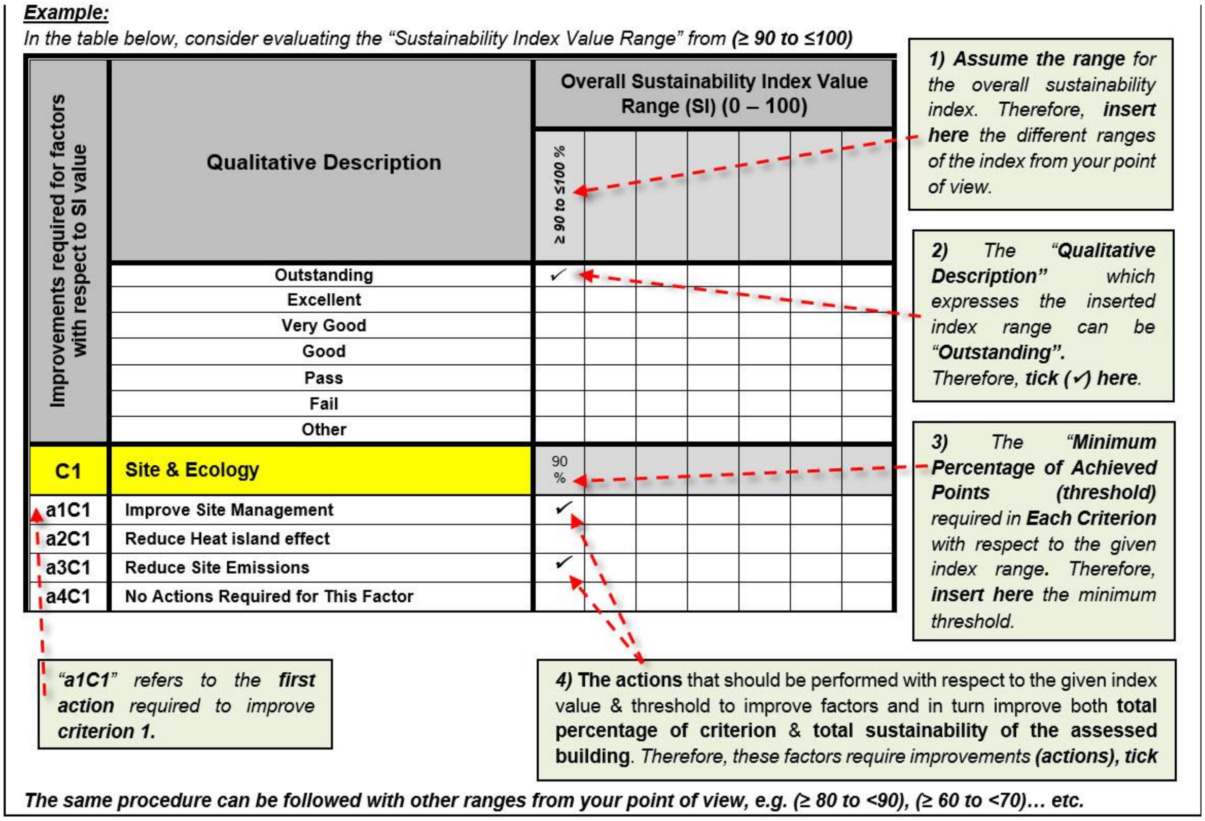
With respect to ***"Each criterion",*** how important is each related factor?

C1	**Site & Ecology Criterion**					
Serial	**Factors**	**Degree of Importance**				
		(------,------,------) **Very High**	(------,------,------) **High**	(------,------,------) **Medium**	(------,------,------) **Low**	(------,------,------) **Very Low**
F1C1	**Site Selection**					
F2C1	**Site Management**					
F3C1	**Reduction of Heat Island Effect**					
F4C1	**Site Emissions**					
C2	**Transportation Criterion**					
F1C2	**Cyclist Facilities & Alternative Means of Transport**					
F2C2	**Public Transport Accessibility & Community Accessibility**					
F3C2	**Provision of Maximum Car Parking Capacity**					
F4C2	**Provision of Low-Emitting & Fuel Efficient Vehicles**					
C3	**Energy Criterion**					
F1C3	**Energy Performance**					
F2C3	**Provision of Energy Management**					
F3C3	**Energy Efficient Systems**					
F4C3	**Energy Efficient Equipment**					

Figure 5.15: Degree of Importance of Each Criterion

5.5.3 Sustainability Assessment Scale

The respondents were asked to select the suitable sustainability scale according to their experience. The proposed sustainability scheme rankings in the questionnaire to select from: 1) outstanding, 2) excellent, 3) very good, 4) good, 5) pass, and 6) fail. Each respondent will select a range of two numbers from zero to 100 that is suitable for each ranking in the proposed scheme as shown in Figure 5.16. Moreover, the respondents were requested to select the minimum threshold percentage required to be fulfilled with each criterion in each of the different sustainability scheme rankings. Figure 5.16 demonstrates an example of the minimum threshold required for the site and ecology criterion to achieve the outstanding rank (i.e. 90% is required as a minimum threshold).



Example:

In the table below, consider evaluating the "Sustainability Index Value Range" from ***(≥ 90 to ≤100)***

Improvements required for factors with respect to SI value	Qualitative Description	Overall Sustainability Index Value Range (SI) (0 – 100)						
		≥ 90 to ≤100 %						
	Outstanding	✓						
	Excellent							
	Very Good							
	Good							
	Pass							
	Fail							
	Other							
C1	**Site & Ecology**	90 %						
a1C1	Improve Site Management	✓						
a2C1	Reduce Heat island effect							
a3C1	Reduce Site Emissions	✓						
a4C1	No Actions Required for This Factor							

1) Assume the range *for the overall sustainability index. Therefore,* ***insert here*** *the different ranges of the index from your point of view.*

2) *The* ***"Qualitative Description"*** *which expresses the inserted index range can be* ***"Outstanding".*** *Therefore,* ***tick (✓) here****.*

3) *The* ***"Minimum Percentage of Achieved Points (threshold)*** *required in* **Each Criterion** *with respect to the given index range. Therefore,* ***insert here*** *the minimum threshold.*

*"****a1C1****" refers to the* ***first action*** *required to improve* ***criterion 1.***

4) **The actions** that should be performed with respect to the given index value & threshold to improve factors and in turn improve both **total percentage of criterion** & **total sustainability of the assessed building**. *Therefore, these factors require improvements* ***(actions), tick***

The same procedure can be followed with other ranges from your point of view, e.g. (≥ 80 to <90), (≥ 60 to <70)… etc.

Figure 5.16: Sustainability Scale and Minimum Threshold Data Entry

5.6 Summary

This chapter showed the various sustainability attributes that have been introduced in the proposed rating system. The proposed system uses three levels of hierarchy starting with the generic level which is the criteria going down to more detailed level in the factor and further to sub-factors. Moreover, the chapter shows a comparative analysis conducted with eight well-known and widespread rating tools to illustrate that the proposed rating system assess the building comprehensively, and comprise diversity of attributes that affect the sustainability of the buildings. Further the chapter introduced the different surveys conducted through the research such as the interviews and questionnaires. Also, this chapter described the different parts of the performed questionnaire that has been utilized to determine the weight of the criteria and factors as well as, to develop the sustainability scale and the thresholds for each sustainability level, which will be described in detail in the following chapter.

CHAPTER 6: CASE STUDIES AND MODELS IMPLEMENTATIONS

6.1 Introduction

This chapter introduces the weight determination procedures through applying fuzzy TOPSIS technique, also, several ways to check data reliability and consistency will be illustrated. Additionally, the chapter shows the assessment scale and threshold development procedures. The BIM models of the two case studies will be shown and the data collected utilizing the BIM modelling will be demonstrated. Further, the results of the energy simulation models for the two case studies will be shown. Moreover, the score determination procedures and points allocation of each sub factor will be described in detail. The implementation of the sustainability assessment model on the two cases study buildings in different regional context will be illustrated. Finally, the output of the optimization model will be explained through six tests using different setting and interpretation of these results will be shown.

6.2 Weight Determination

6.2.1 Data Reliability

Checking data reliability is an important aspect to assure that the collected data from respondents are reliable and of an acceptable degree of confidence for further implementation and analysis. One of the methods that can be used to check the consistency of the data is the coefficient of variance (Chandratilake and Dias, 2013). The coefficient of variance can be calculated using equation (6.1). The second method that was used in data reliability check is the Chronbach's alpha. The Cronbach's alpha was developed in 1951 by Lee Chronbach to measure the consistency or reliability of data that measure single and unidimensional aspect (Cronbach, 1951; Cronbach, 2004). This method reflects the consistency in scale ranging from zero to one, but negative values may occur when the examined items are not positively correlated (Vaske et al., 2017). There are several ways to determine Alpha, however equation (6.2) is commonly used. Many of studies agreed that an alpha value of 0.7 represents an acceptable reliability (Kline, 2000; Pison and Van Aelst, 2004; Vaske et al., 2017)

$$COV = std/\bar{x} \tag{6.1}$$

Where:

COV = coefficient of variance;
std = standard deviation; and
$\bar{x}$ = mean of values.

$$\propto = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{k} \delta_{Y_i}^2}{\delta_X^2}\right) \tag{6.2}$$

Where:

K = number of survey items in the scale;
δ_X^2 = variance of the observed total scores; and
$\delta_{Y_i}^2$ = variance of item I for person Y.

Table 6.1: Statistical Analysis of Sustainability Assessment Criteria and Factors Relative Weight Data (Canada Questionnaires)

Questionnaire	Elements	Mean	Median	Mode	Standard Deviation	Coefficient of Variance	Cronbach Alpha
Criteria Weight	Site and Ecology	0.033	0.038	0.038	0.007	21.38	0.760
	Transportation	0.036	0.038	0.038	0.008	23.08	
	Energy Use	0.044	0.046	0.046	0.005	10.56	
	Water Use	0.035	0.038	0.046	0.011	32.57	
	Material and waste reduction	0.035	0.038	0.038	0.009	24.61	
	IEQ	0.039	0.038	0.046	0.007	17.31	
	Building Management	0.038	0.038	0.038	0.007	18.63	
Site Factors' weight	Site Selection	0.035	0.038	0.038	0.008	23.00	0.491
	Site Management	0.030	0.038	0.046	0.009	28.46	
	Reduce Heat Island Effect	0.038	0.046	0.046	0.008	20.14	
	Site Emissions	0.032	0.043	0.046	0.013	40.44	
Transportation Factors' Weight	Alternative Transportation	0.039	0.038	0.038	0.005	13.81	0.737
	Public Transport	0.033	0.038	0.038	0.007	21.02	
	Car Parking Capacity	0.026	0.034	0.038	0.012	44.79	
	Fuel Efficient Vehicles	0.035	0.043	0.046	0.008	21.88	
Energy Factors' Weight	Energy Performance	0.045	0.046	0.046	0.002	5.55	0.727
	Energy Management	0.040	0.038	0.038	0.006	14.51	
	Energy Efficient Systems	0.042	0.046	0.046	0.006	13.28	
	Energy Efficient Equipment	0.036	0.046	0.046	0.007	19.93	
Water Factors' Weight	Water Conservation	0.041	0.043	0.046	0.006	14.97	0.705
	Water Management	0.041	0.043	0.046	0.005	12.76	
	Effluent Discharge in Foul	0.036	0.039	0.046	0.010	27.88	
Material Factors' Weight	Sustainable Purchasing	0.038	0.038	0.038	0.007	17.69	0.771
	Efficient Use of Materials	0.043	0.043	0.046	0.004	9.54	
	Solid Waste Management	0.041	0.043	0.046	0.006	14.22	
IEQ Factors' Weight	Visual Comfort	0.035	0.038	0.027	0.009	26.10	0.912
	Indoor Air Quality	0.040	0.046	0.046	0.002	6.28	
	Thermal Comfort	0.037	0.046	0.046	0.005	12.35	
	Acoustic Performance	0.030	0.038	0.038	0.008	25.79	
	Hygiene	0.034	0.032	0.032	0.006	17.89	
	Building Amenities	0.026	0.034	0.038	0.008	31.88	
Building Management Factors' Weight	Maintenance Management	0.044	0.046	0.046	0.004	9.93	0.821
	Security Measures	0.031	0.031	0.031	0.013	43.80	
	Green Lease	0.034	0.038	0.043	0.010	29.53	
	Risk Management	0.037	0.038	0.038	0.008	22.59	
	Innovations	0.032	0.034	0.046	0.013	39.16	

Table 6.2: Statistical Analysis of Sustainability Assessment Criteria and Factors Relative Weight Data (Egypt Questionnaires)

Questionnaire	Elements	Mean	Median	Mode	Standard Deviation	Coefficient of Variance	Cronbach's Alpha
Criteria Weight	Site and Ecology	0.020	0.022	0.023	0.004	19.40	0.899
	Transportation	0.015	0.013	0.013	0.004	28.35	
	Energy Use	0.020	0.022	0.023	0.004	19.19	
	Water Use	0.019	0.019	0.019	0.005	25.30	
	Material and waste reduction	0.015	0.015	0.019	0.005	35.22	
	IEQ	0.017	0.019	0.023	0.005	30.24	
	Building Management	0.018	0.019	0.019	0.005	26.62	
Site Factors' weight	Site Selection	0.021	0.023	0.023	0.004	17.36	0.907
	Site Management	0.019	0.019	0.019	0.004	24.14	
	Reduce Heat Island Effect	0.017	0.019	0.019	0.004	27.03	
	Site Emissions	0.016	0.019	0.013	0.006	34.95	
Transportation Factors' Weight	Alternative Transportation	0.016	0.015	0.019	0.004	26.69	0.701
	Public Transport	0.019	0.022	0.023	0.005	26.82	
	Car Parking Capacity	0.019	0.025	0.023	0.004	21.04	
	Fuel Efficient Vehicles	0.022	0.022	0.023	0.005	22.59	
Energy Factors' Weight	Energy Performance	0.021	0.022	0.023	0.003	12.30	0.402
	Energy Management	0.019	0.019	0.019	0.004	18.47	
	Energy Efficient Systems	0.020	0.022	0.023	0.003	16.64	
	Energy Efficient Equipment	0.019	0.022	0.023	0.005	27.24	
Water Factors' Weight	Water Conservation	0.022	0.023	0.023	0.003	13.46	0.883
	Water Management	0.021	0.023	0.023	0.002	10.97	
	Effluent Discharge in Foul	0.019	0.019	0.019	0.004	21.70	
Material Factors' Weight	Sustainable Purchasing	0.019	0.020	0.023	0.004	23.30	0.688
	Efficient Use of Materials	0.021	0.022	0.023	0.003	15.98	
	Solid Waste Management	0.019	0.019	0.019	0.004	19.61	
IEQ Factors' Weight	Visual Comfort	0.017	0.019	0.019	0.004	23.62	0.923
	Indoor Air Quality	0.022	0.023	0.023	0.002	7.43	
	Thermal Comfort	0.020	0.019	0.023	0.003	16.84	
	Acoustic Performance	0.016	0.015	0.019	0.005	28.21	
	Hygiene	0.019	0.020	0.023	0.005	25.88	
	Building Amenities	0.017	0.019	0.019	0.005	28.78	
Building Management Factors' Weight	Maintenance Management	0.021	0.022	0.023	0.003	13.38	0.887
	Security Measures	0.016	0.015	0.023	0.005	31.78	
	Green Lease	0.016	0.013	0.013	0.005	33.61	
	Risk Management	0.019	0.019	0.019	0.004	23.20	
	Innovations	0.017	0.019	0.019	0.005	31.90	

Table 6.1 to Table 6.2 illustrate the reliability and consistency of most of the data collected through the questionnaires that had been conducted in Canada and Egypt. The majority of Cronbach's alpha values are over 0.7 in both of the two tables except for the weight determination of the *Site and Ecology* factors in Canada. Also, the Cronbach's alpha value is over 0.7 in most of the items except for the weight determination of the *Energy* factors as shown in Table 6.2. Moreover, another proof for the consistency of the data is the coefficient of variance, such that most of the data has a low value of coefficient of variance ranging from 5% to 43%. Further, the mean, median, and mode had been determined for all the data collected and as illustrated in the previous tables the median and the mode are very close to the mean which indicates the closeness of the data to each other and thus assures the consistency of the responds to the questionnaires. Consequently, the data had been collected was proved to be robust, consistent, and reliable and can be used for the weight determination for each of the criteria and factors for both Canadian and Egyptian context, and to be used the sustainability assessment model development.

6.2.2 Fuzzification scale

The fuzzification (conversion from linguistic variables to fuzzy numbers) was identified through the responses of the second part of questionnaire by respondents as illustrated in the previous chapter. Twenty two out of sixty respondents answered the part of the numerical representation of the linguistic variables such that the final triangular fuzzy numbers are determined as the mean of all the responses in each column as shown in Table 6.3. As shown in Figure 6.1 the five linguistic variables are very, low, medium, high, and very high varies in the numerical ranges when represented as triangular fuzzy numbers (TFN).

Table 6.3: Determination of the Triangular Fuzzy Numbers

	Very Low			**High**			**medium**			**low**			**very High**		
1	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
2	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
3	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
4	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
5	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
6	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.6	0.7	0.8	0.8	0.9	1
7	0	0.2	0.5	0.5	0.6	0.64	0.65	0.7	0.74	0.75	0.8	0.84	0.85	0.9	1
8	0	0.1	0.2	0.3	0.3	0.3	0.4	0.5	0.6	0.7	0.7	0.7	0.8	0.9	1
9	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
10	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
11	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
12	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
13	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
14	0	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.5	0.7	0.8	0.8	0.9	1	1
15	0	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1
16	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
17	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.8	0.8	0.8	1	1
18	0	0.2	0.4	0.4	0.5	0.6	0.6	0.65	0.7	0.7	0.8	0.9	0.9	0.95	1
19	0.1	0.1	0.2	0.4	0.4	0.5	0.6	0.7	0.8	0.8	0.9	1	0.9	0.9	1
20	0	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.8	0.7	0.8	1	0.8	1	1
21	0	0.1	0.2	0.1	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
22	0	0	0.1	0.2	0.25	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
	0.01	**0.09**	**0.23**	**0.20**	**0.31**	**0.42**	**0.42**	**0.53**	**0.66**	**0.64**	**0.76**	**0.87**	**0.82**	**0.94**	**1.00**

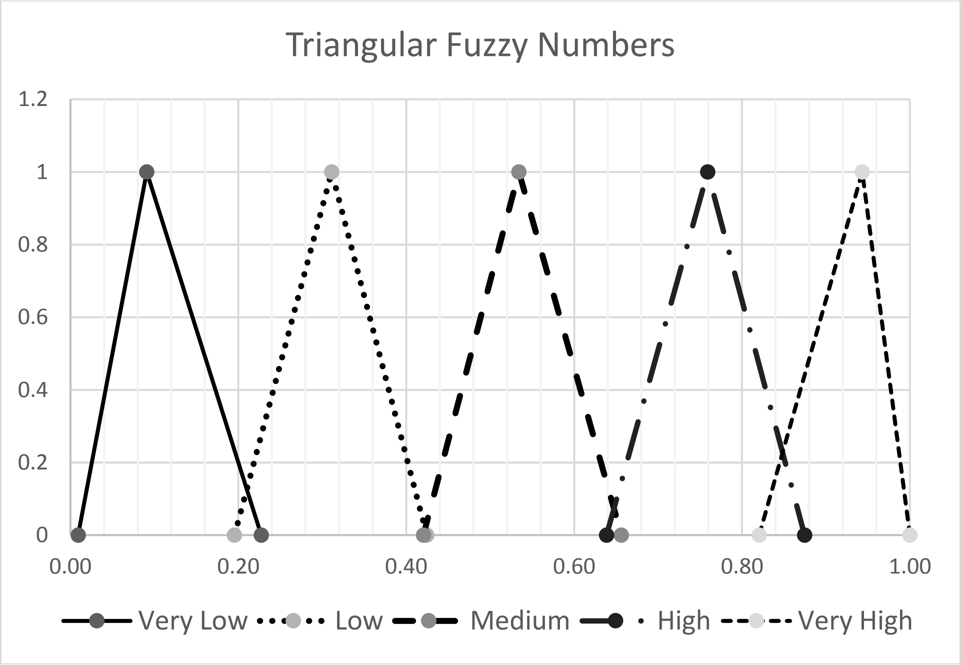


Figure 6.1: Triangular Fuzzy Numbers Representation

6.2.3 Fuzzification and Defuzzification Procedures

As explained formerly in section 2.5 in literature review chapter and section 3.4 in research methodology chapter, the Fuzzy TOPSIS Technique was implemented to determine the weights of 1) the seven criteria, 2) the site and ecology factors, 3) the transportation factors, 4) the energy factors, 5) the water use factors, 6) the material and waste reduction factors, 7) the IEQ factors, and 8) the building management factors. Structured interviews and questionnaires, as illustrated previously, had been performed to stand for the degree of importance of each of the sustainability assessment attributes. Two sets of questionnaires, one for Canada and the other for Egypt, had been distributed among buildings' stakeholders such as engineers, facility managers, sustainability experts. The rationale of these two groups is to highlight the impact of different local contexts of each country on the weights perceptions, also understood to be the fuzzy TOPSIS method. In this section, the detailed weight determination procedures of the seven criteria based on the Canadian and the Egyptian context will be demonstrated. Besides, the overall weight results for all the criteria and factors will be summarized and discussed.

Table 6.4 to Table 6.6 and Table C.1 to Table C.3 demonstrate the detailed stages for criteria eight determination based on the Egyptian context. The process started with gathering the linguistic variable from each respondent which represent their perception about the importance of each criterion to the entire sustainability assessment. Additionally, the fuzzification of these linguistic variables to triangular fuzzy numbers based on the scale was determined in the previous section forming the decision matrix for each of the seven criteria as shown in Table 6.4 and Table C.1. Hence, after the normalized decision matrix was developed based on equation (2.20), all the values of the TFN in for all the criteria in a row (single respondent) are divided by the largest third value of TFN among all the TFNs as illustrated in Table 6.5 and Table C.2. In the same table the weighted normalized decision matrix is obtained by multiplying the reliability weight for each respondent to the all the corresponding values (the same row) for all the criteria. The reliability weight is a value from zero to one expressing the reliability and experience of each respondent, however in all the calculations this weight remains constant among all respondents to prevent subjectivity in determination of this weight. Furthermore, Table 6.6 and Table C.3 shows the defuzzification process was performed by utilizing equation (2.26) such that the generalized mean was determined for all the TFNs. The generalized mean distinguished the positive ideal solution (highest generalized mean) and the negative solution (lowest generalized mean) in among all the criteria for each respondent. The distance of a criterion from positive ideal solution (D^+), and distance of a criterion from the negative solution (D^-) was determined for each criterion in each row as illustrated in Table 6.6 and Table C.3. Finally, the determination of positive similarity and negative similarity were obtained and the closeness coefficient (CC) as well. Then the normalized weight is obtained such that the criterion of the highest CC had the highest weight. As shown in Table 6.6, the *energy* criterion has the highest CC of value 0.738 and normalized weight of value 0.2, while the transportation criterion has the lowest values of 0.284 and 0.077 respectively. In Table C.3, the *energy* criterion has the highest CC and normalized weight 0.915 and 0.220 respectively, while the site criterion has the lowest values of 0.410 and 0.099 respectively. The same procedures were followed to determine the weights for each factor of the seven criterions as demonstrated in Table C.4 to Table C.41.

Each criterion and factor differs in its importance according to the local context of each country. The determined weights concerning Canada and Egypt are illustrated in Table 6.7. Egypt shows higher values of weight in the criteria of *site and ecology* and *water use,* with values 0.191 and 0.196 respectively, than that in Canada of values 0.099 and 0.117 respectively. These values express the importance of site location and water to Egypt due to the high prices of land, the existence of hot weather, scarcity of rain, and the potential for occurrence of water crises. Moreover, both countries nearly have the same weight for *energy* and *building management* which indicates the high concern of energy. Alternatively, Canada experiences higher weight values of 0.123, 0.118, and 0.118 in *transportation*, *IEQ*, and *material* than that in Egypt with values 0.077, 0.080, and 0.136 respectively as shown in Figure 6.2. Moreover, in the factors of the *site* criterion, Egypt demonstrates highest weight in *site selection* and *site management* factors than Canada with values 0.390 and 0.281 respectively. On the other hand, the *reduce heat island effect* and *site emissions factors* are the highest in Canada of values 0.362 and 0.218. In transportation criterion, Canada takes the lead in *alternative means of transportation* and *fuel efficient vehicle* factors, their weights are 0.301 and 0.318 respectively, owing to the great concern of reducing energy consumed in commuting and the emitted carbon. Contrarily, Egypt has highest weights of *public transport accessibility* and *car parking capacity* factors that attributed to the high price of land that urges using public means of transport and minimizing the land dedicated for parking lots.

Furthermore, *energy performance* factor has the highest weight in both countries, while the *energy management*, *energy efficient systems*, and *energy efficient equipment* factors take higher concern in Egypt than Canada with weights 0.195, 0.264, and 0.202 correspondingly. This high interest is attributed to the high prices of fossil fuel consumed in energy production, scarcity of fossil fuel, the hot climate which increases the cooling loads and in turn increase the demand for energy, and the rise in population that increases the energy consumption per capita. Additionally, Egypt demonstrates a high concern in *water conservation* as a result of the increase in water demand, hot climate, and the threat of the water crisis potential. Contrariwise, Canada has less concern for water management than Egypt, as the former country has various resources of water that are harvested from lakes and rain, and low population, consequently, the interest is how to manage the water use not how to get it as shown in Figure 6.2. Hereafter, Canada has the highest values of the *efficient use of material* and the *solid waste management* factors which are 0.508 and 0.363 respectively while in Egypt these values are 0.427 and 0.281 as shown in Table 6.7. These weights are attributed to the existence of various green materials with affordable price, as well as the high concern about the impact of utilizing material on the environment. Additionally, Egypt possesses a higher interest in the *visual comfort* and *building amenities* factors due to the disregard of glare control in buildings, the insufficient lighting levels, and the shortage in building amenities (i.e. energy efficient escalators and means of circulation for disabled persons inside buildings). The a*coustic performance* and *thermal performance* factors acquire the highest weight in Canada because of the increased concern about the impact of these factors on the building users and employees such that the uncomfortable indoor temperature and improper acoustic performance may lead to discomfort and dissatisfaction among the users. Both Canada and Egypt have nearly the same weight values of the *hygiene* and *indoor air quality* in which poor air qualities and lack of hygienic practices have the direct impact on building users that can cause illnesses and absenteeism, which affects one of the sustainability pillars – the social aspect. Finally, the weight values of the *maintenance management* and *green lease* factors are high in Canada as demonstrated in Table 6.7 and Figure 6.2. While the weight of *security measures* factor has a higher interest in Egypt than Canada due to the increased cost of materials that urges the adoption of safety precautions to hinder disruption and damage that could occur due to illegal intruders.

Table 6.4: Fuzzification of Criteria Responses of the Egyptian Respondents

	Site and Ecology Criterion				**Transportation Criterion**				**Energy Criterion**				**Water Use Criterion**			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
2	**High**	064	0.76	0.87	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
3	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Low**	0.20	0.31	0.42
4	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
5	**Very Low**	0.01	0.09	0.23	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66
6	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
7	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
8	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Very Low**	0.01	0.09	0.23
9	**High**	0.64	0.76	0.87	**Very Low**	0.01	0.09	0.23	**Very High**	0.82	0.94	1.00	**Low**	0.20	0.31	0.42
10	**Medium**	0.42	0.53	0.66	**Low**	0.20	0.31	0.42	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00
11	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
12	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00
13	**High**	0.64	0.76	0.87	**Low**	0.20	0.31	0.42	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
14	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00
15	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
16	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
17	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
18	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87
19	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66
20	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
21	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
22	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00
23	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
24	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66
25	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
26	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
27	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
28	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
29	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00
30	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
31	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
32	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**Low**	0.20	0.31	0.42	**Medium**	0.42	0.53	0.66
33	**Very High**	0.82	0.94	1.00	**Low**	0.20	0.31	0.42	**Low**	0.20	0.31	0.42	**Medium**	0.42	0.53	0.66
34	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
35	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
36	**Very High**	0.82	0.94	1.00	**Low**	0.20	0.31	0.42	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87
37	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
38	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
39	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66
40	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87

Continue Table 6.4: Fuzzification of Criteria Responses of the Egyptian Respondents

	Material and Waste Reduction Criterion				**Indoor Environmental Quality Criterion**				**Building Management Criterion**			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87
2	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Low**	0.20	0.31	0.42
3	**Low**	0.20	0.31	0.42	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
4	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
5	**Very Low**	0.01	0.09	0.23	**High**	0.64	0.76	0.87	**Very Low**	0.01	0.09	0.23
6	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66
7	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
8	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00
9	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
10	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00
11	**Medium**	0.42	0.53	0.66	**Low**	0.20	0.31	0.42	**High**	0.64	0.76	0.87
12	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87
13	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
14	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
15	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
16	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
17	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00
18	**Low**	0.20	0.31	0.42	**Very Low**	0.01	0.09	0.23	**Medium**	0.42	0.53	0.66
19	**Very Low**	0.01	0.09	0.23	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
20	**Low**	0.20	0.31	0.42	**Very High**	0.82	0.94	1.00	**Low**	0.20	0.31	0.42
21	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
22	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
23	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
24	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
25	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
26	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66
27	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66
28	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
29	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87
30	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87
31	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66
32	**Low**	0.20	0.31	0.42	**Very Low**	0.01	0.09	0.23	**Low**	0.20	0.31	0.42
33	**Low**	0.20	0.31	0.42	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66
34	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87
35	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
36	**Low**	0.20	0.31	0.42	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
37	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00
38	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87
39	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87
40	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87

Table 6.5: Normalized and Weighted Matrices of Criteria (Egyptian Sample)

Serial	Site and Ecology Criterion						Transportation Criterion						Energy Criterion						Water Use Criterion					
	Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix		
1	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
2	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
3	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.20	0.31	0.42	0.005	0.008	0.011
4	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
5	0.01	0.09	0.23	0.000	0.002	0.006	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
6	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
7	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
8	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.01	0.09	0.23	0.000	0.002	0.006
9	0.64	0.76	0.87	0.016	0.019	0.022	0.01	0.09	0.23	0.000	0.002	0.006	0.82	0.94	1.00	0.021	0.024	0.025	0.20	0.31	0.42	0.005	0.008	0.011
10	0.42	0.53	0.66	0.011	0.013	0.017	0.20	0.31	0.42	0.005	0.008	0.011	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025
11	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
12	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
13	0.64	0.76	0.87	0.016	0.019	0.022	0.20	0.31	0.42	0.005	0.008	0.011	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
14	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
15	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
16	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
17	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
18	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
19	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
20	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
21	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
22	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
23	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
24	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
25	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
26	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
27	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
28	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
29	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
30	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
31	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
32	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.23	0.36	0.48	0.006	0.009	0.012	0.48	0.61	0.76	0.012	0.015	0.019
33	0.82	0.94	1.00	0.021	0.024	0.025	0.20	0.31	0.42	0.005	0.008	0.011	0.20	0.31	0.42	0.005	0.008	0.011	0.42	0.53	0.66	0.011	0.013	0.017
34	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
35	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
36	0.82	0.94	1.00	0.021	0.024	0.025	0.20	0.31	0.42	0.005	0.008	0.011	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
37	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
38	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
39	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019
40	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022

Continue Table 6.5: Normalized and Weighted Matrices of Criteria (Egyptian Sample)

Serial	Material and Waste Reduction Criterion						Indoor Environmental Quality Criterion						Building Management Criterion					
	Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix		
1	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.6	0.8	0.9	0.016	0.019	0.022
2	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.2	0.3	0.4	0.005	0.008	0.011
3	0.20	0.31	0.42	0.005	0.008	0.011	0.82	0.94	1.00	0.021	0.024	0.025	0.6	0.8	0.9	0.016	0.019	0.022
4	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.6	0.8	0.9	0.016	0.019	0.022
5	0.01	0.09	0.23	0.000	0.002	0.006	0.64	0.76	0.87	0.016	0.019	0.022	0.0	0.1	0.2	0.000	0.002	0.006
6	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.4	0.5	0.7	0.011	0.013	0.017
7	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.6	0.8	0.9	0.016	0.019	0.022
8	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.8	0.9	1.0	0.021	0.024	0.025
9	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.6	0.8	0.9	0.016	0.019	0.022
10	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.8	0.9	1.0	0.021	0.024	0.025
11	0.42	0.53	0.66	0.011	0.013	0.017	0.20	0.31	0.42	0.005	0.008	0.011	0.6	0.8	0.9	0.016	0.019	0.022
12	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.6	0.8	0.9	0.016	0.019	0.022
13	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.6	0.8	0.9	0.016	0.019	0.022
14	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.8	0.9	1.0	0.021	0.024	0.025
15	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.6	0.8	0.9	0.016	0.019	0.022
16	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.6	0.8	0.9	0.016	0.019	0.022
17	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.8	0.9	1.0	0.021	0.024	0.025
18	0.20	0.31	0.42	0.005	0.008	0.011	0.01	0.09	0.23	0.000	0.002	0.006	0.4	0.5	0.7	0.011	0.013	0.017
19	0.01	0.09	0.23	0.000	0.002	0.006	0.82	0.94	1.00	0.021	0.024	0.025	0.8	0.9	1.0	0.021	0.024	0.025
20	0.20	0.31	0.42	0.005	0.008	0.011	0.82	0.94	1.00	0.021	0.024	0.025	0.2	0.3	0.4	0.005	0.008	0.011
21	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.6	0.8	0.9	0.016	0.019	0.022
22	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.8	0.9	1.0	0.021	0.024	0.025
23	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.6	0.8	0.9	0.016	0.019	0.022
24	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.6	0.8	0.9	0.016	0.019	0.022
25	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.8	0.9	1.0	0.021	0.024	0.025
26	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.4	0.5	0.7	0.011	0.013	0.017
27	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.4	0.5	0.7	0.011	0.013	0.017
28	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.6	0.8	0.9	0.016	0.019	0.022
29	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.6	0.8	0.9	0.016	0.019	0.022
30	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.6	0.8	0.9	0.016	0.019	0.022
31	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.4	0.5	0.7	0.011	0.013	0.017
32	0.23	0.36	0.48	0.006	0.009	0.012	0.01	0.10	0.26	0.000	0.003	0.007	0.2	0.4	0.5	0.006	0.009	0.012
33	0.20	0.31	0.42	0.005	0.008	0.011	0.64	0.76	0.87	0.016	0.019	0.022	0.4	0.5	0.7	0.011	0.013	0.017
34	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.6	0.8	0.9	0.016	0.019	0.022
35	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.7	0.9	1.0	0.018	0.022	0.025
36	0.20	0.31	0.42	0.005	0.008	0.011	0.64	0.76	0.87	0.016	0.019	0.022	0.6	0.8	0.9	0.016	0.019	0.022
37	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.8	0.9	1.0	0.021	0.024	0.025
38	0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.7	0.9	1.0	0.018	0.022	0.025
39	0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.7	0.9	1.0	0.018	0.022	0.025
40	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.6	0.8	0.9	0.016	0.019	0.022

Table 6.6: Defuzzification of Criteria (Egyptian Sample)

Serial	Site and Ecology Criterion			Transportation Criterion			Energy Criterion			Water Use Criterion			Material and Waste Reduction Criterion			Indoor Environmental			Building Management		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mea**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.013	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006
2	0.019	0.004	0.011	0.013	0.010	0.006	0.023	0.000	0.015	0.023	0.000	0.015	0.019	0.004	0.011	0.023	0.000	0.015	0.008	0.015	0.000
3	0.023	0.000	0.015	0.013	0.010	0.006	0.019	0.004	0.011	0.008	0.015	0.000	0.008	0.015	0.000	0.023	0.000	0.015	0.019	0.004	0.011
4	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006
5	0.003	0.020	0.000	0.013	0.010	0.011	0.023	0.000	0.020	0.013	0.010	0.011	0.003	0.020	0.000	0.019	0.004	0.016	0.003	0.020	0.000
6	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006	0.013	0.010	0.000
7	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
8	0.023	0.000	0.020	0.013	0.010	0.011	0.019	0.004	0.016	0.003	0.020	0.000	0.013	0.010	0.011	0.013	0.010	0.011	0.023	0.000	0.020
9	0.019	0.004	0.016	0.003	0.020	0.000	0.023	0.000	0.020	0.008	0.015	0.005	0.013	0.010	0.011	0.023	0.000	0.020	0.019	0.004	0.016
10	0.013	0.010	0.006	0.008	0.015	0.000	0.013	0.010	0.006	0.023	0.000	0.015	0.023	0.000	0.015	0.013	0.010	0.006	0.023	0.000	0.015
11	0.013	0.010	0.006	0.013	0.010	0.006	0.023	0.000	0.015	0.023	0.000	0.015	0.013	0.010	0.006	0.008	0.015	0.000	0.019	0.004	0.011
12	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006
13	0.019	0.004	0.011	0.008	0.015	0.000	0.019	0.004	0.011	0.019	0.004	0.011	0.023	0.000	0.015	0.023	0.000	0.015	0.019	0.004	0.011
14	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
15	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
16	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
17	0.023	0.000	0.010	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010
18	0.023	0.000	0.020	0.013	0.010	0.011	0.013	0.010	0.011	0.019	0.004	0.016	0.008	0.015	0.005	0.003	0.020	0.000	0.013	0.010	0.011
19	0.023	0.000	0.020	0.019	0.004	0.016	0.019	0.004	0.016	0.013	0.010	0.011	0.003	0.020	0.000	0.023	0.000	0.020	0.023	0.000	0.020
20	0.019	0.004	0.011	0.013	0.010	0.006	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000	0.023	0.000	0.015	0.008	0.015	0.000
21	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
22	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004
23	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
24	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006
25	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
26	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006	0.013	0.010	0.000
27	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.013	0.010	0.000	0.013	0.010	0.000
28	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
29	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006
30	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0.000	0.013	0.010	0.000	0.019	0.004	0.006
31	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0.000	0.013	0.010	0.000	0.013	0.010	0.000
32	0.022	0.000	0.019	0.015	0.006	0.012	0.009	0.013	0.006	0.015	0.006	0.012	0.009	0.013	0.006	0.003	0.019	0.000	0.009	0.013	0.006
33	0.023	0.000	0.015	0.008	0.015	0.000	0.008	0.015	0.000	0.013	0.010	0.006	0.008	0.015	0.000	0.019	0.004	0.011	0.013	0.010	0.006
34	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0.000	0.013	0.010	0.000	0.019	0.004	0.006
35	0.022	0.000	0.006	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
36	0.023	0.000	0.015	0.008	0.015	0.000	0.013	0.010	0.006	0.019	0.004	0.011	0.008	0.015	0.000	0.019	0.004	0.011	0.019	0.004	0.011
37	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010
38	0.022	0.000	0.006	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006
39	0.022	0.000	0.006	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006
40	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
$\Sigma D^+ / \Sigma D^-$		**0.099**	**0.239**		**0.314**	**0.124**		**0.115**	**0.324**		**0.164**	**0.275**		**0.308**	**0.130**		**0.218**	**0.221**		**0.200**	**0.239**
Closeness		**0.708**			**0.284**			**0.738**			**0.627**			**0.297**			**0.503**			**0.545**	
Normalized		**0.191**			**0.077**			**0.200**			**0.169**			**0.080**			**0.136**			**0.147**	

Table 6.7: Comparison between the Weights of Criteria and Factors in Two Countries

Criteria	**Site & Ecology**	**Transportation**	**Energy**	**Water Use**	**Material & Waste Reduction**	**IEQ**	**Building Management**
Canada	**0.099**	**0.123**	**0.220**	**0.117**	**0.118**	**0.167**	**0.156**
Egypt	**0.191**	**0.077**	**0.200**	**0.169**	**0.080**	**0.136**	**0.147**
Factors of 1st Criterion	Site Selection	Site Management	Reduce Heat Island Effect	Site Emissions			
Canada	**0.191**	**0.228**	**0.362**	**0.218**			
Egypt	**0.390**	**0.281**	**0.180**	**0.149**			
Factors of 2nd Criterion	Alternative Means of Transportation	Public Transport Accessibility	Car Parking Capacity	Fuel Efficient Vehicle			
Canada	**0.301**	**0.282**	**0.098**	**0.318**			
Egypt	**0.174**	**0.255**	**0.290**	**0.280**			
Factors of 3rd Criterion	Energy Performance	Provision of Energy Management	Energy Efficient Systems	Energy Efficient Equipment			
Canada	**0.413**	**0.146**	**0.252**	**0.189**			
Egypt	**0.339**	**0.195**	**0.264**	**0.202**			
Factors of 4th Criterion	Water Conservation	Water Management	Effluent Discharge in foul Sewer				
Canada	**0.406**	**0.467**	**0.127**				
Egypt	**0.472**	**0.406**	**0.123**				
Factors of 5th Criterion	Sustainable Purchasing	Efficient Use of Materials	Solid Waste Management				
Canada	**0.129**	**0.508**	**0.363**				
Egypt	**0.291**	**0.427**	**0.281**				
Factors of 6th Criterion	Visual Comfort	Indoor Air Quality	Thermal Comfort	Acoustic Performance	Hygiene	Building Amenities	
Canada	**0.119**	**0.271**	**0.236**	**0.125**	**0.181**	**0.069**	
Egypt	**0.140**	**0.278**	**0.205**	**0.085**	**0.174**	**0.117**	
Factors of 7th Criterion	Maintenance Management	Security Measures	Green Lease	Risk Management	Innovations		
Canada	**0.320**	**0.130**	**0.180**	**0.219**	**0.152**		
Egypt	**0.281**	**0.139**	**0.154**	**0.239**	**0.187**		

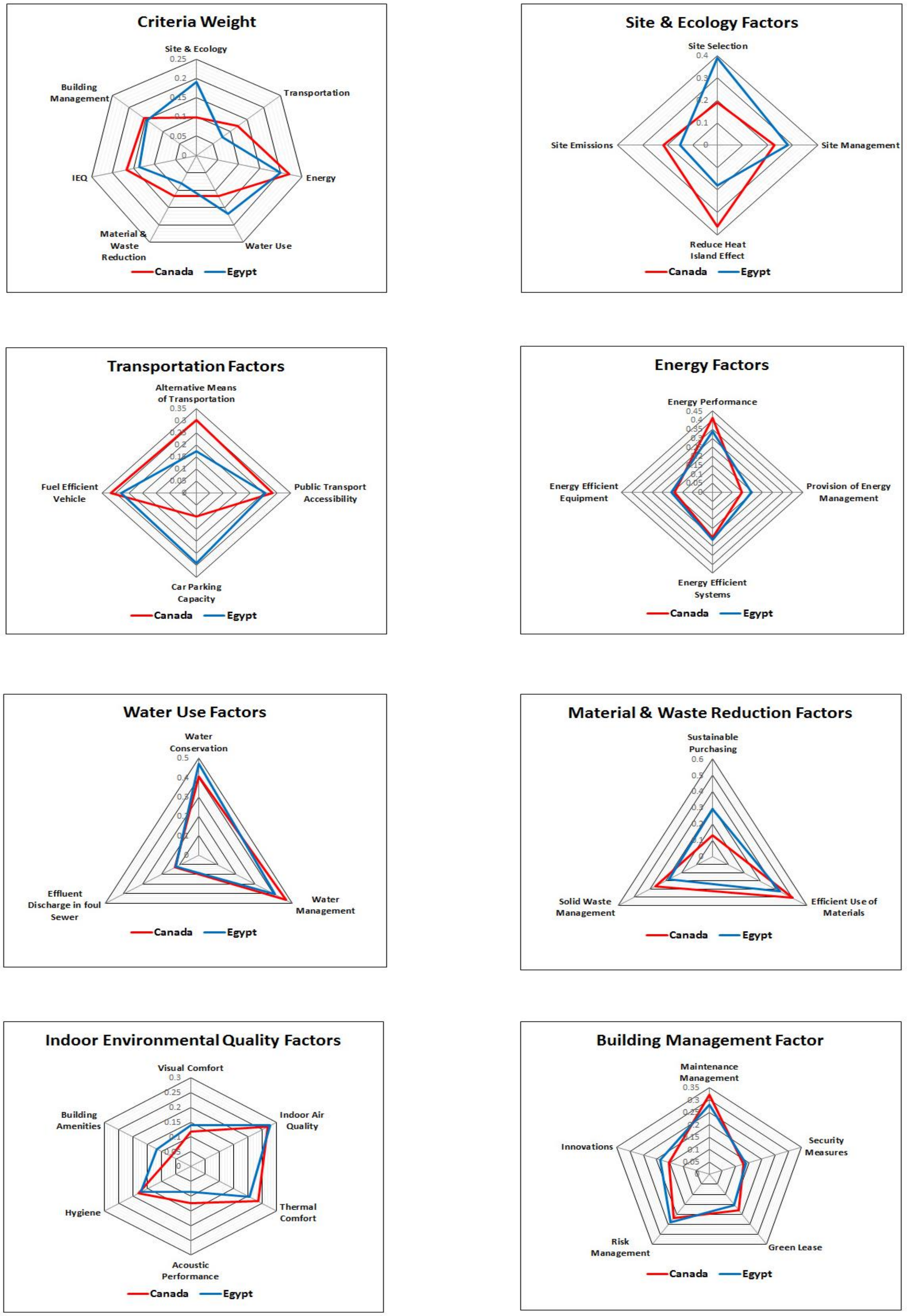


Figure 6.2: Difference between the Weight of Criteria and Factors in Egypt and Canada

6.3 Sustainability Scale Determination

The sustainability scale determination is based on two main strategies, as mentioned in the previous chapter, which are: 1) the responses of respondents to the questionnaire the as shown in Figure A.3; 2) studying the differences between the various rating systems as shown in Table 6.8. According to the collected questionnaires, 45 respondents out of 60 responded to the part of scale determination as illustrated in Table 6.9. The mean value of all the responds were determined for each of the five scaling categories which are pass, good, very good, excellent, and outstanding. Additionally, the mean is rounded to the nearest five unit to obtain a simple representative scale to be from 50 to ≤ 60, 60 to ≤ 70, 70 to ≤ 80, 80 to ≤ 90, 90 to 100 where these ranges corresponding to previously mentioned scaling categories respectively as shown in Figure 6.3.

The minimum threshold required for each criterion to achieve certain rank in the scale was determined by applying the same procedures adopted in the scale determination. The questionnaire responses of the threshold section were gathered, and the mean of the values were determined followed by an approximation of the determined values as shown in Table 6.10. Therefore, in order to achieve a specific rank, the criteria sustainability indices (i.e. summation of sustainability indices of corresponding factors) must pass the required threshold for this rank as shown in Figure 6.4.

