Sustainability Assessment of Heritage Buildings

Abobakr Al-Sakkaf

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____ External to program
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____ Examiner
Dr. F. Nasiri
____ Examiner
Dr. Z. Chen
____ Thesis Co-Supervisor
Dr. T. Zayed
____Thesis Co-Supervisor
Dr. A. Bagchi

Approved by:
Dr. M. Nokken, Graduate Program Director
____

October 30, 2020 Dr. M. Debbabi
Dean of Gina Cody School of Engineering and Computer Science

ABSTRACT
Sustainability Assessment of Heritage Buildings

Abobakr Al-Sakkaf, Ph.D.
Concordia University, 2020

Many existing rating systems such as LEED, CASBEE and ITACA have been developed to evaluate the performance of buildings from a sustainability perspective. These systems however vary in their assessment of sustainability since each system has been designed to evaluate several criteria based on its respective local context. None of the existing rating systems considers energy in its assessment nor proposes a definitive guideline for sustainability assessment of Heritage Buildings (HBs). This limits the processes of decision-making when considering the best renovation alternatives for HBs. Currently, 1092 locations are considered as heritage in the world, of which 77% and 23% are categorized as cultural and natural heritage locations, respectively (Giovine, 2019).

The objectives of this research work were to: i) identify and study the criteria, factors and indicators that impact the sustainability of HBs; ii) design a hybrid, multi-criteria sustainability-rating model and scale for HBs; iii) determine sustainability-based energy savings for the life cycle phases of HBs; and iv) design an automated assessment tool and perform sensitivity analysis for the developed model. To accomplish the first objective, a literature review was done to analyze 12 major existing rating systems and identify the principal criteria, factors and indicators that affect sustainability of buildings. A questionnaire, targeted to experts in Canada and Saudi Arabia, was also prepared and used to determine the importance of the principal criteria, factors and indicators with respect to sustainability of HBs. To accomplish the second objective, sustainability model development for HBs involved the application of 'fuzzy logic' using Fuzzy TOPSIS to calculate the weights and indices of the model parameters. Information from the questionnaire was also useful to examine if the calculated weights reflect reality. To accomplish the third objective, expert responses, regarding the percent energy consumption in each of the six life cycle phases of HBs, were applied on real energy consumption and cost data from two case studies. The exact energy consumption and cost in each life cycle phase was then estimated and compared with simulated energy consumption and cost results from the newly developed model. To accomplish the fourth objective, a web-based graphical user interface was created to automate the assessment process. A webpage, built on Ruby on Rails (for the backend) and HTML, CSS and Javascript (for the front end), was built based on weight calculations. The proposed scale was also applied to obtain the sustainability rating for HBs. Sensitivity analysis for the sustainability model was performed using two case studies and multi-criteria decision-making methods such as *Fuzzy TOPSIS*, Simple Additive Weight *SAW*, Weighted Sum Model *WSM*, Weighted Product Model *WPM,* and Operational Competitiveness Rating Analysis *OCRA*. Two HBs, Murabba Palace (MP) and Grey Nuns (GN), were studied to determine weight values for each of the tested factors.

Results showed that energy was the most important factor for both HBs in the case studies, with a sum indicator index of 1.623 and 1.891 for MP and GN, respectively. Water use was of the least importance, with a sum indicator index of 0.121 and 0.055 for MP and GN, respectively. Moreover, the total Sustainability Assessment for Heritage Buildings (SAHB) was 48% and 63% for MP and GN, respectively. This corresponds to *Unsatisfied* and *Satisfied* for MP and GN, respectively, based on the established scale for the newly developed model (*Unsatisfied* – < 49%, *Pass* – 50-59%, *Satisfied* – 60-69%, *Bronze* – 70-79%, *Silver* – 80-89%, and *Gold* - >90%). The newly developed sustainability model will be beneficial to decision-makers, HB specialists, engineers, architects, and project managers in their efforts to improve the sustainability of their HBs. It will also beneficial in the planning of rehabilitation projects for HBs.