Table 6.8: Comparison between the Proposed Sustainability Certification Scheme and Other Rating Systems

	Fail	1st rating	2nd rating	3rd rating	4th rating	5th rating	6th rating
Proposed Rating System	< 50%	Pass	Good	Very Good	Excellent	Outstanding	
		≥50% - <60%	≥60% - <70%	≥70% - <80%	≥80% - <90%	≥90% - <100%	
LEED	< 40 credits	Certified	Silver	Gold	Platinum		
		40-49 credits	50-59 credits	60-79 credits	80-116		
BREEAM	< 10 %	1 star* (Acceptable)	2 star** (Pass)	3 star*** (Good)	4 star**** (Very Good)	5 star***** (Excellent)	6 star****** (Outstanding)
		≥10% - <29%	≥29% - <40%	≥40% - <55%	≥55% - <70%	≥70% - <85%	≥85% - <100%
BCA Green Mark	< 50 points	Certified	Gold	Gold Plus	Platinum		
		50-74 points	75-84 points	85-89 points	90-180 points		
HK BEAM	< 40 credits	Bronze (Above average)	Silver (Good)	Gold (Very Good)	**Platinum** (Excellent)		
		≥40% - <50%	≥50% - <65%	≥65% - <75%	≥75% - <100%		
Green Building Index	< 50 points	Certified	Silver	Gold	Platinum		
		50-65 points	66-75 points	76-85 points	86-100points		
Green Globes	< 15 %	1 Globe	2 Globes	3 Globes	4 Globes	5 Globes	
		15% - 34%	35% - 54%	55% - 69%	70%-84%	85%-100%	
Green ship Indonesia	< 35 %	Bronze	Silver	Gold	Platinum		
		≥35% - <46%	≥46% - <57%	≥57% - <73%	≥73% - <100%		
CASBEE (Japan)`	**1 star** (Fairy Poor)	**2 stars** (Poor)	**3 stars** (Good)	**4 stars** (Very Good)	**5 stars** (Excellent)		
	BEE<0. 5	BEE=0.5-1.0	BEE=1.0-1.5	BEE=1.5-3.0	BEE=3		

Table 6.9: Sustainability Ranking Scale Determination

Serial	**Pass**	**Good**	**Very-Good**	**Excellent**	**Outstanding**
1	50	65	75	85	95
2	60	70	80	90	100
3	50	60	70	80	90
4	55	70	75	85	95
5	60	70	80	90	95
6	20	40	60	75	90
7	60	61	71	81	91
8	51	61	71	81	91
9	50	60	70	80	90
10	50	60	70	80	90
11	50	60	70	80	90
12	20	30	40	60	80
13	0	60	70	80	90
14	30	40	60	70	90
15	50	65	75	85	95
16	15	30	45	60	75
17	51	61	71	81	91
18	50	65	80	90	95
19	55	65	75	85	95
20	60	70	80	90	0
21	30	40	60	70	90
22	60	70	80	90	95
23	50	60	70	80	100
24	41	51	66	76	91
25	51	66	76	86	96
26	60	70	80	90	0
27	30	50	65	75	85
28	50	65	75	85	95
29	50	60	75	90	95
30	55	65	75	85	95
31	50	65	75	85	90
32	50	60	70	80	90
33	50	60	70	80	90
34	40	55	70	85	95
35	50	60	70	80	90
36	50	60	70	80	90
37	50	60	70	80	90
38	50	60	70	80	90
39	50	60	70	80	90
40	50	60	70	80	90
41	50	60	70	80	90
42	40	50	70	80	95
43	50	65	75	85	95
44	50	65	75	85	95
45	50	70	80	90	95
Mean	47.59	59.33	70.54	81.20	91.74
Rounded	**50.00**	**60.00**	**70.00**	**80.00**	**90.00**

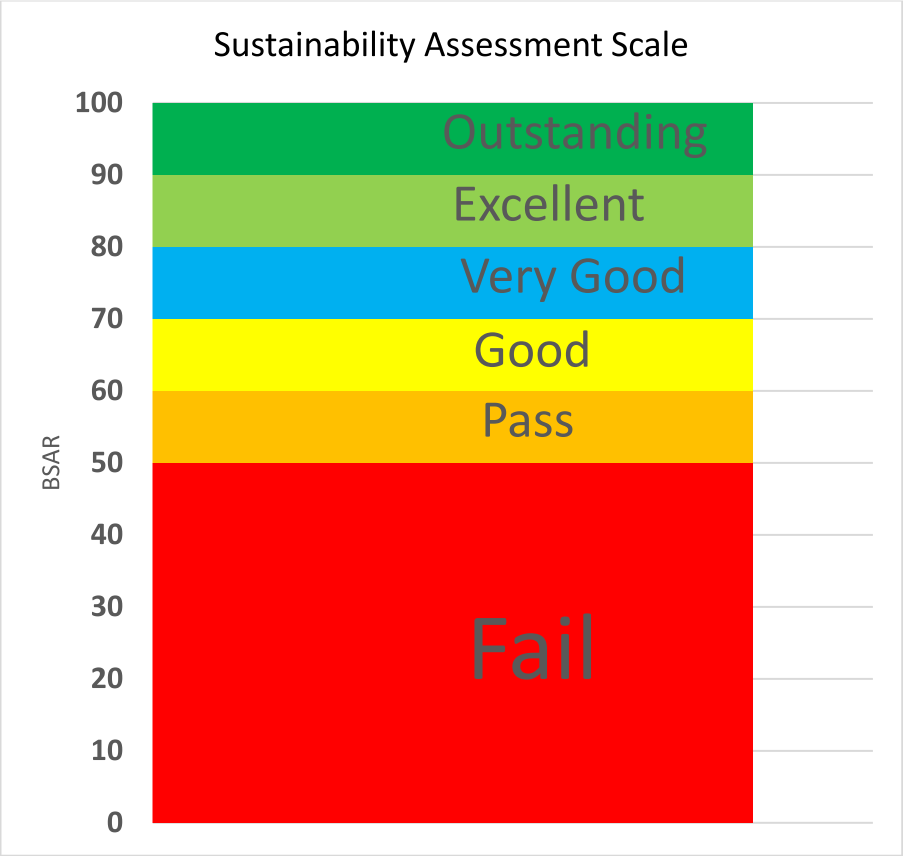


Figure 6.3: The Developed Sustainability Assessment Scale

Table 6.10: Criteria Required Minimum Threshold

Serial	Attribute	Method	Pass	Good	Very-Good	Excellent	Outstanding
1	Site	Mean	47.48	59.72	70.35	79.27	86.84
		Approx..	**45.00**	**60.00**	**70.00**	**80.00**	**85.00**
2	Transportation	Mean	46.32	47.39	59.26	69.16	79.44
		Approx..	**45.00**	**60.00**	**70.00**	**80.00**	**85.00**
3	Energy	Mean	49.52	61.00	72.48	81.94	89.51
		Approx..	**50.00**	**60.00**	**70.00**	**80.00**	**90.00**
4	Water	Mean	49.38	60.06	70.50	80.94	88.32
		Approx..	**50.00**	**60.00**	**70.00**	**80.00**	**90.00**
5	Material	Mean	48.52	60.59	70.90	81.12	88.32
		Approx..	**50.00**	**60.00**	**70.00**	**80.00**	**90.00**
6	IEQ	Mean	48.07	58.29	68.00	78.80	86.51
		Approx..	**50.00**	**60.00**	**70.00**	**80.00**	**85.00**
7	Building Management	Mean	48.00	59.55	71.03	80.43	88.29
		Approx..	**50.00**	**60.00**	**70.00**	**80.00**	**90.00**

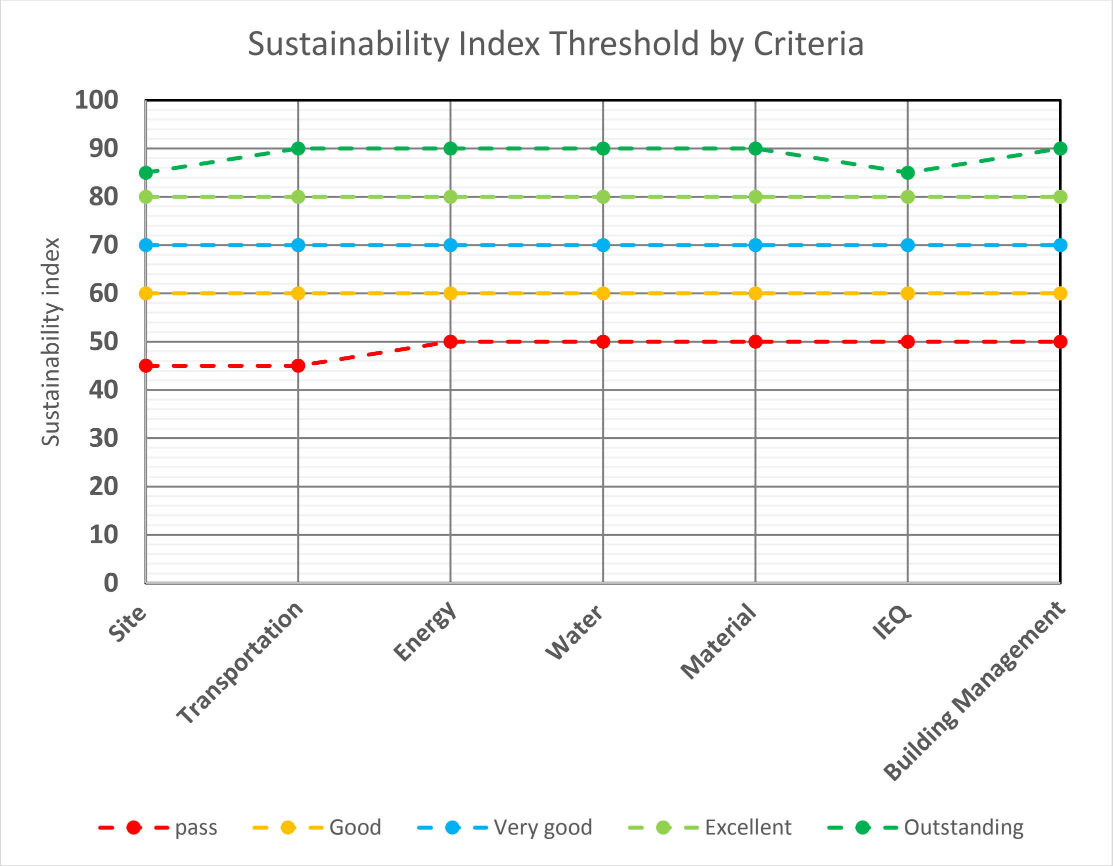


Figure 6.4: Criteria Sustainability Indices Threshold

6.4 Development of BIM and IES Simulation Models

The BIM models for the two case studies (the EV and the MB building) have been executed utilizing the CAD drawings provided by the facility management team at Concordia SGW campus. The available drawings for the EV building are twenty-one CAD files representing sixteen detailed floor plan drawings including the ground level, two mechanical floor plan drawings, and three basement floor drawings. Further, the MB available drawings are 15 floor plan CAD files, two mechanical levels, and two basement floor drawings.

The two developed BIM models include two main groups of data: 1) exterior façade finishing material, and 2) the interior spatial properties. Moreover, the BIM models for the EV and MB buildings are used for three purposes: 1) gather data for the sustainability assessment model, 2) prerequisite model for the IES energy simulation model, and 3) collect data required for the sustainability-based rehabilitation model. The Revit models of the EV and the MB buildings was developed utilizing CAD drawings of the floor plans as shown in Figure 6.5 and Figure 6.6. By utilizing the developed Revit model various data in the calculation process are extracted such as: 1) the gross floor area as shown in Table 6.11 that was utilized in the energy consumption calculations, in the determination of the greenery provision value, and in the determination of the *reduction of the heat island effect of the non-roofed areas* sub-factor; 2) the wall areas as shown in Table 6.12 and Table 6.15 that were used in the determination of the wall exterior wall planting and installed SRI material sub-factor in the *reduce heat island effect* factor; 3) the number of plumbing fixtures as illustrated in Table 6.13, which was used in the calculations of water use criterion; 4) the roof area data as shown in Table 6.14, it was utilized in the calculations of the sub-factor *heat island reduction in the roofed areas* in the factor *reduce heat island effect*; 4) the building area in the prevailing wind direction as shown in Table 6.16, which was used to calculate the sub-factor *consideration of wind movement in buildings*; and 5) the number of interior spaces as shown in Table 6.17 that was utilized in the determination of some sub-factors in energy, water use, and indoor environmental quality criteria. Moreover, these models were used in XML file to develop the IES model, which is used in the energy simulations.

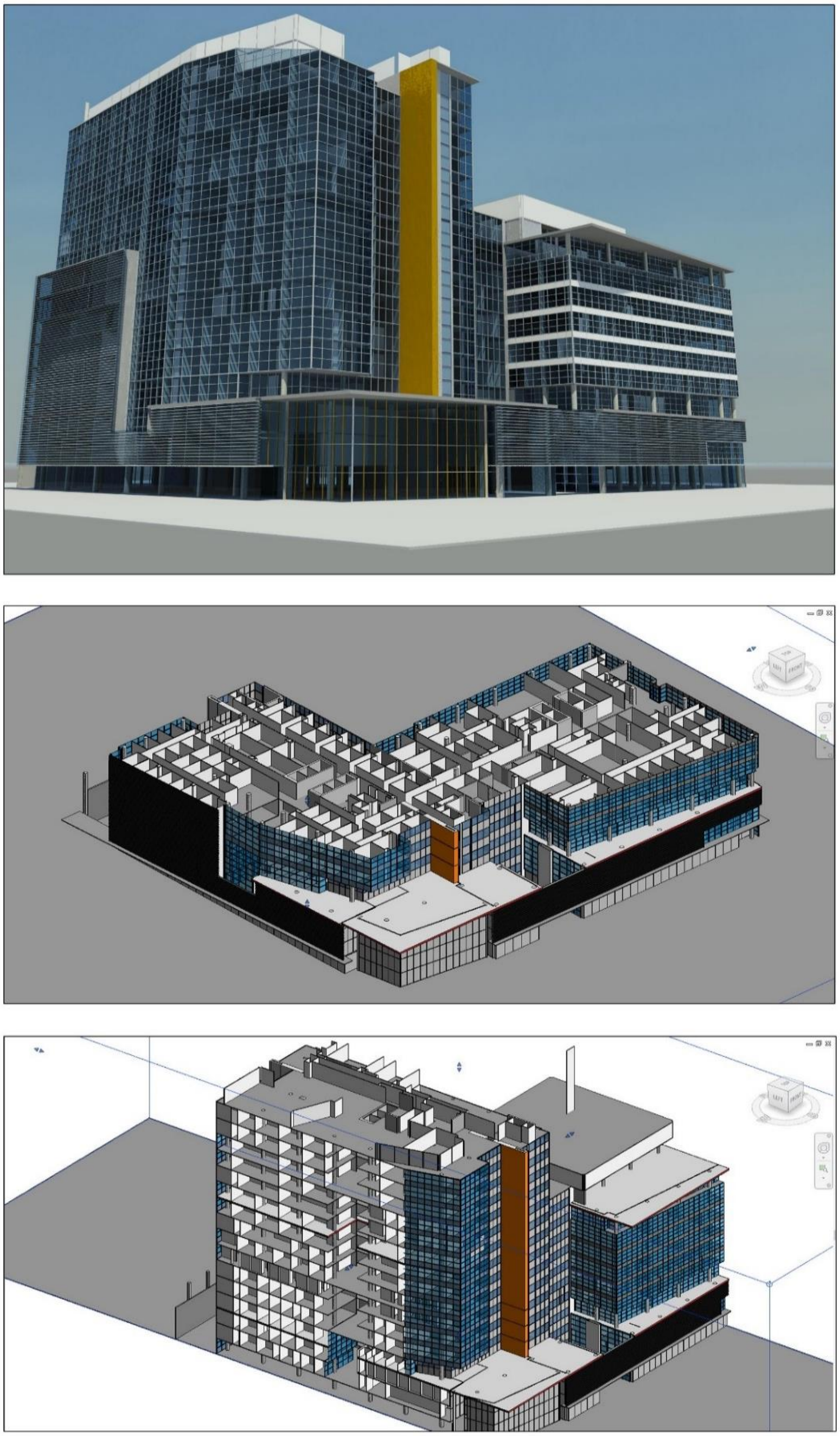


Figure 6.5: The EV BIM Model Façade, Plan Details and Floor Heights

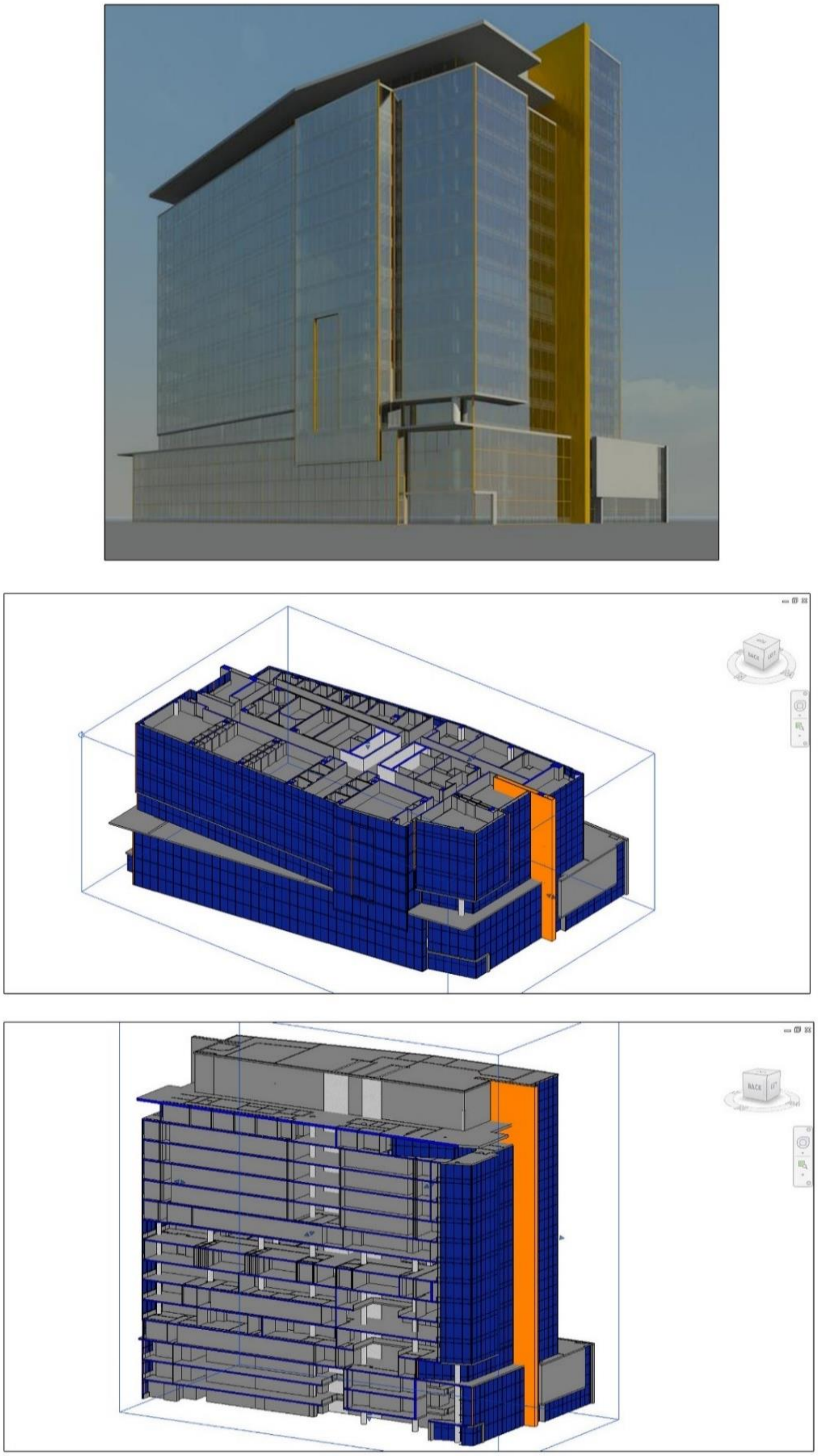


Figure 6.6: The MB BIM Model Façade, Plan Details and Floor Heights

Table 6.11: Floor Area and Total Building Area

Floor Level	EV Building	MB Building
01-Ground floor	4844 m²	2559 m²
02-first floor	5147 m²	2301 m²
03-second floor	5157 m²	2300 m²
04-Third floor	3827 m²	1987 m²
05-fourth floor	4031 m²	1922 m²
06-fifth floor	4031 m²	2022 m²
07-sixth floor	4031 m²	1918 m²
08-seventh floor	4031 m²	2023 m²
09-eighth floor	4031 m²	2023 m²
10-ninth floor	3856 m²	2023 m²
11-tenth floor	3027 m²	2023 m²
12-eleventh	917 m²	2023 m²
13-twelve floor	1879 m²	2023 m²
14-thirteenth	1879 m²	2023 m²
15-fourteenth	1879 m²	1674 m²
16-fifteenth	1768 m²	1049 m²
Gross Area	54335 m²	31893 m²

Table 6.12: Curtain Wall Area

Serial	Elevation by street name	EV	MB
		Area	Area
1	de Maisonneuve	4506 m²	1726 m²
2	Guy elevation	4693 m²	4027 m²
3	Pierce elevation	-	3518 m²
4	Mackay elevation	4268 m²	-
5	Sainte Catherine	4956 m²	1764 m²
Curtain Wall Total Area		18424 m²	11037 m²

Table 6.13: Plumbing Fixtures

Serial	Type of fixture	EV Building	MB
		Total	Total
1	Drinking fountains	56	26
2	Lavatory	132	78
3	Urinal	53	26
4	Water closet	136	105

Table 6.14: Roof area

Serial	Type of fixture	EV Building	MB
		Area	Area
1	3rd floor	894 m²	609 m²
2	10th floor	1034 m²	-
3	11th floor	301 m²	-
4	12th floor	898 m²	-
5	14th floor	-	348 m²
5	15th floor	111 m²	988 m²
6	16th floor EV/ Top level	621 m²	911 m²
7	Top level EV	1252 m²	-
Total		5111 m²	2856 m²

Table 6.15:Wall Area by Function

Serial	Wall Function	Wall Type	EV Building	MB
			Area	Area
1	Core shaft	Basic wall	7432 m²	3689 m²
2	Exterior wall	Basic wall	1843 m²	2944 m²
		Curtain wall	18424 m²	11037 m²
		total	20336 m²	13981 m²
3	Interior wall		73060 m²	44976 m²

Table 6.16: Site Area in Direction of Prevailing Wind

Serial	Building Name	Width	Height	Area of EV site elevation in direction of prevailing wind	Area of MB building elevation in direction of prevailing wind
1	EV Building	76 m	68 m	5168 m²	4859 m²
2	MB Building	70 m	68 m	4760 m²	4760 m²

Table 6.17: EV and MB Interior Spaces

Serial	Spatial areas of EV Building										Spatial areas of MB Building									
	Bathroom		Corridor		Elevator		Room		Stair		Bathroom		Corridor		Elevator		Room		Stair	
	No.	Area (m^2)	No.	Area (m^2)	No.	Area (m^2)	No.	Area (m^2)	No.	Area (m^2)	No.	Area (m^2)	No.	Area	No.	Area	No.	Area	No.	Area
Ground	4	57	7	1870	68	69	41	2117	5	178	3	54	4	1041	2	46	23	971	3	152
1st floor	8	71	7	398	9	68	147	2583	4	129	3	49	2	610	2	46	24	1188	3	97
2nd floor	8	71	7	1261	9	68	147	2788	4	105	3	49	2	610	2	46	23	1188	3	97
3rd floor	8	71	5	855	9	68	142	2220	4	106	3	49	5	624	2	46	60	916	3	103
4th floor	8	70	11	1133	9	68	127	2198	3	76	3	49	4	601	2	46	33	910	3	103
5th floor	8	77	7	803	9	68	131	2431	4	106	3	49	5	673	2	46	45	936	3	103
6th floor	8	77	4	647	9	68	89	2585	4	107	4	48	5	367	2	46	14	1158	3	103
7th floor	9	95	1	780	9	68	74	2624	4	108	3	40	2	428	2	46	36	1045	2	86
8th floor	8	77	3	596	9	68	74	2644	5	122	-	-	1	1707	2	46	3	48	2	86
9th floor	8	77	5	628	9	68	80	2476	4	107	4	44	4	463	2	46	51	1172	2	65
10th floor	8	70	5	623	9	68	57	1858	3	73	4	46	3	512	2	46	72	1127	2	65
11th floor	4	43	4	306	6	41	37	1162	2	58	4	46	3	546	2	46	78	1099	2	65
12th floor	4	40	2	260	6	41	34	1191	2	58	4	40	4	536	2	46	75	1105	2	65
13th floor	4	40	2	360	6	41	39	1230	2	58	4	40	5	499	2	46	54	836	2	58
14th floor	4	40	3	261	6	41	43	1159	2	58	-	-	-	-	-	-	-	-	-	-
15th floor	4	40	4	263	6	41	41	1058	2	58	-	-	-	-	-	-	-	-	-	-

6.5 The Energy Simulation Model Output

The XML Revit model is exported to IES software to develop the energy simulation models for EV and MB buildings. The models are based on the actual size of the building including materials as shown in Figure 6.7. The developed IES models are utilized to perform energy simulations to stand for the building energy consumption in yearly, monthly or daily basis in which these data are required for the assessment of the energy criterion. Various simulations were performed to compare between the energy consumption in different countries to stand for the variations in their energy loads and demands as shown in Figure 6.8. Therefore, based on the simulation results the score of the energy criterion will vary from region to another even the same building is subjected to the assessment.

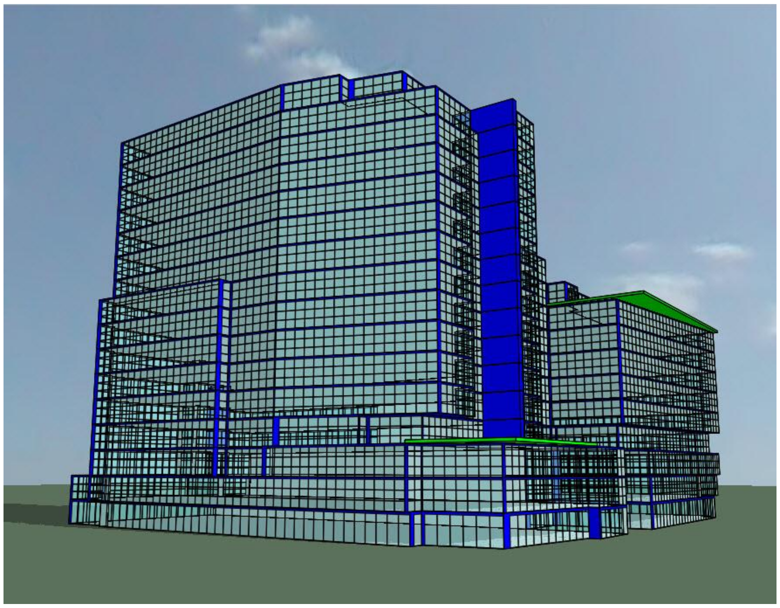


Figure 6.7: The IES model of the EV building

The accuracy of the simulation model output was compared to the actual data of energy consumption of the EV building; the actual total energy consumption of the building is 23,000 MWh, while according to simulation as shown in Table 6.18 it is 23,656 MWh with an error of 0.0285, which increases the confidence in the output of the simulation. Moreover, the main aim of the developed rating tool is to make a comprehensive assessment of sustainability according to the different local contexts of each country based on its environmental, social, and economic considerations. Consequently, seven simulations were performed for the EV Building (1st Case Study) using the environmental data bases of seven cities of seven different countries as illustrated which are: Hong Kong, China; Jakarta, Indonesia; New York, Malaysia; Cairo, Egypt; London, England; Kuala Lumpur, Malaysia: and Montreal, Canada. According to the data output of the simulations, as illustrated in Table 6.18, the total energy consumption (in MWh) in the cold weathered cities, i.e. Montreal and New York, is much higher than other warm weathered countries due to the high increase in demand for space heating and hot water provision, and this is reflected in the carbon emissions which are the main sources of GHG which result in increasing the global warming. However, in all the cities, a single building is responsible for high carbon emissions, even in the cities with low energy consumptions depending on the source of energy. As shown in Figure 6.9, Malaysia has higher share of carbon dioxide emissions comparing with New York even if the energy consumption of Malaysia is 10,557 and that of New York is 20,107 as shown in Table 6.18. The same argue can be noticed in the results of the carbon emissions of the MB building (2nd case study), although the MB Montreal consumes much higher energy than MB Cairo as shown in Table 6.20, but there is a small difference in carbon dioxide emissions as illustrated in Table 6.21 Also, even the case study buildings (i.e. EV and MB Buildings) with the same physical and thermal properties of materials that were used in simulations the EV and MB in Montreal, Canada performed differently than when they were simulated in Cairo, Egypt as illustrated in Figure 6.8, Figure 6.10, Table 6.18 and Table 6.20 respectively. These results show the impact of the local context of each country or a city on the energy consumption and carbon dioxide emissions, so the consideration of the local context of each country should be demonstrated explicitly in the sustainability rating systems.

Furthermore, the energy simulation was utilized to determine the light energy performance of the proposed alternatives in the sustainability-based rehabilitation model data input. Each proposed lighting alternative has a different influence on the total lighting energy and in turn will have different percentages of improvement over the current lighting system. As demonstrated in Figure 6.11, each of the eight proposed alternatives resulted in different total light energy performance ranging from 605 to 955 MWh/yr., therefore each will have different percentage of improvement over the current lighting system energy consumption, which is 3,000 MWh/yr. This percentage is translated into score that can be achieved as one of the decision variables data.

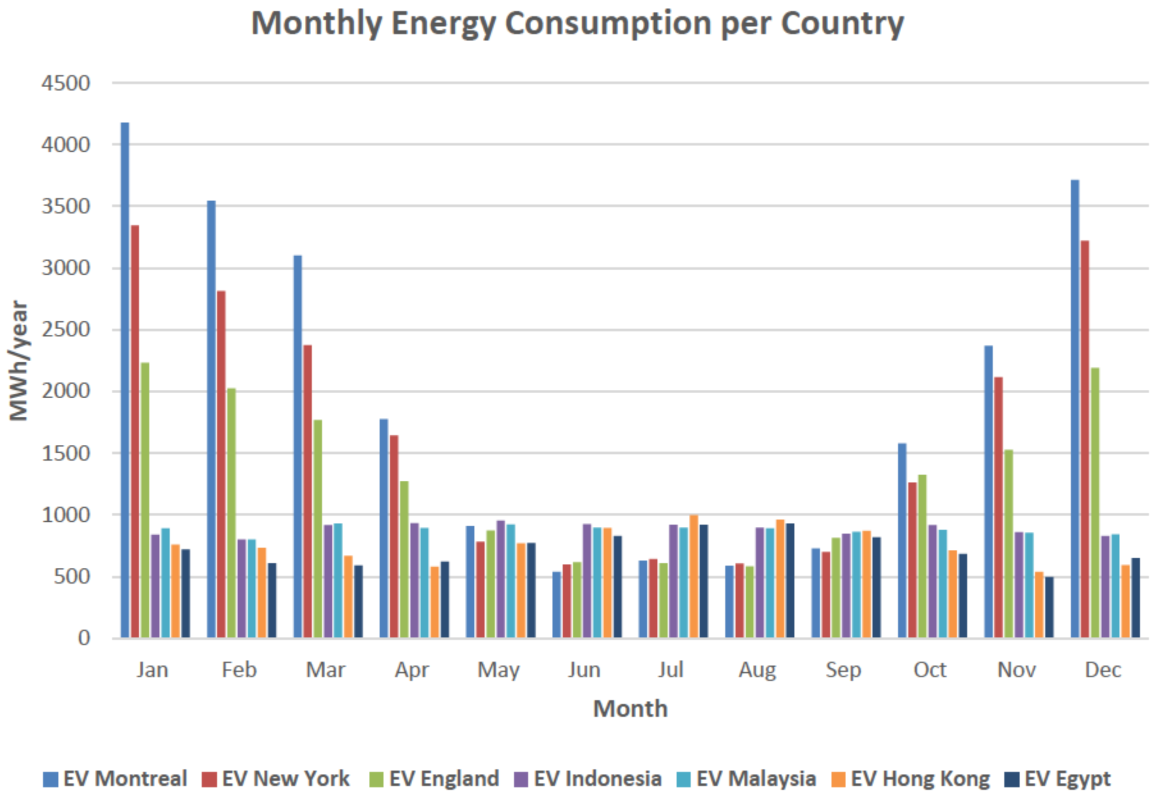


Figure 6.8 : Variation of EV Monthly Energy Consumption in Seven Countries

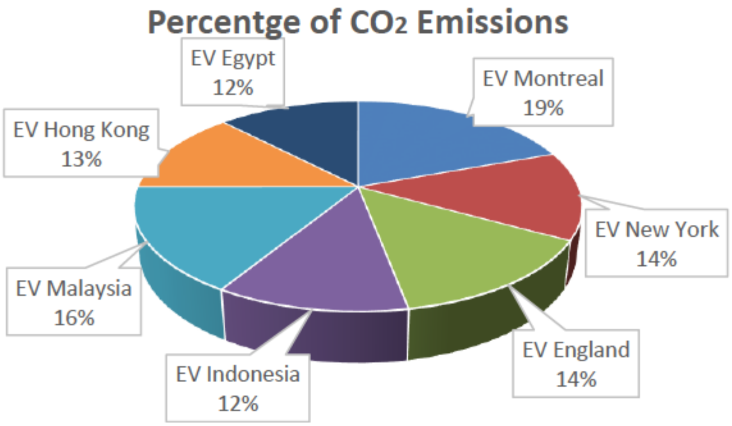


Figure 6.9: The Share of Carbon Emission of EV Building in Each City

Table 6.18: The Monthly and Annual Energy Consumption of EV Building (MWh)

Date	EV Montreal	EV New York	EV England	EV Indonesia	EV Malaysia	EV Hong Kong	EV Egypt
Jan	4,178.4	3,346.8	2,233.2	838.7	890.2	757.8	720.6
Feb	3,545.5	2,814.9	2,025.0	801.5	799.7	732.2	607.9
Mar	3,101.5	2,375.2	1,766.8	916.2	930.5	668.5	591.3
Apr	1,775.0	1,643.4	1,271.9	932.3	892.6	579.9	621.7
May	908.3	782.8	873.0	954.0	921.0	768.7	771.3
Jun	539.3	598.7	615.4	925.3	897.0	894.3	828.8
Jul	628.6	642.5	608.0	920.3	897.1	997.8	920.4
Aug	587.2	607.0	581.8	896.8	890.2	960.3	929.0
Sep	728.5	698.0	813.5	846.3	863.3	871.6	818.5
Oct	1,579.0	1,261.8	1,323.7	917.5	878.8	712.2	682.4
Nov	2,370.9	2,116.0	1,527.6	860.9	855.3	538.7	496.7
Dec	3,714.6	3,220.2	2,191.0	829.2	841.3	592.7	650.6
Energy Consumption	23,657	20,107	15,831	10,639	10,557	9,075	8,639

Table 6.19: EV Building Total CO_2 Emissions for Seven Countries (Kg-CO_2)

Date	EV Montreal	EV New York	EV England	EV Indonesia	EV Malaysia	EV Hong Kong	EV Egypt
Jan	1,000,932	664,939	580,480	307,173	455,082	277,391	259,879
Feb	854,803	563,132	525,928	293,808	408,775	254,054	228,141
Mar	768,365	490,033	481,656	335,965	475,997	273,693	251,276
Apr	480,563	356,719	370,895	342,108	456,517	278,996	307,812
May	303,896	222,173	297,553	350,019	471,049	391,995	392,125
Jun	250,204	201,216	243,516	339,503	458,812	457,439	423,391
Jul	308,587	232,148	236,142	337,498	458,665	510,915	470,734
Aug	281,585	212,999	240,008	328,770	455,077	491,442	475,218
Sep	267,572	204,212	274,835	310,157	441,343	445,645	418,093
Oct	442,903	294,035	385,676	336,468	449,126	361,318	346,989
Nov	607,297	441,309	424,920	315,568	437,164	267,846	238,024
Dec	900,591	641,963	571,331	303,651	429,677	242,790	249,650
Carbon Emissions	6,467,297	4,524,876	4,632,938	3,900,686	5,397,286	4,253,524	4,061,332

Table 6.20: The Monthly and Annual Energy Consumption of MB Building (MWh)

Date	EV Montreal	EV Egypt
Jan	2,018.8	417.1
Feb	1,705.1	365.0
Mar	1,489.7	413.6
Apr	858.2	497.1
May	496.3	608.4
Jun	428.2	643.2
Jul	510.2	702.3
Aug	470.7	708.4
Sep	428.4	631.6
Oct	792.1	552.2
Nov	1,193.8	409.2
Dec	1,820.7	407.4
Energy Consumption	12,212	6,355

Table 6.21: MB Building Total CO_2 Emissions for Montreal and Cairo (Kg-CO_2)

Date	EV Montreal	EV Egypt
Jan	429,243	146,351
Feb	366,399	132,501
Mar	334,035	159,437
Apr	219,830	199,547
May	163,492	245,549
Jun	168,621	260,037
Jul	203,900	284,193
Aug	186,297	286,726
Sep	152,360	255,271
Oct	211,006	222,403
Nov	278,580	162,468
Dec	393,571	148,432
Energy Consumption	3,107,335	2,502,913

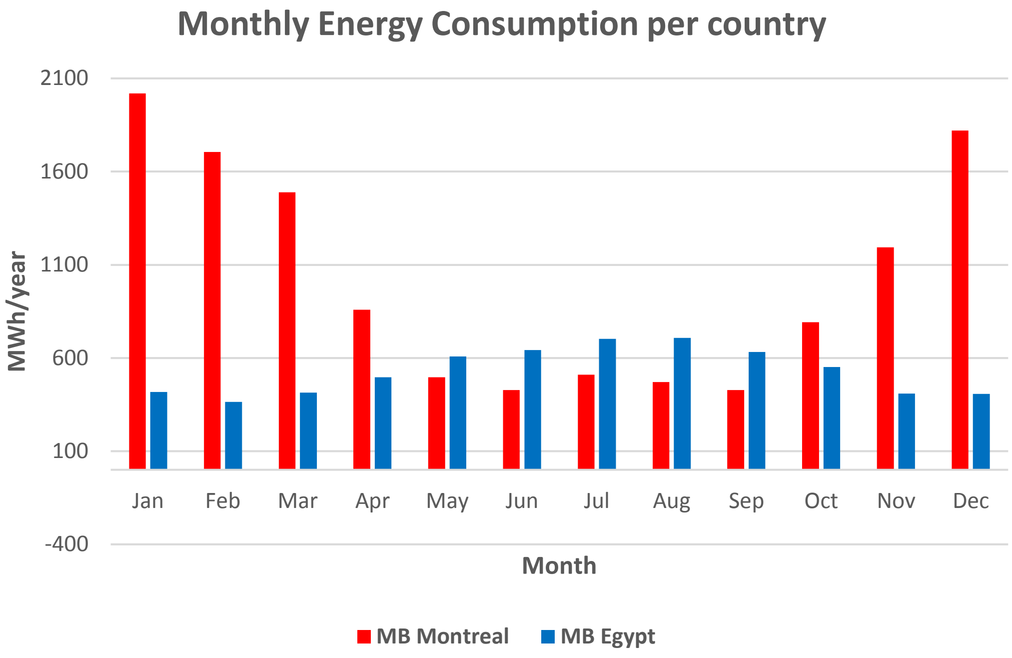


Figure 6.10: MB Monthly Energy Consumption for Montreal and Cairo Simulations

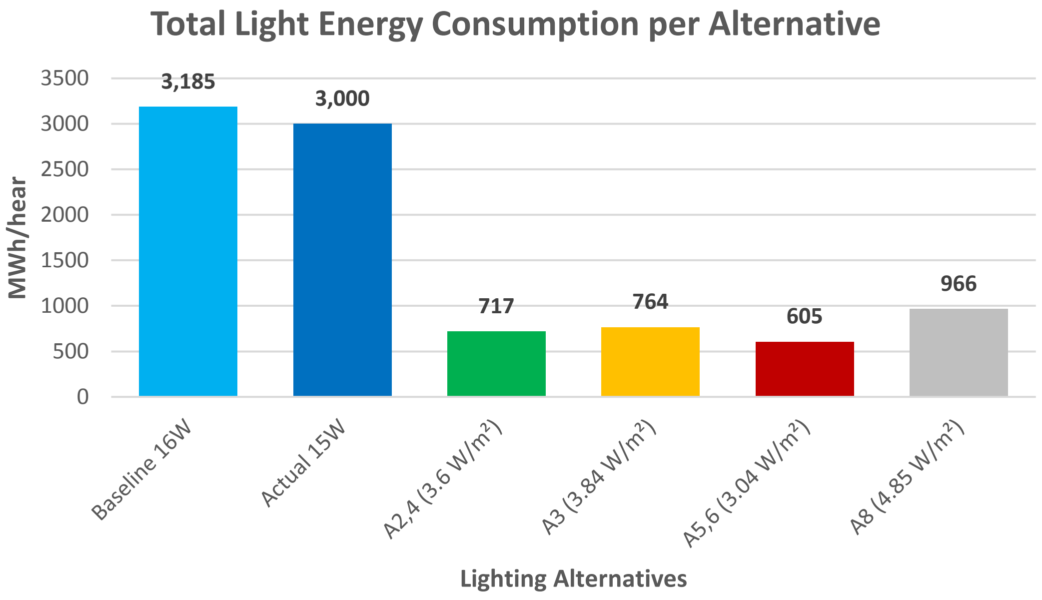


Figure 6.11: EV Light Energy Consumption Per Alternative

6.6 Sustainability Assessment Model Output

6.6.1 Factors' score Determination

i. Site and Ecology Criterion

The *site* and *ecology* criterion comprise four factors: previous consideration of site, site management, reduce heat island effect, and site emissions. The first factor consists of two sub factors which are *previously certified design and construction* and *respect for sites of historic or cultural interest.* The first sub factor determines whether the building was subjected to previous sustainability rating assessment, the second one assess how the building respect the cultural and the historical theme of the city where the building is located. The EV building case study the project was not previously certified, while the MB building case study was certified previously by LEED Canada. Therefore, the first and the second case studies awarded one point and two points out of two respectively according to the point allocation.

The *site management* factor comprises four sub factors: *environmental policy and purchasing plan*, *environmentally purchasing practices*, *building exterior and hardscape management plan*, and *integrated pest management, erosion control, and landscape management plan*. The first sub factor has three items for evaluation: the first one examines the existence of environmental policy that reflects the goal of sustainability; the second part indicates the availability of green guide for occupants or visitors that is displayed through various channels; and the third part assures the presence of a documented environmental purchasing plan illustrates the purchasing of environment friendly material, equipment and products. Each item has three points to be awarded the EV and MB buildings scores 2 points out 3 points due to the inexistence of green guides in both buildings. The second sub factor demonstrates that 70% of all the purchased products in the last 12 month are environmental friendly (i.e. Materials with low embodied energy; durable materials, products and equipment; locally produced materials where available; wood products from well-managed sources; products which do not use CFCs, HCFCs, halons; rapidly renewable materials; furnishes, paints, adhesives, etc. with low levels of emissions; products having significant recyclable content; energy efficient appliances and equipment; and water efficient appliances, etc.). The third sub factor assesses the availability of building exterior and hardscape management plan that addresses utilizing environment friendly practices when dealing with the building exterior envelop and the landscape (i.e. reduction of harmful chemical use, energy waste, water waste, air pollution, solid waste and/or chemical runoff). The fourth factor assesses the procedures which are utilized for land scape management such as: the existence of pest management, erosion control management, and landscape management plan. If the there is no landscape exists in the assessed building, as the in EV and MB case studies, the building fulfils the sub factor and achieves one point.

The reduce heat island effect factor has five sub-factors: reduce heat island in nonroofed area, reduce heat island in roofed area, exterior wall finishing and planting material, consideration of wind movement and building exterior design, and greenery provision and ecological features. The first sub factor assesses applying efficient practices for minimizing the impacts of the existing nonroofed landscape on the neighbouring microclimate. These practices may utilize shaded areas (i.e. architectural elements, trees with large canopies), use light colour hardscape materials or high albedo surfaces, and apply open grid areas instead of dark asphalt for parking lots. This sub-factor is implemented only on the exterior landscapes, consequently the two case studies have no exterior landscape so the buildings gains one point which is the score of this sub-factor owing to the landscapes of the buildings have no impacts on the microclimate. The second sub-factor assesses the existence of roof materials with high solar reflectance index (SRI) and planted roof to mitigate the heat island effect of the building roof on the surrounding environment. By applying the equation (3.9), if the left-hand side is greater than the right-hand side the building fulfils the sub-factor and one point is awarded. In the case of the EV building the total roof area is 5,111 m2 as shown in Table 6.14, the occupied area of the roof is 766 m^2, the weighted roof average is 3,578 m^2. Accordingly, the weighted average roof is smaller than the net roof area which is 4,345 m^2, so the building does not meet the requirements. In the case of the MB building the total roof area is 2,856 m^2 as shown in Table 6.14 the weighted roof average is 3,386 m^2, the weighted average green roof area is 608. m^2. Accordingly, the sum of the weighted average roof area with high albedo and the weighted green roof area is greater than the net roof area which is 2,856 m^2, so the building meets the requirements and scores one point. The third sub-factor determines the ratio between the summation of the area of the installed high reflectance material and the area planted in the exterior wall to the total building envelope area as shown in equation (3.10). The building achieves the sub-factor if the percentage is over 20%. The EV building exterior wall envelope area is 20336 m^2 and the installed high reflectance material (aluminium cladding) area is 1,843 m^2 and the percentage between the two areas is 9%, so the building fails to fulfil the requirement. The MB building exterior wall envelope area is 13,981 m^2 and the installed high reflectance material (aluminium cladding) area is 2,944 m^2 and the percentage between the two areas is 21%, so the building fulfils the requirement. The fourth sub-factor assesses how the building allow the prevailing wind in the prevailing wind direction to path through the neighbour buildings to mitigate the heat island effect aroused due to the existence of the building. The one point is awarded if the ratio between the area of the building in the prevailing wind direction to the total area of the site in the same wind direction is less than 70% as shown in equation (3.11). Both EV and the MB buildings fails to achieve the sub-factor based on the data provided from Table 6.16. Finally, the fifth-sub factor evaluates the ratio of the greenery provisions in the site to the total net area of the site (excluding buildings) and the calculation is based on equation (3.12). Points are awarded based on Table 6.22. The EV building has no sort of greenery provisions so it scores zero points, whereas the MB building has planted roof on the fourth floor with area 304 m^2 while the greenery provision ratio is 0.12 so the building failed to achieve the sub-factor.

Table 6.22: Points Allocation for Greenery Provision Ratio

GnP ratio	**score**
0.5 to < 1.0	1 point
1.0 to < 2	2 points
2 to < 3.0	3 points
3.0 and more	4 points

ii. Transportation Criterion

The *transportation* criterion encourages utilizing of efficient means of transportation, and urge using public means of transportation rather than private ones in commuting. It comprises four factors, which are *cyclist facilities and public means of transport*, *public transport accessibility and community accessibility*, *provision of maximum parking capacity*, and *provision of low-emitting & fuel-efficient* vehicles as shown in Figure 5.1.

The first factor includes three sub-factors: *cyclist facilities*, *Carpooling and Vanpooling*, and *reduction in conventional commuting trips*. The first sub-factor encourages the building users to use bicycles as a mean of commuting while ensuring the existence of an adequate provision of the cyclist facilities. Points are awarded according to the provision of certain facilities which are shown in Table 6.23. Each of the EV and MB buildings scores three points. The second sub factor assesses the availability of one of the following: carpooling, feeder buses, public transportation vouchers and one point is awarded if the sub-factor is fulfilled. The existence of feeder busses (Concordia shuttle bus) that serves both case studies makes each of them achieve one point. Finally, the last sub-factor evaluates the reduction in the commuting trips made by conventional mean transportation, which is private cars using conventional fuel. This reduction can be achieved by alternative transportation which includes telecommuting, compressed workweeks, mass transit, walking, bicycles, carpools, vanpools, and low-emitting or fuel-efficient vehicles. Points are awarded by percentage in reduction of commuting trips as illustrated in Table 6.24, the percentage should be calculated based on how a survey is applied on a sample of regular building occupants to estimate the number of them that use alternative commuting by utilizing equation (3.14). The number of sample that was assumed in the calculation of this sub factor was four hundred, which is nearly 40% of the number of regular occupants which is 1,059 as it was difficult to conduct this survey utilizing a large number of occupants. Both case studies assumed to achieve 57% of reduction in using regular commuting transportation which scores 10 points.

Table 6.23: Score Allocation for Cyclist Facility Sub-factor

Cyclist Facility	score
Secure and well-lit cycle racks are in place	1 point
Secure, well-lit, and gender specific changing facilities are in place	2 points
Secure, well-lit, and gender specific changing facilities, and shower facilities in place.	3 points

Table 6.24: Score Allocation for Reduction in Conventional Commuting Trips Sub-factor

Percentage of Reduction in Conventional Commuting Trips	Score
10 %	1 point
15 %	2 points
20 %	3 points

25 %	4 points
30 %	5 points
35 %	6 points
40 %	7 points
45 %	8 points
50 %	9 points
55 %	10 points
60 %	11 points
65 %	12 points
70 %	13 points
75 %	14 points

The second factor includes two sub-factors which are *public transport accessibility and community accessibility.* The first sub-factor evaluates the provision of an appropriate public mean of transport and their ease of accessibility to the building occupants, hence, points are awarded based on Table 6.25. The EV and MB buildings score seven points owing to the existence of public transport within 300 m maximum away from both buildings. The second sub-factor encourages the existence of amenities by means of safe pedestrian route and points are awarded by matching Table 6.26. Both case studies achieve three points due to the existence of cafés and cash machines within 500m by safe pedestrian route (subway).

Table 6.25: Score Allocation for Public Transport Accessibility Sub-Factor

Proximity to Public Transport	Score
Existence of a public transport 1 km away from the building with a 30-minute service frequency at peak times.	1 point
Existence of a public transport 1 km away from the building with a 15-minute service frequency at peak times.	2 points
The availability of a charted bus service that is provided at the beginning and the end of the working day.	3 points
Providing of a shuttle bus for the building users to reach the public transportation stations or carpooling.	3 points
Existence of a public transport within 500 m away from the building with a 30-minute service frequency at peak times	4 points

Existence of a public transport within 500 m of the building with a 15-minute service frequency at peak times	5 points
Existence of a public transport within 500m of the building with a 15-minute service frequency at peak times	6 points
Existence of a public transport stations within 300 m from the gate outside the building.	7 points

Table 6.26: Score Allocation for Community Accessibility Sub-factor

Community Accessibility	Score
A sandwich bar /cafe within 1km	1 point
A sandwich bar /cafe within 500 m	2 points
A sandwich bar/cafe and bank/cash machine 1 km	2 points
A sandwich bar/cafe and bank/cash machine 500 m	3 points

The *provision of maximum parking capacity* factor encourages the reduction of use private cars in commuting by limiting the over-provision of car parking capacity restricting the size of the parking capacity to the minimum local zoning requirements or providing a preferred parking areas for carpools and vanpools. Both cases achieve one point, which is the maximum points as there are no parking zones integrated in these buildings. Finally, the fourth factor offers a preferred parking priority to fuel efficient vehicles. Both case studies score one point, which is the maximum score that is allocated for this sub-factor, due the inexistence of parking area.

iii. Energy Criterion

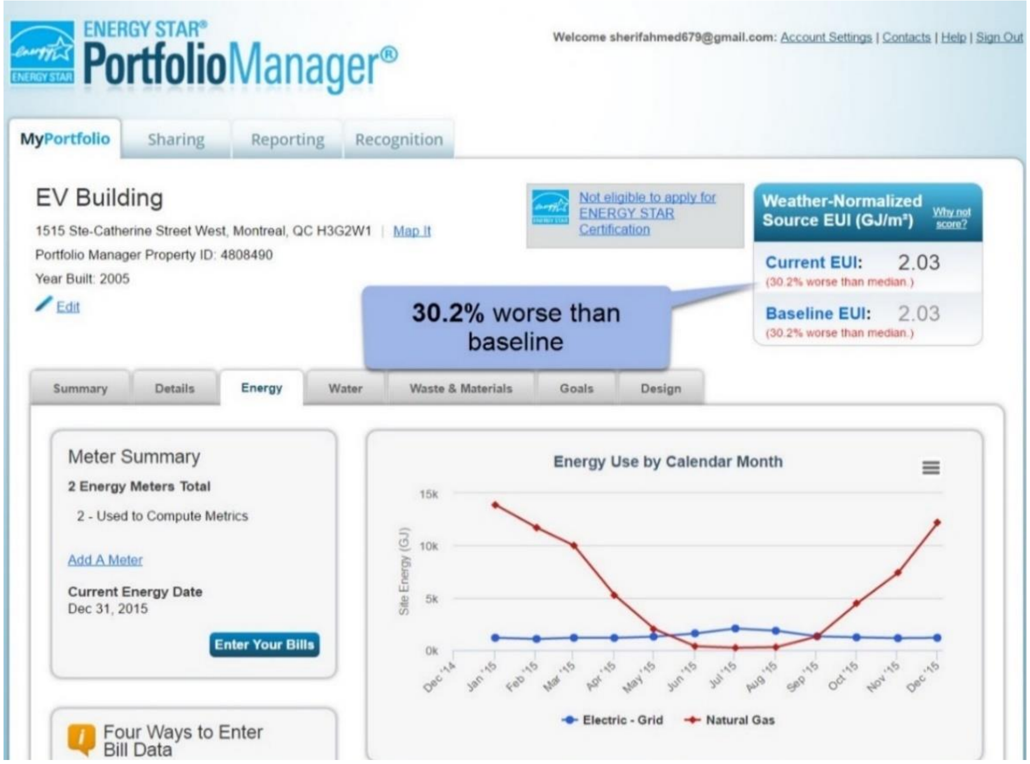
Energy criterion is one of the fundamental aspects of sustainability which aims to reduce the energy consumption and its related impacts. It includes four factors: *energy performance*, *provision of energy management*, *energy efficient systems* and *energy efficient equipment* as demonstrated in Figure 5.1.

The first factor is divided into three sub-factors which are *minimum energy performance*, *optimizing energy efficiency performance*, and *building envelope evaluation and its Thermal performance*, and it evaluates the thermal performance as shown in Figure 5.4. The first sub-factor is a prerequisite for the evaluation process of the *energy* criterion. This prerequisite is not scored but it determines whether the building will proceed for further evaluation in this criterion or not. For the condition to pass the prerequisite is to achieve energy use entensity (EUI) of 20% over the baseline building of the same type. The calculation of the EUI depends on the annual and monthly building energy consumption either using energy simulation or the actual energy records. These records are entered in the Energy Star Portfolio Manager online programme to estimate the EUI performance and compare it with the baseline as demonstrated in Figure 6.12. The EV building fails to fulfill the prerequisite as its EUI is 30% worse than the baseline. Although the EUI of the MB building is higher than the baseline with 17.4%, it fails to achieve the prerequisite as shown in Figure 6.13.

Moreover, the second sub-factor assesses the percentage of the reduction of energy performance compared with the baseline, and the same procedures that are applied in the first sub-factor are used. There are 18 maximum points and the distribution of points are illustrated in Table 6.27. Both case studies did not score any points, as they failed to fulfill the 20% reduction than the base line that is required in the prerequisite.

Finally, the third subfactor evaluates the thermal performance of the building emvelpe to decrease the cooling and heating loads resulting from the heat transfer into the building through its enevelope. This performance is quantified utilizing the GreenMark Singapore concept, which is called envelope thermal transfer value (ETTV) which should not exceedes 50 W/m^2 (BCA, 2012b).

There is another expression that is called overall heat transfer value (OTTV), which is used by the Hong Kong Beam (Hong Kong Institute of Architects, 2012). However, it was proved to be ineffecient in representing the heat gain through the fenestration as illustrated in BCA (2004). The ETTV is calculated by implementing equations (3.15) and (3.16). In equation (3.15), the thermal transmittance of fenestration (U_f) is the amount of heat flow through the unit area of a building section under a steady condition (Hutcheon and Handegord, 1995). The shading Coeffecient (SC), which is the ratio of the amount of heat gained throught a fenestration system, is a combination of shading system and glass to that amount gained through a clear glass 3mm thich (BCA, 2004). The correction factor is a unitless adjustment of the amount heat gain accorrding to orientation of the wall and it ranges from 0.5-1.5 (BCA, 1986). The U_f , the SC, and the CF values were selected to be 1.1 $W/m^2.K$, 0.2, and from (0.8-1.23 according the wall orientation) respectively (BCA, 2004; BCA, 1986; CIBSE, 2006; IEA, 2012). One point for every 1W/m^2 reduction from the baseline (50 W/m^2) with maximum 5 points. The EV building has ETTV of 46.27 W/m^2 scores 4 points, the MB building has ETTV 49.25 W/m^2 and scores one point.



EV Building

1515 Ste-Catherine Street West, Montreal, QC H3G2W1

Portfolio Manager Property ID: 4808490

Year Built: 2005

Current EUI: 2.03 (30.2% worse than median.)

Baseline EUI: 2.03 (30.2% worse than median.)

30.2% worse than baseline

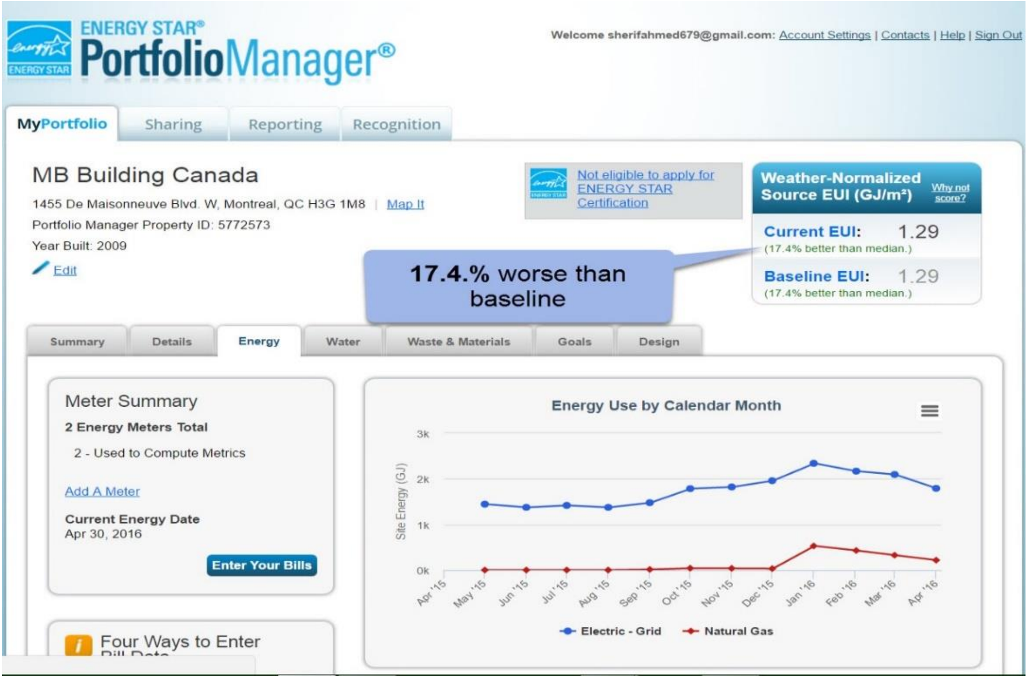
Meter Summary

2 Energy Meters Total

2 - Used to Compute Metrics

Current Energy Date
Dec 31, 2015

Figure 6.12: Snap Shot of the Online Energy Star Portfolio Manager for EV Building



MB Building Canada

1455 De Maisonneuve Blvd. W, Montreal, QC H3G 1M8

Portfolio Manager Property ID: 5772573

Year Built: 2009

Current EUI: 1.29 (17.4% better than median.)

Baseline EUI: 1.29 (17.4% better than median.)

17.4.% worse than baseline

Meter Summary

2 Energy Meters Total

2 - Used to Compute Metrics

Current Energy Date
Apr 30, 2016

Figure 6.13: Snap Shot of the Online Energy Star Portfolio Manager for MB Building

Table 6.27: Score Allocation for Optimizing Energy Efficiency Performance Sub-factor

Percentage of Reduction in Energy Performance	Score
21	1 point
23	2 points
25	3 points
27	4 points
29	5 points
31	6 points
33	7 points
35	8 points
37	9 points
39	10 points
41	11 points
43	12 points
45	13 points
47	14 points
49	15 points
51	16 points
53	17 points
55	18 points

The second factor includes five sub-factors :1) energy operating plan; 2) energy monitoring and metering; 3) auditing, commissioning, and testing of energy systems; 4) building automation system; and 5) sustainable maintenance. The first sub-factor examines the existence of operating plan that provides details on building operation and maintenance, which addresses an occupancy schedule, equipment run-time schedule, the design set points for all HVAC equipment, and the design of lighting levels throughout the building. Moreover, the two case studies were awarded one point which is the maximum points for this sub-factor.

The second sub-factor comprises four assessments aspects:1) metering of electrical loads, 2) monitoring of central HVAC plant; 3) monitoring record; and 4) public display of energy use. The first aspect evaluates the provision of systems or equipment which measure and monitor all major electrical loads in the building such as lighting, small power, transportation, plumbing systems, drainage systems, major air handling equipment such as centralized air handling units for floors/zones and large areas as shown in Figure 6.14. The second aspect determines the availability of monitoring system that address the overall performance of the plant and the individual chillers for all operating modes and ranges of operating conditions. The third aspect assesses the availability of monthly record that consist of results from monitoring and data collection on the kWh meters as shown in Figure 6.15. Finally, the fourth one, requires a presence of displaying information concerning a comparison of total energy use within 12 months of the previous year with total energy usage in year to date. Each one of these aspects has a score of one point. The EV and the MB achieved the maximum score for the first and the third aspects, but zero point was awarded for the rest of aspects due to the inexistence of monitoring of HVAC system and no presence of display information for energy in both buildings.

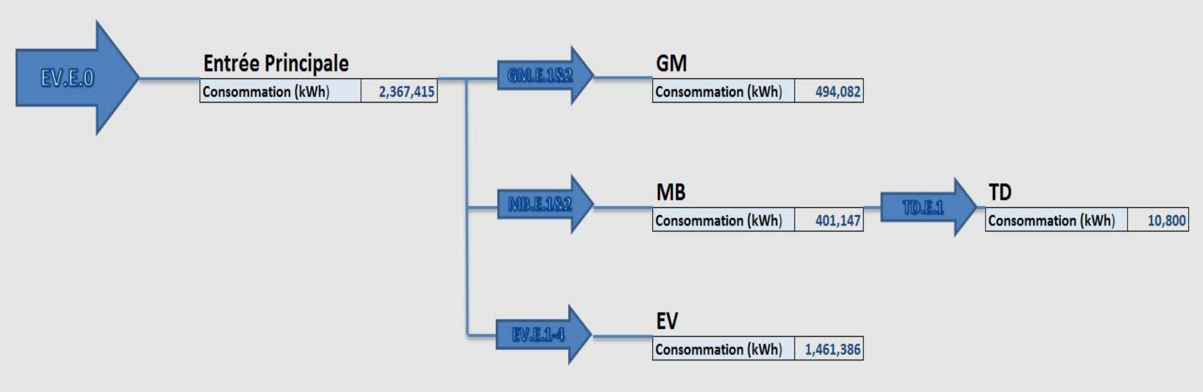
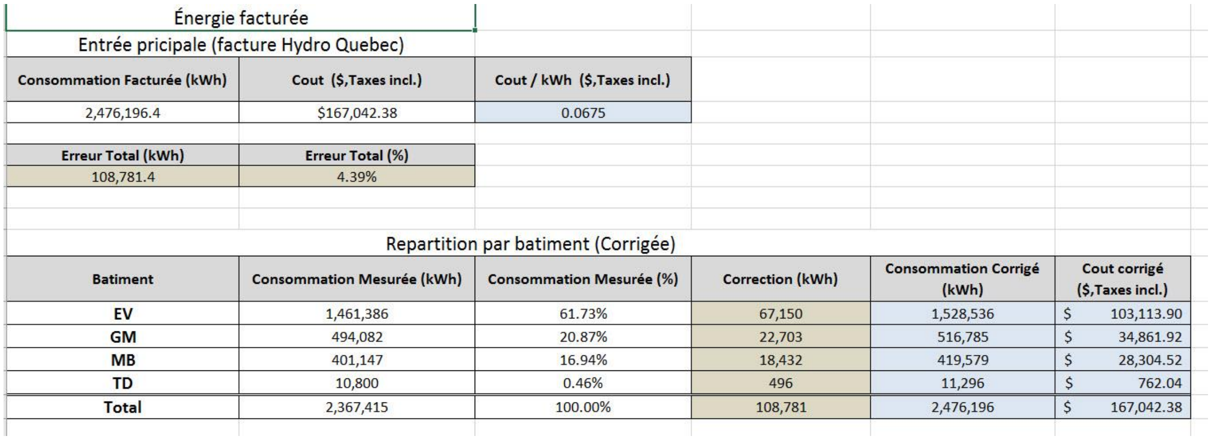


Figure 6.14: Snapshot of the EV and MB Electrical Metering (Facility Management Data)



Énergie facturée

Entrée pricipale (facture Hydro Quebec)

Consommation Facturée (kWh)	Cout ($,Taxes incl.)	Cout / kWh ($,Taxes incl.)
2,476,196.4	$167,042.38	0.0675

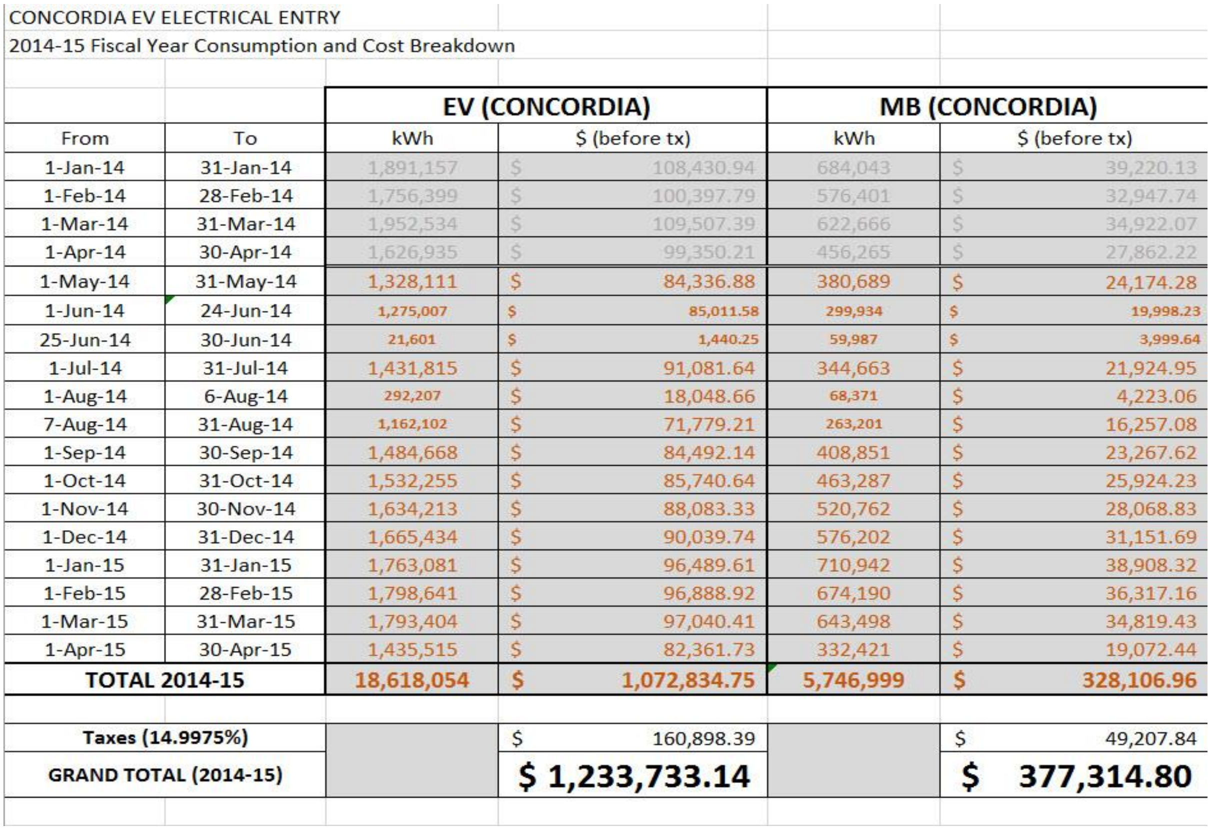
Erreur Total (kWh)	Erreur Total (%)
108,781.4	4.39%

Repartition par batiment (Corrigée)

Batiment	Consommation Mesurée (kWh)	Consommation Mesurée (%)	Correction (kWh)	Consommation Corrigé (kWh)	Cout corrigé ($,Taxes incl.)
EV	1,461,386	61.73%	67,150	1,528,536	$ 103,113.90
GM	494,082	20.87%	22,703	516,785	$ 34,861.92
MB	401,147	16.94%	18,432	419,579	$ 28,304.52
TD	10,800	0.46%	496	11,296	$ 762.04
Total	2,367,415	100.00%	108,781	2,476,196	$ 167,042.38

Figure 6.15: A Monthly Record of Energy Consumption (Facility Management Data)

Further, third sub-factor consists of five aspects: 1) energy auditing; 2) emissions reduction reporting; 3) investigation and analysis; 4) implementation; and 5) ongoing commissioning. The first aspect examines the existence of auditing report which tackles several headlines such as breakdown of energy use by departments/units; individual major services systems and equipment; energy consumption by tenants; energy consumption records, operation, maintenance records; an action plan based on findings exist in place and in good progress to achieve targets; evidence shows that auditing practices are appropriate to the size and complexity of the development; carbon audit or GHG emission audit and action plan of GHG reduction that is in progress is demonstrated (Baechler and Farley, 2011; CIPEC, 2011). The second aspect identifies building performance parameters that reduce conventional energy use and emissions, quantify those reductions and report them to a formal tracking program (USGBC, 2009). The third aspect determines the savings and cost analysis of all practical measures and perform a cost benefit analysis. The fourth aspect appraises the following: implementing the low-cost operational improvements and creating a capital plan for major retrofits or upgrades, providing training for management staff, updating the building operating plan. Finally, the fifth aspect evaluates the implementation of an ongoing commissioning program that includes elements of planning, system testing, performance verification, corrective action response, ongoing measurement and documentation to proactively address operating problems (Baechler and Farley, 2011; CanmetEnergy, 2008; Jump, 2008). All the mentioned aspects have a score of one point each. Both case studies fulfil the requirements of each aspect, based on the information provided by the Concordia facility management Office as shown in Figure 6.16, except for the emission reduction aspect.



CONCORDIA EV ELECTRICAL ENTRY

2014-15 Fiscal Year Consumption and Cost Breakdown

		EV (CONCORDIA)		MB (CONCORDIA)	
From	To	kWh	$ (before tx)	kWh	$ (before tx)
1-Jan-14	31-Jan-14	1,891,157	$ 108,430.94	684,043	$ 39,220.13
1-Feb-14	28-Feb-14	1,756,399	$ 100,397.79	576,401	$ 32,947.74
1-Mar-14	31-Mar-14	1,952,534	$ 109,507.39	622,666	$ 34,922.07
1-Apr-14	30-Apr-14	1,626,935	$ 99,350.21	456,265	$ 27,862.22
1-May-14	31-May-14	1,328,111	$ 84,336.88	380,689	$ 24,174.28
1-Jun-14	24-Jun-14	1,275,007	$ 85,011.58	299,934	$ 19,998.23
25-Jun-14	30-Jun-14	21,601	$ 1,440.25	59,987	$ 3,999.64
1-Jul-14	31-Jul-14	1,431,815	$ 91,081.64	344,663	$ 21,924.95
1-Aug-14	6-Aug-14	292,207	$ 18,048.66	68,371	$ 4,223.06
7-Aug-14	31-Aug-14	1,162,102	$ 71,779.21	263,201	$ 16,257.08
1-Sep-14	30-Sep-14	1,484,668	$ 84,492.14	408,851	$ 23,267.62
1-Oct-14	31-Oct-14	1,532,255	$ 85,740.64	463,287	$ 25,924.23
1-Nov-14	30-Nov-14	1,634,213	$ 88,083.33	520,762	$ 28,068.83
1-Dec-14	31-Dec-14	1,665,434	$ 90,039.74	576,202	$ 31,151.69
1-Jan-15	31-Jan-15	1,763,081	$ 96,489.61	710,942	$ 38,908.32
1-Feb-15	28-Feb-15	1,798,641	$ 96,888.92	674,190	$ 36,317.16
1-Mar-15	31-Mar-15	1,793,404	$ 97,040.41	643,498	$ 34,819.43
1-Apr-15	30-Apr-15	1,435,515	$ 82,361.73	332,421	$ 19,072.44
TOTAL 2014-15		**18,618,054**	**$ 1,072,834.75**	**5,746,999**	**$ 328,106.96**
Taxes (14.9975%)			$ 160,898.39		$ 49,207.84
GRAND TOTAL (2014-15)			**$ 1,233,733.14**		**$ 377,314.80**

Figure 6.16: Sample of the Energy Consumption and annual bills for EV and MB Buildings (Facility Management Data)

The fourth sub-factor assesses the presence of a computer-based building automation system (BAS) which monitors and controls the major building systems to provide information concerning the ongoing energy performance optimization of a building and to identify opportunities for additional energy-saving investments. This sub-factor has one point to be awarded, however both case studies has no building automation systems, hence they got zero points. The fifth sub-factor ensures that all systems of building which require energy for operation will continue to perform efficiently with proper and maintenance (GBI, 2011). Points are awarded based on three criteria as illustrated in Table 6.28, each one will score one point. The EV and MB scores the maximum points which are three points.

Table 6.28: Score Allocation for Sustainable Maintenance Sub-factor

Percentage of Reduction in Energy Performance	Score
existence of 3 years of maintenance budget record	1 point
existence of 3 years of maintenance budget record plus maintenance office	2 points
existence of 3 years of maintenance budget record plus maintenance office plus 75% of the maintenance team participate in commissioning	3 points

The third factor comprises three sub factors: interior lighting efficiency and zoning control, renewable energy systems, and energy efficient circulation systems (Lifts and Escalators). The first sub-factor includes two aspects. The first aspect determines the percentage of reduction in energy consumption by utilizing efficient lighting more than the base line light, while maintaining the required lighting intensity which is measured by lumen per meter squared (BCA, 1986; BCA, 2012a; BCA, 2012b). The baseline of the building lighting intensity varies according to the function of the building (GSA, 2016). Each type of lighting fixture possesses different specifications such as lighting intensity and output wattage which helps in cutting off the power consumption of the overall lighting system and in turn results in energy saving (NSW, 2014). The calculation of the lighting intensity is based on equation (3.17). One point is awarded for every two percent reduction of the total energy consumption or the total lighting energy consumption of the baseline lighting. The EV scored two points as the baseline light energy consumption is 3,185.25 MWh, and the installed light energy consumption is 3,000 MWh the percentage of reduction is 5.82%. The variation in the monthly energy consumption between baseline lighting and the actual one according to simulation is shown in Figure 6.17. Also, as shown Figure 6.18, the lighting represents 19% of the total electricity consumption based on simulation, which indicates its significant impact on the total consumption of buildings. The second aspect aims to provide different light and zoning control to increase the energy savings (GBI, 2011). Points were awarded based on Table 6.29. The EV and MB achieved two points out of three as the missed point due to the unfulfillment of the daylighting sensors.

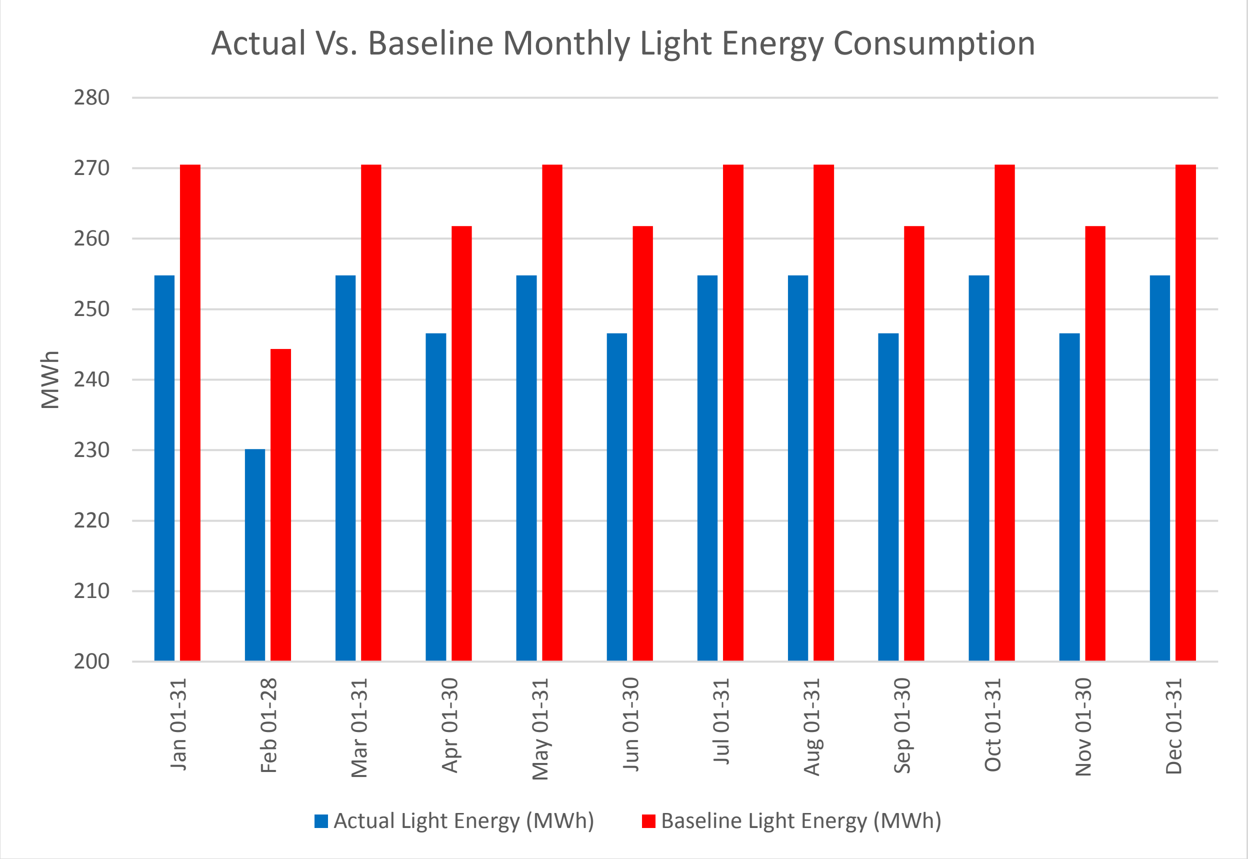


Figure 6.17: Comparison between Actual and Baseline Monthly Light Consumption

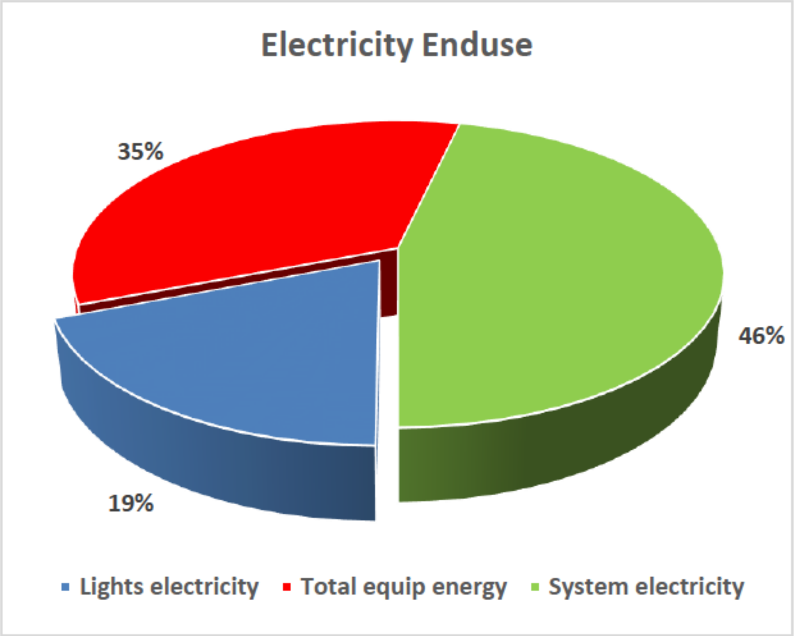


Figure 6.18: Percentage of Lighting Electricity Consumption

Table 6.29: Points Allocation for Zoning Control Aspect

Assessment Criteria	Score
Enclosed spaces equipped with individual switches	1 point
Daylighting sensor control for all perimeter areas	1 point
Provide motion or occupancy sensors for at least 25% of the total floor area	1 point

The second sub-factor evaluates the percentage of energy produced from the renewable resources to the total energy demand (BRE, 2015; BCA, 2012b; GBC Indonesia, 2011; GBI, 2011; JaGBC, 2008; USGBC, 2009). Points are awarded adopting GBI, Greenship, and LEED rating systems and as shown in Table 6.30. The EV building scored zero points in this sub factor as there are no renewable resources of energy installed. While the MB scored four points due to the installation of solar cells of power 24.5 kWp (Concordia, 2017; NSERC, 2016).

Table 6.30: Points Allocation for Renewable Resources Sub-factor

Assessment Criteria	Score
Produce 3% of energy or install solar cells of 2 kWp	1 point
Produce 4.5% of energy or install solar cells of 5 kWp	2 points
Produce 6% of energy or install solar cells of 10 kWp	3 points
Produce 7.5% of energy or install solar cells of 20 kWp	4 points
Produce 9% of energy or install solar cells of 40 kWp	5 points
Produce 12% of energy or install solar cells of greater than 40 kWp	6 points

Finally, the third sub-factor encourages the use of Variable Voltage Variable Frequency (VVVF) moto and sleep mode features in the circulation systems such as the lifts and escalators. The VVVF can reduce the energy consumption of the conventional systems with considerable percentages (John et al., 2013; NRC, 2009). Two points are awarded according to the existence of VVVF or sleep mode control in both of the circulation systems. Both case studies adopt the VVVF control system in both elevators and escalators, so both buildings awarded two points.

iv. Water Use Criterion

This criterion assesses the practices used to conserve water and decrease water consumption by employing efficient and innovative methods. It is composed of three factors as illustrated in Table 2. The *water use efficiency* factor evaluates the effectiveness of the indoor plumbing fixtures, water recycling and rainwater harvesting, the water efficient landscaping and irrigation, and water tab efficiency in public areas. The *water management* factor appraises using procedures to control and reduce water demand such as the persence of water conservation plan, the actions taken for checking and fixing leaks, performing water quality and quantity survey, monitoring water performance, cooling tower water management, and storm water quantity control and surface water runoff. The final factor estimates the percentage of reduction in discharged water.

v. Material and Waste Reduction Criterion

This criterion evaluates the efficient use of materials and assesses the practices used to manage the solid waste efficiently, safely and environment-friendly. It comprises three factors as shown in Table 2. The *material management* factor ensures the existence of sustainable purchasing policy for all materials consumed in the building. The *sustainable purchasing practice* factor quantifies the amount of sustainable material utilized in the building. This factor is concerned with ongoing goods and durable goods, the facility alternations and additions, lamps of low mercury content, rapidly renewable materials, using sustainable forest products, utilizing local materials, using of non-ozone depleting materials, and monitoring the leak of refrigerants. The *efficient use of materials* factor estimates the reused content of the primary building elements, encourage modular and standard design, considering adaptability and deconstruction in design, and considering robustness for the asset and landscape. Finally, the *solid waste management* factor determines the existence of solid waste management policy, hazardous waste management, waste stream audit. Also, it addresses the amount of the reused or recycled content of the waste of consumables and durable goods, and the treatment of the waste resulted from facility alteration and addition. It evaluates the existence of collection, storage and disposal of recyclables, and the provision of installed equipment for waste reduction.

vi. Indoor Environmental Quality Criterion

This criterion encourages the use of efficient practices that help in improving the wellbeing of occupants while minimizing the environmental hazards. It has six factors as demonstrated in Table 3 as follows: *visual comfort*, *indoor air quality*, *thermal comfort*, *acoustic performance*, *hygiene*, and *building amenities*. The *visual comfort* factor assesses the amount of natural lighting and glare;

the practices used to reduce and control glare; the adequacy of internal light distribution in normally and non-normally occupied areas; the systems installed to control artificial lighting, and the use of high-frequency ballasts in lighting. The *indoor air quality* factor evaluates the required minimum indoor air quality, environmental tobacco smoke control, indoor air quality performance and management that addresses, indoor air quality, and green cleaning policy that assesses the maintenance and cleaning practices and procedures. Besides, it evaluates the minimum ventilation performance, the increased ventilation performance to meet the increasing number of occupants, the efficiency of the localized ventilation, and the ventilation in the public areas. The ventilation efficiency is assessed utilizing equations (3.20) and (3.21) (ASHRAE, 2007; USGBC, 2009). The points are awarded according to the ratio between the calculated required outdoor air flow and the one required by the standard. The *thermal comfort* factor determines the design for thermal loads and its mitigation, monitoring and testing the air speed and radiant temperature for system development, the existence of temperature control, and the degree of thermal comfort in both naturally and mechanically ventilated areas. The *acoustic performance* factor assesses the noise isolation efficiency and background noise. The *hygiene* factor determines plumbing and drainage system to ensure that it is contaminant free, minimize impacts of chemical leakage in storage, reduce and control the biological contamination such as legionellosis, and the provision of a deodorizing system in all refuse collection rooms. Lastly, the *building amenities* factor assesses the delivery of facilities for disabled persons and the percentage of the amenity features that are provided within the building to increase the functionality of the building.

vii. Building Management Criterion

This is the seventh criterion comprises five factors which are *operation and maintenance management*, *security measures & intruder alarm system*, *green lease, risk management*, and *innovations* as shown in Figure 5.8.

The first factor includes five factor: condition survey; staffing quality and resources; building user manual and information; operation and maintenance policy; and operation and maintenance procedures, and manuals. The first sub-factor appraises the frequency of the condition survey carrying out, the type of issues that have been addressed (i.e. major or minor issues), and the action taken to rectify these issues. This sub-factor aims to provide the buildings' stakeholders to understand the physical condition of their property and to help them in managing any deficiencies addressed in any of the building components. Points were awarded by adopting BREEAM in use rating system as shown in Table 6.31 (BRE, 2015). The two case-studies scores three points as all the major issues are addressed.

Table 6.31: Points Allocation for Condition Survey (BRE, 2015)

Assessment Criteria	Score
Building is over 5 years old and no condition survey has been carried out or a condition survey carried out but no works has been carried out to rectify the defects.	Zero points
A condition survey has been carried out and an action plan is in place which establishes when issues will be addressed.	1 point
A condition survey has been carried out and some of the defects has been addressed and others are remaining.	2 points
A condition survey has been carried out and all major issues/defects have been addressed.	3 points
A condition survey has been carried out and all identified defects have been rectified.	4 points

The second sub-factor determines the existence of evidence that illustrates the adequacy of staff and the availability of resources that helps in performing the operation and maintenance of the building efficiently (HK GBC, 2012). One point is awarded according to the availability of report that indicates the adequacy of resources and staff. Both case studies fulfil the sub-factor. Moreover, the third sub-factor comprises two aspects: *building user manual* and *building user information*. The first aspect evaluates the existence of guidance and instructions for tenants and users, which helps in promoting environmental friendly use of the building (BCA, 2012b; BRE, 2015; HK GBC, 2012; GBI, 2011). The second aspect encourages the use of information display to provide staff and visitors with information related to the environmental policies and performance of the building. One point is allocated for each aspect. Both case studies fulfil the first aspect only and awards one point. Further, the fourth sub-factor assesses the existence of current proactive maintenance plan that assure the efficient operation of the building (BRE, 2015; GBC Indonesia, 2011). Points are awarded adopting BREEAM assessment as shown Table 6.32. The EV and the MB buildings achieves four points in this sub-factor.

Table 6.32: Points Allocation for Maintenance Policy (BRE, 2015)

Assessment Criteria	Score
Existence of reactive policy only that reviewed more than 1 year ago	1 point
Existence of reactive policy only that reviewed within the last year	2 points
Existence of proactive policy that reviewed more than 1 year ago	3 points
Existence of proactive policy that reviewed within the last year	4 points

Finally, the fifth sub-factor comprises three aspects which are maintenance procedure, operation procedures, and operation and maintenance manuals. The first aspect examines the existence of maintenance procedure in place for building elements/services to ensure the sustainable operation of the building systems. One point is awarded for the existence of a maintenance procedure for each system (1) Building fabric, (2) HVAC systems, and (3) lighting system. Both case studies achieve three points. The second aspect evaluates the procedures used to control and minimize the building energy consumption. One point is awarded if an energy plan is in place, while two points are awarded if the first part exists in addition to availability of reduction measures are in place to decrease the energy consumption. The third aspect ensures the existence of operation and maintenance manuals available for the building facility management. One point is available for this aspect. Both buildings fulfil the second and the third aspect.

The second factor includes two sub-factors which are security measures and intruder alarm. The first sub-factor evaluates the detection of minor, major defects, and all defects are rectified. Three points are allocated for this sub-factor. The second sub-factor determines the availability of a suitable mean to guard the asset to prevent expected damage. One point is awarded for the availability of security alarm or personal surveillance 24 hours (BRE, 2015). Both case studies scored the four points of this factor.

The third factor assures the implementation of lease agreements that contain incentives to engage tenants to consider energy, water, and waste efficient practices. These practices are: energy efficiency targets, tenant handbook/Environmental policy/Energy management plan data, reporting, improvements, financial incentives (BCA, 2012b; BRE, 2015; GBC Indonesia, 2011). One point is awarded if the green lease agreements/contracts with tenants contains qualitative targets, and two pints if contains both quantitative and qualitative targets. The EV and the MB buildings is not subjected to lease agreement as they are educational buildings.

The fourth factor comprises two sub-factors: *fire risk management* and *natural hazard management*. The first sub-factor embraces two aspects which are fire risk assessment and fire risk manager. The first aspect evaluates the procedures that identifies fire risks to the building and actions that should be taken to keep these risks as minimum as possible. The second aspect determine the presence of a fire risk manager or staff which can monitor, manage and initiate reviews. Each of the two aspects has one point as a maximum score. Both case studies scored one point for the existence of fire risk assessment. The second sub-factor evaluates the presence of a policy which reduces the risk of damage to the property and the environment arise from natural hazards. One point is allocated for this sub-factor and both buildings fulfilled it.

The fifth factor tackles two sub-factors which are innovations in techniques and performance enhancement. The first sub-factor distinguishes the application of new practices, technologies and techniques and the associated enhancement to sustainable living, energy use, materials use, improved comfort, reduced pollution (BRE, 2015; GBC Indonesia, 2011; HK GBC, 2012; USGBC, 2009). The second one estimates the procedures that achieve a performance enhancement that exceeds the requirements of existing rating system credits. One point is awarded for each sub-factor. The EV building failed to achieve any sub-factor while the MB building achieved one point for the first sub-factor due to the existence of some innovative sustainable procedures such as existence of solar panels and green roofs.

6.7 Sustainability Assessment Model Output

The score of each sub-factor was determined based on 1) the collected data of the two case studies, 2) the output of the BIM model and the energy simulations, and 3) utilizing the equations mentioned above in the score determination section. The whole assessment process and the scores for each factor and its sustainability index are illustrated in Table 6 and Table 7. These tables represent the sustainability index determination for the EV (1st case study) and the MB (2nd case study) based on the Canadian and the Egyptian weight respectively. Each table comprises six sections which are 1) the sustainability assessment attribute description, 2) the local and the global weight determination, 3) the score determination for each factor for the EV and the MB buildings assessment, 4) the sustainability index of each factor, 5) the BSI of the two case studies, and 6) the BSAR of the two case studies. Furthermore, in each case study, the score and the sustainability index of each factor are subdivided into achieved and maximum sections; the achieved scores and indices are the current assessment of the building while the maximum ones represent 100% of points are awarded for each factor as shown in Table 6.33 and Table 6.34.

The assessment of the sustainability of buildings undergoes four steps. The first step is the factor score (SC) determination by utilizing equation (3.2). The second step is the evaluation of the sustainability index of each factor (SI) by applying equation (3.3), therefore, the achieved and the maximum sustainability index $(SI)_{max}$ of the site management factor in the canadian case is 0.113 and 0.135 respectively as shown in Table 6.33. Moreover, the third step is the evaluation of the BSI and the BSI_{max} using equation (3.4), these values for the EV building for the Canadian case are 5.762 and 11.227 respectively. Finally, the fourth step is determining the BSAR which is the percentage of the BSI to the BSI_{max} as illustrated in equation (3.6) indices. The BSAR for the EV and the MB buildings for Canadian case are 51.23% and 59.73% respectively as shown in Table 6.33, while these values in the Egyptian case are 61.69% and 68.50% respectively as shown in Table 6.34. Accordingly, the EV building in the Canadian scenario and the Egyptian scenario achieved the sustainability ranking pass and good respectively as shown in Table 6.33. All the assessment attributes in both scenarios, except for energy criterion, have the same achieved points but they have different indices dependent on the weight variations. Consequently, as shown in Figure 6.19, the criteria sustainability index ratio, excluding energy criterion, in the EV Canadian scenario are 42%, 86%, 42%, 60%, 60% and 73%, while for the EV Egyptian scenario are 54%, 89%, 43%, 55%, 59%, and 73%. Furthermore, the criteria sustainability index ratio for the MB building in the Canadian and the Egyptian scenarios varies even though the same data are used and the same points achieved, except in energy criterion. The criteria sustainability index ratio of the criteria of MB Canadian scenario are 60%, 86%, 50%, 67%, 60%, and 88% respectively, while the corresponding values for the MB Egyptian cases are 72%, 89%, 53%, 61%, 59%, and 88% as illustrated in Figure 6.19.

Moreover, the energy data in two case studies in both the Canadian and the Egyptian scenarios differs according to the variation in energy performance of the building due to the environmental difference between the two countries. The Environmental variations affect the energy demand, the energy consumption, and the base line bench marks of energy consumption. Hence, the energy scores are achieved according to the percentage of consumption conservation more than the baseline bench mark.