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Firstly, I would like to first thank God for granting me the health, peace and wellbeing required to complete my Ph.D. thesis.

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DEDICATION

I dedicate this work to my family, and I would like to express my gratitude to them. Without their support and encouragement, this thesis would not have been completed.

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List of Nomenclature and Abbreviations

AHP	Analytical Hierarchy Process
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
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
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
ETTV	Envelope Thermal Transfer Value
EUI	Energy Use Intensity
GAI	Green Area Index
GB	Green Building Tool
GBI	Green Building Index
HBs	Heritage Buildings
HBIM	Heritage Building Information Modeling
HK-BEAM	Hong Kong Building Environmental Assessment Model
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
IPCC	Intergovernmental Panel for Climate Change
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
MADM	Multi Attribute Decision Making
PIS	Positive Ideal Solution

ICOMOS	International Council on Monuments and Sites
SHBs	Sustainability of Heritage Buildings
SAHB	Sustainability Assessment for Heritage Buildings
SI	Sustainability Index
SC c_k	The Score of k^{th} Criterion
SC f_j	The Score of j^{th} Factor
SC total	Total Assessment Score
If_i	I^{th} Indicator
TAFN	Trapezoidal Fuzzy Numbers
TFN	Triangular Fuzzy Numbers
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TSI	Total Sustainability Index
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organisation
USGBC	United States Green Building Council
W c_k	Weight of k^{th} Criterion
W f_j	Weight of j^{th} Factor

CHAPTER 1 : INTRODUCTION

1.1 Research Background

1.1.1 Heritage Buildings: Sustainability

As of August 2018, there were 1092 sites on the World Heritage List that are located across 167 states. 845 of these are cultural sites, 209 natural and 38 are mixed properties (UNESCO, 2009). Their geographic distributions are as follows: 47% of these sites are in Europe, 24% in Asia and the Pacific, 13% in Latin America, 9% in Africa and the rest in the Arab states. As of July 2019, a total of 1,121 World Heritage Sites were reported to be located in 167 states around the globe (McLennan, 2004). Figure 1.1 and Table 1.1 provide a summary of the number of World Heritage Buildings by region.

Since heritage is continuously under threat by urbanization and global, ecological and political issues, sustainability of heritage buildings has become a fundamental thought. Sustainability of heritage buildings can be defined as the design of a built environment that follows the standards of social, economic and ecological sustainability (McLennan, 2004).