Table 6.33: Sustainability Index Determination - Canada Case Studies

Criterion Name	Criterion Weight (W)	Factors	Weight local (WL)	Weight global (WG)	EV Building				MB Building			
					Achieved score (SC)	Maximum Score (SC)$_{max}$	Factor Index (SI)	Maximum Factor Index) SI)$_{max}$	Achieved score (SC)	Maximum Score (SC)$_{max}$	Factor Index (SI)	Maximum Factor Index) SI)$_{max}$
Site and Ecology	**0.099**	Site Selection	0.191	0.019	1	2	0.019	0.038	2	2	0.038	0.038
		Site Management	0.228	0.023	5	6	0.113	0.135	5	6	0.113	0.135
		Reduce Heat island effect	0.362	0.036	1	8	0.036	0.287	3	8	0.108	0.287
		Site Emissions	0.218	0.022	2	2	0.043	0.043	2	2	0.043	0.043
		Total	**-**	**0.099**	**9**	**18**	**0.211**	**0.503**	**12**	**18**	**0.301**	**0.503**
Transport	**0.123**	alternative methods of transport	0.301	0.037	14	18	0.518	0.666	14	18	0.518	0.666
		Public transport accessibility	0.282	0.035	10	10	0.347	0.347	10	10	0.347	0.347
		maximum car parking capacity	0.098	0.012	1	1	0.012	0.012	1	1	0.012	0.012
		Provision of Fuel efficient vehicles	0.318	0.039	1	1	0.039	0.039	1	1	0.039	0.039
		Total	**-**	**0.123**	**26**	**30**	**0.916**	**1.064**	**26**	**30**	**0.916**	**1.064**
Energy	**0.220**	Energy Performance	0.413	0.091	7	28	0.636	2.544	9	28	0.818	2.544
		Provision of energy management	0.146	0.032	8	12	0.257	0.385	8	12	0.257	0.385
		Energy efficient systems	0.252	0.055	5	17	0.277	0.942	10	17	0.554	0.942
		Energy efficient equipment	0.189	0.042	11	11	0.457	0.457	11	11	0.457	0.457
		Total	**-**	**0.220**	**31**	**68**	**1.628**	**4.329**	**38**	**68**	**2.086**	**4.329**
Water	**0.117**	Water Use	0.406	0.048	10	18	0.475	0.855	13	18	0.618	0.855
		Water Management	0.467	0.055	5	17	0.273	0.929	5	17	0.273	0.929
		Effluent discharge in foul sewer	0.127	0.015	0	1	0.000	0.015	1	1	0.015	0.015
		Total	**-**	**0.117**	**15**	**46**	**0.748**	**1.799**	**19**	**46**	**0.906**	**1.799**
Material	**0.118**	Sustainable Purchasing Policy	0.406	0.048	1	5	0.015	0.076	1	5	0.015	0.076
		Efficient Use of Materials	0.467	0.055	5	7	0.300	0.420	6	7	0.360	0.420
		Solid Waste Management Practice	0.127	0.015	5	9	0.214	0.386	5	9	0.214	0.386
		Total	**-**	**0.118**	**11**	**21**	**0.529**	**0.881**	**12**	**21**	**0.589**	**0.881**
Indoor Environmental Quality	**0.167**	Visual Comfort	0.119	0.020	6	9	0.119	0.179	6	9	0.119	0.179
		Indoor Air Quality	0.271	0.045	10	17	0.453	0.769	10	17	0.453	0.769
		Thermal comfort	0.236	0.039	4	5	0.158	0.197	4	5	0.158	0.197
		Acoustic Performance	0.125	0.021	3	3	0.063	0.063	3	3	0.063	0.063
		Hygiene	0.181	0.030	3	9	0.091	0.272	3	9	0.091	0.272

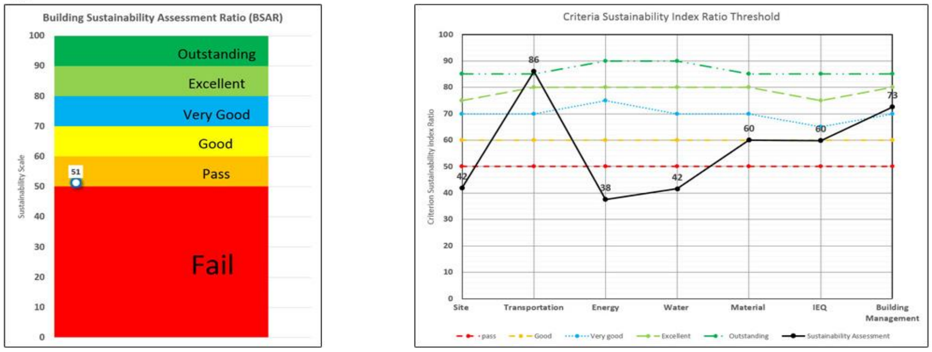
Criterion Name	Criterion Weight (W)	Factors	Weight local (WL)	Weight global (WG)	EV Building				MB Building			
					Achieved score (SC)	Maximum Score $(SC)_{max}$	Factor Index (SI)	Maximum Factor Index $) SI)_{max}$	Achieved score (SC)	Maximum Score $(SC)_{max}$	Factor Index (SI)	Maximum Factor Index $) SI)_{max}$
		Building amenities	0.069	0.012	2	3	0.023	0.035	2	3	0.023	0.035
		Total	**-**	**0.167**	**28**	**46**	**0.906**	**1.515**	**28**	**46**	**0.906**	**1.515**
Building Management	**0.156**	Operation & maintenance	0.320	0.050	12	17	0.599	0.849	15	17	0.749	0.849
		Security Measures	0.130	0.020	4	4	0.081	0.081	4	4	0.081	0.081
		Green Lease	0.180	0.028	1	2	0.028	0.056	2	2	0.056	0.056
		Risk Management	0.180	0.028	2	3	0.068	0.102	2	3	0.068	0.102
		Innovations	0.152	0.024	2	2	0.047	0.047	2	2	0.047	0.047
		Total	**-**	**0.156**	**21**	**28**	**0.824**	**1.136**	**25**	**28**	**1.002**	**1.136**
Total Sustainability Index (TSI)							**5.762**	**11.227**			**6.706**	**11.227**
Building Sustainability Assessment Ratio (BSAR)							**51.32**				**59.73**	

Table 6.34: Sustainability Index Determination – Egypt Case Studies

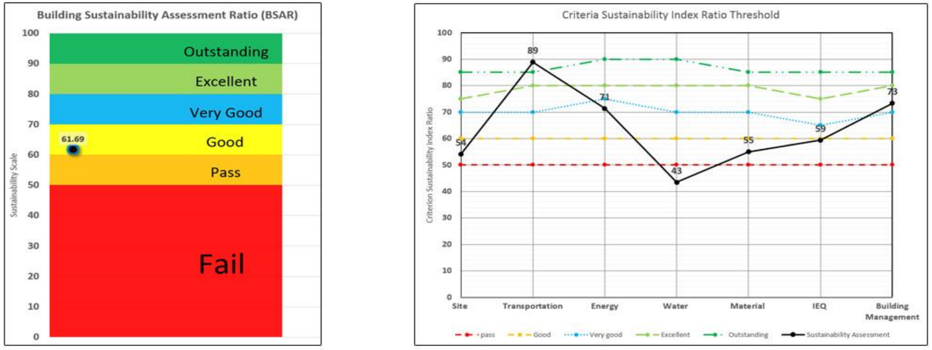
Criterion Name	Criterion Weight (W)	Factors	Weight local (WL)	Weight global (WG)	EV Building				MB Building			
					Achieved score (SC)	Maximum Score (SC)$_{max}$	Factor Index (SI)	Maximum Factor Index) SI)$_{max}$	Achieved score (SC)	Maximum Score (SC)$_{max}$	Factor Index (SI)	Maximum Factor Index) SI)$_{max}$
Site and Ecology	**0.191**	Site Selection	0.390	0.074	1	2	0.074	0.149	2	2	0.149	0.149
		Site Management	0.281	0.054	5	6	0.268	0.322	5	6	0.054	0.268
		Reduce Heat island effect	0.180	0.034	1	8	0.103	0.275	3	8	0.103	0.275
		Site Emissions	0.149	0.028	2	2	0.057	0.057	2	2	0.057	0.057
		Total	**-**	**0.191**	**9**	**18**	**0.434**	**0.803**	**12**	**18**	**0.577**	**0.803**
Transport	**0.077**	alternative methods of transport	0.174	0.013	14	18	0.188	0.241	14	18	0.188	0.241
		Public transport accessibility	0.255	0.020	10	10	0.196	0.196	10	10	0.196	0.196
		maximum car parking capacity	0.290	0.022	1	1	0.022	0.022	1	1	0.022	0.022
		Provision of Fuel efficient vehicles	0.280	0.022	1	1	0.022	0.022	1	1	0.022	0.022
		Total	**-**	**0.077**	**26**	**30**	**0.428**	**0.481**	**26**	**30**	**0.428**	**0.481**
Energy	**0.200**	Energy Performance	0.339	0.068	24	28	1.627	1.898	22	28	1.492	1.898
		Provision of energy management	0.195	0.039	8	12	0.312	0.468	8	12	0.312	0.468
		Energy efficient systems	0.264	0.053	5	17	0.264	0.898	10	17	0.528	0.898
		Energy efficient equipment	0.202	0.040	11	11	0.444	0.444	11	11	0.444	0.444
		Total	**-**	**0.200**	**48**	**68**	**2.648**	**3.708**	**51**	**68**	**2.776**	**3.708**
Water	**0.169**	Water Use	0.472	0.080	10	18	0.798	1.436	13	18	1.037	1.436
		Water Management	0.406	0.069	5	17	0.343	1.166	5	17	0.343	1.166
		Effluent discharge in foul sewer	0.123	0.021	0	1	0.000	0.021	1	1	0.021	0.021
		Total	**-**	**0.169**	**15**	**46**	**1.141**	**2.623**	**19**	**46**	**1.401**	**2.623**
Material	**0.080**	Sustainable Purchasing Policy	0.291	0.023	1	5	0.023	0.116	1	5	0.023	0.116
		Efficient Use of Materials	0.427	0.034	5	7	0.171	0.239	6	7	0.205	0.239
		Solid Waste Management Practice	0.281	0.022	5	9	0.112	0.202	5	9	0.112	0.202
		Total	**-**	**0.080**	**11**	**21**	**0.306**	**0.558**	**12**	**21**	**0.341**	**0.558**
Indoor Environmental Quality	**0.136**	Visual Comfort	0.14	0.019	6	9	0.114	0.171	6	9	0.114	0.171
		Indoor Air Quality	0.278	0.038	10	17	0.378	0.643	10	17	0.378	0.643
		Thermal comfort	0.205	0.028	4	5	0.112	0.139	4	5	0.112	0.139
		Acoustic Performance	0.085	0.012	3	3	0.035	0.035	3	3	0.035	0.035
		Hygiene	0.174	0.024	3	9	0.071	0.213	3	9	0.071	0.213
		Building amenities	0.117	0.016	2	3	0.032	0.048	2	3	0.032	0.048
		Total	**-**	**0.136**	**28**	**46**	**0.741**	**1.249**	**28**	**46**	**0.741**	**1.249**

Criterion Name	Criterion Weight (W)	Factors	Weight local (WL)	Weight global (WG)	EV Building				MB Building			
					Achieved score (SC)	Maximum Score $(SC)_{max}$	Factor Index (SI)	Maximum Factor Index $) SI)_{max}$	Achieved score (SC)	Maximum Score $(SC)_{max}$	Factor Index (SI)	Maximum Factor Index $) SI)_{max}$
Building Management	**0.147**	Operation & maintenance	0.281	0.041	12	17	0.496	0.702	15	17	0.620	0.702
		Security Measures	0.139	0.020	4	4	0.082	0.082	4	4	0.082	0.082
		Green Lease	0.154	0.023	1	2	0.023	0.045	2	2	0.045	0.045
		Risk Management	0.239	0.035	2	3	0.070	0.105	2	3	0.070	0.105
		Innovations	0.187	0.027	2	2	0.055	0.055	2	2	0.055	0.055
		Total	**-**	**0.147**	**21**	**28**	**0.725**	**0.990**	**25**	**28**	**0.872**	**0.990**
Total Sustainability Index (TSI)							**6.423**	**10.412**			**7.136**	**10.412**
Building Sustainability Assessment Ratio (BSAR)							**61.69**				**68.5**	

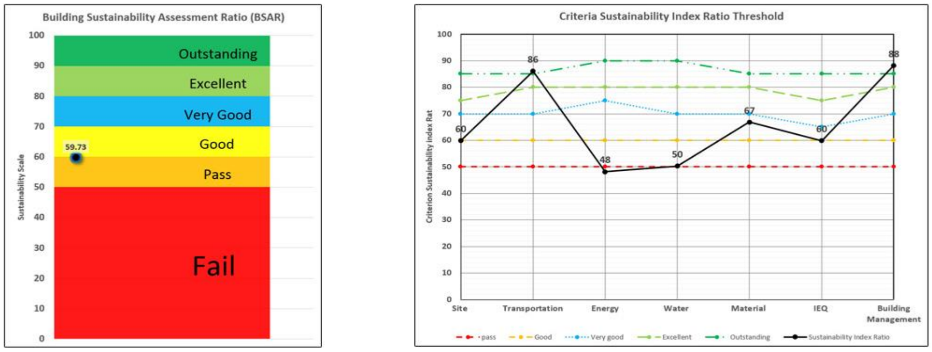
a) EV Building Canada Case



b) EV Building Egypt Case



c) MB Building Canada Case



d) MB Building Egypt Case

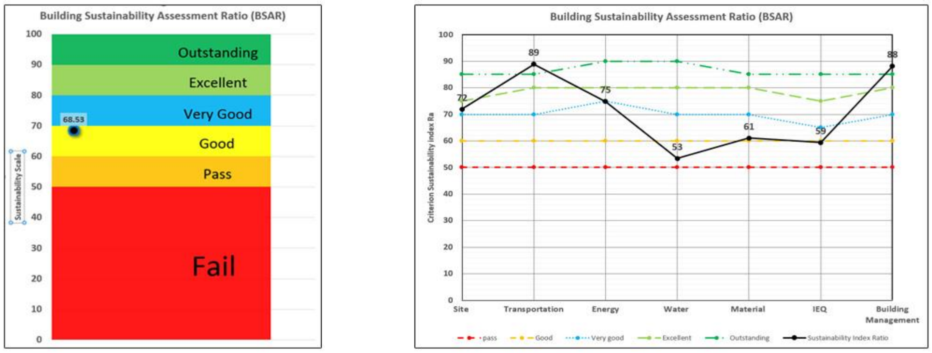


Figure 6.19: Criteria Sustainability Index Ratio and the Sustainability Ranking for EV And MB Buildings-Case of Canada and Egypt Contexts

6.8 Sustainability-Based Rehabilitation Model Output

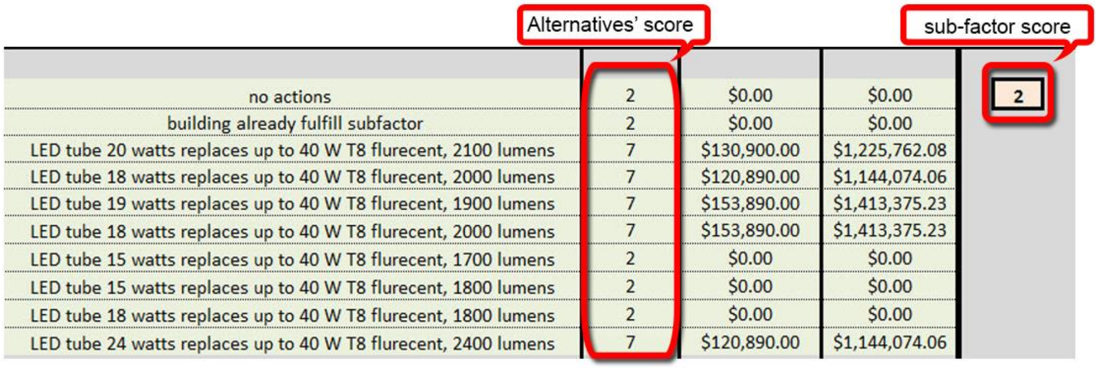
The sustainability-based rehabilitation model is implemented to provide the decision variables with different sets of alternatives that can upgrade the sustainability of the building within the minimal LCC. The optimization model also provides the decision makers with diverse of non-dominated solutions; for example, the solution x is non-dominated by the solution y, if solution y is not better than the solution x in all the objectives. Therefore, the output of the model guarantees that the determined solutions are the best solutions with respect to all objectives. The optimization process is based on the decision variables scores and LCC determination and will be illustrated in the following sub-sections.

6.8.1 Decision Variables

There are two groups of decision variables in the optimization model which are 1) qualitative decision variables, and 2) quantitative decision variables. The qualitative decision variables are corresponding to the sub-factors which are assessed according to availability of certain plans, procedures, or manuals; they have no LCC to be introduced for upgrade. Contrarily, the quantitative decision variables are related to the sub-factors that are based on going beyond or above certain threshold. Determining the score for these decision variables is based on specific equations as illustrated in CHAPTER 3. Moreover, these quantitative decision variables require adding or introducing new elements to the building that are accompanied with increase in capital cost and in turn more LCC is added.

6.8.2 Alternative Score and LCC Determination

Each decision variable comprises several alternatives as illustrated in CHAPTER 4. The determining procedures of the score of each alternative is the same as the score determination of its corresponding sub-factor. There are two scenarios for an alternative score; 1) the alternative score is greater than the achieved score of the corresponding sub-factor, and 2) the alternative score is lower than its corresponding sub-factor. In the first scenario, the score of the alternative is introduced as achieved, while in the other scenario the alternative takes the score of the corresponding sub-factor and the LCC of the alternative is zero as it is considered to have no impact on upgrading the sustainability of the building as shown in Figure 6.20. The rationale for this procedure is to force the optimization process in Matlab to select the alternatives of higher or equal score compared with the already achieved score by the corresponding sub-factor by setting the boundaries of the alternatives' score to be higher or equal to the achieved score. Also, another reason for this process is to decrease the computation time in the optimization process which is consumed in checking feasibility and non-feasibility of each sub factor when constraints are introduced to the score.



no actions	2	$0.00	$0.00	2
building already fulfill subfactor	2	$0.00	$0.00	
LED tube 20 watts replaces up to 40 W T8 flurecent, 2100 lumens	7	$130,900.00	$1,225,762.08	
LED tube 18 watts replaces up to 40 W T8 flurecent, 2000 lumens	7	$120,890.00	$1,144,074.06	
LED tube 19 watts replaces up to 40 W T8 flurecent, 1900 lumens	7	$153,890.00	$1,413,375.23	
LED tube 18 watts replaces up to 40 W T8 flurecent, 2000 lumens	7	$153,890.00	$1,413,375.23	
LED tube 15 watts replaces up to 40 W T8 flurecent, 1700 lumens	2	$0.00	$0.00	
LED tube 15 watts replaces up to 40 W T8 flurecent, 1800 lumens	2	$0.00	$0.00	
LED tube 18 watts replaces up to 40 W T8 flurecent, 1800 lumens	2	$0.00	$0.00	
LED tube 24 watts replaces up to 40 W T8 flurecent, 2400 lumens	7	$120,890.00	$1,144,074.06	

Figure 6.20: Score Determination of Alternatives

6.8.3 *The Model Output*

The optimization process was performed six times with different settings to stand for the impact of these setting on the output of the optimization results. These tests are divided into two groups:

1) maximum iteration number change and 2) population number change. The maximum iteration number change group test was based on changing the number of iterations from 100 to 200 iterations with an increment increase 50 iterations, while keeping the population number (Np) fixed at a value of 100 Np. Further, the population number change group test was dependent on changing the Np each run ranging from 100 to 400 with an increment increase of 100 Np per run. The purpose of these trials was to distinguish which variable will have better impact on the optimization results.

The final optimal or near optimal solutions of each trial are demonstrated in Figure 6.21 a, b, c, d, e, and f as a Pareto frontier. From this figure, it can be seen that the more solutions were explored and introduced, especially for BSAR > 90%, when increasing the number of iteration as the case in Figure 6.21c, or when increasing the number of Np as in Figure 6.21 d, e, and f. Moreover, when the six Pareto frontiers a combined in Figure 6.22, the fifth and the sixth runs (i.e. 300_Np/100_iteration and 400_Np/ 100_iteration respectively) achieve better results than the other runs which they tend to reach the true Pareto; in other words, the solutions of the fifth and sixth runs dominates most of the solutions of the other runs.

As discussed previously in the literature review chapter, the result of multi-objective optimization in a run (from 1st to maximum iteration) is a group of non-dominated optimal or near optimal solutions or trade-offs, which shows the impact of a change in one objective on the other. This opportunity provides the decision maker with many trade-offs to select from. Moreover, each solution consists of the selected alternatives of each decision variable for the previously mentioned tests each solution in each test comprises 134 different decision variables, which achieves the illustrated BSAR and LCC in Table 6.35. For the group of iteration number change, the third test

(100_Np/ 200_iteration) performs better than the other two tests of lower number of iterations; such that in the BSAR level greater than 70%, it achieves BSAR of 79.75% for a LCC $49,399, and for the BSAR level greater than 80%, this test achieves BSAR of 88.71% for a $3,429,660. Also, the third test was able to find a solution for the level of BSAR greater than 90%. Furthermore, in the second group which is the increase of population number, when Np increased to 400 in the sixth test it performs better than the previous tests in most of the solutions except for the BSAR level greater than 70% as shown in Table 6.35. In the BSAR level greater than 80%, the sixth test achieves a BSAR of 89.97% for LCC $4,940,688.

In this research, a new terminology was introduced, which is the cost sustainability ratio (CSR) that represents the unit cost of one sustainability score obtained in each solution. The benefit of each the CSR to make the comparison between the solutions much easier and to let the decision makers easily distinguish which solution is worth the dedicated budget to achieve a certain level of BSAR. As shown in Table 6.36, especially in the BSAR level greater than 80%, the results can be easily compared, for example, to the last solution in the sixth test, which is the highest in BSAR value 89.97%. However, its corresponding CSR is $54,911, while in the sixth solution of BSAR value 88.61% and the corresponding CSR is $30,523 it seems to be more economic than the previous solution of higher BSAR. That is because nearly one percent as a difference between the two solutions in the same level will cost nearly CSR of $24,000, which is unworthy. So, this terminology is an easy way to compare and analyse the solutions to detect which is more economical solution to apply rather than comparing the large numbers as in Table 6.36.

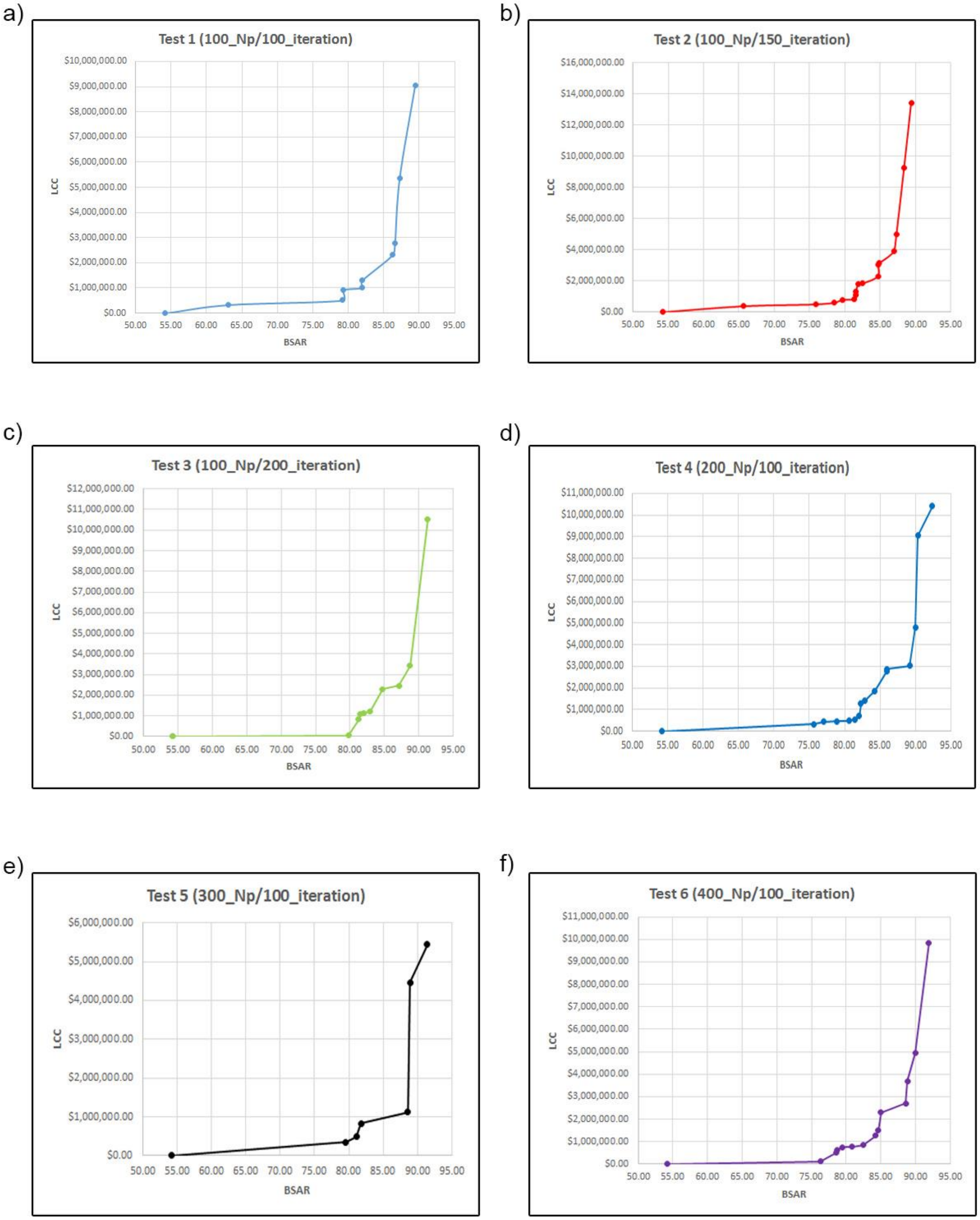


Figure 6.21: The Near Optimal Pareto Frontier of the Performed Test

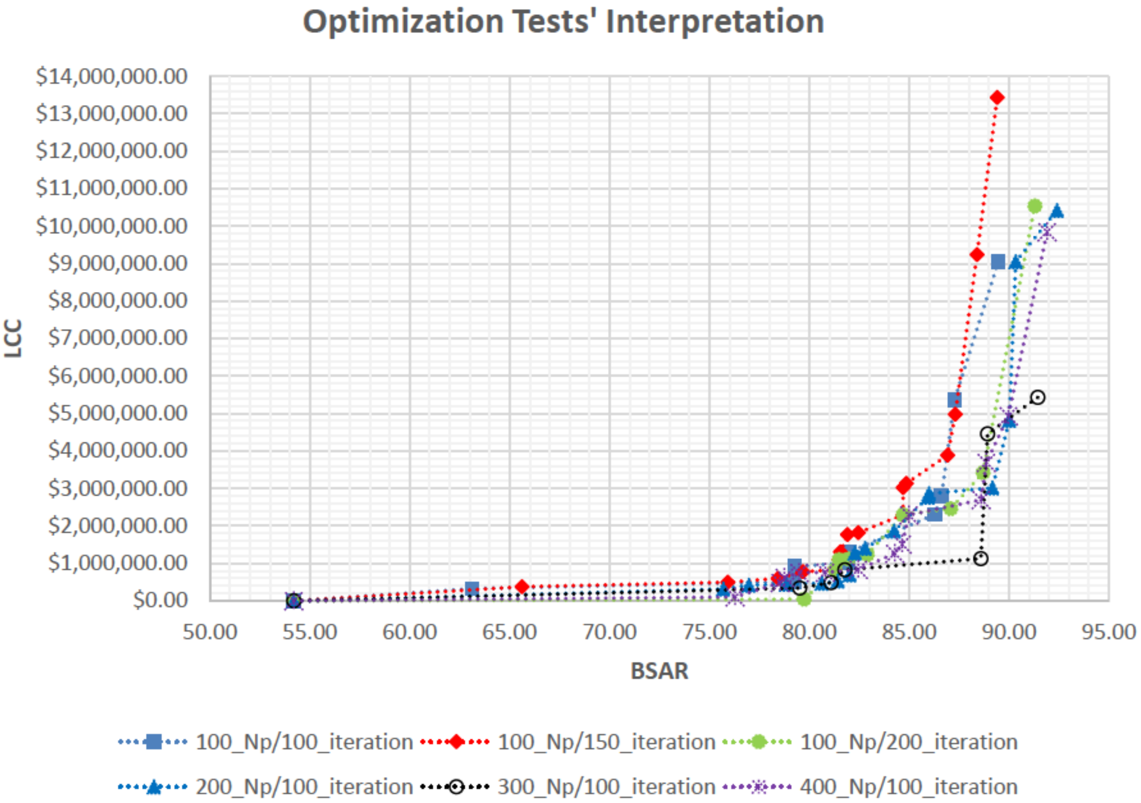


Figure 6.22: Overlapping of Six Pareto Frontiers

Table 6.35: BSAR And LCC of Each Solution for Each Test

Serial	100_Np/100_ iteration		100_Np/150_ iteration		100_Np/200_ iteration		200_Np/100_ iteration		300_Np/100_ iteration		400_Np/100_ iteration	
	BSAR	**LCC**	**BSAR**	**LCC**	**BSAR**	**LCC**	**BSAR**	**LCC**	**BSAR**	**LCC**	**BSAR**	**LCC**
1	54.20	$0	54.20	$0	54.20	$0	54.20	$0	54.20	$0	54.20	$0
2	-	-	-	-	54.20	$0	-	-	-	-	-	-
	60 ≤ BSAR < 70											
3	63.13	$330,995	65.62	$381,522								
	70 ≤ BSAR < 80											
4	79.23	$511,805	75.92	$502,111	79.75	$49,399	75.70	$315,842	79.54	$346,523	76.29	$106,889
5	79.27	$913,598	78.44	$603,295	-	-	76.99	$424,839	-	-	78.56	$490,890
6	-	-	79.70	$783,034	-	-	78.85	$449,576	-	-	78.75	$629,240
7	-	-	-	-	-	-	-	-	-	-	79.50	$750,128
	80 ≤ BSAR < 90											
8	81.96	$1,015,725	81.29	$832,975	81.29	$832,975	80.63	$473,855	81.10	$486,444	80.81	$763,629
9	81.99	$1,300,420	81.50	$1,107,420	81.50	$1,107,420	81.44	$532,389	81.78	$827,329	82.45	$837,479
10	86.27	$2,309,588	81.56	$1,305,831	81.98	$1,122,775	82.04	$691,529	88.59	$1,128,310	84.28	$1,270,015
11	86.63	$2,794,994	81.92	$1,767,575	82.91	$1,233,175	82.28	$1,278,351	88.93	$4,464,617	84.65	$1,512,364
12	87.28	$5,368,064	82.46	$1,824,519	84.70	$2,295,972	82.79	$1,402,988	-	-	84.99	$2,291,005
13	89.47	$9,046,248	84.70	$2,295,972	87.09	$2,459,501	84.25	$1,862,483	-	-	88.61	$2,704,577
14	-	-	84.71	$3,024,680	88.71	$3,429,660	85.96	$2,772,744	-	-	88.86	$3,696,088
15	-	-	84.86	$3,136,203	-	-	86.00	$2,863,311	-	-	89.97	$4,940,688
16	-	-	86.93	$3,891,827	-	-	89.18	$3,017,383	-	-	-	-
17	-	-	87.32	$4,979,179	-	-	-	-	-	-	-	-
18	-	-	88.40	$9,245,212	-	-	-	-	-	-	-	-
19	-	-	89.42	$13,440,138	-	-	-	-	-	-	-	-
	90 ≤ BSAR ≤ 100											
20	-	-	-	-	91.30	$10,540,158	90.02	$4,818,736	91.45	$5,434,199	91.91	$9,850,875
21	-	-	-	-	-	-	90.35	$9,057,575	-	-	-	-
22	-	-	-	-	-	-	92.40	$10,425,095	-	-	-	-

Table 6.36: BSAR And CSR of Each Solution for Each Test

Serial	100_Np/100_ iteration		100_Np/150_ iteration		100_Np/200_ iteration		200_Np/100_ iteration		300_Np/100_ iteration		400_Np/100_ iteration	
	BSAR	**CSR**	**BSAR**	**CSR**	**BSAR**	**CSR**	**BSAR**	**CSR**	**BSAR**	**CSR**	**BSAR**	**CSR**
1	54.20		54.20	$0	54.20	$0	54.20	$0	54.20	$0	54.20	$0
2	-	-	-	-	54.20	$0	-	-	-	-	-	-
	60 ≤ BSAR < 70											
3	5243.3	$5,243	65.62	$5,814	-	-	-	-	-	-	-	-
	70 ≤ BSAR < 80											
4	79.23	$6,459	75.92	$6,613	79.75	$619	75.70	$4,172	79.54	$4,356	76.29	$1,401
5	79.27	$11,525	78.44	$7,691	-	-	76.99	$5,518	-	-	78.56	$6,248
6	-	-	79.70	$9,825	-	-	78.85	$5,701	-	-	78.75	$7,990
7	-	-	-	-	-	-	-	-	-	-	79.50	$9,4355
	80 ≤ BSAR < 90											
8	81.96	$12,393	81.29	$10,247	81.29	$10,247	80.63	$5,876	81.10	$5,998	80.81	$9,449
9	81.99	$15,860	81.50	$13,587	81.50	$13,587	81.44	$6,537	81.78	$10,116	82.45	$10,156
10	86.27	$26,772	81.56	$16,009	81.98	$13,695	82.04	$8,429	88.59	$12,735	84.28	$15,068
11	86.63	$32,264	81.92	$21,576	82.91	$14,873	82.28	$15,535	88.93	$50,203	84.65	$17,865
12	87.28	$61,500	82.46	$22,124	84.70	$27,106	82.79	$16,945	-	-	84.99	$26,954
13	89.47	$101,113	84.70	$27,106	87.09	$28,241	84.25	$22,106	-	-	88.61	$30,523
14	-	-	84.71	$35,705	88.71	$38,663	85.96	$32,256	-	-	88.86	$41,593
15	-	-	84.86	$36,955	-	-	86.00	$33,294	-	-	89.97	$54,911
16	-	-	86.93	$44,770	-	-	89.18	$33,836	-	-	-	-
17	-	-	87.32	$57,024	-	-	-	-	-	-	-	-
18	-	-	88.40	$104,580	-	-	-	-	-	-	-	-
19	-	-	89.42	$150,305	-	-	-	-	-	-	-	-
	90 ≤ BSAR ≤ 100											
20	-	-	-	-	91.30	$115,448	90.02	$53,527	91.45	$59,423	91.91	$107,175
21	-	-	-	-	-	-	90.35	$100,255	-	-	-	-
22	-	-	-	-	-	-	92.40	$112,820	-	-	-	-

6.9 Summary

This chapter tackles the developed models' implementations through different sections. The first section is the weight determination in which it describes the procedures that were followed to determine the final values. It started with the data reliability, which checks the consistency of the collected data from questionnaires. These questionnaires were divided into two groups: Egypt and Canada questionnaires. Then, the membership function and the fuzzy numbers were identified and the procedures of fuzzification and defuzzification were demonstrated showing the final values of weights for each criterion and factor for both Egyptian and Canadian case.

Moreover, the sustainability scare determination procedures were illustrated, which were based on questionnaire and comparative analysis of some widely-used rating tools. Also, the procedures and the data output were shown for each of the BIM models and the energy simulation models for the two case studies which are the EV and the MB buildings of Concordia University were are in Montreal, Canada. Further, the procedures of determining the score of each factor were illustrated in detail; also, the sustainability assessment output were shown for the two case studies in two local contexts which were Montreal, Canada and Cairo, Egypt. The output illustrates the impact of the local context of each country and how they affect the weight and BSAR values as well.

The final part is the implementation of the sustainability based rehabilitation model, which illustrated the decision variables and their representations. The alternatives score and LCC determination were shown. Finally, the optimization output of the model was demonstrated through different tests showing the influence of the change in the number of iterations and the number of populations on the results output.

CHAPTER 7: AN AUTOMATED TOOL (ISART)

7.1 Introduction:

This chapter demonstrates the development and the key features of the **I**ntegrated **S**ustainability **A**ssessment and **R**ehabilitation **T**ool (ISART). The development of this tool is based on the sustainability assessment model and sustainability-based rehabilitation model previously illustrated in Chapters 3 and 4. The main aim for this tool is to allow the decision-maker to: 1) assess the current sustainability of their building; 2) provide statistical charts related to the determined sustainability of the building; and 3) provide an illustrative set of alternatives, including a detailed description of their decision variables to upgrade the sustainability of their buildings with minimal LCC. This chapter is comprised of five parts: 1) tool technical features; 2) graphical user interface; 3) sustainability assessment process; 4) optimization process; and 5) results display.

7.2 ISART Main Features

ISART is a standalone tool that is programmed utilizing visual basic.net. The tool integrates Excel and Matlab software used in data entry, sustainability assessment and optimization processing. The tool is divided into four tiers as follows:

1. **Data Entry**: This links the tool's user interface with the predeveloped spreadsheets, which allows the user to enter the project data required for the sustainability assessment and for the rehabilitation alternatives for each decision variable.

2. **Sustainability Assessment**: After data entry into the spreadsheets, the current sustainability is evaluated based on predefined equations and thresholds as illustrated in Chapter 6.
3. **Optimization Process**: The optimization is processed in Matlab based on the data entry for the rehabilitation alternatives in the first tier and on the prewritten AIS optimization code in Matlab.
4. **Output display**: This displays two sets of outputs: 1) the sustainability assessment, and 2) the optimization output.

The tool requires installation of Excel and Matlab software to navigate through the different tiers of the tool. In addition, it requires installation of Visual Basic.net software to run the main GUI of the automated tool.

7.3 ISART Graphical User interface GUI:

The tool's GUI allows the user to navigate through the features of the tool as illustrated in the previous section. The main window consists of three main groups as shown in Figure 7.1. The first is the data entry for the sustainability assessment. This process includes seven keys, which allow the user to access the predeveloped spreadsheets for each of the seven criteria: site and ecology, transportation, energy, water use, material and waste reduction, indoor environmental quality and building management. The second is the optimization process in which the user runs the optimization through Matlab. The third group is the output display for the sustainability assessment and optimization.

7.3.1 The Sustainability Assessment Process

The user can navigate through the seven assessment criteria and open the required Excel spreadsheet for data entry as shown in Figure 7.2. Each criterion spreadsheet includes its related factors and sub-factors names, navigation tabs, dropdown menus, calculation tables for each sub-factor and the achieved score for the sub-factor. There are two types of assessment attributes in each spreadsheet, which are a dropdown-menu attribute and a threshold-based attribute.

i. Dropdown menu attribute

For the dropdown menu attribute, a button is located beside to direct the user to the required menu as illustrated in Figure 7.3a. The score is determined depending on the selection of one of the features listed in the dropdown menu; each selection achieves a particular score as illustrated in Figure 7.4b and c.

ii. Threshold-based attribute

The threshold attribute is dependent on calculation tables that are related to predefined equations as illustrated in the score determination in Chapter 3. As demonstrated in Figure 7.4, the process of score calculation for the threshold attribute starts by selecting the "*Start Data Entry for Evaluation*" button as shown in section (a) of this figure. This button will lead to a calculation table that requires data entry from the user, followed by an automated calculation for a value, which is either percentage or quantity according to the type of the attribute as illustrated in Figure 7.4b. The obtained value is automatically compared with a predefined threshold to obtain the achieved score as shown in section (c). Finally, the score is determined automatically and demonstrated as well as a description statement that indicates whether the building fulfils the sub factor as shown in Figure 7.4d.

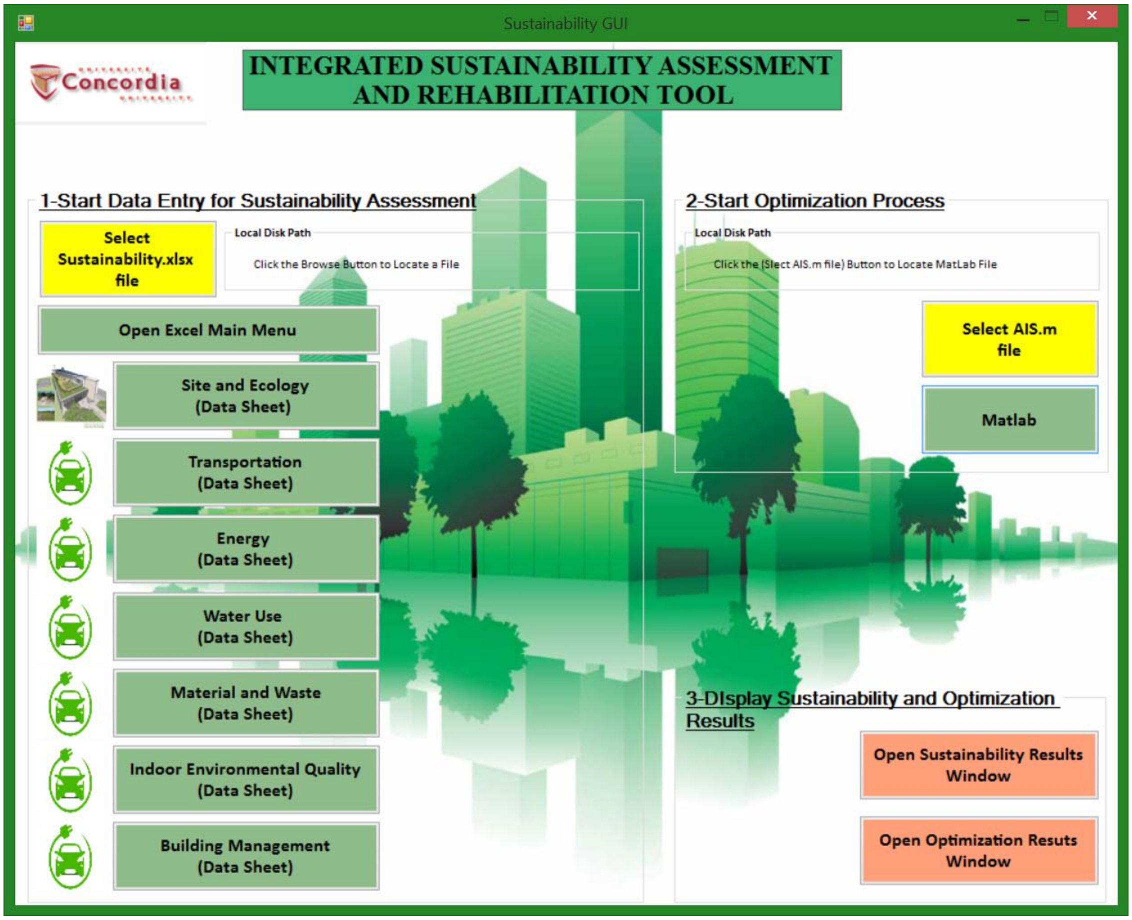
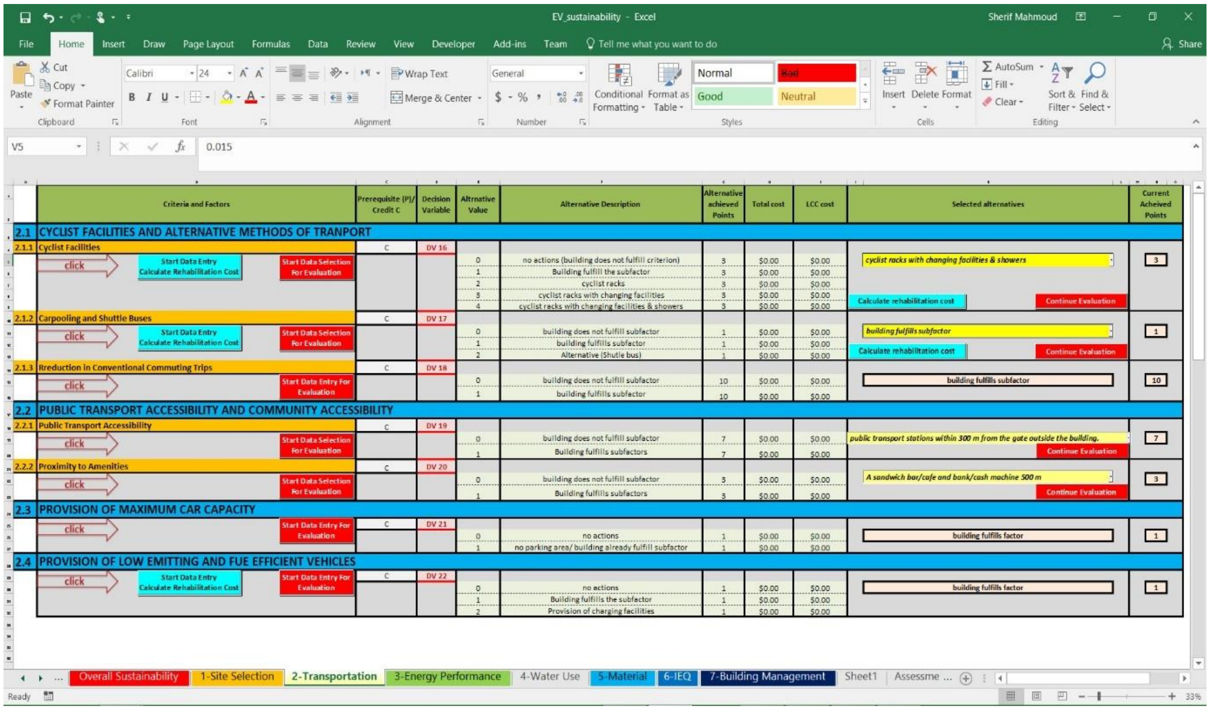


Figure 7.1: The First Navigation Window GUI



	Criteria and Factors	Prerequisite (P)/ Credit C	Decision Variable	Altrnative Value	Alternative Description	Alternative achieved Points	Total cost	LCC cost	Selected alternatives	Current Acheived Points
2.1	CYCLIST FACILITIES AND ALTERNATIVE METHODS OF TRANPORT									
2.1.1	Cyclist Facilities	C	DV 16	0	no actions (building does not fulfill criterion)	3	$0.00	$0.00	cyclist racks with changing facilities & showers	3
				1	Building fulfill the subfactor	3	$0.00	$0.00		
				2	cyclist racks	3	$0.00	$0.00		
				3	cyclist racks with changing facilities	3	$0.00	$0.00		
				4	cyclist racks with changing facilities & showers	3	$0.00	$0.00		
2.1.2	Carpooling and Shuttle Buses	C	DV 17	0	building does not fulfill subfactor	1	$0.00	$0.00	building fulfills subfactor	1
				1	building fulfills subfactor	1	$0.00	$0.00		
				2	Alternative (Shutle bus)	1	$0.00	$0.00		
2.1.3	Rreduction in Conventional Commuting Trips	C	DV 18	0	building does not fulfill subfactor	10	$0.00	$0.00	building fulfills subfactor	10
				1	building fulfills subfactor	10	$0.00	$0.00		
2.2	PUBLIC TRANSPORT ACCESSIBILITY AND COMMUNITY ACCESSIBILITY									
2.2.1	Public Transport Accessibility	C	DV 19	0	building does not fulfill subfactor	7	$0.00	$0.00	public transport stations within 300 m from the gate outside the building.	7
				1	Building fulfills subfactors	7	$0.00	$0.00		
2.2.2	Proximity to Amenities	C	DV 20	0	building does not fulfill subfactor	3	$0.00	$0.00	A sandwich bar/cafe and bank/cash machine 500 m	3
				1	Building fulfills subfactors	3	$0.00	$0.00		
2.3	PROVISION OF MAXIMUM CAR CAPACITY	C	DV 21	0	no actions	1	$0.00	$0.00	building fulfills factor	1
				1	no parking area/ building already fulfill subfactor	1	$0.00	$0.00		
2.4	PROVISION OF LOW EMITTING AND FUE EFFICIENT VEHICLES	C	DV 22	0	no actions	1	$0.00	$0.00	building fulfills factor	1
				1	Building fulfills the subfactor	1	$0.00	$0.00		
				2	Provision of charging facilities	1	$0.00	$0.00		

Figure 7.2: Criterion Data Entry Spreadsheet Main Window

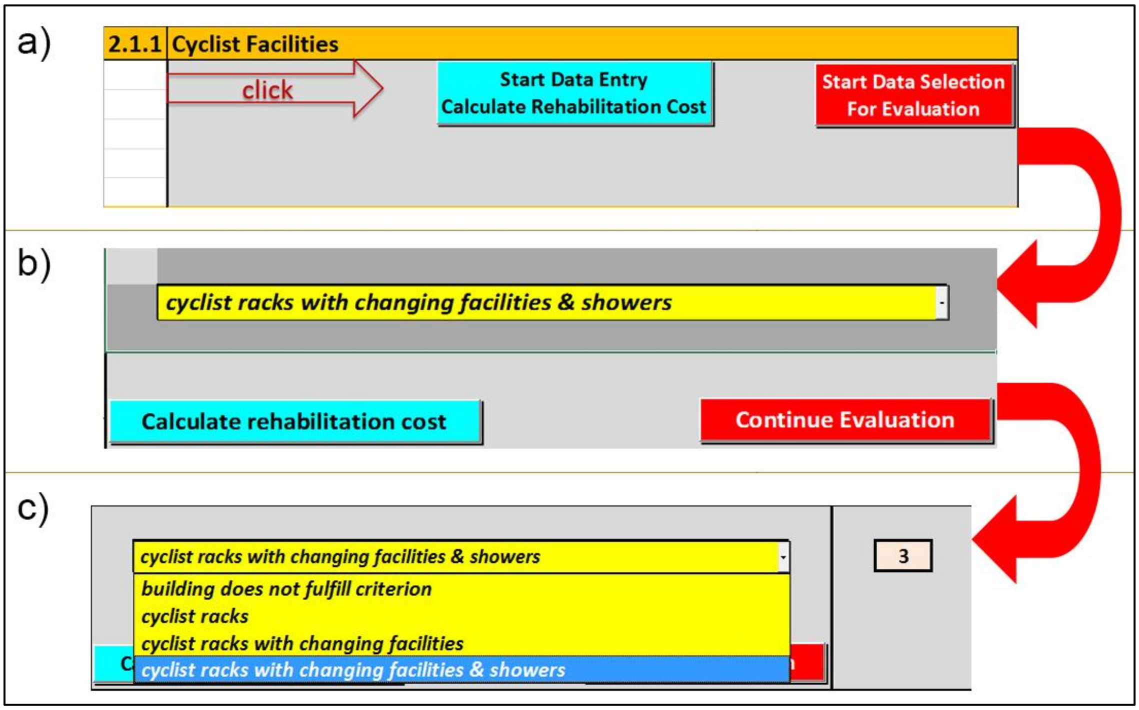


Figure 7.3: Dropdown Menu Attribute

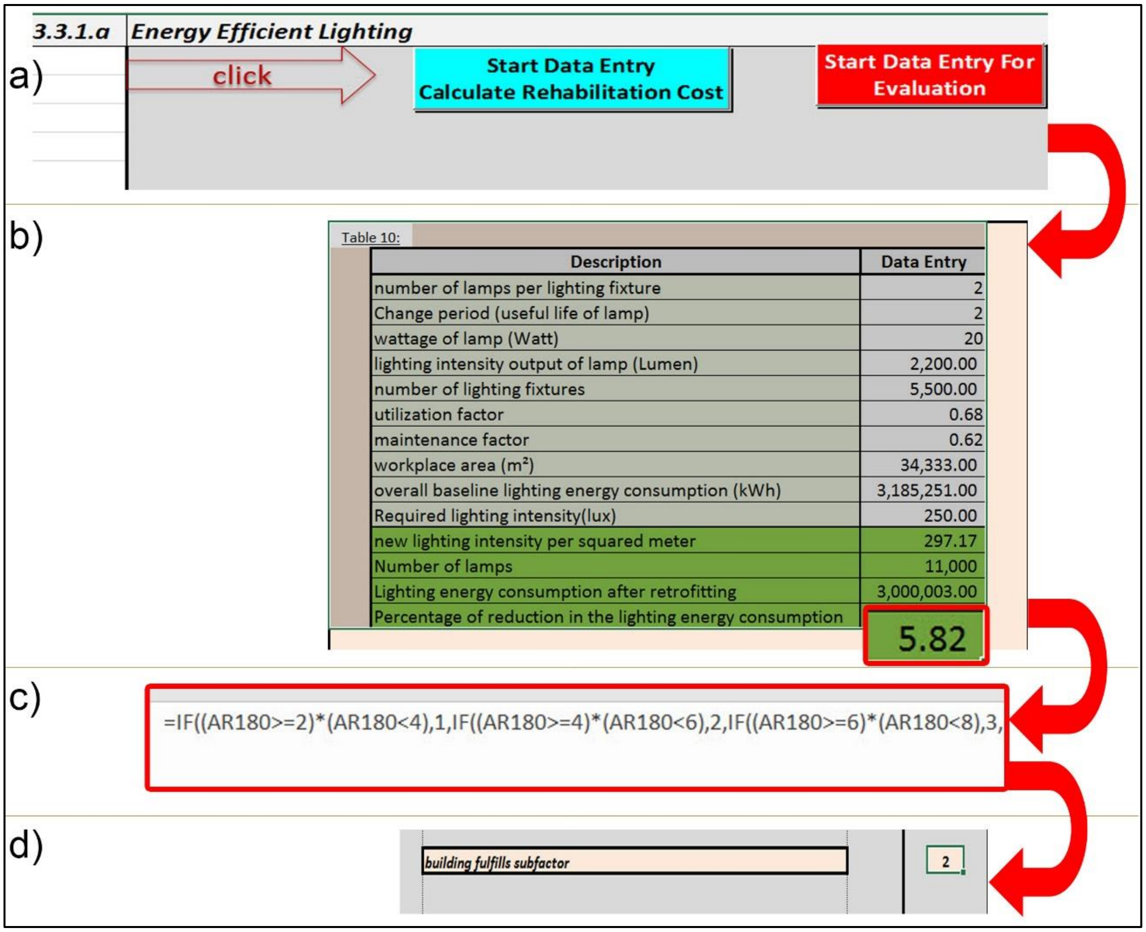


Table 10:

Description	Data Entry
number of lamps per lighting fixture	2
Change period (useful life of lamp)	2
wattage of lamp (Watt)	20
lighting intensity output of lamp (Lumen)	2,200.00
number of lighting fixtures	5,500.00
utilization factor	0.68
maintenance factor	0.62
workplace area (m²)	34,333.00
overall baseline lighting energy consumption (kWh)	3,185,251.00
Required lighting intensity(lux)	250.00
new lighting intensity per squared meter	297.17
Number of lamps	11,000
Lighting energy consumption after retrofitting	3,000,003.00
Percentage of reduction in the lighting energy consumption	5.82

```
=IF((AR180>=2)*(AR180<4),1,IF((AR180>=4)*(AR180<6),2,IF((AR180>=6)*(AR180<8),3,
```

building fulfills subfactor	2

Figure 7.4: Threshold Attribute

7.3.2 The Optimization Process

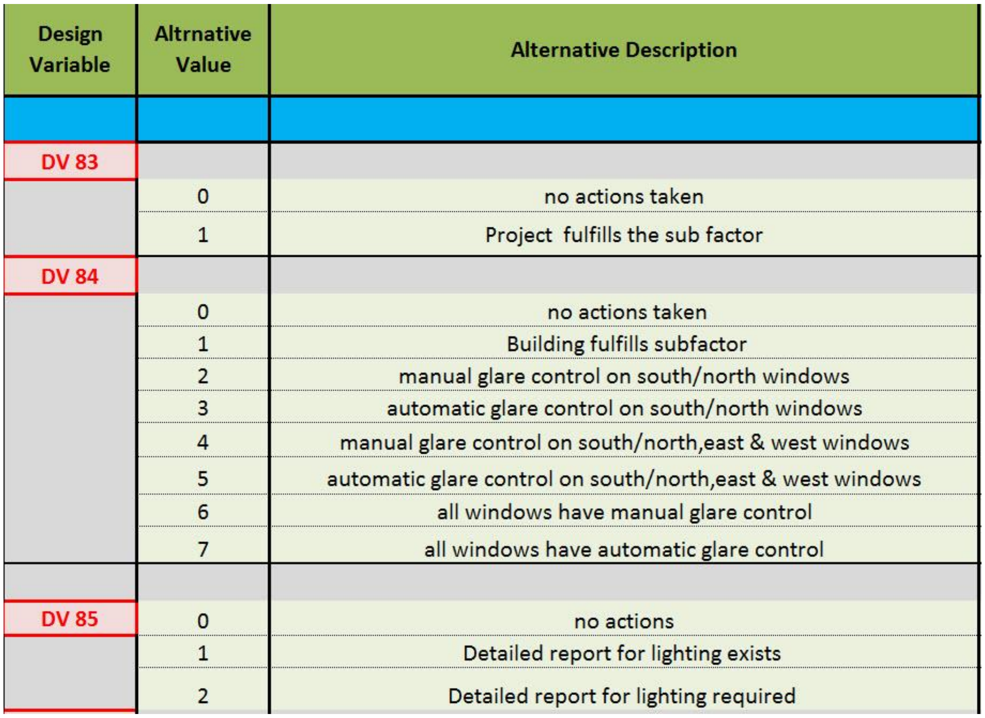
The optimization process in the tool passes through five stages: 1) the rehabilitation alternatives data entry; 2) the score and LCC evaluation for these alternatives; 3) Matlab reading process; 4) the optimization processing; and 5) exporting the optimal solutions to the Excel file. The first process is performed manually by means of the tool user in the predesigned spreadsheets, whereas the other four stages are performed automatically. The entire process will be explained below.

i. The rehabilitation alternatives data entry

There are 134 decision variables included in the optimization process covering the entire defined aspects of sustainability. Each decision variable consists of several sustainability-based rehabilitation alternatives, in which these alternatives vary from one decision variable to another as shown in Figure 7.5. A button is located beside each decision variable to direct the user to the calculation tables, which determine the achieved percentage or the quantity for each decision variable as shown in Figure 7.6a.

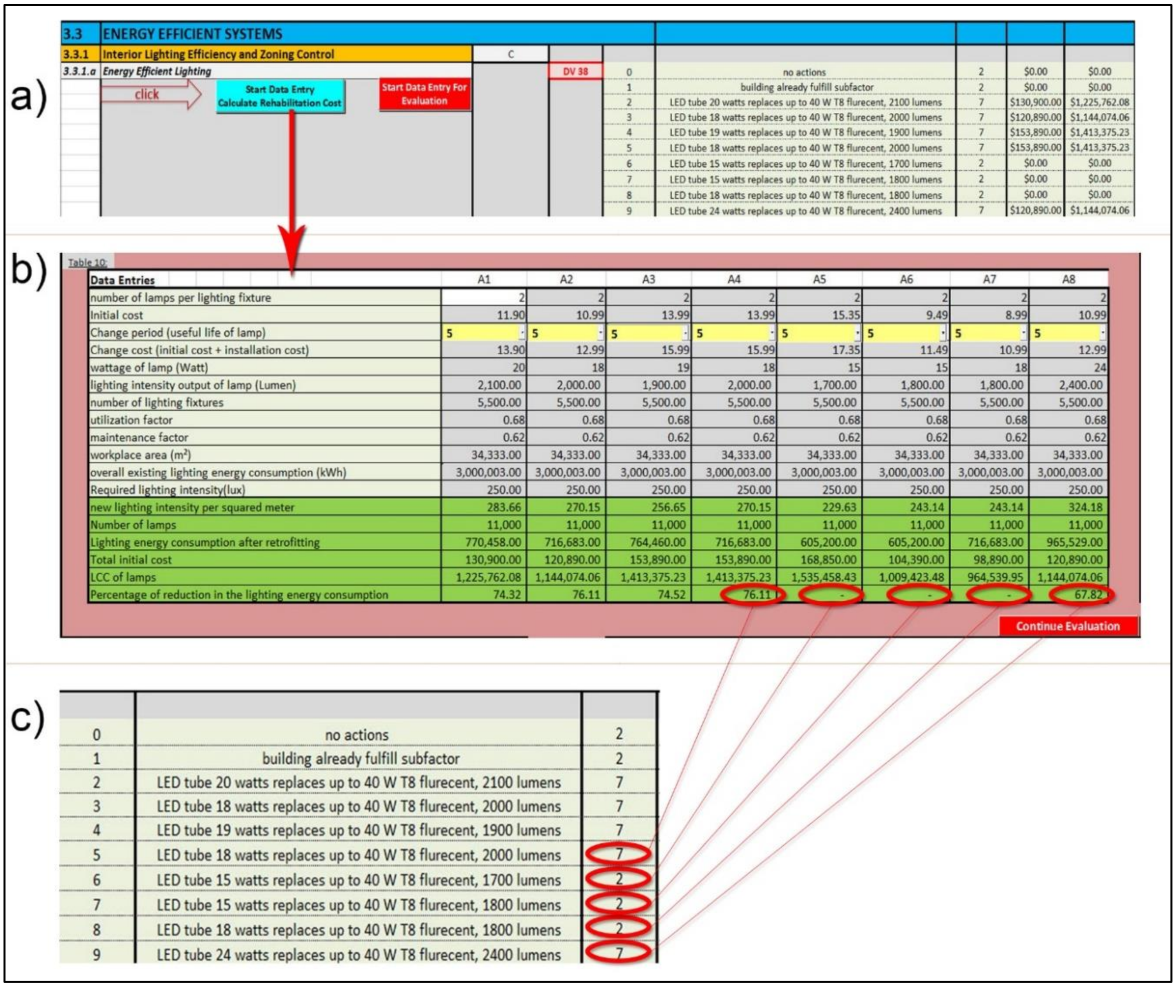
ii. The score and LCC evaluation

The score determination process for each alternative starts with the data entry required for each alternative in the calculation table as illustrated in Figure 7.6b. The calculation for the achieved percentages or values is performed automatically using a predefined equation that differs from one decision variable to another. The achieved percentage is compared with the required threshold to obtain the score for each alternative as shown in Figure 7.6b and c. In the calculation table, the user is allowed to select the maintenance frequency or the change frequency of an alternative through a dropdown menu as shown in Figure 7.7. Finally, the score and LCC of each alternative are displayed beside each alternative; if an alternative does not score more than the achieved score in the previous sustainability assessment before rehabilitation, the alternative takes the score of the previous sustainability assessment and the LCC is zero, which means that this alternative will either not be used or has no effect. The rationale of this modification is that the optimization process selects the index of the alternative, and if this alternative scores zero points and the current assessment (before rehabilitation) scores 2 points, then the optimization process will not be reasonable to select a decision variable that scores less than the one already achieved. In addition, this process saves computation time in the optimization processing because instead of introducing this procedure, a constraint should be set for each decision variable of the 134 decision variables to hinder the selection of an alternative with a lower score than the one achieved. Introducing such constraints with this number (134) that should be processed in each iteration will multiply the computation time.



Design Variable	Altrnative Value	Alternative Description
DV 83		
	0	no actions taken
	1	Project fulfills the sub factor
DV 84		
	0	no actions taken
	1	Building fulfills subfactor
	2	manual glare control on south/north windows
	3	automatic glare control on south/north windows
	4	manual glare control on south/north,east & west windows
	5	automatic glare control on south/north,east & west windows
	6	all windows have manual glare control
	7	all windows have automatic glare control
DV 85	0	no actions
	1	Detailed report for lighting exists
	2	Detailed report for lighting required

Figure 7.5: Alternatives for Each Decision Variable



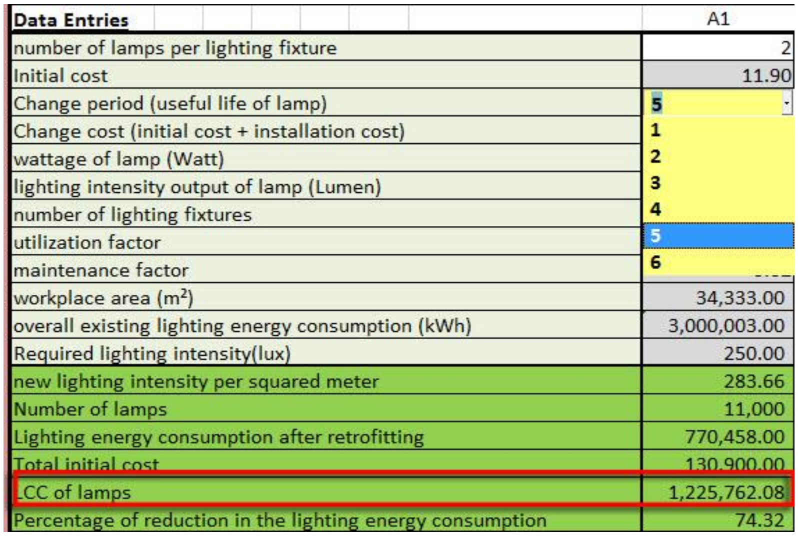
3.3	ENERGY EFFICIENT SYSTEMS							
3.3.1	Interior Lighting Efficiency and Zoning Control	C						
3.3.1.a	*Energy Efficient Lighting*		DV 38	0	no actions	2	$0.00	$0.00
				1	building already fulfill subfactor	2	$0.00	$0.00
				2	LED tube 20 watts replaces up to 40 W T8 flurecent, 2100 lumens	7	$130,900.00	$1,225,762.08
				3	LED tube 18 watts replaces up to 40 W T8 flurecent, 2000 lumens	7	$120,890.00	$1,144,074.06
				4	LED tube 19 watts replaces up to 40 W T8 flurecent, 1900 lumens	7	$153,890.00	$1,413,375.23
				5	LED tube 18 watts replaces up to 40 W T8 flurecent, 2000 lumens	7	$153,890.00	$1,413,375.23
				6	LED tube 15 watts replaces up to 40 W T8 flurecent, 1700 lumens	2	$0.00	$0.00
				7	LED tube 15 watts replaces up to 40 W T8 flurecent, 1800 lumens	2	$0.00	$0.00
				8	LED tube 18 watts replaces up to 40 W T8 flurecent, 1800 lumens	2	$0.00	$0.00
				9	LED tube 24 watts replaces up to 40 W T8 flurecent, 2400 lumens	7	$120,890.00	$1,144,074.06

Table 10:

Data Entries	A1	A2	A3	A4	A5	A6	A7	A8
number of lamps per lighting fixture	2	2	2	2	2	2	2	2
Initial cost	11.90	10.99	13.99	13.99	15.35	9.49	8.99	10.99
Change period (useful life of lamp)	5	5	5	5	5	5	5	5
Change cost (initial cost + installation cost)	13.90	12.99	15.99	15.99	17.35	11.49	10.99	12.99
wattage of lamp (Watt)	20	18	19	18	15	15	18	24
lighting intensity output of lamp (Lumen)	2,100.00	2,000.00	1,900.00	2,000.00	1,700.00	1,800.00	1,800.00	2,400.00
number of lighting fixtures	5,500.00	5,500.00	5,500.00	5,500.00	5,500.00	5,500.00	5,500.00	5,500.00
utilization factor	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
maintenance factor	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
workplace area (m²)	34,333.00	34,333.00	34,333.00	34,333.00	34,333.00	34,333.00	34,333.00	34,333.00
overall existing lighting energy consumption (kWh)	3,000,003.00	3,000,003.00	3,000,003.00	3,000,003.00	3,000,003.00	3,000,003.00	3,000,003.00	3,000,003.00
Required lighting intensity(lux)	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
new lighting intensity per squared meter	283.66	270.15	256.65	270.15	229.63	243.14	243.14	324.18
Number of lamps	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000
Lighting energy consumption after retrofitting	770,458.00	716,683.00	764,460.00	716,683.00	605,200.00	605,200.00	716,683.00	965,529.00
Total initial cost	130,900.00	120,890.00	153,890.00	153,890.00	168,850.00	104,390.00	98,890.00	120,890.00
LCC of lamps	1,225,762.08	1,144,074.06	1,413,375.23	1,413,375.23	1,535,458.43	1,009,423.48	964,539.95	1,144,074.06
Percentage of reduction in the lighting energy consumption	74.32	76.11	74.52	76.11	-	-	-	67.82

0	no actions	2
1	building already fulfill subfactor	2
2	LED tube 20 watts replaces up to 40 W T8 flurecent, 2100 lumens	7
3	LED tube 18 watts replaces up to 40 W T8 flurecent, 2000 lumens	7
4	LED tube 19 watts replaces up to 40 W T8 flurecent, 1900 lumens	7
5	LED tube 18 watts replaces up to 40 W T8 flurecent, 2000 lumens	7
6	LED tube 15 watts replaces up to 40 W T8 flurecent, 1700 lumens	2
7	LED tube 15 watts replaces up to 40 W T8 flurecent, 1800 lumens	2
8	LED tube 18 watts replaces up to 40 W T8 flurecent, 1800 lumens	2
9	LED tube 24 watts replaces up to 40 W T8 flurecent, 2400 lumens	7

Figure 7.6: Score Determination Process for Each Rehabilitation Alternative

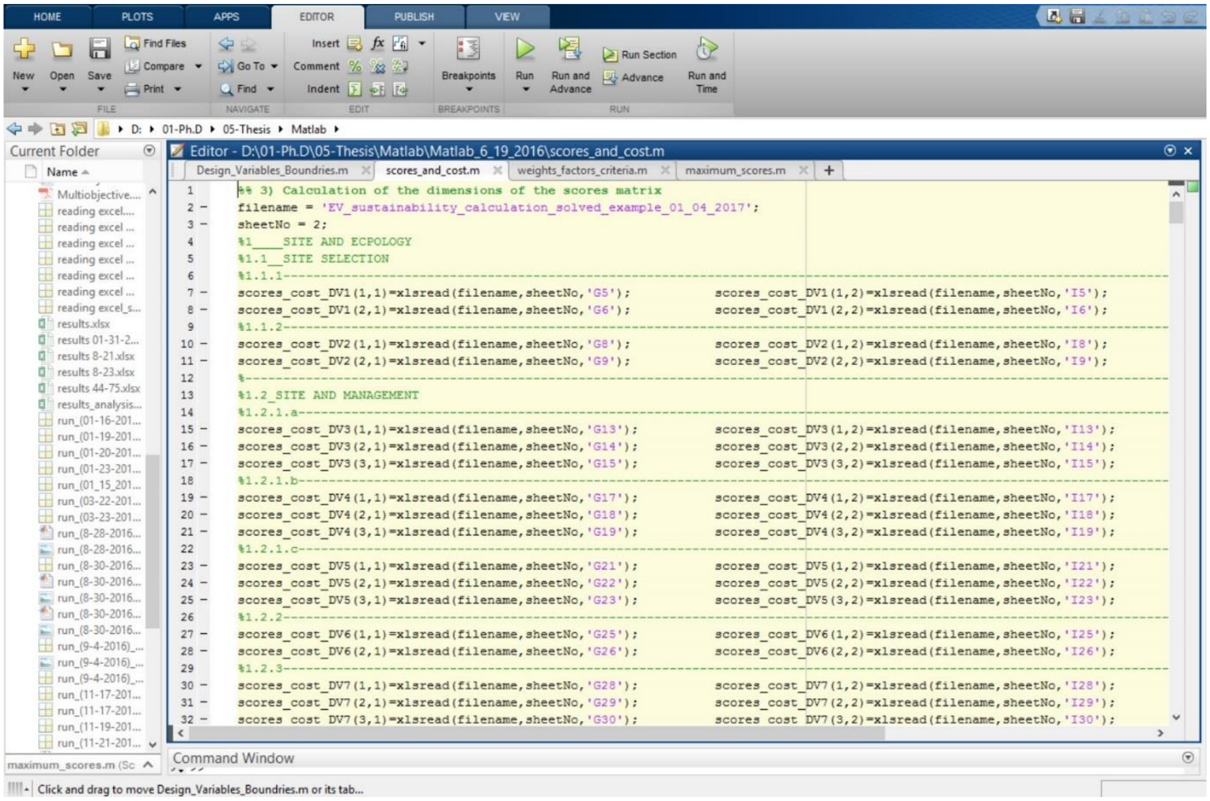


Data Entries	A1
number of lamps per lighting fixture	2
Initial cost	11.90
Change period (useful life of lamp)	5
Change cost (initial cost + installation cost)	1
wattage of lamp (Watt)	2
lighting intensity output of lamp (Lumen)	3
number of lighting fixtures	4
utilization factor	5
maintenance factor	6
workplace area (m²)	34,333.00
overall existing lighting energy consumption (kWh)	3,000,003.00
Required lighting intensity(lux)	250.00
new lighting intensity per squared meter	283.66
Number of lamps	11,000
Lighting energy consumption after retrofitting	770,458.00
Total initial cost	130,900.00
LCC of lamps	1,225,762.08
Percentage of reduction in the lighting energy consumption	74.32

Figure 7.7: The Rehabilitation Alternative LCC Determination

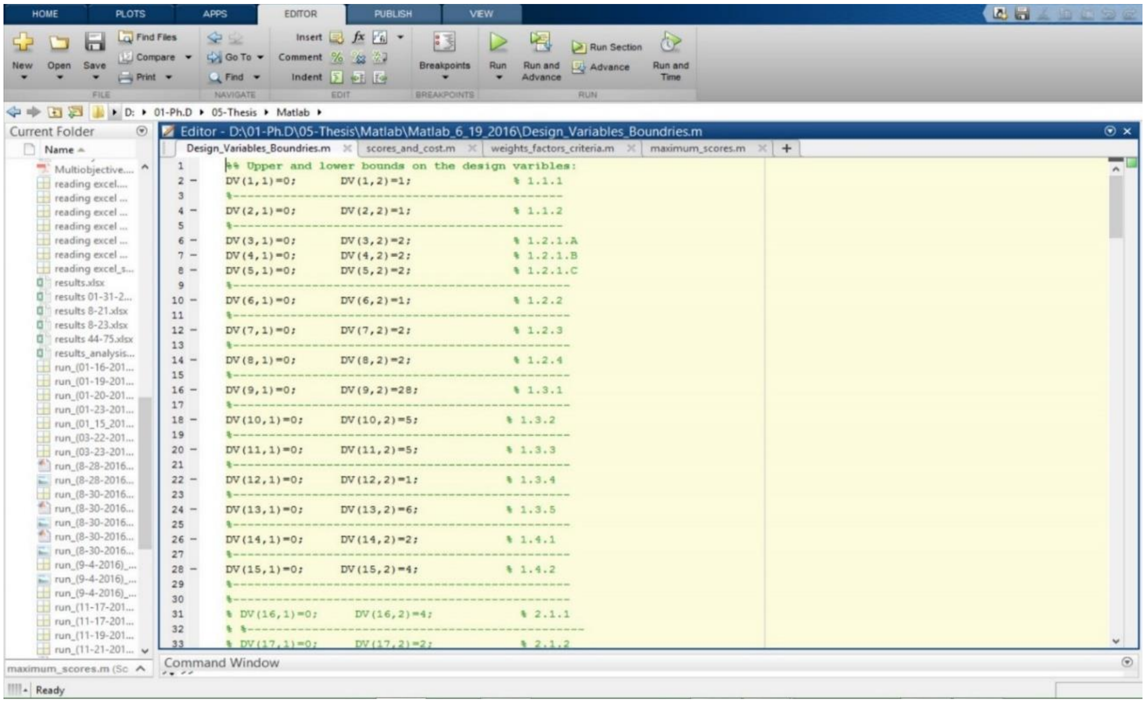
iii. Matlab data reading

The third stage is reading the Excel data by means of Matlab, which is comprised of different types of data. The first is reading the score and the cost for each decision alternative for each of the decision variables, which is called *score_and_cost* in a Matlab file as shown in Figure 7.8. The second type is reading the upper and lower boundaries of each decision variable. These boundaries represent the number of alternatives under each decision variable and the file that stores this data is the *Design_Variables_Boundaries* as shown in Figure 7.9. The third type is reading the weights of the criteria and factors, which are used to calculate the BSAR, and the sustainability percentage for each antibody (particle in the population). These data are contained within a file named *weights_factors_criteria*. The last file, *maximum_scores,* contains the maximum score for the factors to calculate the $\mathrm{BSI}_{\mathrm{max.}}$ and to compare it with the achieved BSI to obtain the BSAR.



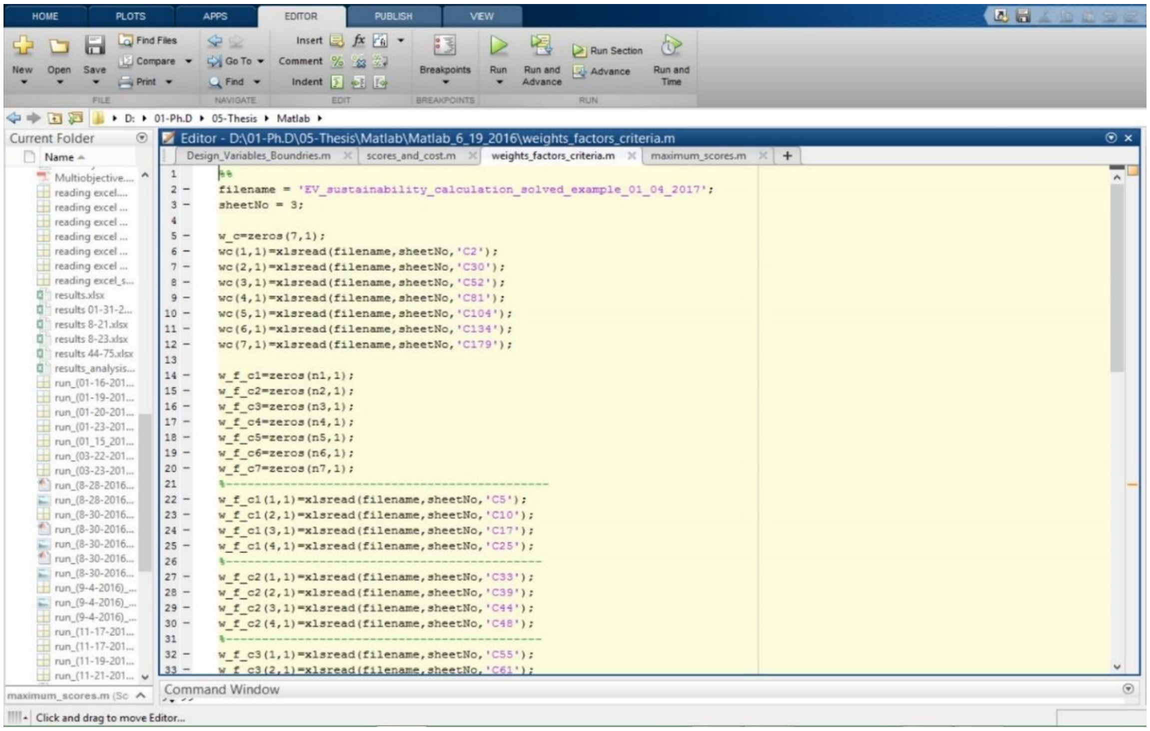
```
%% 3) Calculation of the dimensions of the scores matrix
filename = 'EV_sustainability_calculation_solved_example_01_04_2017';
sheetNo = 2;
%1____SITE AND ECPOLOGY
%1.1__SITE SELECTION
%1.1.1----------------------------------------------------------------------------------------------------
scores_cost_DV1(1,1)=xlsread(filename,sheetNo,'G5');          scores_cost_DV1(1,2)=xlsread(filename,sheetNo,'I5');
scores_cost_DV1(2,1)=xlsread(filename,sheetNo,'G6');          scores_cost_DV1(2,2)=xlsread(filename,sheetNo,'I6');
%1.1.2----------------------------------------------------------------------------------------------------
scores_cost_DV2(1,1)=xlsread(filename,sheetNo,'G8');          scores_cost_DV2(1,2)=xlsread(filename,sheetNo,'I8');
scores_cost_DV2(2,1)=xlsread(filename,sheetNo,'G9');          scores_cost_DV2(2,2)=xlsread(filename,sheetNo,'I9');
%---------------------------------------------------------------------------------------------------------
%1.2_SITE AND MANAGEMENT
%1.2.1.a--------------------------------------------------------------------------------------------------
scores_cost_DV3(1,1)=xlsread(filename,sheetNo,'G13');         scores_cost_DV3(1,2)=xlsread(filename,sheetNo,'I13');
scores_cost_DV3(2,1)=xlsread(filename,sheetNo,'G14');         scores_cost_DV3(2,2)=xlsread(filename,sheetNo,'I14');
scores_cost_DV3(3,1)=xlsread(filename,sheetNo,'G15');         scores_cost_DV3(3,2)=xlsread(filename,sheetNo,'I15');
%1.2.1.b--------------------------------------------------------------------------------------------------
scores_cost_DV4(1,1)=xlsread(filename,sheetNo,'G17');         scores_cost_DV4(1,2)=xlsread(filename,sheetNo,'I17');
scores_cost_DV4(2,1)=xlsread(filename,sheetNo,'G18');         scores_cost_DV4(2,2)=xlsread(filename,sheetNo,'I18');
scores_cost_DV4(3,1)=xlsread(filename,sheetNo,'G19');         scores_cost_DV4(3,2)=xlsread(filename,sheetNo,'I19');
%1.2.1.c--------------------------------------------------------------------------------------------------
scores_cost_DV5(1,1)=xlsread(filename,sheetNo,'G21');         scores_cost_DV5(1,2)=xlsread(filename,sheetNo,'I21');
scores_cost_DV5(2,1)=xlsread(filename,sheetNo,'G22');         scores_cost_DV5(2,2)=xlsread(filename,sheetNo,'I22');
scores_cost_DV5(3,1)=xlsread(filename,sheetNo,'G23');         scores_cost_DV5(3,2)=xlsread(filename,sheetNo,'I23');
%1.2.2----------------------------------------------------------------------------------------------------
scores_cost_DV6(1,1)=xlsread(filename,sheetNo,'G25');         scores_cost_DV6(1,2)=xlsread(filename,sheetNo,'I25');
scores_cost_DV6(2,1)=xlsread(filename,sheetNo,'G26');         scores_cost_DV6(2,2)=xlsread(filename,sheetNo,'I26');
%1.2.3----------------------------------------------------------------------------------------------------
scores_cost_DV7(1,1)=xlsread(filename,sheetNo,'G28');         scores_cost_DV7(1,2)=xlsread(filename,sheetNo,'I28');
scores_cost_DV7(2,1)=xlsread(filename,sheetNo,'G29');         scores_cost_DV7(2,2)=xlsread(filename,sheetNo,'I29');
scores_cost_DV7(3,1)=xlsread(filename,sheetNo,'G30');         scores_cost_DV7(3,2)=xlsread(filename,sheetNo,'I30');
```

Figure 7.8: Matlab Reading for the Alternative Scores and Costs



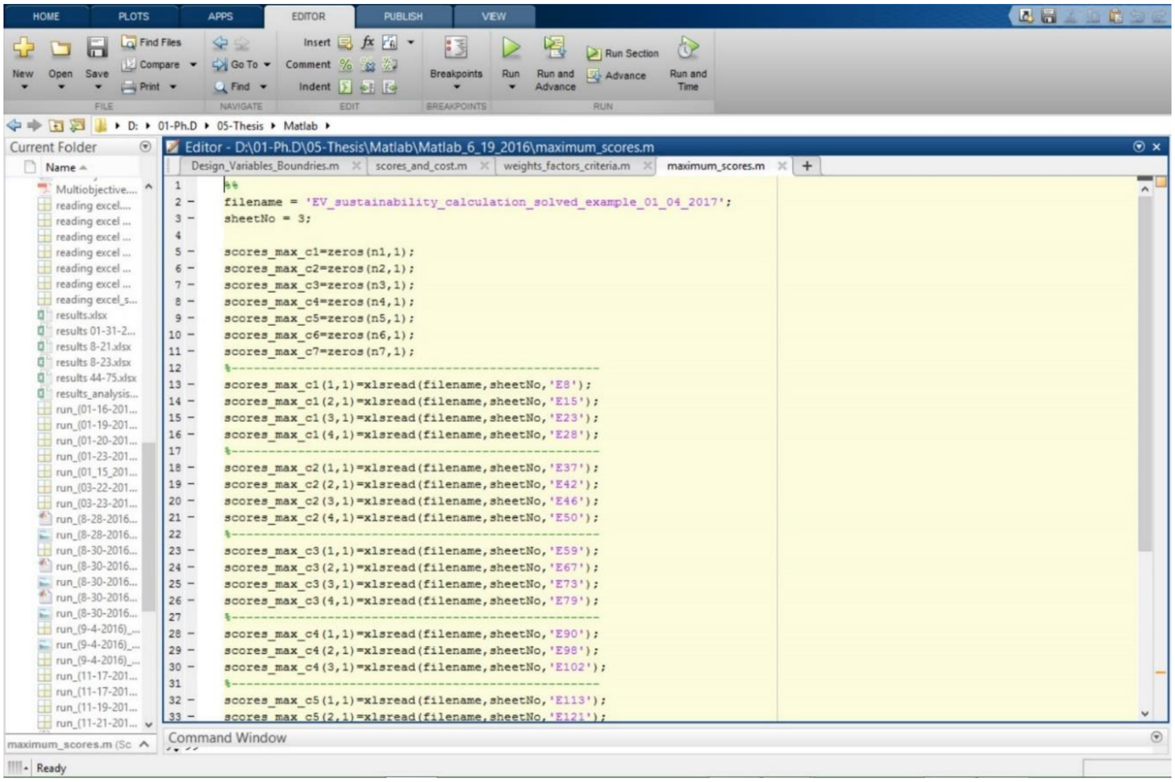
```
%% Upper and lower bounds on the design varibles:
DV(1,1)=0;       DV(1,2)=1;                  % 1.1.1
%-----------------------------------------------
DV(2,1)=0;       DV(2,2)=1;                  % 1.1.2
%-----------------------------------------------
DV(3,1)=0;       DV(3,2)=2;                  % 1.2.1.A
DV(4,1)=0;       DV(4,2)=2;                  % 1.2.1.B
DV(5,1)=0;       DV(5,2)=2;                  % 1.2.1.C
%-----------------------------------------------
DV(6,1)=0;       DV(6,2)=1;                  % 1.2.2
%-----------------------------------------------
DV(7,1)=0;       DV(7,2)=2;                  % 1.2.3
%-----------------------------------------------
DV(8,1)=0;       DV(8,2)=2;                  % 1.2.4
%-----------------------------------------------
DV(9,1)=0;       DV(9,2)=28;                 % 1.3.1
%-----------------------------------------------
DV(10,1)=0;      DV(10,2)=5;                % 1.3.2
%-----------------------------------------------
DV(11,1)=0;      DV(11,2)=5;                % 1.3.3
%-----------------------------------------------
DV(12,1)=0;      DV(12,2)=1;                % 1.3.4
%-----------------------------------------------
DV(13,1)=0;      DV(13,2)=6;                % 1.3.5
%-----------------------------------------------
DV(14,1)=0;      DV(14,2)=2;                % 1.4.1
%-----------------------------------------------
DV(15,1)=0;      DV(15,2)=4;                % 1.4.2
%-----------------------------------------------
%-----------------------------------------------
% DV(16,1)=0;      DV(16,2)=4;                % 2.1.1
% %-----------------------------------------------
% DV(17,1)=0;      DV(17,2)=2;                % 2.1.2
```

Figure 7.9: Matlab Reading for the Upper and Lower Boundaries of Decision Variables



```
%%
filename = 'EV_sustainability_calculation_solved_example_01_04_2017';
sheetNo = 3;

w_c=zeros(7,1);
wc(1,1)=xlsread(filename,sheetNo,'C2');
wc(2,1)=xlsread(filename,sheetNo,'C30');
wc(3,1)=xlsread(filename,sheetNo,'C52');
wc(4,1)=xlsread(filename,sheetNo,'C81');
wc(5,1)=xlsread(filename,sheetNo,'C104');
wc(6,1)=xlsread(filename,sheetNo,'C134');
wc(7,1)=xlsread(filename,sheetNo,'C179');

w_f_c1=zeros(n1,1);
w_f_c2=zeros(n2,1);
w_f_c3=zeros(n3,1);
w_f_c4=zeros(n4,1);
w_f_c5=zeros(n5,1);
w_f_c6=zeros(n6,1);
w_f_c7=zeros(n7,1);
%-----------------------------------------
w_f_c1(1,1)=xlsread(filename,sheetNo,'C5');
w_f_c1(2,1)=xlsread(filename,sheetNo,'C10');
w_f_c1(3,1)=xlsread(filename,sheetNo,'C17');
w_f_c1(4,1)=xlsread(filename,sheetNo,'C25');
%-----------------------------------------
w_f_c2(1,1)=xlsread(filename,sheetNo,'C33');
w_f_c2(2,1)=xlsread(filename,sheetNo,'C39');
w_f_c2(3,1)=xlsread(filename,sheetNo,'C44');
w_f_c2(4,1)=xlsread(filename,sheetNo,'C48');
%-----------------------------------------
w_f_c3(1,1)=xlsread(filename,sheetNo,'C55');
w_f_c3(2,1)=xlsread(filename,sheetNo,'C61');
```

Figure 7.10: Matlab Reading for the Weights of the Criteria and Factors



```matlab
%%
filename = 'EV_sustainability_calculation_solved_example_01_04_2017';
sheetNo = 3;

scores_max_c1=zeros(n1,1);
scores_max_c2=zeros(n2,1);
scores_max_c3=zeros(n3,1);
scores_max_c4=zeros(n4,1);
scores_max_c5=zeros(n5,1);
scores_max_c6=zeros(n6,1);
scores_max_c7=zeros(n7,1);
%-----------------------------------------
scores_max_c1(1,1)=xlsread(filename,sheetNo,'E8');
scores_max_c1(2,1)=xlsread(filename,sheetNo,'E15');
scores_max_c1(3,1)=xlsread(filename,sheetNo,'E23');
scores_max_c1(4,1)=xlsread(filename,sheetNo,'E28');
%-----------------------------------------
scores_max_c2(1,1)=xlsread(filename,sheetNo,'E37');
scores_max_c2(2,1)=xlsread(filename,sheetNo,'E42');
scores_max_c2(3,1)=xlsread(filename,sheetNo,'E46');
scores_max_c2(4,1)=xlsread(filename,sheetNo,'E50');
%-----------------------------------------
scores_max_c3(1,1)=xlsread(filename,sheetNo,'E59');
scores_max_c3(2,1)=xlsread(filename,sheetNo,'E67');
scores_max_c3(3,1)=xlsread(filename,sheetNo,'E73');
scores_max_c3(4,1)=xlsread(filename,sheetNo,'E79');
%-----------------------------------------
scores_max_c4(1,1)=xlsread(filename,sheetNo,'E90');
scores_max_c4(2,1)=xlsread(filename,sheetNo,'E98');
scores_max_c4(3,1)=xlsread(filename,sheetNo,'E102');
%-----------------------------------------
scores_max_c5(1,1)=xlsread(filename,sheetNo,'E113');
scores_max_c5(2,1)=xlsread(filename,sheetNo,'E121');
```

Figure 7.11: Matlab Reading for the Maximum Scores

iv. Optimization processing

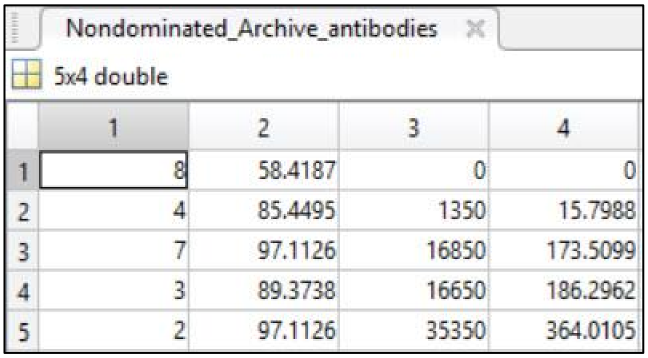
After reading all the required data as demonstrated, the optimization process runs automatically through the code illustrated in Chapter 4. A progress bar is displayed to inform the user about the number of iterations performed and the progress percentage as shown in Figure 7.12.

AIS iteration No. 21 Progress %30

Figure 7.12: Optimization Process Progress Bar

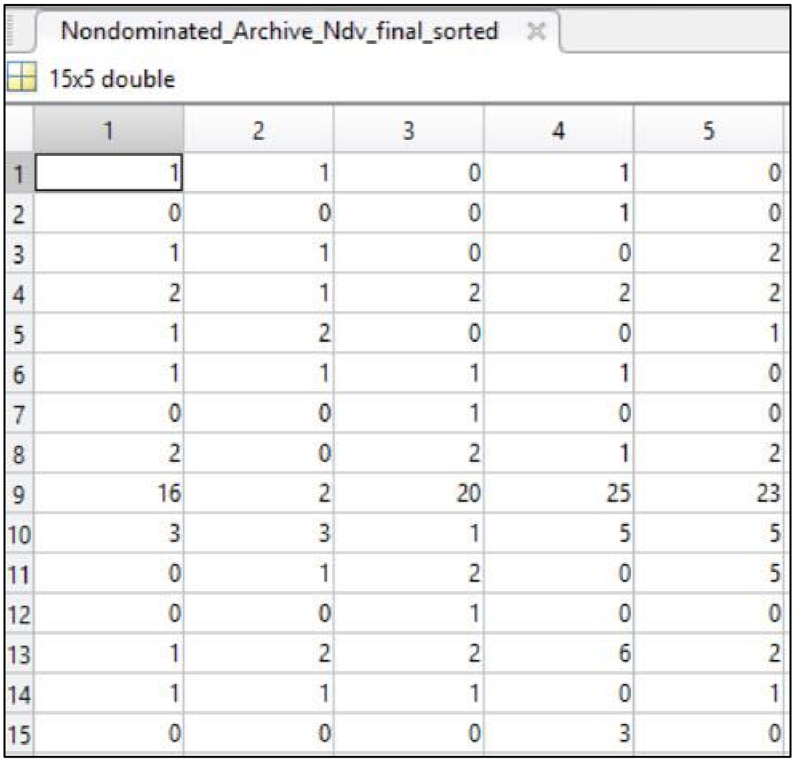
v. Writing optimal solutions to the Excel file

At the end of the optimization process, or when reaching the required maximum iterations (k_max), the final solutions are stored in four matrices in Matlab. The first one is Nondominated_Archive_antibodies, which stores the achieved near optimal antibodies (solutions) and their related scores and LCC and cost sustainability ratio (CSR) as shown in Figure 7.13. The second matrix is Nondominated_Archive_Ndv_final_Sorted, which stores the index of all the alternatives for each decision variable in each solution as illustrated in Figure 7.14. The third matrix is Score_Corresponding, which demonstrates the corresponding score for each alternative in each decision variable based on the obtained index in the previous matrix as shown in Figure 7.15. The final matrix is Cost_Corresponding, which stores the corresponding LCC for each alternative in each decision variable based on the obtained index in the previous matrix as shown in Figure 7.16. These matrices are written in specific Excel sheets in particular tables and cells by utilizing the code at the end of the optimization code as shown in Figure 7.17.