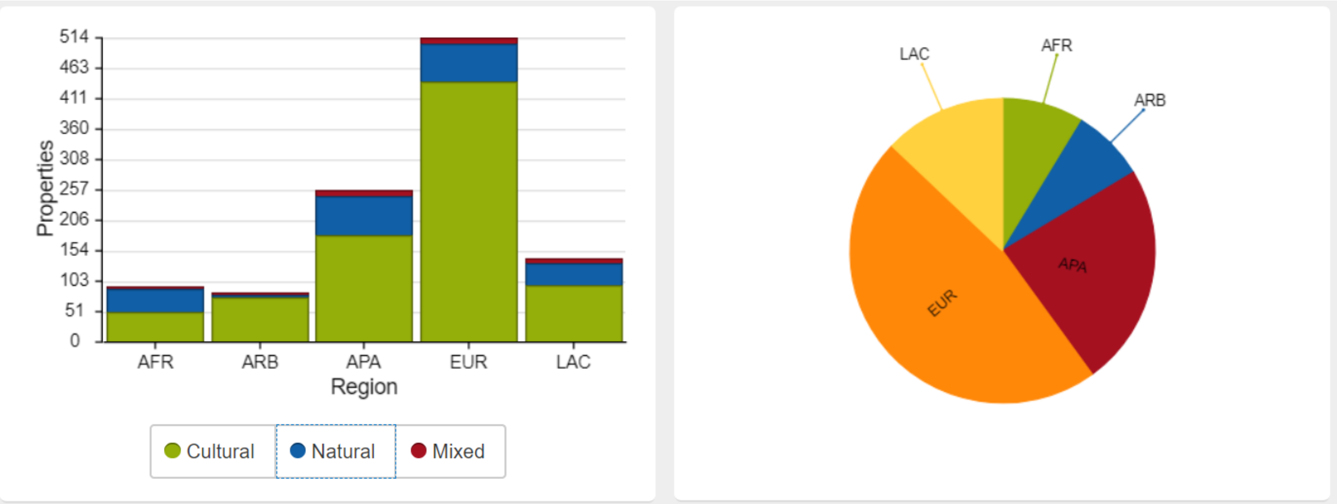


Figure 1-1: Summary of the number of World Heritage Buildings by region (Frey & Steiner, 2019b)

Table 1-1: Number of World Heritage Buildings by region (UNESCO, 2018)

Region	Cultural	Natural	Mixed	Total	%
Africa	52	38	5	95	8.70%
Arab States	76	5	3	84	7.69%
Asia and the Pacific	181	65	12	258	23.63
Europe and North America	440	63	11	514	47.07%
Latin America and the Caribbean	96	38	7	141	12.91%
Total	**845**	**209**	**38**	**1092**	**100%**

Inherited from the past, heritage buildings are crucial components in the society. Heritage includes buildings, structures, artifacts and areas that are historically, aesthetically and architectural significant. The three factors that determine if a property is worthy of being listed as heritage are historical significance, historical integrity and historical context. Historical significance is related to the importance of a property with respect to history, archaeology, engineering or culture of a community. This also includes any heritage building that is associated with past events or relevant people or has distinctive physical design characteristics that are a masterpiece. Historical integrity refers to the authenticity of a building's identity with an evidence of the existence of its physical characteristics during the building's historical period (Jokilehto, 2006; "Central Public Works Department," 2010; Central Public Works Department, 2013; Giovine, 2019; Dawoud & Elgizawy, 2018). 'Historical context' is an essential part of life and literature and in technical terms, it refers to the social, religious, economic, and political conditions that existed during a specific time and place. It concerns all the details of the time and place in which a situation occurs, which enables us to interpret and analyze works or events of the past, or even the future, instead of judging them by contemporary standards, the number of world heritage properties inscribed each year per region as shown in Figure 1.2 (Central Public Works Department, 2010; Central Public Works Department, 2013; Grace, 2019).

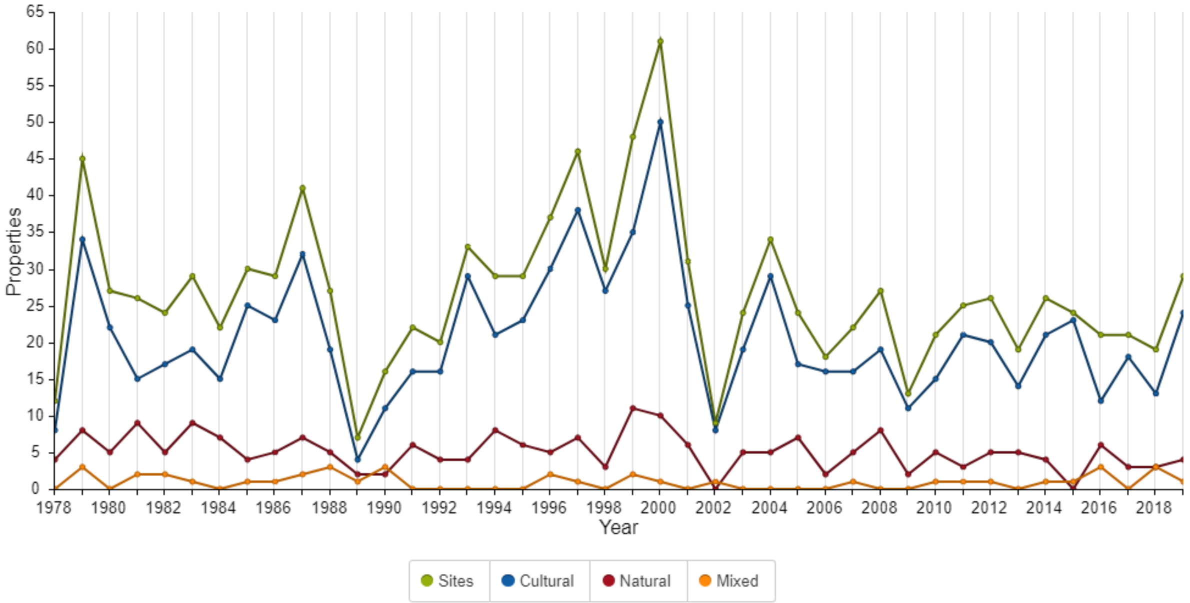


Figure 1-2: The number of world heritage properties inscribed each year per region (Frey & Steiner, 2019a)

Historic heritage buildings are very vulnerable. They were built with low resistant materials and the connections between main structures tend to be inadequate. Causes of damage include lack of maintenance, deterioration due to induced water from rain or rising dampness, and natural disasters such as earthquakes. In addition, from a structural point of view, damage may occur due to high stress from gravity loading, alterations in lay-out constructions or repetitive environmental actions (Perovic, 2015).

1.1.2 Heritage Buildings: Revenue

Heritage buildings are of great value. The tourism sector utilizes heritage buildings to make decisions regarding hotel settlement or transportation options. Most of the revenue in the tourism sector comes from heritage buildings. For example, heritage buildings account for 5.5% of the EU's GDP, create over 30% of its income from outer administration exchange, and employ 6% of the EU's workforce (Nypan, 2006). Tourism represents 6% (2003 data, in US$) of the world's products and ventures and includes an ever-increasing number of regions, some of which comprise of ancient and phenomenally rich civilizations such as China, India and Egypt. Table 1.3 demonstrates a list of 10 nations that recorded the most significant number of visitors in 2005 (UNESCO, 2006; UNESCO, 2018; & Giovine, 2019).

Table 1-2: Ten (10) countries with the most significant number of visitors in 2005 (Frey & Steiner, 2019a)

Country	Arrivals, M	Receipts G US$	No. of W.H.P UNESCO sites
France	76.0	42.3	30
Spain	55.6	47.9	39
USA	49.4	81.7	20
China	46.8	29.3	33
Italy	36.5	35.4	41
UK	30	30.4	33
Mexico	21.9	30.0	26
Germany	21.5	29.2	32
Turkey	20.3	18.2	9
Austria	20.0	15.5	8

According to a 2017 Canadian survey that gathered information from 1820 Canadian heritage sites, the following four provinces had the highest concentration of heritage revenue: Ontario’s revenue accounted for $1.1 billion (43%), Quebec for $619 million (25%), Alberta for $236 million (9%) and British Columbia for $225 million (9%). Table 1.3 summarizes the revenue by type of heritage institution.

Table 1-3: Summary profile of the revenue and expenditure of not-for-profit heritage institutions, by institution types, Canada, 2015 (Canadian Heritage, 2018)

Item#	**Art Galleries**	**Museums**	**Historic Sites**	**Archives**	**Zoos and Botanical Gardens**	**Total (Canada 2015)**
Unearned revenues	$350,716	$696,231	$86,588	$347,300	$128,145	$1,608,980
Earned revenues	$208,554	$424,977	$58,659	$20,919	$205,093	$918,202
Total Revenues	$559,270	$1,121,207	$145,247	$368,219	$333,238	$2,527,181
Total Expenditures	$523,711	$1,040,653	$134,454	$371,920	$321,489	$2,392,226
Profit margin (percent)	6.4%	7.2%	7.4%	-1.0%	3.5%	5.3%

(Note: all figures are in thousands of dollars)