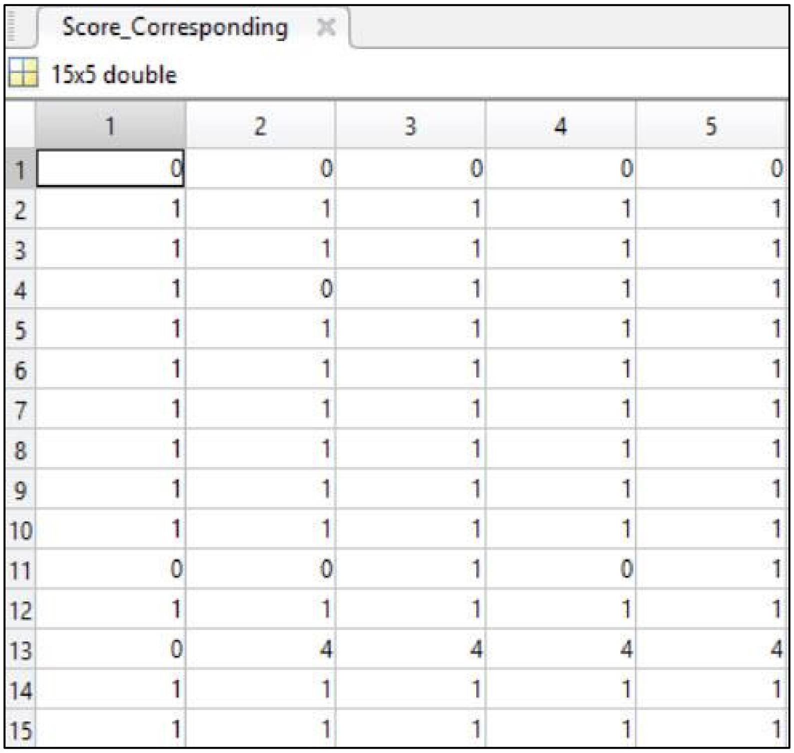
	1	2	3	4
1	8	58.4187	0	0
2	4	85.4495	1350	15.7988
3	7	97.1126	16850	173.5099
4	3	89.3738	16650	186.2962
5	2	97.1126	35350	364.0105

Figure 7.13: Final Optimal Solutions



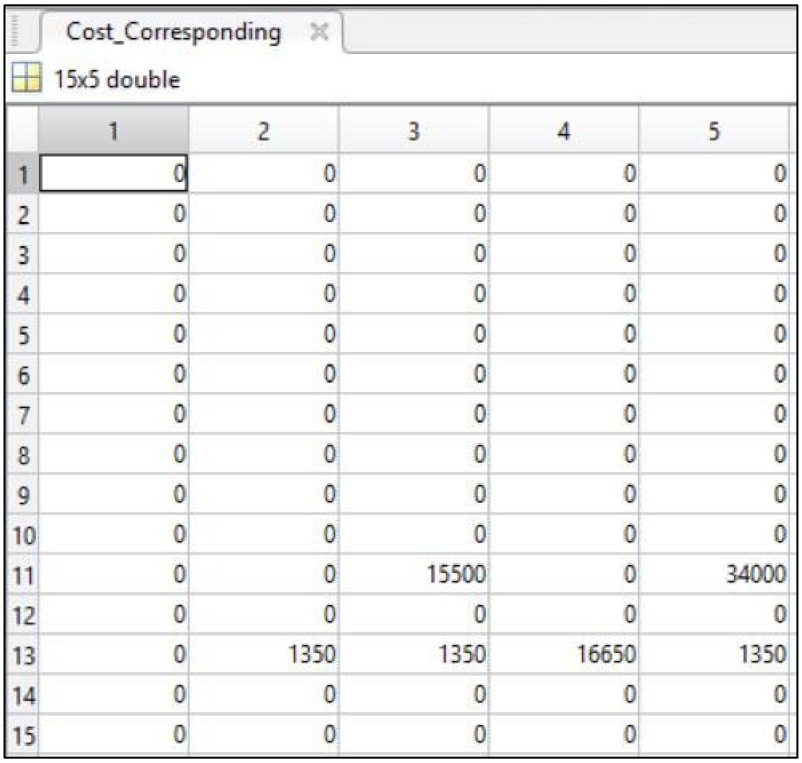
	1	2	3	4	5
1	1	1	0	1	0
2	0	0	0	1	0
3	1	1	0	0	2
4	2	1	2	2	2
5	1	2	0	0	1
6	1	1	1	1	0
7	0	0	1	0	0
8	2	0	2	1	2
9	16	2	20	25	23
10	3	3	1	5	5
11	0	1	2	0	5
12	0	0	1	0	0
13	1	2	2	6	2
14	1	1	1	0	1
15	0	0	0	3	0

Figure 7.14: The Index of the Decision Variables Included in Each Solution



	1	2	3	4	5
1	0	0	0	0	0
2	1	1	1	1	1
3	1	1	1	1	1
4	1	0	1	1	1
5	1	1	1	1	1
6	1	1	1	1	1
7	1	1	1	1	1
8	1	1	1	1	1
9	1	1	1	1	1
10	1	1	1	1	1
11	0	0	1	0	1
12	1	1	1	1	1
13	0	4	4	4	4
14	1	1	1	1	1
15	1	1	1	1	1

Figure 7.15: Corresponding Score for Each Decision Variable

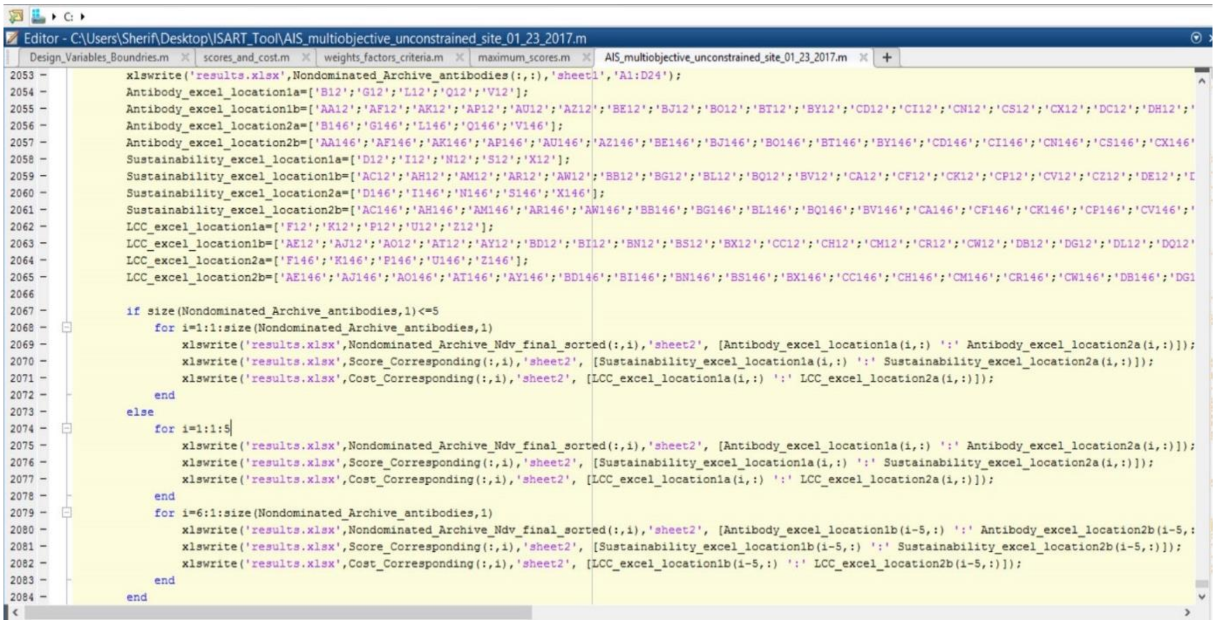


Cost_Corresponding

15x5 double

	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	15500	0	34000
12	0	0	0	0	0
13	0	1350	1350	16650	1350
14	0	0	0	0	0
15	0	0	0	0	0

Figure 7.16: Corresponding LCC for Each Decision Variable



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```
        xlswrite('results.xlsx',Nondominated_Archive_antibodies(:,:),'sheet1','A1:D24');
        Antibody_excel_location1a=['B12';'G12';'L12';'Q12';'V12'];
        Antibody_excel_location1b=['AA12';'AF12';'AK12';'AP12';'AU12';'AZ12';'BE12';'BJ12';'BO12';'BT12';'BY12';'CD12';'CI12';'CN12';'CS12';'CX12';'DC12';'DH12';'
        Antibody_excel_location2a=['B146';'G146';'L146';'Q146';'V146'];
        Antibody_excel_location2b=['AA146';'AF146';'AK146';'AP146';'AU146';'AZ146';'BE146';'BJ146';'BO146';'BT146';'BY146';'CD146';'CI146';'CN146';'CS146';'CX146'
        Sustainability_excel_location1a=['D12';'I12';'N12';'S12';'X12'];
        Sustainability_excel_location1b=['AC12';'AH12';'AM12';'AR12';'AW12';'BB12';'BG12';'BL12';'BQ12';'BV12';'CA12';'CF12';'CK12';'CP12';'CV12';'CZ12';'DE12';'
        Sustainability_excel_location2a=['D146';'I146';'N146';'S146';'X146'];
        Sustainability_excel_location2b=['AC146';'AH146';'AM146';'AR146';'AW146';'BB146';'BG146';'BL146';'BQ146';'BV146';'CA146';'CF146';'CK146';'CP146';'CV146';'
        LCC_excel_location1a=['F12';'K12';'P12';'U12';'Z12'];
        LCC_excel_location1b=['AE12';'AJ12';'AO12';'AT12';'AY12';'BD12';'BI12';'BN12';'BS12';'BX12';'CC12';'CH12';'CM12';'CR12';'CW12';'DB12';'DG12';'DL12';'DQ12'
        LCC_excel_location2a=['F146';'K146';'P146';'U146';'Z146'];
        LCC_excel_location2b=['AE146';'AJ146';'AO146';'AT146';'AY146';'BD146';'BI146';'BN146';'BS146';'BX146';'CC146';'CH146';'CM146';'CR146';'CW146';'DB146';'DG1

        if size(Nondominated_Archive_antibodies,1)<=5
            for i=1:1:size(Nondominated_Archive_antibodies,1)
                xlswrite('results.xlsx',Nondominated_Archive_Ndv_final_sorted(:,i),'sheet2', [Antibody_excel_location1a(i,:) ':' Antibody_excel_location2a(i,:)]);
                xlswrite('results.xlsx',Score_Corresponding(:,i),'sheet2', [Sustainability_excel_location1a(i,:) ':' Sustainability_excel_location2a(i,:)]);
                xlswrite('results.xlsx',Cost_Corresponding(:,i),'sheet2', [LCC_excel_location1a(i,:) ':' LCC_excel_location2a(i,:)]);
            end
        else
            for i=1:1:5
                xlswrite('results.xlsx',Nondominated_Archive_Ndv_final_sorted(:,i),'sheet2', [Antibody_excel_location1a(i,:) ':' Antibody_excel_location2a(i,:)]);
                xlswrite('results.xlsx',Score_Corresponding(:,i),'sheet2', [Sustainability_excel_location1a(i,:) ':' Sustainability_excel_location2a(i,:)]);
                xlswrite('results.xlsx',Cost_Corresponding(:,i),'sheet2', [LCC_excel_location1a(i,:) ':' LCC_excel_location2a(i,:)]);
            end
            for i=6:1:size(Nondominated_Archive_antibodies,1)
                xlswrite('results.xlsx',Nondominated_Archive_Ndv_final_sorted(:,i),'sheet2', [Antibody_excel_location1b(i-5,:) ':' Antibody_excel_location2b(i-5,:
                xlswrite('results.xlsx',Score_Corresponding(:,i),'sheet2', [Sustainability_excel_location1b(i-5,:) ':' Sustainability_excel_location2b(i-5,:)]);
                xlswrite('results.xlsx',Cost_Corresponding(:,i),'sheet2', [LCC_excel_location1b(i-5,:) ':' LCC_excel_location2b(i-5,:)]);
            end
        end
```

Figure 7.17: The Code to Write Results Excel

7.3.3 The Sustainability Assessment and Optimization Results Display

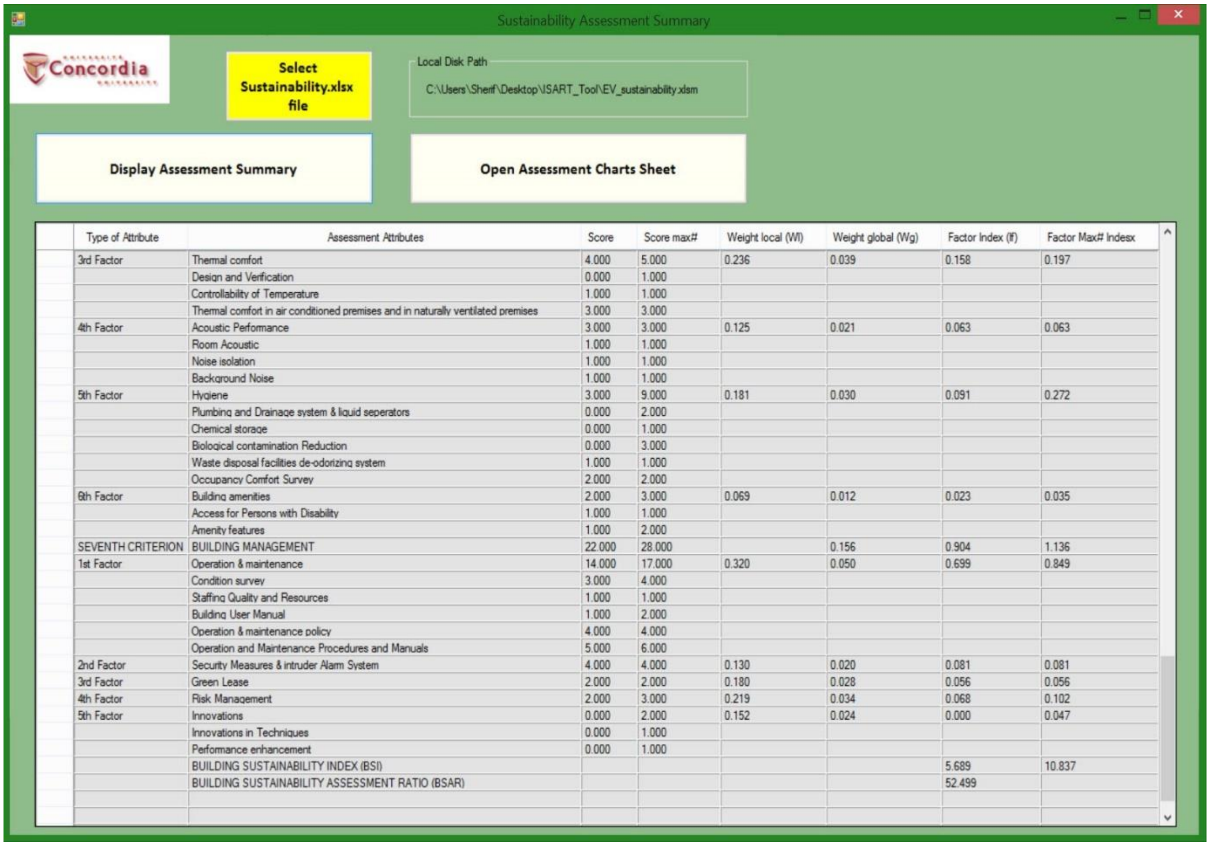
In this stage, the user displays some detailed results of the sustainability assessment process and the optimization output as follow.

i. Sustainability assessment display

In this process, a new window is opened by the user when the open sustainability results in the main window are pressed. This window provides the user with two options: 1) display a summary for the whole assessment process and 2) display different illustrative charts in in Excel. The summary table, as shown in Figure 7.18, demonstrates eight columns: 1) type of the assessment attribute (criteria, factors and sub-factors); 2) the title of the assessment attribute; 3) the achieved scores for the factors and the sub-factors (SC); 4) the maximum score for each factor (SC_{max}); 5) the local weight for the factors; 6) the global weights of the factors; 7) the factor sustainability index (SI); and 8) the factor maximum sustainability index (SI_{max}). Moreover, at the bottom of the table, the building sustainability index and the building sustainability assessment ratio are displayed. The second part of display contains the illustrative charts, which show several types of graphs, such as the plotting of BSAR on the developed scale, the achieved sustainability index for each criterion and its relation to the threshold for each sustainability rank and a detailed bar chart for each criterion that illustrates the percentage of achievement for each of its related factors.

ii. Optimization output display

After the optimization process is finished and the output is written to the corresponding sheets, the user can display all the decision variables for each alternative. This display shows three different data: 1) the index obtained for each decision variable; 2) the description for each index; and 3) the score and LCC for each decision variable.



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Type of Attribute	Assessment Attributes	Score	Score max#	Weight local (Wl)	Weight global (Wg)	Factor Index (If)	Factor Max# Indesx
3rd Factor	Thermal comfort	4.000	5.000	0.236	0.039	0.158	0.197
	Design and Verification	0.000	1.000				
	Controllability of Temperature	1.000	1.000				
	Thermal comfort in air conditioned premises and in naturally ventilated premises	3.000	3.000				
4th Factor	Acoustic Performance	3.000	3.000	0.125	0.021	0.063	0.063
	Room Acoustic	1.000	1.000				
	Noise isolation	1.000	1.000				
	Background Noise	1.000	1.000				
5th Factor	Hygiene	3.000	9.000	0.181	0.030	0.091	0.272
	Plumbing and Drainage system & liquid seperators	0.000	2.000				
	Chemical storage	0.000	1.000				
	Biological contamination Reduction	0.000	3.000				
	Waste disposal facilities de-odorizing system	1.000	1.000				
	Occupancy Comfort Survey	2.000	2.000				
6th Factor	Building amenities	2.000	3.000	0.069	0.012	0.023	0.035
	Access for Persons with Disability	1.000	1.000				
	Amenity features	1.000	2.000				
SEVENTH CRITERION	BUILDING MANAGEMENT	22.000	28.000		0.156	0.904	1.136
1st Factor	Operation & maintenance	14.000	17.000	0.320	0.050	0.699	0.849
	Condition survey	3.000	4.000				
	Staffing Quality and Resources	1.000	1.000				
	Building User Manual	1.000	2.000				
	Operation & maintenance policy	4.000	4.000				
	Operation and Maintenance Procedures and Manuals	5.000	6.000				
2nd Factor	Security Measures & intruder Alarm System	4.000	4.000	0.130	0.020	0.081	0.081
3rd Factor	Green Lease	2.000	2.000	0.180	0.028	0.056	0.056
4th Factor	Risk Management	2.000	3.000	0.219	0.034	0.068	0.102
5th Factor	Innovations	0.000	2.000	0.152	0.024	0.000	0.047
	Innovations in Techniques	0.000	1.000				
	Performance enhancement	0.000	1.000				
	BUILDING SUSTAINABILITY INDEX (BSI)					5.689	10.837
	BUILDING SUSTAINABILITY ASSESSMENT RATIO (BSAR)					52.499	

Figure 7.18: Sustainability Assessment Summary

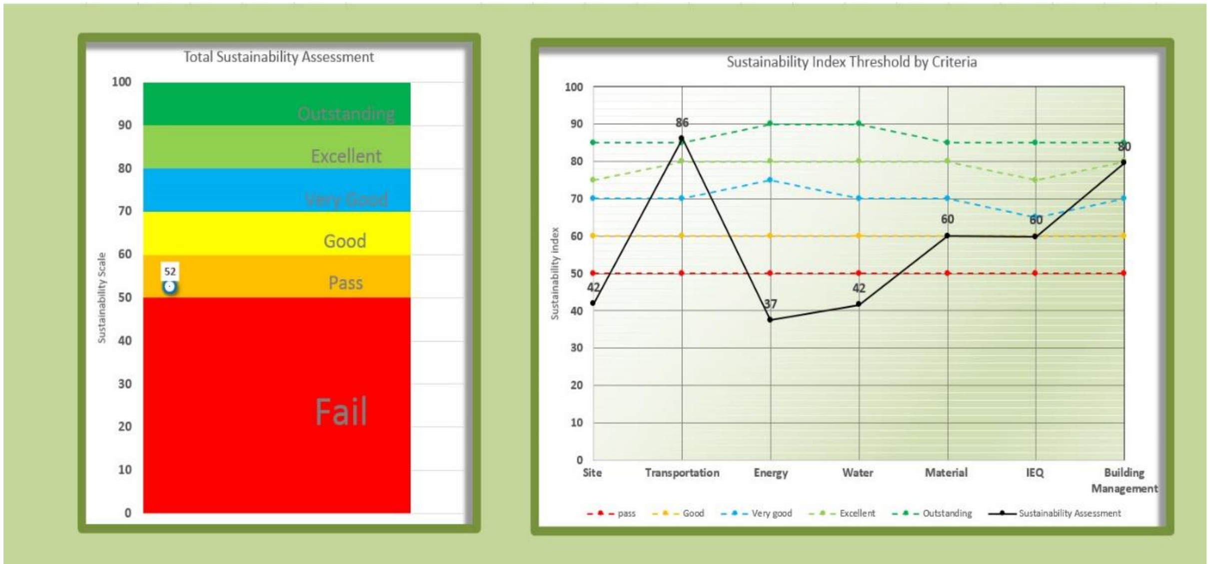
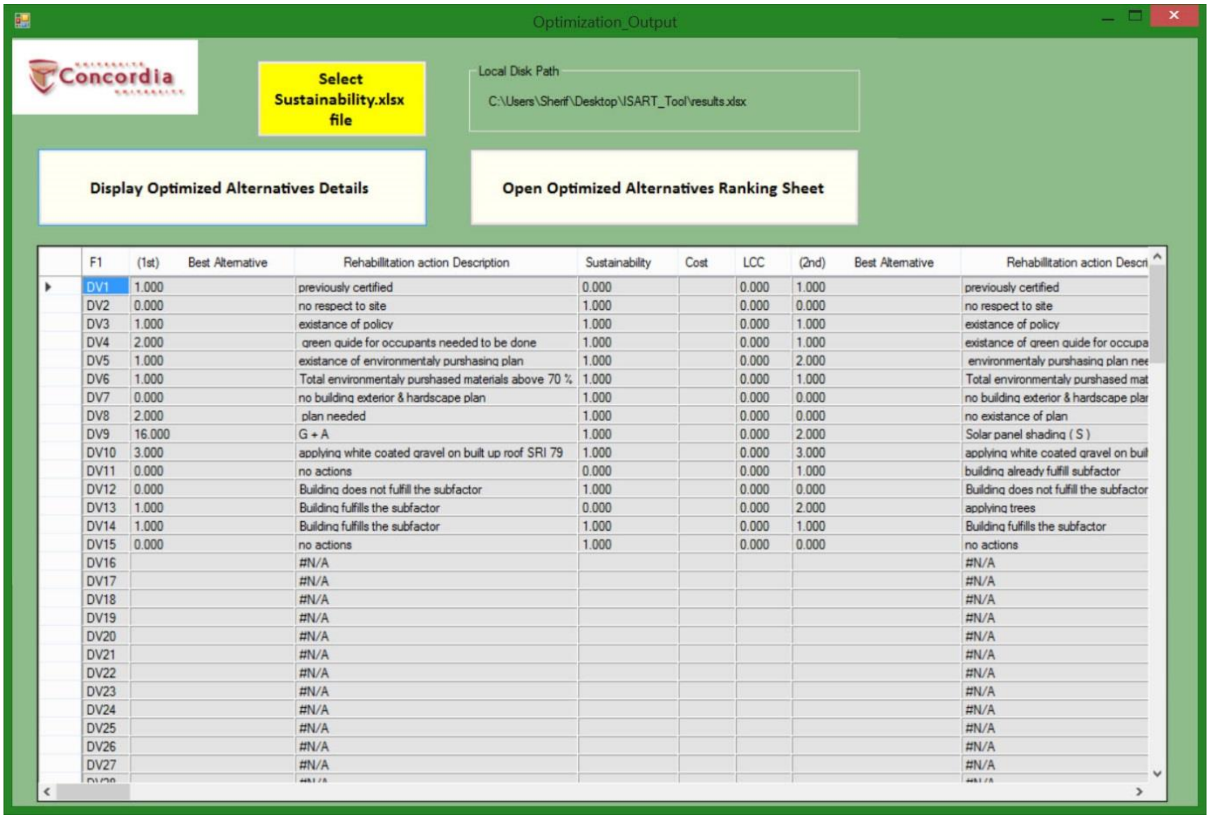


Figure 7.19: Sustainability Assessment Charts



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F1	(1st) Best Alternative	Rehabilitation action Description	Sustainability	Cost	LCC	(2nd) Best Alternative	Rehabilitation action Descri
DV1	1.000	previously certified	0.000		0.000	1.000	previously certified
DV2	0.000	no respect to site	1.000		0.000	0.000	no respect to site
DV3	1.000	existance of policy	1.000		0.000	1.000	existance of policy
DV4	2.000	green guide for occupants needed to be done	1.000		0.000	1.000	existance of green guide for occupa
DV5	1.000	existance of environmentaly purshasing plan	1.000		0.000	2.000	environmentaly purshasing plan nee
DV6	1.000	Total environmentaly purshased materials above 70 %	1.000		0.000	1.000	Total environmentaly purshased mat
DV7	0.000	no building exterior & hardscape plan	1.000		0.000	0.000	no building exterior & hardscape plar
DV8	2.000	plan needed	1.000		0.000	0.000	no existance of plan
DV9	16.000	G + A	1.000		0.000	2.000	Solar panel shading (S)
DV10	3.000	applying white coated gravel on built up roof SRI 79	1.000		0.000	3.000	applying white coated gravel on buil
DV11	0.000	no actions	0.000		0.000	1.000	building already fulfill subfactor
DV12	0.000	Building does not fulfill the subfactor	1.000		0.000	0.000	Building does not fulfill the subfactor
DV13	1.000	Building fulfills the subfactor	0.000		0.000	2.000	applying trees
DV14	1.000	Building fulfills the subfactor	1.000		0.000	1.000	Building fulfills the subfactor
DV15	0.000	no actions	1.000		0.000	0.000	no actions
DV16		#N/A					#N/A
DV17		#N/A					#N/A
DV18		#N/A					#N/A
DV19		#N/A					#N/A
DV20		#N/A					#N/A
DV21		#N/A					#N/A
DV22		#N/A					#N/A
DV23		#N/A					#N/A
DV24		#N/A					#N/A
DV25		#N/A					#N/A
DV26		#N/A					#N/A
DV27		#N/A					#N/A

Figure 7.20: Optimization Output Summary

7.4 Validation of the Proposed Methodology and the Developed Models

The validation of the performed research work is comprised of two parts. The first one is the validation of the proposed research methodology to develop an integrated sustainability assessment and rehabilitation framework, and the second is validating the proposed models, which are the sustainability assessment model and the sustainability-based rehabilitation model. The validation process is illustrated as follows:

7.4.1 Validation of the Proposed Methodology

Due to the absence of an integrated sustainability assessment and rehabilitation tool that assesses the sustainability of buildings and proposes set of optimal solutions to upgrade the sustainability of the building within minimal LCC, the validation procedures that was followed by Eweda (2012) is adopted to validate the proposed research methodology. The validation method is divided into six validation criteria as illustrated in Moody et al. (2003) and that as shown in Figure 7.21. These validation criteria are actual efficiency, actual effectiveness, perceived ease of use, perceived usefulness, intention to use and actual usage.

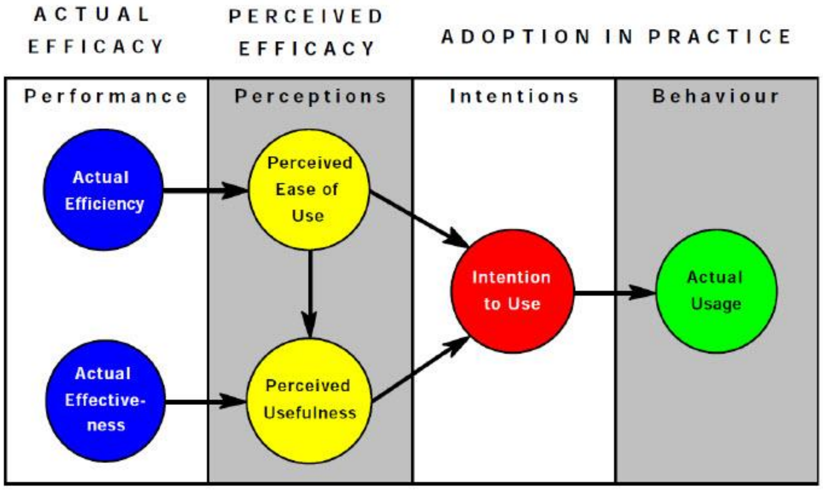
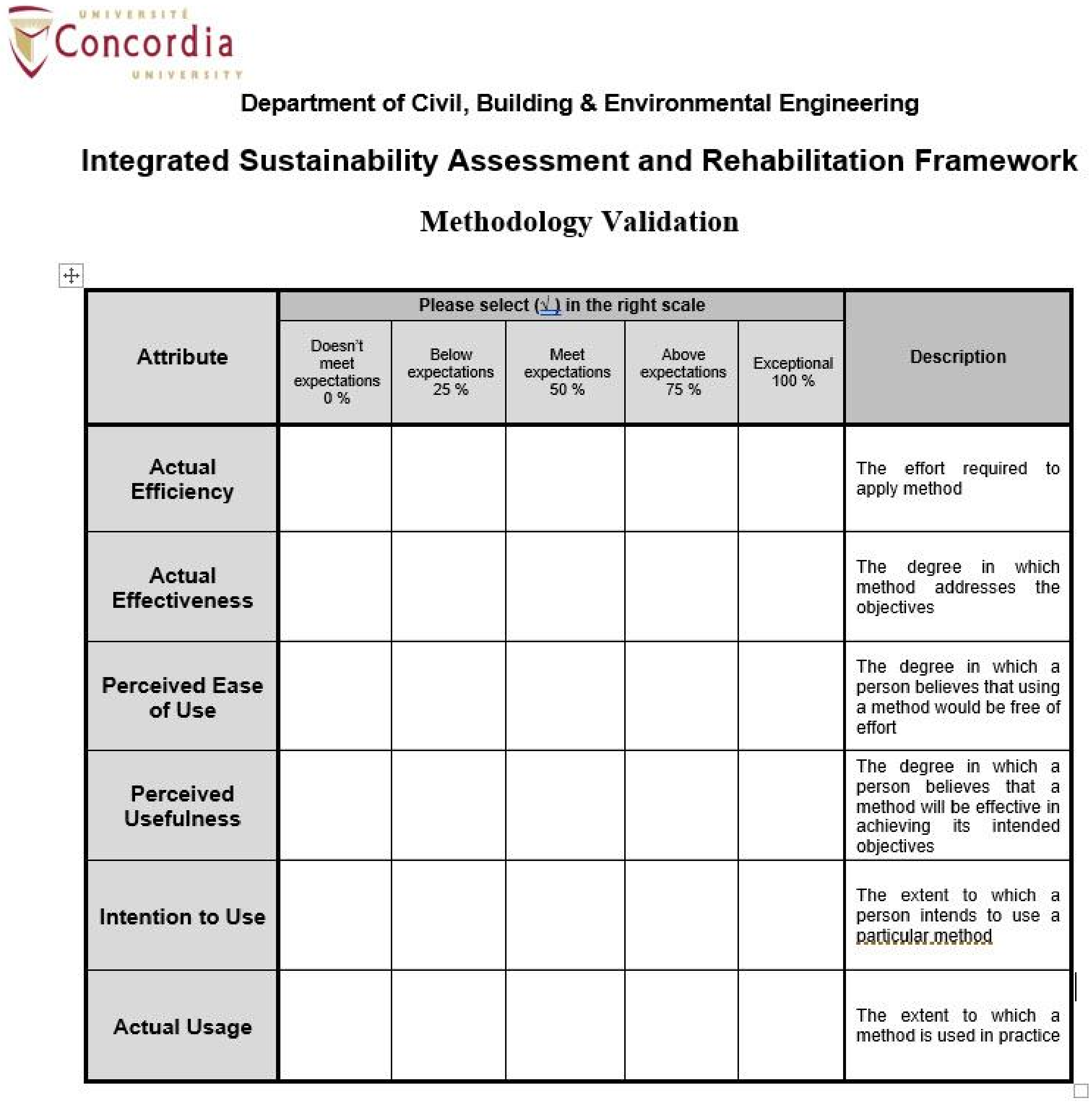


Figure 7.21: Validation Criteria (Eweda, 2012; Moody et al., 2003)

The validation process was performed through a structured interview with facility managers of Concordia University and sustainability experts. The interview began with a presentation showing the objectives of the research, the developed rating system and the assessment model, the optimization model and its output results, and ended with the description of the developed tool and its various features. Further, the presentation was followed by a session of questions in which they asked technical questions concerning the inputs and outputs of the model as well as the data required for the assessment. The participants showed their interest in the methodology and the tool and illustrated their importance. A questionnaire was distributed among the attendance to investigate how the industry might react towards the developed methodology and reflected the effectiveness of the developed models as illustrated in Figure 7.22. Each respondent to the questionnaire was asked to enter his perception about each of the six attributes ranging from “doesn’t meet expectations” to “exceptional”.



UNIVERSITÉ Concordia UNIVERSITY

Department of Civil, Building & Environmental Engineering

Integrated Sustainability Assessment and Rehabilitation Framework

Methodology Validation

Attribute	**Please select (√) in the right scale**					**Description**
	Doesn’t meet expectations 0 %	Below expectations 25 %	Meet expectations 50 %	Above expectations 75 %	Exceptional 100 %	
Actual Efficiency						The effort required to apply method
Actual Effectiveness						The degree in which method addresses the objectives
Perceived Ease of Use						The degree in which a person believes that using a method would be free of effort
Perceived Usefulness						The degree in which a person believes that a method will be effective in achieving its intended objectives
Intention to Use						The extent to which a person intends to use a particular method
Actual Usage						The extent to which a method is used in practice

Figure 7.22 : Questionnaire for Methodology Validation

The data collected from respondents were analysed to predict the acceptance of the developed methodology and tool and the intention to use in the future. After analysis, all six criteria scores achieved a score of 75%, which represents above expectations, and the criterion “perceived usefulness” achieved the highest score at 88% as shown in Figure 7.23.

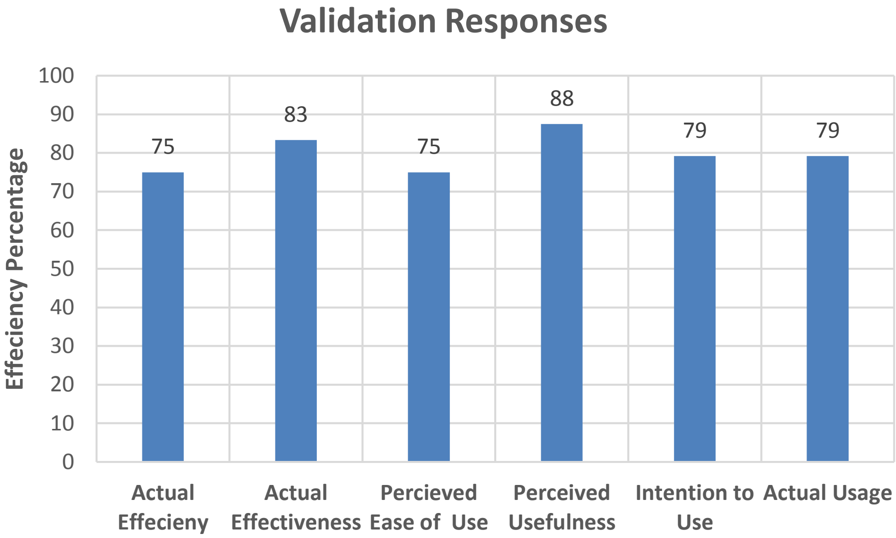


Figure 7.23: Methodology Validation Results

7.4.2 Validation of the Models

Energy is considered the most important criterion in the sustainability assessment (Al-Geelawe and Mohsin, 2015; Berardi, 2012; Perez-Lombard et al., 2008; Schwartz and Raslan, 2013); therefore, a comparison was performed concerning energy conservation assessment among selected rating systems and the developed one with the understanding that the more conservation required in particular rating system, the better it will be. Based on the simulation results that were demonstrated in the chapters of the case study and implementation of the models, a comparison had been conducted between five rating systems and the proposed one to determine the degree of improvement in energy performance that the proposed model can perform when compared with each of the selected rating systems as illustrated in Table 7.1. These rating systems are LEED, USA; LEED, Canada; Greenship, Indonesia; Green Building Index, Malaysia; and HK-BEAM, Hong Kong. These five rating systems have been selected because they utilize energy consumption in their assessment and not the amount of carbon dioxide emissions as in BREEAM. Moreover, all the rating systems in Table 7.1, except Green Building Index, have minimum energy performance prerequisites that achieve a certain amount of energy to start the assessment. The proposed rating system requires a fulfilment of a 19% of energy conservation above a baseline, which is the median of weathered normalized energy use intensity (EUI) in the Energy Star Portfolio Manager website. This concept of assessment is also adopted in LEED. The rationale for using this method in evaluation in the proposal is that the Energy Star Portfolio Manager possesses a large weather and energy consumption database of most of the countries with different weather stations in each city. Additionally, the aim of the proposed rating system is to set a unified basis of assessment in most of the sustainability categories, especially the energy category. Based on this argument, the energy simulation and the EUI are used for the assessment. The baseline EUI for USA, Canada, Indonesia, Malaysia and Hong Kong are 31,427.16, 16,403.85, 31,392.07, 31,430.63 and 31,430.63 MWh/year, respectively. The current EUI assessments of the five countries according to the simulation are higher than the median with 0.8%, 86.7%, 4.6%, 3.8% and 23.3%, respectively. Besides, the energy category is not rated in three out of the five rating systems, as the energy performance of the building does not fulfil the prerequisites, except for the Green Building Index and HK_BEAM. While applying the proposed rating for assessing energy category implementing the simulated consumption of the five countries, the energy category is not rated in four countries using the developed rating tool, although it is rated in Hong Kong. The amount of energy reduction required for the building to be rated using the developed rating system in USA, Canada, Indonesia, and Malaysia are 5,971.16, 17,338.9, 7400.53 and 7,166.75 MWh/year respectively, while the amount of energy reduction required to be rated with the other four rating systems of the aforementioned countries are 3,790.05, 13,393.3, 896.82 and 4,872.78 MWh/year respectively. Consequently, the proposed method surpasses the other rating systems in energy reduction and is capable of conserving 2,181.11, 3,945.60, 6,503.71 and 2,293.97 MWh/year than LEED USA, LEED Canada, Greenship Indonesia, and Green building index Malaysia respectively.

Table 7.1: Comparison of Energy Assessment – Developed Model vs. Existing Rating Systems

	USA		**Canada**		**Indonesia**		**Malaysia**		**Hong Kong**	
	LEED	**Proposed System (EUI)**	**LEED Canada**	**Proposed System (EUI)**	**Greenship**	**Proposed System (EUI)**	**Green building Index**	**Proposed System (EUI)**	**HK-BEAM**	**Proposed System (EUI)**
Energy consumption (MWh)	20,107	31,679	23,657	30,626	10,639	32,836	10,556	32,626	9,0745	24,101
Baseline consumption (MWh)	19,948	31,428	12,671	16,404	9,472	31,393	5,683	31,431	13,612	31,422
Compared to baseline	0.8% higher	0.8 % higher	86.7 % higher	86.7 % higher	9.5 % higher	4.6 % higher	47 % higher	3.8 % higher	33.3% lower	23.3 % lower
Existence of prerequisite	Exist	Exist	Exist	Exist	Exist	Exist	Not Exist	Exist	Exist	Exist
Prerequisite statement	19% above baseline	19% above baseline	19% above baseline	19% above baseline	250kWh/m^2. yr Or 5% reduction in next 6 months	19% above baseline	-	19% above baseline	150 % higher than baseline	19% above baseline
Rating status	Not rated	Not rated	Not rated	Not rated	Not rated	Not rated	Rated	Not rated	Rated	Rated
Energy value required	16,158	25,456	10,264	13,287	9,472	25,428	-	25,459	-	-
Energy reduction required to achieve base line (MWh)	3,790	5,971	13,393	17,339	897	7,401	4,873	7,167	-	-
Achieved score (1)	-	-	-	-	-	-	14	-	31	18
Max. available score (2)	35	-	35	-	36	-	38	-	38	63
Percentage between (1) and (2)	-	-	-	-	-	-	28.6 %	-	81.6 %	29.5 %

Furthermore, a sensitivity analysis has been conducted by utilizing the same achieved points for each of the four energy factors (see Chapter 5) while applying seven whole changes for the weight values of each factor, considering that the sum of the four values in each changing case is constrained to one. As shown in Figure 7.24, the values of the criteria sustainability index ratio (the ratio between the available sustainability indices of related factors to the maximum sustainability indices of the same factors) changes dramatically from 37.8% to 72.4%, which are represented on the upper horizontal axis. These differences emphasize the importance of introducing multi-level weighting scheme in the sustainability assessment, which reflects the impact of the local variations on the sustainability assessment process to obtain a realistic sustainability evaluation.

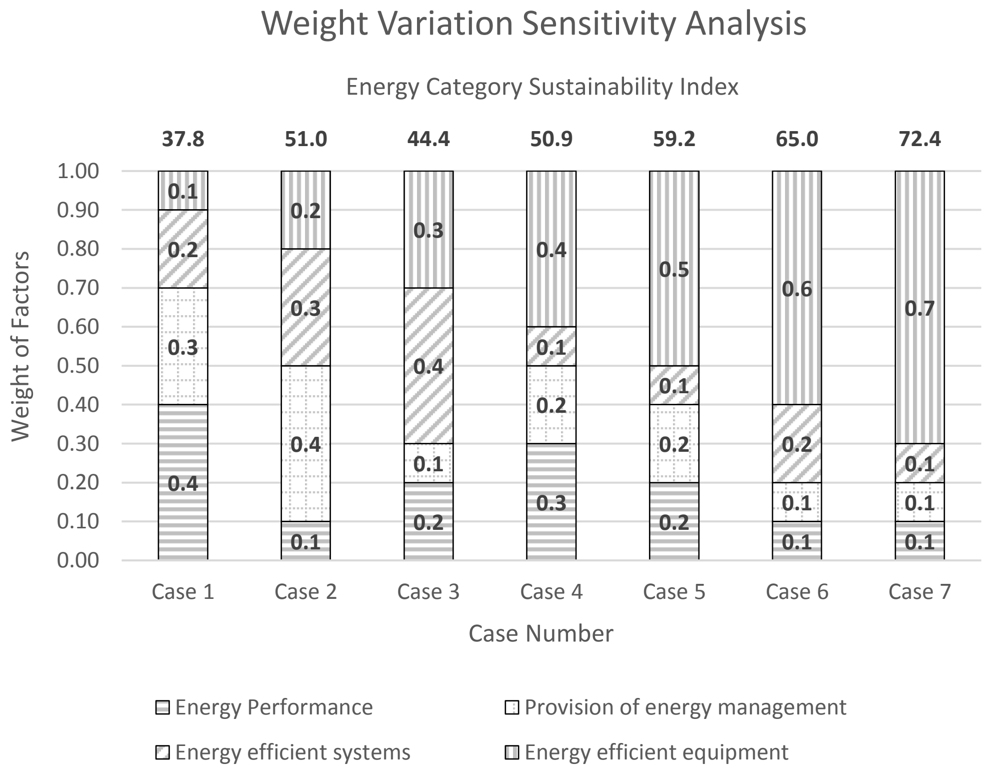


Figure 7.24: Different Weight Effect on the Sustainability Index of Energy Category

CHAPTER 8: CONCLUSION AND FUTURE RESEARCH

8.1 Research Conclusions

This research proposes an integrated sustainability assessment and rehabilitation framework for existing buildings. This framework takes into consideration the triple bottom line of sustainability, which includes environment, society and economy. These three pillars are integrated into the framework through the sustainability assessment attributes that have been carried out through several stages beginning with an extensive literature review. The developed framework can be considered as a two-tier decision-making tool for sustainable existing buildings. The first tier is the sustainability assessment model, which provides the decision-makers with a holistic current sustainability of their built properties to highlight the points of weakness and strength of their buildings for further upgrade. The second tier assists the decision-makers to effectively select from different optimal or near optimal alternatives to upgrade the overall sustainability of their building based on the LCC approach.

Several previous studies and some of the well-known and commonly used world rating tools for existing buildings have been explored to determine the most important aspects that influence the sustainability of buildings on a global scale. The rationale for proposing a global assessment tool is that the impacts of the building sector affect our environment in terms of water scarcity, resource depletion, fossil fuel runoff, greenhouse gas emissions, global warming etc. and every building is impacted irrespective of the location. In addition, many of the UN programs have begun to set legislations and agreements among several countries to improve the sustainability of their built environment and in turn reduce global warming. Further, many green building councils that are represented in their rating tools, such as LEED, BREEAM and Green Globes, are working on developing a unified standard to assess the sustainability of buildings on a global scale. Lastly, another reason is to allow decision-makers to assess and compare the performance of their globally scattered properties on a unified and consistent basis while taking into consideration regional variations.

The research also highlights the importance of the regional variations or the local context of every country or project. These variations must be expressed explicitly in the sustainability assessment without changing the consistency of the assessment attributes. This challenge is solved through the adoption of a two-level weighting scheme through the assessment process. The first level contains the weights of the main criteria, while the second contains the weights of the corresponding factors to each criterion. The weight of the assessment attributes was considered for two countries: Canada and Egypt. The reason for selecting these two countries is because they have different environmental, social and economic variations that can obviously be expressed in the diversity of the weight values for the same attributes. The data to assess the weight was gathered from questionnaires sent to a selection of experts in the two countries. The reliability of the collected data was checked by several statistical analyses, such as mean, median, standard deviation, coefficient of variance and Cronbach's alpha, which showed the consistency of the data as the values are above 0.7, the acceptable value for data reliability.

Moreover, after the consistency of the collected data was checked, the determination of weight process was performed utilizing the fuzzy TOPSIS technique. This technique has proved through many studies that it is capable, to some extent, to overcome the uncertainty accompanied with the collected data, and its ability to transform linguistic data into numerical crisp values. The research revealed the difference of weight for each assessment attribute (i.e. criteria and factors) between the two countries according to the local context of each.

Further, an assessment scale and criterion percentage threshold was determined by utilizing questionnaires and comparative analysis of the ranking and certification schemes of some existing rating tools. The developed scale represents the degree of sustainability of the assessed building. There are five proposed ranking scales which are pass, good, very good, excellent, and outstanding in which all correspond to sustainability percentages, respectively, as follows: > 50 to < 60; ≥60 to <70; ≥70 to <80; ≥80 to <90; and ≥90 to 100.

Hence, a sustainability assessment model was developed to evaluate the sustainability assessment of a building taking into consideration the three pillars of sustainability and reflecting the local context of each region, country or even project through the introduced weighing scheme. The model introduced three new terminologies, which are the BSI, BSI_{max} and the BSAR. These terms express the relativity in the assessment, which means that the final building sustainability assessment ratio is a ratio between the achieved BSI and the maximum BSI as illustrated in the methodology chapter. The advantage of this relativity is the consistency through the whole assessment process, which means that the assessment attributes and maximum available dedicated score for each attribute remains the same when applied to different local contexts. However, the only element that will be subjected to dynamic change is the weight value of each attribute, which addresses the variations of the impact of each assessment attribute from one country to another. This idea is advantageous when decision-makers want to compare the sustainability of their buildings located in different counties on a unified and consistent basis while regarding the local variations and its impact on sustainability.

Additionally, two case studies, which are the EV and the MB buildings at Concordia University in Montreal, were utilized to implement the developed assessment model. The data of the two buildings were gathered from the Concordia Facility Management Office and the Concordia University website. Additionally, the CAD plans, which were gathered from the Facility Management Office, were used to develop the BIM models and the energy simulation models. The BIM models built in Revit software were utilized to obtain information that was needed for the assessment. The energy simulation models that were developed utilizing the IES VE software were utilized for the energy consumption of the two buildings in Egypt and the improvement in energy consumption of each of the proposed rehabilitation alternatives. Further, each of the buildings were assessed two times (once using the Egyptian determined weighting scheme and the other using the Canadian scheme) to stand for the impact of weight and local context on the assessment as well as to prove the functionality of the proposed model and its global applications. The results reveal that the EV building BSAR using the Egyptian and Canadian weights are 51.32% and 59.73%, respectively, whereas these values for the MB building are 61.69% and 68.50%, respectively. These values indicate the impact of the local context on the assessment even if the same copy of the building is utilized. In addition, the results proved that the local context should be introduced explicitly in the sustainability assessment.

Next, an optimization algorithm was developed using artificial immune evolutionary optimization to provide the decision-makers with sets of alternatives to upgrade the overall building performance while considering a minimal LCC. The optimization model includes 134 decision variables that cover all the possible rehabilitation actions in each criterion. The input of the model is the sustainability score and LCC of each alternative in each decision variable. The output of the model as illustrated in CHAPTER 6 and CHAPTER 7 was different sets of non-dominated solutions that covered a wide range of BSAR values with minimal LCC. Each solution contains 134 alternatives that were determined by the optimization model. These solutions provide the decisions made with different trade-offs which can be implemented to upgrade the sustainability of the building.

Finally, the fruit of this research is the developed standalone tool: Integrated Sustainability Assessment and Rehabilitation Tool (IS-ART). This tool was developed using the visual basic programming language and links different software, such as Excel spreadsheets and Matlab. The tool provides decision-makers with a two-tier sustainability-based management tool. The first tier is the current state sustainability assessment of the building considering the local variations as well as seven criteria that address the overall sustainability of the building. The current assessment is beneficial to highlight the weak areas in the building performance that require greater attention and budget allocation. The second tier is the optimization module, which can address different sustainability-based rehabilitation alternatives to upgrade the sustainability of the building in which the decision-maker can benefit from in the future planning and management.

8.2 Research Challenges

There are some challenges encountered during development phase of this research that can be summarized as follows:

- The lack of some historical data and records concerning the water consumption, material recycling and waste disposal applicable to the case study.

- Unavailability of any software or a reference code using artificial immune system as an optimization engine.

8.3 Research Contributions

The research of the integrated sustainability assessment and rehabilitation framework for existing building covers different research areas related to the sustainability of buildings, which can be beneficial for the stakeholders, such as owners, facility managers and even tenants. Based upon the developed models, the research contributions can be summarized as follows:

1. **Identification of sustainability assessment attributes** that have a direct influence on the sustainability of existing buildings. These assessment attributes cover most of the sustainability areas of the existing buildings and can address the sustainability globally. In addition, the identified attributes of the proposed sustainability tool were shown to be more and cover many areas when compared with the well-known rating tools of LEED, BREEAM and HK-BEAM. Furthermore, no rating system tackled all the determined attributes in a single assessment framework; in which these attributes can provide a holistic and comprehensive assessment of the sustainability of buildings.
2. **Development of a comprehensive weight-based sustainability assessment model,** which can address the local context of the assessed building through weight determination of each attribute. Besides, the assessment model introduced a multi-level weighting scheme, which means criteria weight and factors weight that incorporates higher accuracy in addressing the impact of regional variations. As most of the existing rating tools introduce a single-level weighting scheme, the introduced model addresses the relativity of sustainability impact within different regions by introducing three terminologies: the

building sustainability index (BSI), maximum building sustainability index (BSI_{max}) and building sustainability assessment ratio (BSAR). The benefit of BSI and BSI_{max} is preserving standard assessment attributes and its maximum available scores to address consistency among assessment of different buildings in different regions while changing the weight of each attribute according to its impact on the sustainability based on local context.

3. **Development of a sustainability-based rehabilitation model,** which provides facility managers with a set of alternatives that can upgrade the sustainability of their buildings within minimal LCC. Additionally, the developed model is linked with a detailed calculation sheet that allows the user to introduce various rehabilitation alternatives for each decision variable. The Excel spreadsheet automatically calculates the score and the life cycle cost of each rehabilitation alternative based on the data entry of the user. In addition, the calculation table for each alternative allows the user to select the maintenance period or the changing frequency of each rehabilitation alternative, which shows more flexibility for the user, and to address the LCC accurately. These sheets are linked to the developed Matlab code to import and read the score and LCC of each alternative. Moreover, the developed model that considers both the sustainability upgrading and the life cycle cost of the upgrading alternatives was not developed previously.
4. **Developed Matlab code using artificial immune system evolutionary algorithm (AIS)**. This code is used to solve a multi-objective problem, which maximizes the BSAR and minimizes the LCC. The AIS has not been previously investigated or applied to solve an optimization problem related to the sustainability of buildings. The majority of the

previous research work uses a genetic algorithm in solving an optimization problem while others use ant colony and particle swarm optimization algorithms. In addition, there is no available software that uses AIS as a built-in optimization engine, therefore the developed algorithm was written from scratch using a Matlab software. Further, the AIS was selected as an optimization engine according to its robustness and capability to solve complicated combinatorial problems and its ability to find the global optimal or the near optimal solutions as stated in many studies.

5. **Developed an integrated sustainability assessment and rehabilitation tool** to assess the current sustainability of the building and proposed alternatives to upgrade the sustainability of buildings with minimal cost. This two-tier automated tool can be beneficial for the decision-makers for budget allocation and future planning. This tool addresses the weak areas of the building performance through different graphical representations in which decision-makers can dedicate additional resources to upgrade these areas. Moreover, the tool can propose alternatives to upgrade these areas considering the LCC. Most of the previous work uses a single-objective optimization problem, either to maximize the sustainability measures of the buildings or minimize the upgrade cost. This single-objective problem results in a single solution in a run while the proposed multi-objective problem provides a set of non-dominated solutions in a single run. Besides, the previous research work deals with quantitative areas, such as energy, water and material, whereas the proposed tool deals with both quantitative and qualitative sustainability areas.

8.4 Research Limitations

The developed models have some limitations that can be addressed as follows:

- The weights were determined in two levels (criteria and factors) and it is better to determine the weight for the sub-factor level. The impact of the sub-factors on the sustainability may change from region to another. However, introducing the weight of each sub-factor may increase the complexity of the assessment model.
- The weights of the respondents' reliability were constant in the fuzzy TOPSIS calculations and did not change according to the years of experience in the field sustainability as it was hard to gather information concerning to the years of expertise in the area of sustainability. This type of question should be added to the questionnaire to determine reliability weights based on the expert's experience in the field of sustainability.
- The economic aspects are embedded in calculation procedures in some of the assessment attributes as in the case of the material criterion. It is better to introduce this item explicitly as a separate criterion adding also the payback period as a factor in the economy criterion. This payback period addresses the savings that may result from the energy saving and water saving measures that exist in the building.
- The sustainability assessment model utilizes the current cost or the purchase cost, which it is more sustainable to include LCC analysis in the assessment of the sustainability of buildings.
- The planning horizon that is used in the calculation of LCC in the optimization model is 30 years, which is too short and needs to be extended to 50 or 60 years. In addition,

the planning horizon should be able to be changed by the user to add greater flexibility to the model.

- The data collected from the BIM model and energy simulation model is performed manually. It is better to use an automated interface that can link the Revit software, the IES VE software and the excel spreadsheets that are used for both sustainability assessment and the score calculations for the rehabilitation alternatives.

8.5 Recommendations for Future Research

As this research developed an integrated sustainability assessment and rehabilitation framework, any future research may enhance the structure of the developed models and in turn increase the reliability and the usability of the models and the developed tool. The recommendations for enhancement to the model and future research are summarized as follows:

8.5.1 Model Enhancement

- Increase the sample size of the data collected through questionnaires as this may enhance the values of the determined weights. As illustrated the responses collected from Egypt and Canada were 40 and 20 responses respectively. So, the reliability of the determined weights may increase by gathering and analyse more responses.
- Allow greater flexibility in the sustainability-based rehabilitation model to extend the planning horizon that is used to determine the LCC as this will increase the reliability of the model. For the calculation of the LCC in the optimization model, a planning horizon of 30 years was used. By extending the planning horizon to 50 or 60 years will provide more realistic output of the model.

- Introducing the economic aspect explicitly is recommended, as it is one of the three sustainability pillars. In addition, adding payback period analysis may enhance the structure of the sustainability assessment model. Also, the payback period will be advantageous if introduced as a constraint in the optimization model to highlight the economic effect of the sustainability upgrade.

8.5.2 Recommendations for Future Research

- Integrating BIM and energy simulation software with the calculation spreadsheet may enhance the automation of the developed tool. This integration can be performed by linking the BIM modelling software and the energy simulation ones along with the Excel spreadsheets to collect the data which is required for assessment automatically. This procedure will assure the accuracy of the data entry and may enhance the time consumed in this process and prevent the personal mistakes.
- Extending the weight determination to include additional countries and regions will be beneficial in enhancing the dynamism of the assessment model. This research is concerned with the weights of Canada and Egypt only, in order to assure the efficiency of the developed assessment tool more weights of other countries are needed to be introduced in the model. Also, an extended analysis and comparisons between the assessment results of other countries are required to be highlighted.
- More defining criteria for determining the weights of the assessments attributes are needed to be explored based on the regional contexts. Although, using the opinion of experts is beneficial for weight determination, but it may be biased in sometimes. Therefore, more research work is required in the area of weight determination to

provide the assessment model with the opportunity to change the weights based on predefined databases and defining criteria of the countries. This field of research will enhance the dynamism of the assessment model and will minimize the time and the drawbacks of using questionnaires in the determination of weights.

- Integrating BIM with the developed sustainability assessment model will be a new area to explore. This will speed up the process of the sustainability assessment and will improve the automation process of the data transfer. As a huge amount of information and diverse of data are both required to perform the sustainability of building, the BIM modelling is capable of providing all sort of data required for the assessment. Therefore. coding the assessment model in BIM packages, especially Revit, will be a great contribution.
- Introducing life cycle impact assessment (LCA) in the energy and material criterion will be advantageous in expressing the impacts of energy consumption and resources consumption in the sustainability assessment.
- Extend the sustainability assessment tool to include new constructions rather than only existing buildings as this may enhance the flexibility and usability of the tool. The developed tool was concerned with the assessment attributes of the existing buildings only. Hence, introducing other attributes that are concerned with the sustainability assessment of the other phases, e.g. construction and demolition or recycling phases will enrich the value of the tool and its contribution to the industry and to our environment as well.

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Appendix A : SAMPLE OF THE QUESTIONNAIRE

UNIVERSITÉ
Concordia
UNIVERSITY

Department of Civil, Building & Environmental Engineering

Adaptive Rating System for Sustainable Existing Buildings

Dear Sir/Madam

We would like to present our appreciation and thanks to you for taking part of your time to complete this questionnaire. This questionnaire aims to identify the degree of importance of the factors affecting the assessment of sustainability of existing buildings, as well as, identifying required rehabilitation actions to increase the score of sustainability of this type of buildings. This questionnaire is a part of the requirements for an academic research which is done under the supervision of Concordia University to establish an international adaptive rating system for sustainable buildings, as well as, a sustainable based rehabilitation model which aims to increase sustainability of buildings with the least cost among different attributes and variables. The information in the questionnaire will be used for academic research with complete commitment for absolute confidential to your information. Based on literature review and interviews with experts, the main factors that were found to have an effect on sustainability of existing buildings can be summarized as shown in Figure 1 below:

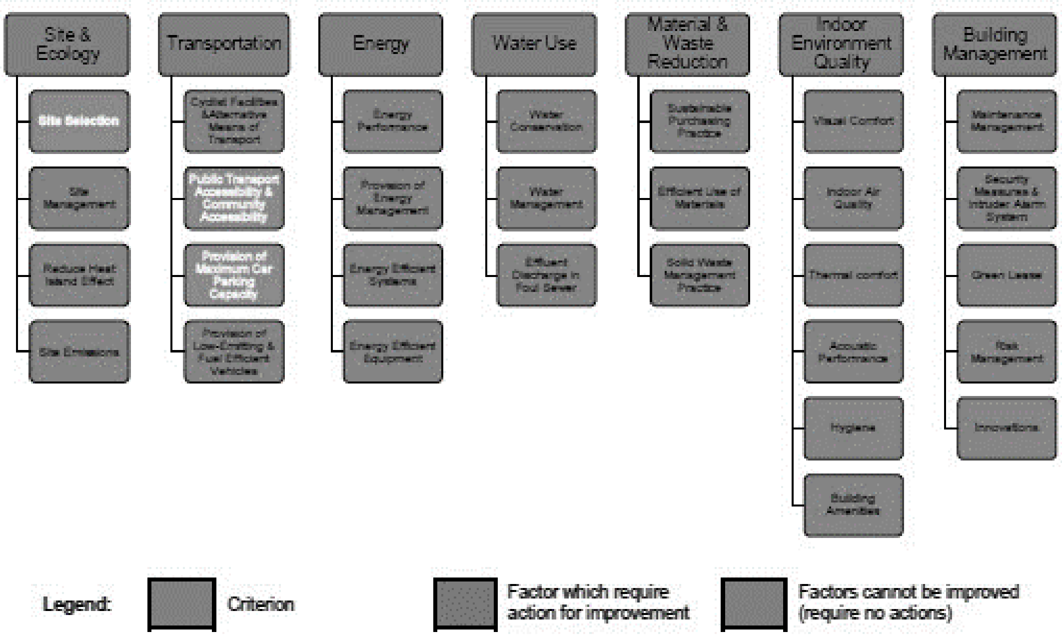


Figure 1: Factors affecting the assessment of sustainability of buildings

After reviewing the main factors listed; please kindly fill in parts (1) to (3) of this questionnaire.

PART (1): GENERAL INFORMATION

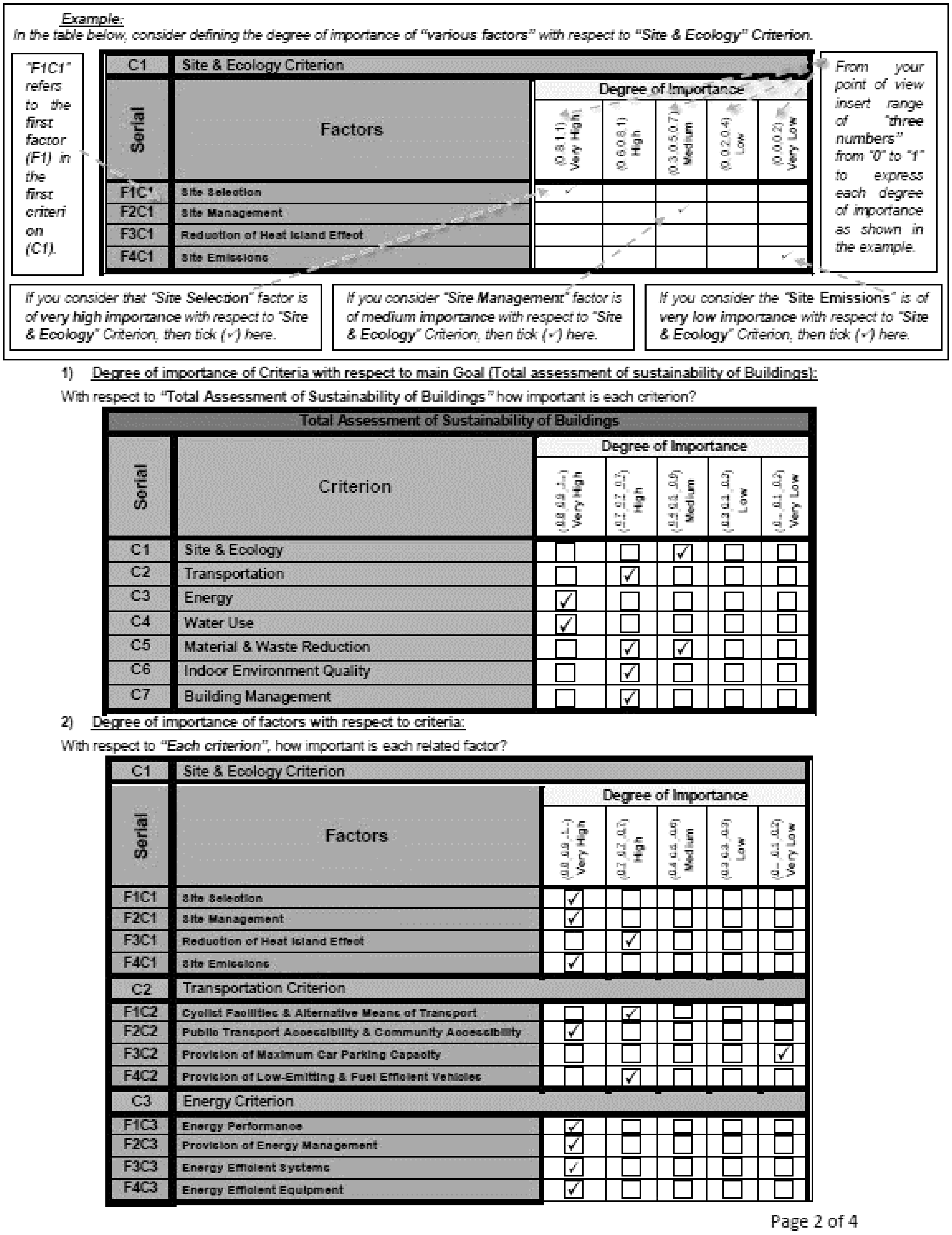
1) How do you describe your occupation?
- ☐ Civil Engineer
- ☐ Mechanical/Electrical Engineer
- ☐ Architect
- ☑ Others green building consultant

2) Which best describes your working experience?
- ☐ Less than 5 years
- ☐ 6 -10 years
- ☐ 11 – 15 years
- ☐ 16 – 20 years
- ☑ More than 20 years

PART (2): Degree of Importance of Criteria & Factors

In an attempt to determine the degree of importance of criteria & factors affecting the assessment of the sustainability of buildings, please kindly fill the tables in the next pages by ticking (✓) in the appropriate box from your point of view.

Figure A.1: Questionnaire Part 1 (Introduction and Respondent information)



Example:
In the table below, consider defining the degree of importance of "various factors" with respect to "Site & Ecology" Criterion.

"F1C1" refers to the first factor (F1) in the first criterion (C1).

C1	Site & Ecology Criterion					
		Degree of Importance				
Serial	Factors	(0.8,1,1) Very High	(0.6,0.8,1) High	(0.3,0.5,0.7) Medium	(0,0.2,0.4) Low	(0,0,0.2) Very Low
F1C1	Site Selection	✓				
F2C1	Site Management			✓		
F3C1	Reduction of Heat Island Effect					
F4C1	Site Emissions					✓

From your point of view insert range of "three numbers" from "0" to "1" to express each degree of importance as shown in the example.

If you consider that "Site Selection" factor is of very high importance with respect to "Site & Ecology" Criterion, then tick (✓) here.

If you consider "Site Management" factor is of medium importance with respect to "Site & Ecology" Criterion, then tick (✓) here.

If you consider the "Site Emissions" is of very low importance with respect to "Site & Ecology" Criterion, then tick (✓) here.

1) Degree of importance of Criteria with respect to main Goal (Total assessment of sustainability of Buildings):

With respect to "Total Assessment of Sustainability of Buildings" how important is each criterion?

Total Assessment of Sustainability of Buildings						
		Degree of Importance				
Serial	Criterion	[illegible] Very High	[illegible] High	[illegible] Medium	[illegible] Low	[illegible] Very Low
C1	Site & Ecology	☐	☐	☑	☐	☐
C2	Transportation	☐	☑	☐	☐	☐
C3	Energy	☑	☐	☐	☐	☐
C4	Water Use	☑	☐	☐	☐	☐
C5	Material & Waste Reduction	☐	☑	☑	☐	☐
C6	Indoor Environment Quality	☐	☑	☐	☐	☐
C7	Building Management	☐	☑	☐	☐	☐

2) Degree of importance of factors with respect to criteria:

With respect to "Each criterion", how important is each related factor?

C1	Site & Ecology Criterion					
		Degree of Importance				
Serial	Factors	[illegible] Very High	[illegible] High	[illegible] Medium	[illegible] Low	[illegible] Very Low
F1C1	Site Selection	☑	☐	☐	☐	☐
F2C1	Site Management	☑	☐	☐	☐	☐
F3C1	Reduction of Heat Island Effect	☐	☑	☐	☐	☐
F4C1	Site Emissions	☑	☐	☐	☐	☐
C2	Transportation Criterion					
F1C2	Cyclist Facilities & Alternative Means of Transport	☐	☑	☐	☐	☐
F2C2	Public Transport Accessibility & Community Accessibility	☑	☐	☐	☐	☐
F3C2	Provision of Maximum Car Parking Capacity	☐	☐	☐	☐	☑
F4C2	Provision of Low-Emitting & Fuel Efficient Vehicles	☐	☑	☐	☐	☐
C3	Energy Criterion					
F1C3	Energy Performance	☑	☐	☐	☐	☐
F2C3	Provision of Energy Management	☑	☐	☐	☐	☐
F3C3	Energy Efficient Systems	☑	☐	☐	☐	☐
F4C3	Energy Efficient Equipment	☑	☐	☐	☐	☐

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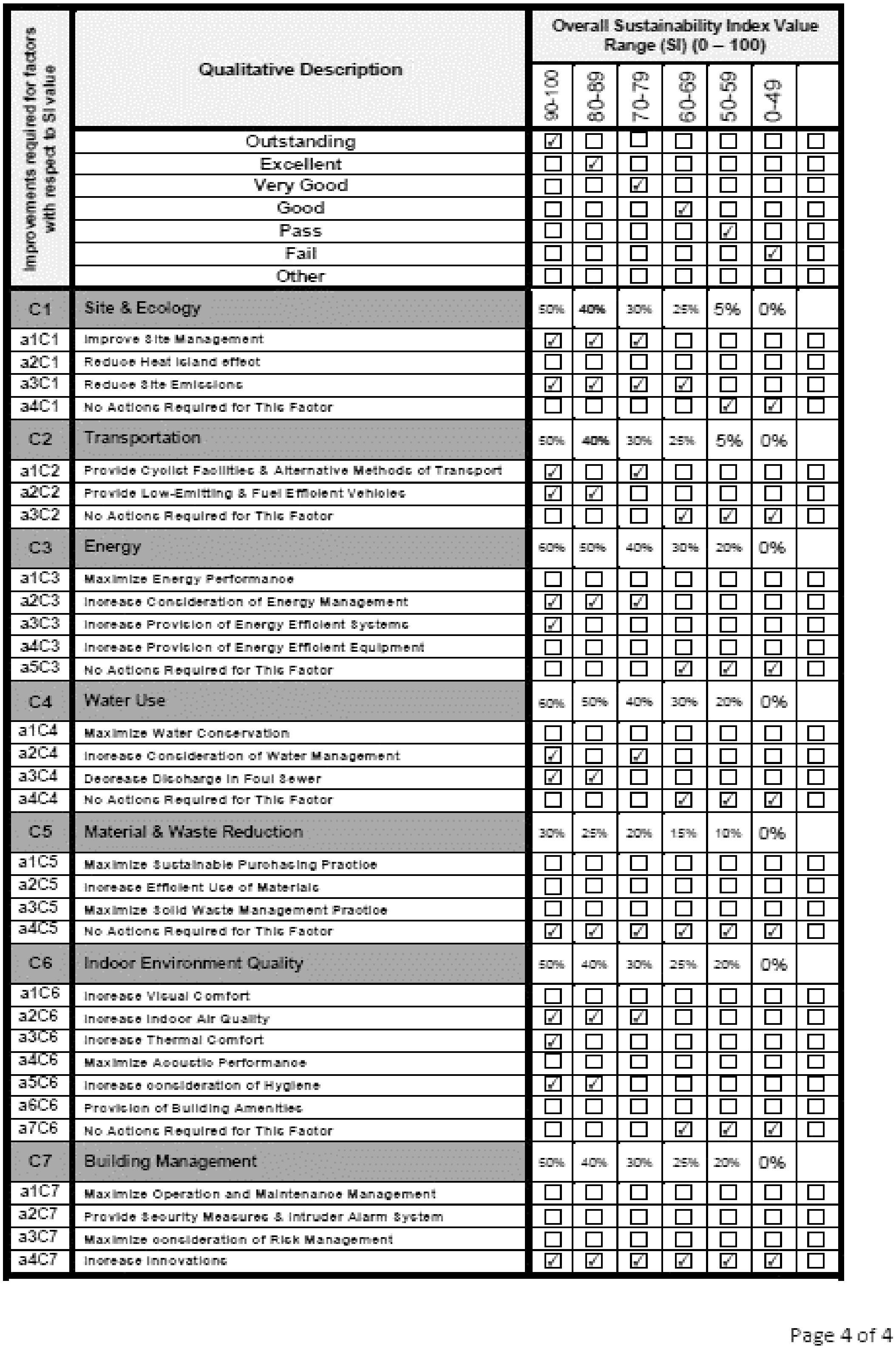
Figure A.2 : Questionnaire Part 2 (Criteria and Factors Degree of Importance)



Improvements required for factors with respect to SI value	Qualitative Description	Overall Sustainability Index Value Range (SI) (0 – 100)						
		90-100	80-89	70-79	60-69	50-59	0-49	
	Outstanding	☑	☐	☐	☐	☐	☐	☐
	Excellent	☐	☑	☐	☐	☐	☐	☐
	Very Good	☐	☐	☑	☐	☐	☐	☐
	Good	☐	☐	☐	☑	☐	☐	☐
	Pass	☐	☐	☐	☐	☑	☐	☐
	Fail	☐	☐	☐	☐	☐	☑	☐
	Other	☐	☐	☐	☐	☐	☐	☐
C1	Site & Ecology	50%	40%	30%	25%	5%	0%	
a1C1	Improve Site Management	☑	☑	☑	☐	☐	☐	☐
a2C1	Reduce Heat Island effect	☐	☐	☐	☐	☐	☐	☐
a3C1	Reduce Site Emissions	☑	☑	☑	☑	☐	☐	☐
a4C1	No Actions Required for This Factor	☐	☐	☐	☐	☑	☑	☐
C2	Transportation	50%	40%	30%	25%	5%	0%	
a1C2	Provide Cyclist Facilities & Alternative Methods of Transport	☑	☐	☑	☐	☐	☐	☐
a2C2	Provide Low-Emitting & Fuel Efficient Vehicles	☑	☑	☐	☐	☐	☐	☐
a3C2	No Actions Required for This Factor	☐	☐	☐	☑	☑	☑	☐
C3	Energy	60%	50%	40%	30%	20%	0%	
a1C3	Maximize Energy Performance	☐	☐	☐	☐	☐	☐	☐
a2C3	Increase Consideration of Energy Management	☑	☑	☑	☐	☐	☐	☐
a3C3	Increase Provision of Energy Efficient Systems	☑	☐	☐	☐	☐	☐	☐
a4C3	Increase Provision of Energy Efficient Equipment	☐	☐	☐	☐	☐	☐	☐
a5C3	No Actions Required for This Factor	☐	☐	☐	☑	☑	☑	☐
C4	Water Use	60%	50%	40%	30%	20%	0%	
a1C4	Maximize Water Conservation	☐	☐	☐	☐	☐	☐	☐
a2C4	Increase Consideration of Water Management	☑	☐	☑	☐	☐	☐	☐
a3C4	Decrease Discharge in Foul Sewer	☑	☑	☐	☐	☐	☐	☐
a4C4	No Actions Required for This Factor	☐	☐	☐	☑	☑	☑	☐
C5	Material & Waste Reduction	30%	25%	20%	15%	10%	0%	
a1C5	Maximize Sustainable Purchasing Practice	☐	☐	☐	☐	☐	☐	☐
a2C5	Increase Efficient Use of Materials	☐	☐	☐	☐	☐	☐	☐
a3C5	Maximize Solid Waste Management Practice	☐	☐	☐	☐	☐	☐	☐
a4C5	No Actions Required for This Factor	☑	☑	☑	☑	☑	☑	☐
C6	Indoor Environment Quality	50%	40%	30%	25%	20%	0%	
a1C6	Increase Visual Comfort	☐	☐	☐	☐	☐	☐	☐
a2C6	Increase Indoor Air Quality	☑	☑	☑	☐	☐	☐	☐
a3C6	Increase Thermal Comfort	☑	☐	☐	☐	☐	☐	☐
a4C6	Maximize Acoustic Performance	☐	☐	☐	☐	☐	☐	☐
a5C6	Increase consideration of Hygiene	☑	☑	☐	☐	☐	☐	☐
a6C6	Provision of Building Amenities	☐	☐	☐	☐	☐	☐	☐
a7C6	No Actions Required for This Factor	☐	☐	☐	☑	☑	☑	☐
C7	Building Management	50%	40%	30%	25%	20%	0%	
a1C7	Maximize Operation and Maintenance Management	☐	☐	☐	☐	☐	☐	☐
a2C7	Provide Security Measures & Intruder Alarm System	☐	☐	☐	☐	☐	☐	☐
a3C7	Maximize consideration of Risk Management	☐	☐	☐	☐	☐	☐	☐
a4C7	Increase Innovations	☑	☑	☑	☑	☑	☑	☐

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Figure A.3: Questionnaire Part 3 (Scale Determination)

Appendix B : BUILDING ENVELOPE CLEANING PRODUCT FACT SHEET

(for the assessment of sub-factor Building Exterior and Hardscape Management Plan)

Material Safety Data Sheet

Choisy
SOLUTIONS D'HYGIÈNE
HYGIENE SOLUTIONS

Section 1. Product and company identification

Product name : **ENVIRO-TECHNIK 7501** **Code** : 7501

Product description : Concentrated glass cleaner

Supplier/Manufacturer :
CHOISY LABORATORIES LTD. **Phone: (819) 228-5564**
390, St-Laurent East, P.O. Box 6 E-mail: info@choisy.com
Louiseville (Quebec) J5V 2L7 www.choisy.com

In case of emergency :
Quebec Poison Control Centre: (24 hours service)
-Quebec: (800) 463-5060 (no charge)
-All other places: (418) 656-8090
CANUTEC: (613) 996-6666 (collect)

Section 2. Hazards identification

Physical state : Liquid. [Transparent liquid.]

Signal word : CAUTION!

MAY CAUSE EYE AND SKIN IRRITATION.

See toxicological information (Section 11)

Section 3. Composition/information on ingredients

Name	CAS number	% by weight
- Alkyl polyglucoside	68515-73-1/ 110615-47-9	1 - 5

Section 4. First aid measures

Eye contact : Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention.

Skin contact : Flush contaminated skin with plenty of water. If irritation persists, get medical attention.

Inhalation : Move exposed person to fresh air. Get medical attention if symptoms occur.

Ingestion : If material has been swallowed, give small quantities of water to drink. Do not induce vomiting unless directed to do so by medical personnel. Get medical attention if adverse health effects persist or are severe.

Section 5. Fire-fighting measures

Flammability of the product : No specific fire or explosion hazard.

Flash point : Closed cup: >93.3°C [Pensky-Martens, closed cup.] [Product does not sustain combustion.]

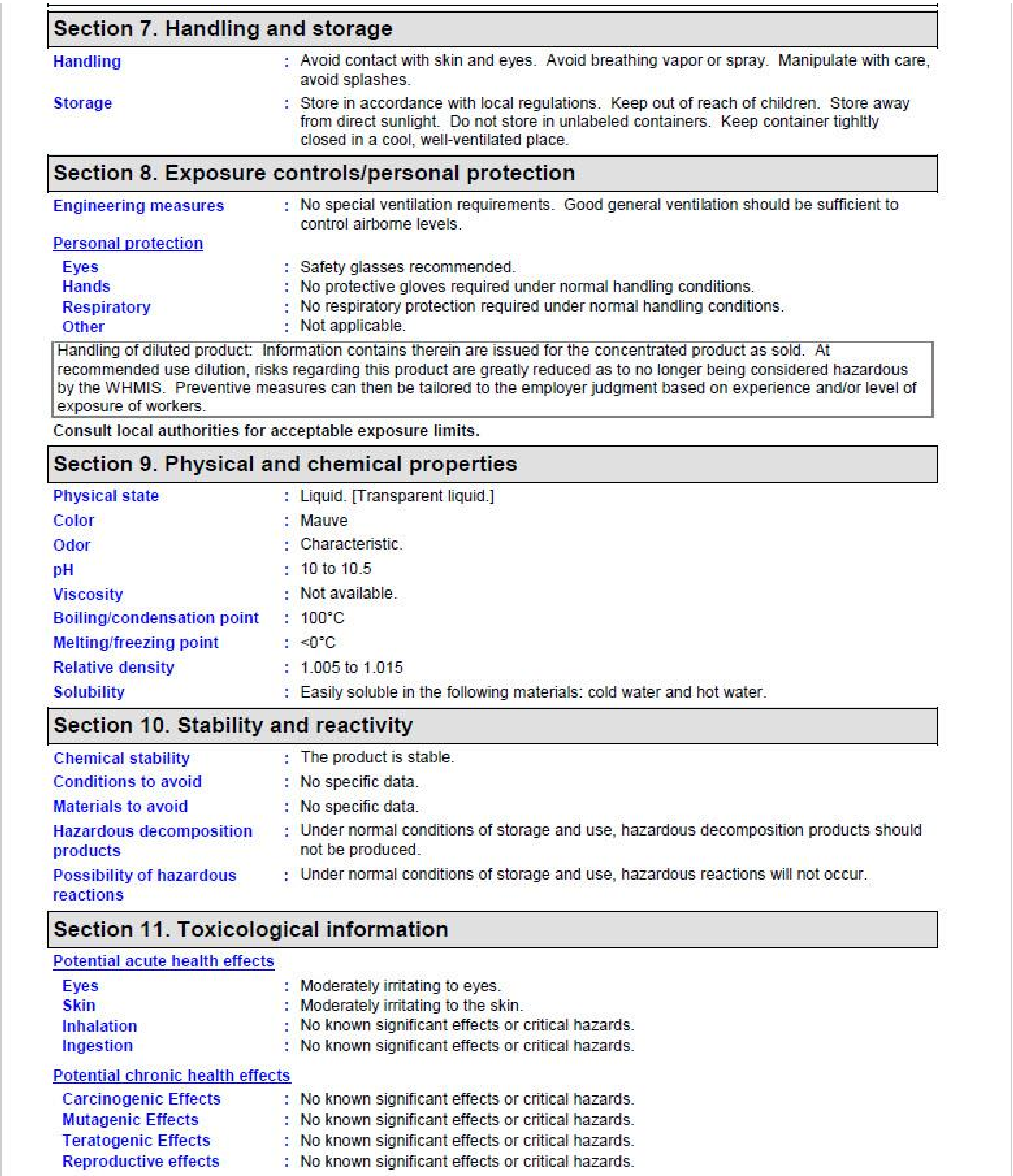
Extinguishing media : Use an extinguishing agent suitable for the surrounding fire.

Section 6. Accidental release measures

Personal precautions : No action shall be taken involving any personal risk or without suitable training. Do not touch or walk through spilled material.

Environmental precautions : Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods for cleaning up : Stop leak if without risk. Dilute with water and mop up if water-soluble or absorb with an inert dry material and place in an appropriate waste disposal container.



Section 7. Handling and storage

Handling	Avoid contact with skin and eyes. Avoid breathing vapor or spray. Manipulate with care, avoid splashes.
Storage	Store in accordance with local regulations. Keep out of reach of children. Store away from direct sunlight. Do not store in unlabeled containers. Keep container tighltly closed in a cool, well-ventilated place.

Section 8. Exposure controls/personal protection

Engineering measures	No special ventilation requirements. Good general ventilation should be sufficient to control airbome levels.
Personal protection	
Eyes	Safety glasses recommended.
Hands	No protective gloves required under normal handling conditions.
Respiratory	No respiratory protection required under normal handling conditions.
Other	Not applicable.

Handling of diluted product: Information contains therein are issued for the concentrated product as sold. At recommended use dilution, risks regarding this product are greatly reduced as to no longer being considered hazardous by the WHMIS. Preventive measures can then be tailored to the employer judgment based on experience and/or level of exposure of workers.

Consult local authorities for acceptable exposure limits.

Section 9. Physical and chemical properties

Physical state	Liquid. [Transparent liquid.]
Color	Mauve
Odor	Characteristic.
pH	10 to 10.5
Viscosity	Not available.
Boiling/condensation point	100°C
Melting/freezing point	<0°C
Relative density	1.005 to 1.015
Solubility	Easily soluble in the following materials: cold water and hot water.

Section 10. Stability and reactivity

Chemical stability	The product is stable.
Conditions to avoid	No specific data.
Materials to avoid	No specific data.
Hazardous decomposition products	Under normal conditions of storage and use, hazardous decomposition products should not be produced.
Possibility of hazardous reactions	Under normal conditions of storage and use, hazardous reactions will not occur.

Section 11. Toxicological information

Potential acute health effects	
Eyes	Moderately irritating to eyes.
Skin	Moderately irritating to the skin.
Inhalation	No known significant effects or critical hazards.
Ingestion	No known significant effects or critical hazards.
Potential chronic health effects	
Carcinogenic Effects	No known significant effects or critical hazards.
Mutagenic Effects	No known significant effects or critical hazards.
Teratogenic Effects	No known significant effects or critical hazards.
Reproductive effects	No known significant effects or critical hazards.

Section 11. Toxicological information

Sensitizer : No known significant effects or critical hazards.

Toxicity data

Product/ingredient name	Test	Species	Result
- Alkyl polyglucoside	LD50 Dermal	Rat	>2000 mg/kg
	LD50 Oral	Rat	>5000 mg/kg

Section 12. Ecological information

Ecotoxicity : No known significant effects or critical hazards.
Phosphate-free product.

Biodegradability : Organic components are readily biodegradable based on OECD tests of the 301 serie (A to F) Eco-Logo certified product.

Section 13. Disposal considerations

Waste disposal : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

Consult your local or regional authorities.

Section 14. Transport information

Regulatory information	UN number	Proper shipping name	Classes	PG*	Label	Additional information
TDG Class	Not regulated.	-	-	-		**Remarks** Not regulated product (TDG)

PG* : Packing group

Section 15. Regulatory information

WHMIS (Canada) : D-2B

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations.

Section 16. Other information

Date of issue : 2016-06-22.

Prepared by:Department of Research and Development of Choisy Laboratories Ltd. **Phone: (819) 228-5564**

Notice to reader

Appendix C : WEIGHT DETERMINATION PROCEDURES

Table C.1: Fuzzification of Criteria Responses of the Canadian Respondents

	Site and Ecology Criterion				**Transportation Criterion**				**Energy Criterion**				**Water Use Criterion**				**Material and Waste Reduction Criterion**				**Indoor Environmental Quality Criterion**				**Building Management Criterion**			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	**Low**	0.20	0.31	0.42	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
2	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66
3	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**Low**	0.20	0.31	0.42	**Low**	0.20	0.31	0.42	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00
4	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**Low**	0.20	0.31	0.42	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
5	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66
6	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
7	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Low**	0.20	0.31	0.42	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87
8	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66
9	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66
10	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
11	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
12	**Medium**	0.42	0.53	0.66	**Low**	0.20	0.31	0.42	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66
13	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
14	**Medium**	0.42	0.53	0.66	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
15	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00
16	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87
17	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Medium**	0.42	0.53	0.66	**Very High**	0.82	0.94	1.00
18	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87
19	**Medium**	0.42	0.53	0.66	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Low**	0.20	0.31	0.42	**Low**	0.20	0.31	0.42	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00
20	**High**	0.64	0.76	0.87	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87	**Very High**	0.82	0.94	1.00	**Very High**	0.82	0.94	1.00	**High**	0.64	0.76	0.87

Table C.2: Normalized and Weighted Matrices for Criteria (Canadian Samples)

Serial	Site and Ecology Criterion						Transportation Criterion						Energy Criterion						Water Use Criterion					
	Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix		
1	0.20	0.31	0.42	0.010	0.016	0.021	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.021	0.024	0.025
2	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.82	0.94	1.00	0.021	0.024	0.025
3	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033	0.20	0.31	0.42	0.005	0.008	0.011
4	0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.016	0.019	0.022
5	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.011	0.013	0.017
6	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.016	0.019	0.022
7	0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.82	0.94	1.00	0.021	0.024	0.025
8	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.01	0.09	0.23	0.000	0.002	0.006
9	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.20	0.31	0.42	0.005	0.008	0.011
10	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.021	0.024	0.025
11	0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.021	0.024	0.025
12	0.42	0.53	0.66	0.021	0.027	0.033	0.20	0.31	0.42	0.010	0.016	0.021	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.021	0.024	0.025
13	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.016	0.019	0.022
14	0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.021	0.024	0.025
15	0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.021	0.024	0.025
16	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.016	0.019	0.022
17	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.021	0.024	0.025
18	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.016	0.019	0.022
19	0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.011	0.013	0.017
20	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.016	0.019	0.022

Continue Table C.2: Normalized and Weighted Matrices for Criteria (Canadian Samples)

Serial	**Material and Waste Reduction Criterion**						**Indoor Environmental Quality Criterion**						**Building Management Criterion**					
	Normalized Matrix			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**		
1	0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.6	0.8	0.9	0.032	0.038	0.044
2	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.5	0.6	0.8	0.024	0.030	0.038
3	0.20	0.31	0.42	0.010	0.016	0.021	0.64	0.76	0.87	0.032	0.038	0.044	0.8	0.9	1.0	0.041	0.047	0.050
4	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.8	0.9	1.0	0.041	0.047	0.050
5	0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033	0.4	0.5	0.7	0.021	0.027	0.033
6	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.8	0.9	1.0	0.041	0.047	0.050
7	0.48	0.61	0.76	0.024	0.030	0.038	0.48	0.61	0.76	0.024	0.030	0.038	0.7	0.9	1.0	0.037	0.044	0.050
8	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.4	0.5	0.7	0.021	0.027	0.033
9	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.4	0.5	0.7	0.021	0.027	0.033
10	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.6	0.8	0.9	0.032	0.038	0.044
11	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.6	0.8	0.9	0.032	0.038	0.044
12	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.4	0.5	0.7	0.021	0.027	0.033
13	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.8	0.9	1.0	0.041	0.047	0.050
14	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.6	0.8	0.9	0.032	0.038	0.044
15	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.8	0.9	1.0	0.041	0.047	0.050
16	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.6	0.8	0.9	0.032	0.038	0.044
17	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.8	0.9	1.0	0.041	0.047	0.050
18	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.6	0.8	0.9	0.032	0.038	0.044
19	0.20	0.31	0.42	0.010	0.016	0.021	0.64	0.76	0.87	0.032	0.038	0.044	0.8	0.9	1.0	0.041	0.047	0.050
20	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.6	0.8	0.9	0.032	0.038	0.044

Table C.3: Defuzzification of Criteria (Canadian Sample)

Serial	**Site and Ecology Criterion**			**Transportation Criterion**			**Energy Criterion**			**Water Use Criterion**			**Material and Waste Reduction**			**Indoor Environmental**			**Building Management**		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mea**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.013	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006
2	0.019	0.004	0.011	0.013	0.010	0.006	0.023	0.000	0.015	0.023	0.000	0.015	0.019	0.004	0.011	0.023	0.000	0.015	0.008	0.015	0.000
3	0.023	0.000	0.015	0.013	0.010	0.006	0.019	0.004	0.011	0.008	0.015	0.000	0.008	0.015	0.000	0.023	0.000	0.015	0.019	0.004	0.011
4	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006
5	0.003	0.020	0.000	0.013	0.010	0.011	0.023	0.000	0.020	0.013	0.010	0.011	0.003	0.020	0.000	0.019	0.004	0.016	0.003	0.020	0.000
6	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006	0.013	0.010	0.000
7	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
8	0.023	0.000	0.020	0.013	0.010	0.011	0.019	0.004	0.016	0.003	0.020	0.000	0.013	0.010	0.011	0.013	0.010	0.011	0.023	0.000	0.020
9	0.019	0.004	0.016	0.003	0.020	0.000	0.023	0.000	0.020	0.008	0.015	0.005	0.013	0.010	0.011	0.023	0.000	0.020	0.019	0.004	0.016
10	0.013	0.010	0.006	0.008	0.015	0.000	0.013	0.010	0.006	0.023	0.000	0.015	0.023	0.000	0.015	0.013	0.010	0.006	0.023	0.000	0.015
11	0.013	0.010	0.006	0.013	0.010	0.006	0.023	0.000	0.015	0.023	0.000	0.015	0.013	0.010	0.006	0.008	0.015	0.000	0.019	0.004	0.011
12	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006
13	0.019	0.004	0.011	0.008	0.015	0.000	0.019	0.004	0.011	0.019	0.004	0.011	0.023	0.000	0.015	0.023	0.000	0.015	0.019	0.004	0.011
14	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
15	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
16	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
17	0.023	0.000	0.010	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010
18	0.023	0.000	0.020	0.013	0.010	0.011	0.013	0.010	0.011	0.019	0.004	0.016	0.008	0.015	0.005	0.003	0.020	0.000	0.013	0.010	0.011
19	0.023	0.000	0.020	0.019	0.004	0.016	0.019	0.004	0.016	0.013	0.010	0.011	0.003	0.020	0.000	0.023	0.000	0.020	0.023	0.000	0.020
20	0.019	0.004	0.011	0.013	0.010	0.006	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000	0.023	0.000	0.015	0.008	0.015	0.000
$\Sigma D^+/ \Sigma D^-$		**0.248**	**0.172**		**0.205**	**0.214**		**0.036**	**0.383**		**0.216**	**0.203**		**0.214**	**0.205**		**0.128**	**0.291**		**0.147**	**0.272**
Closeness coefficient		**0.410**			**0.510**			**0.915**			**0.484**			**0.490**			**0.694**			**0.649**	
Normalized weight		**0.099**			**0.123**			**0.220**			**0.117**			**0.118**			**0.167**			**0.156**	

Table C.4: Fuzzification of the Factors of Site and Ecology Criterion Responses of the Egyptian Respondents

Serial	Previous Consideration of Site				Site Management				Reduce Heat Island Effect				Site Emissions			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
2	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
3	Very High	0.82	0.94	1.00	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
4	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
5	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42	Very High	0.82	0.94	1.00	Very Low	0.01	0.09	0.23
6	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42
7	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
8	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very Low	0.01	0.09	0.23	High	0.64	0.76	0.87
9	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
10	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
11	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
12	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
13	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
14	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
15	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
16	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
17	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42
18	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
19	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very Low	0.01	0.09	0.23
20	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Low	0.20	0.31	0.42
21	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
22	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
23	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
24	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
25	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
26	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
27	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
28	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
29	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66
30	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
31	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42
32	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42
33	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
34	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
35	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
36	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
37	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
38	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
39	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
40	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66

Table C.5: Normalized and Weighted Matrices for the Factors of Site and Ecology Criterion (Egyptian Samples)

Previous Consideration of Site						**Site Management**						**Reduce Heat Island Effect**						**Site Emissions**					
Normalized Matrix			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**		
0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.20	0.31	0.42	0.005	0.008	0.011	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.20	0.31	0.42	0.005	0.008	0.011	0.20	0.31	0.42	0.005	0.008	0.011	0.82	0.94	1.00	0.021	0.024	0.025	0.01	0.09	0.23	0.000	0.002	0.006
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.23	0.36	0.48	0.006	0.009	0.012
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.01	0.09	0.23	0.000	0.002	0.006	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025
0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.20	0.31	0.42	0.005	0.008	0.011
0.74	0.87	1.00	0.018	0.022	0.025	0.23	0.36	0.48	0.006	0.009	0.012	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.01	0.09	0.23	0.000	0.002	0.006
0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.20	0.31	0.42	0.005	0.008	0.011
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.20	0.31	0.42	0.005	0.008	0.011	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.20	0.31	0.42	0.005	0.008	0.011	0.20	0.31	0.42	0.005	0.008	0.011
0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.23	0.36	0.48	0.006	0.009	0.012
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017

Table C.6: Defuzzification of the Factors of Site and Ecology Criterion (Egyptian Sample)

Serial	**Previous Consideration of Site**			**Site Management**			**Reduce Heat Island Effect**			**Site Emissions**		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.013	0.010	0.000
2	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
3	0.023	0.000	0.015	0.008	0.015	0.000	0.019	0.004	0.011	0.013	0.010	0.006
4	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
5	0.008	0.015	0.005	0.008	0.015	0.005	0.023	0.000	0.020	0.003	0.020	0.000
6	0.015	0.006	0.007	0.022	0.000	0.013	0.015	0.006	0.007	0.009	0.013	0.000
7	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
8	0.023	0.000	0.020	0.013	0.010	0.011	0.003	0.020	0.000	0.019	0.004	0.016
9	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006
10	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010
11	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000	0.022	0.000	0.006
12	0.013	0.010	0.000	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010
13	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
14	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
15	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
16	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.013	0.010	0.000
17	0.023	0.000	0.015	0.019	0.004	0.011	0.013	0.010	0.006	0.008	0.015	0.000
18	0.022	0.000	0.013	0.009	0.013	0.000	0.015	0.006	0.007	0.022	0.000	0.013
19	0.023	0.000	0.020	0.019	0.004	0.016	0.019	0.004	0.016	0.003	0.020	0.000
20	0.023	0.000	0.015	0.013	0.010	0.006	0.019	0.004	0.011	0.008	0.015	0.000
21	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
22	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
23	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
24	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
25	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
26	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.013	0.010	0.000
27	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010	0.013	0.010	0.000
28	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000
29	0.023	0.000	0.015	0.013	0.010	0.006	0.008	0.015	0.000	0.013	0.010	0.006
30	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006
31	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000	0.008	0.015	0.000
32	0.022	0.000	0.013	0.015	0.006	0.007	0.015	0.006	0.007	0.009	0.013	0.000
33	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.013	0.010	0.000
34	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.013	0.010	0.000
35	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.013	0.010	0.000
36	0.023	0.000	0.010	0.023		0.010	0.013	0.010	0.000	0.019	0.004	0.006
37	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
38	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.013	0.010	0.000
39	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
40	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.013	0.010	0.000
$\Sigma D^+ / \Sigma D^-$		**0.069**	**0.229**		**0.175**	**0.218**		**0.253**	**0.139**		**0.277**	**0.115**
Closeness coefficient		**0.768**			**0.555**			**0.354**			**0.294**	
Normalized weight		**0.390**			**0.281**			**0.180**			**0.149**	

Table C.7: Fuzzification of the Factors of Site and Ecology Criterion Responses of the Canadian Respondents

Serial	Previous Consideration of Site				Site Management				Reduce Heat Island Effect				Site Emissions			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	Low	0.2	0.3	0.4	Medium	0.4	0.5	0.7	Very High	0.8	0.9	1.0	High	0.6	0.8	0.9
2	High	0.6	0.8	0.9	High	0.6	0.8	0.9	High	0.6	0.8	0.9	High	0.6	0.8	0.9
3	High	0.6	0.8	0.9	Very High	0.8	0.9	1.0	Medium	0.4	0.5	0.7	Low	0.2	0.3	0.4
4	Medium	0.4	0.5	0.7	Medium	0.4	0.5	0.7	Very High	0.8	0.9	1.0	Low	0.2	0.3	0.4
5	High	0.6	0.8	0.9	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0	Medium	0.4	0.5	0.7
6	High	0.6	0.8	0.9	Medium	0.4	0.5	0.7	High	0.6	0.8	0.9	High	0.6	0.8	0.9
7	High	0.6	0.8	0.9	Medium	0.4	0.5	0.7	High	0.6	0.8	0.9	Low	0.2	0.3	0.4
8	High	0.6	0.8	0.9	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0
9	High	0.6	0.8	0.9	High	0.6	0.8	0.9	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0
10	High	0.6	0.8	0.9	Medium	0.4	0.5	0.7	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0
11	Medium	0.4	0.5	0.7	High	0.6	0.8	0.9	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0
12	Medium	0.4	0.5	0.7	Low	0.2	0.3	0.4	Very High	0.8	0.9	1.0	High	0.6	0.8	0.9
13	Medium	0.4	0.5	0.7	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0	Medium	0.4	0.5	0.7
14	Medium	0.4	0.5	0.7	Medium	0.4	0.5	0.7	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0
15	Medium	0.4	0.5	0.7	High	0.6	0.8	0.9	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0
16	High	0.6	0.8	0.9	High	0.6	0.8	0.9	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0
17	High	0.6	0.8	0.9	Very High	0.8	0.9	1.0	High	0.6	0.8	0.9	High	0.6	0.8	0.9
18	Very High	0.8	0.9	1.0	High	0.6	0.8	0.9	High	0.6	0.8	0.9	Very High	0.8	0.9	1.0
19	Very High	0.8	0.9	1.0	Very High	0.8	0.9	1.0	Low	0.2	0.3	0.4	Very Low	0.0	0.1	0.2
20	High	0.6	0.8	0.9	High	0.6	0.8	0.9	High	0.6	0.8	0.9	Very High	0.8	0.9	1.0

Table C.8: Normalized and Weighted Matrices the Factors of Site and Ecology Criterion (Canadian Sample)

Previous Consideration of Site						**Site Management**						**Reduce Heat Island Effect**						**Site Emissions**					
Normalized Matrix			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**		
0.20	0.31	0.42	0.010	0.016	0.021	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033	0.20	0.31	0.42	0.010	0.016	0.021
0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.20	0.31	0.42	0.010	0.016	0.021
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033
0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.23	0.36	0.48	0.011	0.018	0.024
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.42	0.53	0.66	0.021	0.027	0.033	0.20	0.31	0.42	0.010	0.016	0.021	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033
0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.20	0.31	0.42	0.010	0.016	0.021	0.01	0.09	0.23	0.001	0.005	0.012
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050

Table C.9: Defuzzification of the Factors of Site and Ecology Criterion (Canadian Sample)

Serial	**Previous Consideration of Site**			**Site Management**			**Reduce Heat Island Effect**			**Site Emissions**		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.016	0.031	0.000	0.027	0.019	0.011	0.046	0.000	0.031	0.038	0.008	0.022
2	0.043	0.000	0.000	0.043	0.000	0.000	0.043	0.000	0.000	0.043	0.000	0.000
3	0.038	0.008	0.022	0.046	0.000	0.031	0.027	0.019	0.011	0.016	0.031	0.000
4	0.027	0.019	0.011	0.027	0.019	0.011	0.046	0.000	0.031	0.016	0.031	0.000
5	0.038	0.008	0.011	0.046	0.000	0.019	0.046	0.000	0.019	0.027	0.019	0.000
6	0.043	0.000	0.013	0.031	0.013	0.000	0.043	0.000	0.013	0.043	0.000	0.013
7	0.043	0.000	0.026	0.031	0.013	0.013	0.043	0.000	0.026	0.018	0.026	0.000
8	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008	0.046	0.000	0.008
9	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
10	0.038	0.008	0.011	0.027	0.019	0.000	0.046	0.000	0.019	0.046	0.000	0.019
11	0.027	0.019	0.000	0.038	0.008	0.011	0.046	0.000	0.019	0.046	0.000	0.019
12	0.027	0.019	0.011	0.016	0.031	0.000	0.046	0.000	0.031	0.038	0.008	0.022
13	0.027	0.019	0.000	0.046	0.000	0.019	0.046	0.000	0.019	0.027	0.019	0.000
14	0.027	0.019	0.000	0.027	0.019	0.000	0.046	0.000	0.019	0.046	0.000	0.019
15	0.027	0.019	0.000	0.038	0.008	0.011	0.046	0.000	0.019	0.046	0.000	0.019
16	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
17	0.038	0.008	0.000	0.046	0.000	0.008	0.038	0.008	0.000	0.038	0.008	0.000
18	0.046	0.000	0.008	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008
19	0.046	0.000	0.041	0.046	0.000	0.041	0.016	0.031	0.010	0.006	0.041	0.000
20	0.038	0.008	0.000	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008
$\Sigma D^+ / \Sigma D^-$		**0.212**	**0.154**		**0.182**	**0.184**		**0.075**	**0.291**		**0.190**	**0.175**
Closeness coefficient		**0.421**			**0.502**			**0.796**			**0.480**	
Normalized weight		**0.191**			**0.228**			**0.362**			**0.218**	

Table C.10: Fuzzification of the Factors of Transportation Criterion's Responses of the Egyptian Respondents

Serial	**Alternative Transportation Means**				**Public Transport Accessibility**				**Car Parking Capacity**				**Fuel Efficient Vehicle**			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
2	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
3	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
4	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
5	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
6	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
7	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
8	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very Low	0.01	0.09	0.23
9	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
10	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
11	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
12	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
13	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
14	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
15	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
16	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
17	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	Very Low	0.01	0.09	0.23
18	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
19	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
20	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
21	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
22	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
23	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
24	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
25	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
26	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
27	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
28	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
29	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
30	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
31	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
32	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
33	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
34	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	High	0.64	0.76	0.87
35	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	High	0.64	0.76	0.87
36	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
37	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
38	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
39	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
40	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66

Table C.11: Normalized and Weighted Matrices for the Factors of Transportation Criterion (Egyptian Sample)

Alternative Transportation Means						**Public Transport Accessibility**						**Car Parking Capacity**						**Fuel Efficient Vehicle**					
Normalized Matrix			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**		
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025
0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.01	0.09	0.23	0.000	0.002	0.006
0.20	0.31	0.42	0.005	0.008	0.011	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.23	0.36	0.48	0.006	0.009	0.012	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.23	0.36	0.48	0.006	0.009	0.012	0.01	0.10	0.26	0.000	0.003	0.007
0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025
0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.20	0.31	0.42	0.005	0.008	0.011	0.20	0.31	0.42	0.005	0.008	0.011	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.30	0.47	0.64	0.008	0.012	0.016	0.30	0.47	0.64	0.008	0.012	0.016	0.64	0.80	1.00	0.016	0.020	0.025	0.64	0.80	1.00	0.016	0.020	0.025
0.20	0.31	0.42	0.005	0.008	0.011	0.20	0.31	0.42	0.005	0.008	0.011	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.48	0.61	0.76	0.012	0.015	0.019	0.23	0.36	0.48	0.006	0.009	0.012	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.23	0.36	0.48	0.006	0.009	0.012	0.23	0.36	0.48	0.006	0.009	0.012	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017

Table C.12: Defuzzification of the Factors of Transportation Criterion (Egyptian Sample)

Serial	**Alternative Transportation**			**Public Transport Accessibility**			**Car Parking Capacity**			**Fuel Efficient Vehicle**		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000
2	0.019	0.004	0.006	0.023	0.000	0.010	0.013	0.010	0.000	0.023	0.000	0.010
3	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
4	0.015	0.006	0.000	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006
5	0.013	0.010	0.000	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
6	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
7	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
8	0.023	0.000	0.020	0.019	0.004	0.016	0.023	0.000	0.020	0.003	0.020	0.000
9	0.008	0.015	0.000	0.013	0.010	0.006	0.019	0.004	0.011	0.023	0.000	0.015
10	0.009	0.013	0.000	0.022	0.000	0.013	0.022	0.000	0.013	0.022	0.000	0.013
11	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000
12	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.023	0.000	0.010
13	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.015	0.006	0.000
14	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
15	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010
16	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.006
17	0.015	0.006	0.012	0.022	0.000	0.019	0.009	0.013	0.006	0.003	0.019	0.000
18	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010
19	0.019	0.004	0.006	0.023	0.000	0.010	0.013	0.010	0.000	0.023	0.000	0.010
20	0.019	0.004	0.006	0.023	0.000	0.010	0.013	0.010	0.000	0.013	0.010	0.000
21	0.019	0.004	0.006	0.023	0.000	0.010	0.013	0.010	0.000	0.023	0.000	0.010
22	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010
23	0.019	0.004	0.006	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006
24	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
25	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
26	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.015	0.006	0.000
27	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.013	0.010	0.000
28	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
29	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
30	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
31	0.008	0.015	0.000	0.008	0.015	0.000	0.023	0.000	0.015	0.013	0.010	0.006
32	0.012	0.009	0.000	0.012	0.009	0.000	0.020	0.000	0.009	0.020	0.000	0.009
33	0.008	0.015	0.000	0.008	0.015	0.000	0.023	0.000	0.015	0.019	0.004	0.011
34	0.015	0.006	0.007	0.009	0.013	0.000	0.022	0.000	0.013	0.022	0.000	0.013
35	0.009	0.013	0.000	0.009	0.013	0.000	0.022	0.000	0.013	0.022	0.000	0.013
36	0.013	0.010	0.000	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
37	0.013	0.010	0.000	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
38	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.006
39	0.013	0.010	0.000	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
40	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.013	0.010	0.000
$\Sigma D^+ / \Sigma D^-$		**0.157**	**0.099**		**0.159**	**0.206**		**0.130**	**0.235**		**0.139**	**0.226**
Closeness coefficient		**0.386**			**0.565**			**0.643**			**0.620**	
Normalized weight		**0.174**			**0.255**			**0.290**			**0.280**	

Table C.13: Fuzzification of the Factors of Transportation Criterion's Responses of the Canadian Respondents

Serial	Alternative Transportation Means				Public Transport Accessibility				Car Parking Capacity				Fuel Efficient Vehicle			
	Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN		
1	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
2	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
3	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
4	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
5	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
6	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66
7	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	High	0.64	0.76	0.87
8	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
9	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
10	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
11	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
12	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	Very High	0.82	0.94	1.00
13	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
14	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
15	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
16	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
17	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very Low	0.01	0.09	0.23	High	0.64	0.76	0.87
18	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
19	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
20	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00

Table C.14: Normalized and Weighted Matrices for the Factors of Transportation Criterion (Canadian Sample)

Alternative Transportation Means						Public Transport Accessibility						Car Parking Capacity						Fuel Efficient Vehicle					
Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix		
0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.48	0.61	0.76	0.024	0.030	0.038
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033
0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.20	0.31	0.42	0.010	0.016	0.021	0.42	0.53	0.66	0.021	0.027	0.033
0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033	0.20	0.31	0.42	0.010	0.016	0.021	0.64	0.76	0.87	0.032	0.038	0.044
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.20	0.31	0.42	0.010	0.016	0.021	0.82	0.94	1.00	0.041	0.047	0.050
0.48	0.61	0.76	0.024	0.030	0.038	0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.01	0.09	0.23	0.001	0.005	0.012	0.64	0.76	0.87	0.032	0.038	0.044
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050

Table C.15: Defuzzification of the Factors of Transportation Criterion (Canadian Sample)

Serial	**Alternative Transportation Means**			**Public Transport Accessibility**			**Car Parking Capacity**			**Fuel Efficient Vehicle**		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.043	0.000	0.000	0.043	0.000	0.000	0.043	0.000	0.000	0.043	0.000	0.000
2	0.043	0.000	0.013	0.043	0.000	0.013	0.031	0.013	0.000	0.031	0.013	0.000
3	0.038	0.008	0.000	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008
4	0.038	0.008	0.011	0.046	0.000	0.019	0.027	0.019	0.000	0.027	0.019	0.000
5	0.043	0.000	0.013	0.031	0.013	0.000	0.043	0.000	0.013	0.043	0.000	0.013
6	0.038	0.008	0.022	0.046	0.000	0.031	0.016	0.031	0.000	0.027	0.019	0.011
7	0.046	0.000	0.031	0.027	0.019	0.011	0.016	0.031	0.000	0.038	0.008	0.022
8	0.046	0.000	0.008	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
9	0.038	0.008	0.011	0.027	0.019	0.000	0.027	0.019	0.000	0.046	0.000	0.019
10	0.038	0.008	0.011	0.027	0.019	0.000	0.027	0.019	0.000	0.046	0.000	0.019
11	0.046	0.000	0.008	0.046	0.000	0.008	0.038	0.008	0.000	0.046	0.000	0.008
12	0.038	0.008	0.022	0.038	0.008	0.022	0.016	0.031	0.000	0.046	0.000	0.031
13	0.031	0.013	0.000	0.031	0.013	0.000	0.043	0.000	0.013	0.043	0.000	0.013
14	0.027	0.019	0.000	0.038	0.008	0.011	0.046	0.000	0.019	0.046	0.000	0.019
15	0.031	0.013	0.000	0.043	0.000	0.013	0.031	0.013	0.000	0.043	0.000	0.013
16	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
17	0.046	0.000	0.041	0.046	0.000	0.041	0.006	0.041	0.000	0.038	0.008	0.032
18	0.046	0.000	0.019	0.046	0.000	0.019	0.038	0.008	0.011	0.027	0.019	0.000
19	0.038	0.008	0.011	0.046	0.000	0.019	0.027	0.019	0.000	0.027	0.019	0.000
20	0.038	0.008	0.000	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008
$\Sigma D^+/\ \Sigma D^-$		**0.119**	**0.221**		**0.132**	**0.207**		**0.267**	**0.072**		**0.106**	**0.233**
Closeness coefficient		**0.650**			**0.610**			**0.212**			**0.688**	
Normalized weight		**0.301**			**0.282**			**0.098**			**0.318**	

Table C.16: Fuzzification of the Factors of Energy Criterion's Responses of the Egyptian Respondents

Serial	**Energy Performance**				**Provision of Energy Management**				**Energy Efficient Systems**				**Energy Efficient Equipment**			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
2	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
3	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
4	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
5	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
6	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
7	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
8	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very Low	0.01	0.09	0.23
9	Very High	0.82	0.94	1.00	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
10	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42
11	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
12	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
13	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
14	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
15	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
16	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
17	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
18	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very Low	0.01	0.09	0.23
19	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
20	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
21	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
22	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
23	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
24	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
25	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
26	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
27	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
28	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
29	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
30	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
31	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
32	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42
33	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
34	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
35	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
36	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
37	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
38	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
39	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
40	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87

Table C.17: Normalized and Weighted Matrices for the Factors of Energy Criterion (Egyptian Sample)

Energy Performance						**Provision of Energy Management**						**Energy Efficient Systems**						**Energy Efficient Equipment**					
Normalized Matrix			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**		
0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.01	0.09	0.23	0.000	0.002	0.006
0.82	0.94	1.00	0.021	0.024	0.025	0.20	0.31	0.42	0.005	0.008	0.011	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.23	0.36	0.48	0.006	0.009	0.012
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.01	0.09	0.23	0.000	0.002	0.006
0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.64	0.80	1.00	0.016	0.020	0.025	0.64	0.80	1.00	0.016	0.020	0.025	0.30	0.47	0.64	0.008	0.012	0.016	0.30	0.47	0.64	0.008	0.012	0.016
0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025

Table C.18: Defuzzification of the Factors of Energy Criterion (Egyptian Sample)

Serial	Energy Performance			Provision of Energy Management			Energy Efficient Systems			Energy Efficient Equipment		
	Mean	D^+	D^-	Mean	D^+	D^-	Mean	D^+	D^-	Mean	D^+	D^-
1	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
2	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
3	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.013	0.010	0.000
4	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
5	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
6	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
7	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000
8	0.023	0.000	0.020	0.019	0.004	0.016	0.013	0.010	0.011	0.003	0.020	0.000
9	0.023	0.000	0.015	0.008	0.015	0.000	0.019	0.004	0.011	0.013	0.010	0.006
10	0.022	0.000	0.013	0.022	0.000	0.013	0.015	0.006	0.007	0.009	0.013	0.000
11	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
12	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
13	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
14	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
15	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
16	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
17	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
18	0.013	0.010	0.011	0.023	0.000	0.020	0.013	0.010	0.011	0.003	0.020	0.000
19	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
20	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
21	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
22	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
23	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
24	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
25	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004
26	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
27	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006
28	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010	0.013	0.010	0.000
29	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
30	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.006
31	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
32	0.020	0.000	0.009	0.020	0.000	0.009	0.012	0.009	0.000	0.012	0.009	0.000
33	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
34	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
35	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
36	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
37	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004
38	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
39	0.022	0.000	0.006	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006
40	0.022	0.000	0.006	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
$\Sigma D^+ / \Sigma D^-$		**0.045**	**0.140**		**0.133**	**0.103**		**0.097**	**0.139**		**0.129**	**0.106**
Closeness coefficient		**0.758**			**0.436**			**0.589**			**0.451**	
Normalized weight		**0.339**			**0.195**			**0.264**			**0.202**	

Table C.19: Fuzzification of the Factors of Energy Criterion's Responses of the Canadian Respondents

Serial	Energy Performance				Provision of Energy Management				Energy Efficient Systems				Energy Efficient Equipment			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
2	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
3	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
4	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
5	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
6	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
7	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
8	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
9	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
10	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
11	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
12	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
13	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
14	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
15	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
16	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
17	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
18	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
19	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
20	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00

Table C.20: Normalized and Weighted Matrices for the Factors of Energy Criterion (Canadian Sample)

Energy Performance						**Provision of Energy Management**						**Energy Efficient Systems**						**Energy Efficient Equipment**					
Normalized Matrix			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**		
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050
0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.48	0.61	0.76	0.024	0.030	0.038
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050

Table C.21: Defuzzification of the Factors of Energy Criterion (Canadian Sample)

Serial	**Energy Performance**			**Provision of Energy Management**			**Energy Efficient Systems**			**Energy Efficient Equipment**		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.046	0.000	0.008	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008
2	0.043	0.000	0.013	0.031	0.013	0.000	0.043	0.000	0.013	0.043	0.000	0.013
3	0.043	0.000	0.013	0.031	0.013	0.000	0.043	0.000	0.013	0.043	0.000	0.013
4	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000
5	0.046	0.000	0.019	0.046	0.000	0.019	0.046	0.000	0.019	0.027	0.019	0.000
6	0.038	0.008	0.000	0.046	0.000	0.008	0.038	0.008	0.000	0.038	0.008	0.000
7	0.046	0.000	0.008	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008
8	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008	0.038	0.008	0.000
9	0.046	0.000	0.008	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
10	0.046	0.000	0.008	0.038	0.008	0.000	0.038	0.008	0.000	0.038	0.008	0.000
11	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000
12	0.046	0.000	0.019	0.038	0.008	0.011	0.027	0.019	0.000	0.027	0.019	0.000
13	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000
14	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000
15	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000
16	0.043	0.000	0.013	0.043	0.000	0.013	0.031	0.013	0.000	0.031	0.013	0.000
17	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000
18	0.046	0.000	0.008	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
19	0.046	0.000	0.019	0.027	0.019	0.000	0.038	0.008	0.011	0.027	0.019	0.000
20	0.046	0.000	0.008	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
$\Sigma D^+ / \Sigma D^-$		**0.017**	**0.145**		**0.111**	**0.051**		**0.073**	**0.089**		**0.095**	**0.067**
Closeness coefficient		**0.898**			**0.316**			**0.548**			**0.412**	
Normalized weight		**0.413**			**0.146**			**0.252**			**0.189**	

Table C.22: Fuzzification of the Factors of Water Use Criterion's Responses of the Egyptian Respondents

Serial	**Water Conservation**				**Water Management**				**Effluent Discharge in foul Sewer**			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
2	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Low	0.20	0.31	0.42
3	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
4	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
5	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
6	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
7	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
8	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
9	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
10	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
11	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
12	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
13	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
14	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
15	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
16	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
17	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
18	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Low	0.20	0.31	0.42
19	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
20	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
21	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
22	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
23	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
24	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
25	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
26	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
27	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
28	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
29	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
30	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
31	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
32	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
33	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
34	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
35	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
36	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
37	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
38	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
39	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
40	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00

Table C.23: Normalized and Weighted Matrices for the Factors of Water Use Criterion (Egyptian Sample)

Water Conservation						**Water Management**						**Effluent Discharge in foul Sewer**					
Normalized Matrix			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**		
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.20	0.31	0.42	0.005	0.008	0.011
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.64	0.80	1.00	0.016	0.020	0.025	0.64	0.80	1.00	0.016	0.020	0.025	0.64	0.80	1.00	0.016	0.020	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.20	0.31	0.42	0.005	0.008	0.011	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.20	0.31	0.42	0.005	0.008	0.011
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025

Table C.24: Defuzzification of the Factors of Water Use Criterion (Egyptian Sample)

Serial	Water Conservation			Water Management			Effluent Discharge in foul Sewer		
	Mean	D^+	D^-	Mean	D^+	D^-	Mean	D^+	D^-
1	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000
2	0.023	0.000	0.015	0.023	0.000	0.015	0.008	0.015	0.000
3	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
4	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
5	0.020	0.000	0.000	0.020	0.000	0.000	0.020	0.000	0.000
6	0.022	0.000	0.006	0.015	0.006	0.000	0.022	0.000	0.006
7	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
8	0.008	0.015	0.000	0.013	0.010	0.006	0.023	0.000	0.015
9	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000
10	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
11	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
12	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
13	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
14	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
15	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
16	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000
17	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
18	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000
19	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
20	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000
21	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
22	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
23	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
24	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
25	0.022	0.000	0.006	0.022	0.000	0.006	0.015	0.006	0.000
26	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000
27	0.019	0.004	0.006	0.023	0.000	0.010	0.013	0.010	0.000
28	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
29	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
30	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
31	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
32	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
33	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
34	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
35	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
36	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
37	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
38	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
39	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
40	0.013	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
$\Sigma D^+ / \Sigma D^-$		**0.032**	**0.134**		**0.057**	**0.131**		**0.148**	**0.039**
Closeness coefficient		**0.808**			**0.695**			**0.210**	
Normalized weight		**0.472**			**0.406**			**0.123**	

Table C.25: Fuzzification of the Factors of Water Use Criterion's Responses of the Canadian Respondents

Serial	Water Conservation				Water Management				Effluent Discharge in foul Sewer			
	Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN		
1	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
2	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
3	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
4	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
5	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
6	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
7	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Low	0.20	0.31	0.42
8	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
9	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Low	0.20	0.31	0.42
10	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
11	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
12	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
13	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
14	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
15	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
16	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
17	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
18	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
19	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Low	0.20	0.31	0.42
20	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87

Table C.26: Normalized and Weighted Matrices for the Factors of Water Use Criterion (Canadian Sample)

Water Conservation						**Water Management**						**Effluent Discharge in foul Sewer**					
Normalized Matrix			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**		
0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.48	0.61	0.76	0.024	0.030	0.038
0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044
0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.23	0.36	0.48	0.011	0.018	0.024
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.20	0.31	0.42	0.010	0.016	0.021
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.80	1.00	0.032	0.040	0.050	0.64	0.80	1.00	0.032	0.040	0.050	0.64	0.80	1.00	0.032	0.040	0.050
0.64	0.80	1.00	0.032	0.040	0.050	0.64	0.80	1.00	0.032	0.040	0.050	0.64	0.80	1.00	0.032	0.040	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.48	0.61	0.76	0.024	0.030	0.038
0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.23	0.36	0.48	0.011	0.018	0.024
0.48	0.61	0.76	0.024	0.030	0.038	0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050

Table C.27: Defuzzification of the Factors of Water Use Criterion (Canadian Sample)

Serial	**Water Conservation**			**Water Management**			**Effluent Discharge in foul Sewer**		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.043	0.000	0.013	0.031	0.013	0.000	0.031	0.013	0.000
2	0.043	0.000	0.000	0.043	0.000	0.000	0.043	0.000	0.000
3	0.027	0.019	0.000	0.038	0.008	0.011	0.046	0.000	0.019
4	0.046	0.000	0.008	0.038	0.008	0.000	0.038	0.008	0.000
5	0.043	0.000	0.000	0.043	0.000	0.000	0.043	0.000	0.000
6	0.038	0.008	0.000	0.046	0.000	0.008	0.038	0.008	0.000
7	0.031	0.013	0.013	0.043	0.000	0.026	0.018	0.026	0.000
8	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
9	0.046	0.000	0.031	0.046	0.000	0.031	0.016	0.031	0.000
10	0.046	0.000	0.019	0.038	0.008	0.011	0.027	0.019	0.000
11	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000
12	0.041	0.000	0.000	0.041	0.000	0.000	0.041	0.000	0.000
13	0.041	0.000	0.000	0.041	0.000	0.000	0.041	0.000	0.000
14	0.046	0.000	0.008	0.046	0.000	0.008	0.038	0.008	0.000
15	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000
16	0.038	0.008	0.011	0.046	0.000	0.019	0.027	0.019	0.000
17	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000
18	0.043	0.000	0.013	0.031	0.013	0.000	0.031	0.013	0.000
19	0.031	0.013	0.013	0.043	0.000	0.026	0.018	0.026	0.000
20	0.031	0.013	0.000	0.031	0.013	0.000	0.043	0.000	0.013
$\Sigma D^+ / \Sigma D^-$		**0.082**	**0.129**		**0.063**	**0.148**		**0.170**	**0.040**
Closeness coefficient		**0.611**			**0.702**			**0.191**	
Normalized weight		**0.406**			**0.467**			**0.127**	

Table C.28: Fuzzification of the Factors of Material and Waste Reduction Criterion's Responses of the Egyptian Respondents

Serial	Sustainable Purchasing Policy				Efficient Use of Materials				Solid Waste Management			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
2	Low	0.20	0.31	0.42	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
3	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
4	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
5	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Low	0.20	0.31	0.42
6	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42
7	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
8	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
9	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
10	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
11	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
12	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
13	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
14	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66
15	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
16	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
17	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
18	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42
19	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
20	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
21	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
22	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
23	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
24	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
25	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
26	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
27	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66
28	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
29	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
30	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
31	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
32	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
33	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
34	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
35	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
36	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
37	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
38	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
39	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
40	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87

Table C.29: Normalized and Weighted Matrices for the Factors of Material and Waste Reduction Criterion (Egyptian Sample)

Sustainable Purchasing Policy						Efficient Use of Materials						Solid Waste Management					
Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix		
0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.20	0.31	0.42	0.005	0.008	0.011	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.23	0.36	0.48	0.006	0.009	0.012
0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.23	0.36	0.48	0.006	0.009	0.012
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.20	0.31	0.42	0.005	0.008	0.011	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019
0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.80	1.00	0.016	0.020	0.025	0.30	0.47	0.64	0.008	0.012	0.016	0.64	0.80	1.00	0.016	0.020	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019
0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.23	0.36	0.48	0.006	0.009	0.012
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.80	1.00	0.016	0.020	0.025	0.64	0.80	1.00	0.016	0.020	0.025	0.64	0.80	1.00	0.016	0.020	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.23	0.36	0.48	0.006	0.009	0.012	0.48	0.61	0.76	0.012	0.015	0.019
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.80	1.00	0.016	0.020	0.025	0.64	0.80	1.00	0.016	0.020	0.025	0.64	0.80	1.00	0.016	0.020	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022

Table C.30: Defuzzification of the Factors of Material and Waste Reduction Criterion (Egyptian Sample)

Serial	**Sustainable Purchasing Policy**			**Efficient Use of Materials**			**Solid Waste Management**		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
2	0.008	0.015	0.000	0.023	0.000	0.015	0.019	0.004	0.011
3	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
4	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
5	0.022	0.000	0.013	0.022	0.000	0.013	0.009	0.013	0.000
6	0.022	0.000	0.013	0.015	0.006	0.007	0.009	0.013	0.000
7	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
8	0.008	0.015	0.000	0.019	0.004	0.011	0.023	0.000	0.015
9	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000
10	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
11	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
12	0.013	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
13	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
14	0.020	0.000	0.009	0.012	0.009	0.000	0.020	0.000	0.009
15	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
16	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000
17	0.023	0.000	0.010	0.013	0.010	0.000	0.023	0.000	0.010
18	0.022	0.000	0.013	0.015	0.006	0.007	0.009	0.013	0.000
19	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
20	0.020	0.000	0.000	0.020	0.000	0.000	0.020	0.000	0.000
21	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
22	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
23	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
24	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
25	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
26	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
27	0.022	0.000	0.013	0.009	0.013	0.000	0.015	0.006	0.007
28	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000
29	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
30	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
31	0.020	0.000	0.000	0.020	0.000	0.000	0.020	0.000	0.000
32	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
33	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
34	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
35	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000
36	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
37	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
38	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
39	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
40	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
$\Sigma D^+ / \Sigma D^-$		**0.103**	**0.108**		**0.064**	**0.196**		**0.131**	**0.129**
Closeness		**0.513**			**0.753**			**0.496**	
Normalized		**0.291**			**0.427**			**0.281**	

Table C.31: Fuzzification of the Factors of Material and Waste Reduction Criterion’s Responses of the Canadian Respondents

Serial	Sustainable Purchasing Policy				Efficient Use of Materials				Solid Waste Management			
	Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN		
1	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
2	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
3	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
4	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
5	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
6	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
7	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
8	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
9	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
10	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
11	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
12	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
13	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
14	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
15	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
16	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
17	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
18	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
19	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
20	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00

Table C.32: Normalized and Weighted Matrices for the Factors of Material and Waste Reduction Criterion (Canadian Sample)

Sustainable Purchasing Policy						Efficient Use of Materials						Solid Waste Management					
Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix		
0.23	0.36	0.48	0.011	0.018	0.024	0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.80	1.00	0.032	0.040	0.050	0.64	0.80	1.00	0.032	0.040	0.050	0.64	0.80	1.00	0.032	0.040	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038
0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050
0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.48	0.61	0.76	0.024	0.030	0.038
0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050

Table C.33: Defuzzification of the Factors of Material and Waste Reduction Criterion (Canadian Sample)

Serial	Sustainable Purchasing Policy			Efficient Use of Materials			Solid Waste Management		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.018	0.026	0.000	0.043	0.000	0.026	0.031	0.013	0.013
2	0.038	0.008	0.000	0.046	0.000	0.008	0.038	0.008	0.000
3	0.038	0.008	0.000	0.046	0.000	0.008	0.038	0.008	0.000
4	0.038	0.008	0.000	0.046	0.000	0.008	0.038	0.008	0.000
5	0.043	0.000	0.000	0.043	0.000	0.000	0.043	0.000	0.000
6	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
7	0.043	0.000	0.013	0.043	0.000	0.013	0.031	0.013	0.000
8	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008
9	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008
10	0.041	0.000	0.000	0.041	0.000	0.000	0.041	0.000	0.000
11	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
12	0.046	0.000	0.008	0.046	0.000	0.008	0.038	0.008	0.000
13	0.031	0.013	0.000	0.043	0.000	0.013	0.031	0.013	0.000
14	0.031	0.013	0.000	0.043	0.000	0.013	0.043	0.000	0.013
15	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008
16	0.043	0.000	0.000	0.043	0.000	0.000	0.043	0.000	0.000
17	0.046	0.000	0.000	0.046	0.000	0.000	0.046	0.000	0.000
18	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008
19	0.043	0.000	0.013	0.031	0.013	0.000	0.031	0.013	0.000
20	0.027	0.019	0.000	0.038	0.008	0.011	0.046	0.000	0.019
$\Sigma D^+ / \Sigma D^-$		**0.144**	**0.034**		**0.046**	**0.132**		**0.084**	**0.094**
Closeness coefficient		**0.188**			**0.744**			**0.530**	
Normalized weight		**0.129**			**0.508**			**0.363**	

Table C.34: Fuzzification of the Factors of Indoor Environmental Quality Criterion's Responses of the Egyptian Respondents

Serial	Visual Comfort				Indoor Air Quality				Thermal Comfort				Acoustic Performance				Hygiene				Building Amenities			
	Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN		
1	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	High	0.64	0.76	0.87
2	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42
3	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
4	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
5	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42
6	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
7	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
8	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very Low	0.01	0.09	0.23
9	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42
10	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
11	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
12	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
13	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
14	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
15	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
16	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
17	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
18	Low	0.20	0.31	0.42	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very Low	0.01	0.09	0.23	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
19	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
20	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42
21	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
22	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
23	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
24	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
25	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
26	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
27	Low	0.20	0.31	0.42	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
28	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
29	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
30	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
31	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
32	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
33	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	High	0.64	0.76	0.87
34	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
35	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
36	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
37	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
38	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
39	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
40	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87

Table C.35: Normalized and Weighted Matrices for the Factors of Indoor Environmental Quality Criterion (Egyptian Sample)

Visual Comfort						Indoor Air Quality						Thermal Comfort						Acoustic Performance						Hygiene						Building Amenities					
Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix		
0.42	0.53	0.6	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.42	0.53	0.66	0.20	0.31	0.42	0.005	0.008	0.011	0.64	0.76	0.87	0.016	0.019	0.022
0.42	0.53	0.6	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.42	0.53	0.66	0.20	0.31	0.42	0.005	0.008	0.011	0.20	0.31	0.42	0.005	0.008	0.011
0.82	0.94	1.0	0.82	0.94	1.00	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.82	0.94	1.00	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.42	0.53	0.6	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.64	0.76	0.87	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.0	0.82	0.94	1.00	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.20	0.31	0.42	0.20	0.31	0.42	0.20	0.31	0.42	0.005	0.008	0.011	0.20	0.31	0.42	0.005	0.008	0.011
0.48	0.61	0.7	0.48	0.61	0.76	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.42	0.53	0.66	0.48	0.61	0.76	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025
0.42	0.53	0.6	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.42	0.53	0.66	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.0	0.82	0.94	1.00	0.64	0.76	0.87	0.016	0.019	0.022	0.20	0.31	0.42	0.005	0.008	0.011	0.64	0.76	0.87	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.01	0.09	0.23	0.000	0.002	0.006
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.42	0.53	0.66	0.20	0.31	0.42	0.005	0.008	0.011	0.20	0.31	0.42	0.005	0.008	0.011
0.42	0.53	0.6	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.42	0.53	0.66	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.82	0.94	1.00	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.42	0.53	0.6	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.0	0.82	0.94	1.00	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.64	0.76	0.87	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.42	0.53	0.6	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.8	0.64	0.76	0.87	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.0	0.82	0.94	1.00	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.20	0.31	0.4	0.20	0.31	0.42	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.01	0.09	0.23	0.01	0.09	0.23	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.20	0.31	0.42	0.20	0.31	0.42	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.64	0.76	0.87	0.42	0.53	0.66	0.011	0.013	0.017	0.20	0.31	0.42	0.005	0.008	0.011
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.0	0.82	0.94	1.00	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.82	0.94	1.00	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.42	0.53	0.66	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.64	0.76	0.87	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
0.42	0.53	0.6	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.42	0.53	0.6	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.82	0.94	1.00	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.20	0.31	0.4	0.20	0.31	0.42	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.0	0.82	0.94	1.00	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.42	0.53	0.66	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.0	0.82	0.94	1.00	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.42	0.53	0.66	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.42	0.53	0.66	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.48	0.61	0.7	0.48	0.61	0.76	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.42	0.53	0.66	0.48	0.61	0.76	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019
0.48	0.61	0.7	0.48	0.61	0.76	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.42	0.53	0.66	0.48	0.61	0.76	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.42	0.53	0.6	0.42	0.53	0.66	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.20	0.31	0.42	0.20	0.31	0.42	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.48	0.61	0.7	0.48	0.61	0.76	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.42	0.53	0.66	0.48	0.61	0.76	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.48	0.61	0.7	0.48	0.61	0.76	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.42	0.53	0.66	0.48	0.61	0.76	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.42	0.53	0.6	0.42	0.53	0.66	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.8	0.64	0.76	0.87	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.82	0.94	1.00	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022

Table C.36: Defuzzification of the Factors of Indoor Environmental Quality Criterion (Egyptian Sample)

Serial	**Visual Comfort**			**Indoor Air Quality**			**Thermal Comfort**			**Acoustic Performance**			**Hygiene**			**Building Amenities**		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.013	0.010	0.006	0.023	0.000	0.015	0.023	0.000	0.015	0.013	0.010	0.006	0.008	0.015	0.000	0.019	0.004	0.011
2	0.013	0.010	0.006	0.023	0.000	0.015	0.023	0.000	0.015	0.013	0.010	0.006	0.008	0.015	0.000	0.008	0.015	0.000
3	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000
4	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0.000
5	0.023	0.000	0.015	0.023	0.000	0.015	0.023	0.000	0.015	0.008	0.015	0.000	0.008	0.015	0.000	0.008	0.015	0.000
6	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006
7	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006	0.013	0.010	0.000
8	0.023	0.000	0.020	0.019	0.004	0.016	0.008	0.015	0.005	0.019	0.004	0.016	0.023	0.000	0.020	0.003	0.020	0.000
9	0.019	0.004	0.011	0.023	0.000	0.015	0.023	0.000	0.015	0.013	0.010	0.006	0.008	0.015	0.000	0.008	0.015	0.000
10	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
11	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
12	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.013	0.010	0.000
13	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
14	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
15	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
16	0.019	0.004	0.006	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
17	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
18	0.008	0.015	0.005	0.023	0.000	0.020	0.019	0.004	0.016	0.003	0.020	0.000	0.013	0.010	0.011	0.019	0.004	0.016
19	0.019	0.004	0.011	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000	0.023	0.000	0.015	0.023	0.000	0.015
20	0.019	0.004	0.011	0.023	0.000	0.015	0.023	0.000	0.015	0.019	0.004	0.011	0.013	0.010	0.006	0.008	0.015	0.000
21	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
22	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
23	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
24	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006
25	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
26	0.013	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.013	0.010	0.000
27	0.008	0.015	0.000	0.023	0.000	0.015	0.023	0.000	0.015	0.019	0.004	0.011	0.023	0.000	0.015	0.013	0.010	0.006
28	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.019	0.004	0.006	0.013	0.010	0.000
29	0.023	0.000	0.010	0.023	0.000	0.010	0.013	0.010	0.000	0.013	0.010	0.000	0.013	0.010	0.000	0.019	0.004	0.006
30	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
31	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000
32	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
33	0.013	0.010	0.006	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000	0.019	0.004	0.011	0.019	0.004	0.011
34	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
35	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
36	0.015	0.006	0.000	0.022	0.000	0.006	0.015	0.006	0.000	0.015	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
37	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
38	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
39	0.013	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006
40	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
$\Sigma D^+ / \Sigma D^-$		**0.165**	**0.149**		**0.023**	**0.357**		**0.116**	**0.264**		**0.271**	**0.109**		**0.157**	**0.223**		**0.229**	**0.151**
Closeness coefficient		**0.474**			**0.940**			**0.694**			**0.287**			**0.588**			**0.397**	
Normalized weight		**0.140**			**0.940**			**0.205**			**0.085**			**0.174**			**0.117**	

Table C.37: Fuzzification of the Factors of Indoor Environmental Quality Criterion’s Responses of the Canadian Respondents

	Visual Comfort				**Indoor Air Quality**				**Thermal Comfort**				**Acoustic Performance**				**Hygiene**				**Building Amenities**			
	Linguistic variable	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**			**Linguistic variable**	**TFN**		
1	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
2	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
3	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
4	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
5	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
6	Low	0.20	0.31	0.42	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
7	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
8	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
9	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42
10	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Low	0.20	0.31	0.42
11	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
12	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
13	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
14	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
15	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
16	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87
17	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
18	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
19	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
20	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87

Table C.38: Normalized and Weighted Matrices for the Factors of Indoor Environmental Quality Criterion (Canadian Sample)

Visual Comfort						Indoor Air Quality						Thermal Comfort						Acoustic Performance						Hygiene						Building Amenities					
Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix			Normalized Matrix			Weighted Matrix		
0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033
0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050
0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033
0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038
0.20	0.31	0.42	0.010	0.016	0.021	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.20	0.31	0.42	0.010	0.016	0.021	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033
0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.42	0.53	0.66	0.021	0.027	0.033	0.20	0.31	0.42	0.010	0.016	0.021
0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.20	0.31	0.42	0.010	0.016	0.021
0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.42	0.53	0.66	0.021	0.027	0.033
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033
0.64	0.76	0.87	0.032	0.038	0.044	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044
0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.48	0.61	0.76	0.024	0.030	0.038	0.48	0.61	0.76	0.024	0.030	0.038	0.74	0.87	1.00	0.037	0.044	0.050	0.74	0.87	1.00	0.037	0.044	0.050
0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044
0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.42	0.53	0.66	0.021	0.027	0.033	0.64	0.76	0.87	0.032	0.038	0.044
0.42	0.53	0.66	0.021	0.027	0.033	0.82	0.94	1.00	0.041	0.047	0.050	0.82	0.94	1.00	0.041	0.047	0.050	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044	0.64	0.76	0.87	0.032	0.038	0.044

Table C.39: Defuzzification of the Factors of Indoor Environmental Quality Criterion (Canadian Sample)

Serial	**Visual Comfort**			**Indoor Air Quality**			**Thermal Comfort**			**Acoustic Performance**			**Hygiene**			**Building Amenities**		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.027	0.019	0.000	0.046	0.000	0.019	0.038	0.008	0.011	0.027	0.019	0.000	0.038	0.008	0.011	0.027	0.019	0.000
2	0.046	0.000	0.019	0.046	0.000	0.019	0.046	0.000	0.019	0.038	0.008	0.011	0.046	0.000	0.019	0.027	0.019	0.000
3	0.046	0.000	0.019	0.038	0.008	0.011	0.046	0.000	0.019	0.038	0.008	0.011	0.027	0.019	0.000	0.046	0.000	0.019
4	0.027	0.019	0.000	0.046	0.000	0.019	0.038	0.008	0.011	0.027	0.019	0.000	0.046	0.000	0.019	0.027	0.019	0.000
5	0.043	0.000	0.013	0.043	0.000	0.013	0.043	0.000	0.013	0.043	0.000	0.013	0.043	0.000	0.013	0.031	0.013	0.000
6	0.016	0.031	0.000	0.046	0.000	0.031	0.046	0.000	0.031	0.016	0.031	0.000	0.038	0.008	0.022	0.027	0.019	0.011
7	0.038	0.008	0.000	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008	0.038	0.008	0.000	0.038	0.008	0.000
8	0.038	0.008	0.011	0.046	0.000	0.019	0.038	0.008	0.011	0.027	0.019	0.000	0.046	0.000	0.019	0.038	0.008	0.011
9	0.027	0.019	0.011	0.046	0.000	0.031	0.038	0.008	0.022	0.027	0.019	0.011	0.027	0.019	0.011	0.016	0.031	0.000
10	0.027	0.019	0.011	0.046	0.000	0.031	0.046	0.000	0.031	0.038	0.008	0.022	0.038	0.008	0.022	0.016	0.031	0.000
11	0.027	0.019	0.000	0.046	0.000	0.019	0.038	0.008	0.011	0.038	0.008	0.011	0.046	0.000	0.019	0.027	0.019	0.000
12	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008	0.038	0.008	0.000	0.046	0.000	0.008	0.038	0.008	0.000
13	0.046	0.000	0.019	0.046	0.000	0.019	0.046	0.000	0.019	0.038	0.008	0.011	0.046	0.000	0.019	0.027	0.019	0.000
14	0.046	0.000	0.019	0.046	0.000	0.019	0.046	0.000	0.019	0.046	0.000	0.019	0.038	0.008	0.011	0.027	0.019	0.000
15	0.038	0.008	0.000	0.046	0.000	0.008	0.046	0.000	0.008	0.038	0.008	0.000	0.038	0.008	0.000	0.038	0.008	0.000
16	0.046	0.000	0.008	0.046	0.000	0.008	0.046	0.000	0.008	0.046	0.000	0.008	0.038	0.008	0.000	0.038	0.008	0.000
17	0.031	0.013	0.000	0.043	0.000	0.013	0.031	0.013	0.000	0.031	0.013	0.000	0.043	0.000	0.013	0.043	0.000	0.013
18	0.027	0.019	0.000	0.046	0.000	0.019	0.038	0.008	0.011	0.038	0.008	0.011	0.038	0.008	0.011	0.038	0.008	0.011
19	0.046	0.000	0.019	0.046	0.000	0.019	0.046	0.000	0.019	0.038	0.008	0.011	0.027	0.019	0.000	0.038	0.008	0.011
20	0.027	0.019	0.000	0.046	0.000	0.019	0.046	0.000	0.019	0.038	0.008	0.011	0.038	0.008	0.011	0.038	0.008	0.011
$\Sigma D^+ / \Sigma D^-$		**0.211**	**0.151**		**0.017**	**0.345**		**0.062**	**0.299**		**0.203**	**0.159**		**0.132**	**0.230**		**0.274**	**0.087**
Closeness coefficient		**0.417**			**0.954**			**0.828**			**0.440**			**0.635**			**0.241**	
Normalized weight		**0.119**			**0.271**			**0.236**			**0.125**			**0.181**			**0.069**	

Table C.40: Fuzzification of the Factors of Building Management Criterion's Responses of the Egyptian Respondents

Serial	Maintenance Management				Security Measures				Green Lease				Risk Management				Innovations			
	Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN			Linguistic variable	TFN		
1	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Low	0.20	0.31	0.42
2	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42	High	0.64	0.76	0.87
3	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
4	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
5	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Very Low	0.01	0.09	0.23	Very Low	0.01	0.09	0.23
6	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
7	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Low	0.20	0.31	0.42
8	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Low	0.20	0.31	0.42
9	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
10	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
11	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
12	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
13	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
14	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
15	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
16	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
17	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
18	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
19	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
20	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
21	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
22	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00
23	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66
24	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
25	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00
26	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	High	0.64	0.76	0.87
27	Very High	0.82	0.94	1.00	Low	0.20	0.31	0.42	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Very Low	0.01	0.09	0.23
28	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00
29	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
30	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66
31	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
32	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	High	0.64	0.76	0.87
33	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	High	0.64	0.76	0.87
34	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66
35	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very Low	0.01	0.09	0.23	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87
36	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Low	0.20	0.31	0.42	High	0.64	0.76	0.87	High	0.64	0.76	0.87
37	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
38	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87
39	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Medium	0.42	0.53	0.66	High	0.64	0.76	0.87	High	0.64	0.76	0.87
40	Very High	0.82	0.94	1.00	Very High	0.82	0.94	1.00	High	0.64	0.76	0.87	Very High	0.82	0.94	1.00	Medium	0.42	0.53	0.66

Table C.41: Normalized and Weighted Matrices for the Factors of Building Management Criterion (Egyptian Sample)

Maintenance Management						Security Measures						Green Lease						Risk Management						Innovations					
Normalized Matrix			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**			**Normalized Matrix**			**Weighted Matrix**		
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.20	0.31	0.42	0.005	0.008	0.011
0.74	0.87	1.00	0.018	0.022	0.025	0.23	0.36	0.48	0.006	0.009	0.012	0.23	0.36	0.48	0.006	0.009	0.012	0.23	0.36	0.48	0.006	0.009	0.012	0.74	0.87	1.00	0.018	0.022	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019
0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.23	0.36	0.48	0.006	0.009	0.012	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.01	0.09	0.23	0.000	0.002	0.006	0.01	0.09	0.23	0.000	0.002	0.006
0.42	0.53	0.66	0.011	0.013	0.017	0.20	0.31	0.42	0.005	0.008	0.011	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.20	0.31	0.42	0.005	0.008	0.011
0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.20	0.31	0.42	0.005	0.008	0.011
0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.42	0.53	0.66	0.011	0.013	0.017	0.20	0.31	0.42	0.005	0.008	0.011	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.74	0.87	1.00	0.018	0.022	0.025	0.23	0.36	0.48	0.006	0.009	0.012	0.23	0.36	0.48	0.006	0.009	0.012	0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019
0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025
0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019	0.48	0.61	0.76	0.012	0.015	0.019
0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.64	0.76	0.87	0.016	0.019	0.022	0.20	0.31	0.42	0.005	0.008	0.011	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.20	0.31	0.42	0.005	0.008	0.011	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.01	0.09	0.23	0.000	0.002	0.006
0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.00	0.87	0.016	0.000	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.00	0.87	0.016	0.000	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.42	0.53	0.66	0.011	0.013	0.017
0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.00	0.76	0.012	0.000	0.019	0.23	0.36	0.48	0.006	0.009	0.012	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.00	1.00	0.018	0.000	0.025	0.23	0.36	0.48	0.006	0.009	0.012	0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.87	1.00	0.018	0.022	0.025
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.00	1.00	0.018	0.000	0.025	0.23	0.36	0.48	0.006	0.009	0.012	0.74	0.87	1.00	0.018	0.022	0.025	0.48	0.61	0.76	0.012	0.015	0.019
0.74	0.87	1.00	0.018	0.022	0.025	0.74	0.00	1.00	0.018	0.000	0.025	0.01	0.10	0.26	0.000	0.003	0.007	0.48	0.61	0.76	0.012	0.015	0.019	0.74	0.87	1.00	0.018	0.022	0.025
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.00	0.87	0.016	0.000	0.022	0.20	0.31	0.42	0.005	0.008	0.011	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.00	0.87	0.016	0.000	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.00	0.87	0.016	0.000	0.022	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.64	0.00	0.87	0.016	0.000	0.022	0.42	0.53	0.66	0.011	0.013	0.017	0.64	0.76	0.87	0.016	0.019	0.022	0.64	0.76	0.87	0.016	0.019	0.022
0.82	0.94	1.00	0.021	0.024	0.025	0.82	0.00	1.00	0.021	0.000	0.025	0.64	0.76	0.87	0.016	0.019	0.022	0.82	0.94	1.00	0.021	0.024	0.025	0.42	0.53	0.66	0.011	0.013	0.017