1.1.3 Building Sector and Related Environmental Impacts

The rapid rise in the level of global energy consumption in recent decades has drawn the international community's attention towards urgently addressing the resulting detrimental environmental impacts such as the rising levels of observable greenhouse gas emissions (GHG) and their connection to global warming and climate change. This rise in energy consumption is closely linked to increasing urbanization and industrialization in both developing and developed countries. Figure 2 below shows the countries that contribute the most to global warming. It is well-known that the building sector is a significant contributor to energy consumption in the world. Buildings such as residential, commercial or public places require about 2 billion Tons Oil Equivalent (TOE) fuel, which is about 31% of fuel for global energy use. Buildings also consume 0.84 billion TOE in electricity and heating, which is about 46% and 51% for energy use. The energy consumption of the building sector in developing and developed countries is about 20% - 25% and about 30%–40%, respectively (Yau, 2014; Akande et al., 2014; Akande, 2015; Zhang et al., 2017; Han et al., 2020). The building industry contributes to about 32% of the global energy consumption, which far exceeds that of material resource consumption by more than a third. It also contributes to 12% of all freshwater usage. These percentages contribute to an estimated 40% of global solid waste generation and 40% of CO_2 emissions (IIASA, 2012; IPCC, 2007, 2014; Mckinsey, 2009; Ürge-Vorsatz, Harvey, Mirasgedis, & Levine, 2007; UNEP, 2009, 2011; UNEP, 2016; WEC, 2013). Hence, sustainable buildings are needed to help decrease GHG emissions and their related side effects, as seen in Figure 1.3. Sustainable buildings will impact the environment and society positively by creating job and business opportunities, minimizing air pollution, increasing productivity, generating better standard of living, reducing poverty, increasing energy security, and improving social welfare (IPCC, 2007; UNEP, 2009). Consequently, sustainability rating tools are vital in order to evaluate the performance of buildings, reduce their harmful impacts on the environment, and encourage facility managers and investors in making environmentally-friendly decisions with respect to their buildings (Al-Waer & Sibley, 2005).

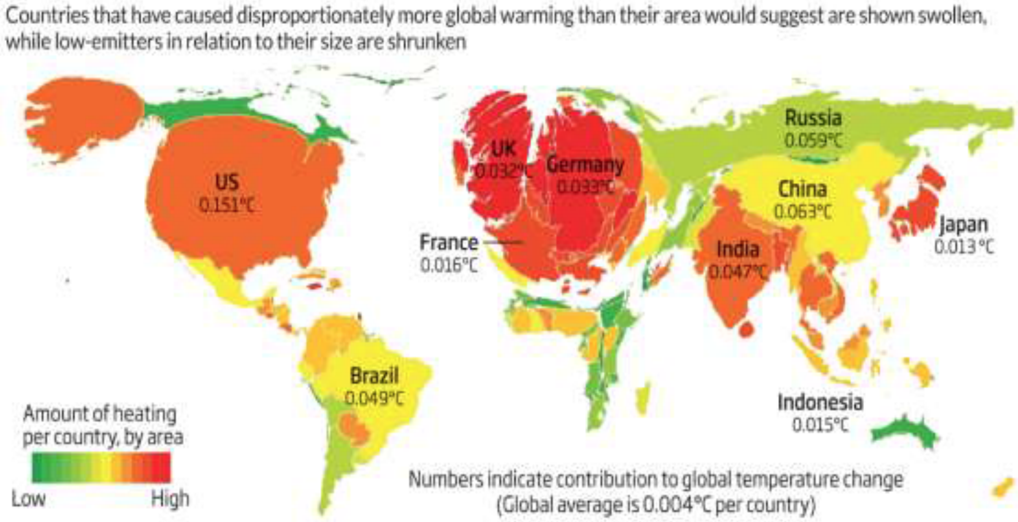


Figure 1-3: Global warming contributions per country (Environmental Research Letter adapted from New Scientist Magazine 2014)

Currently, compared to other countries, the Gulf countries in the Middle East region have the highest greenhouse gas emissions per capita, which is a function of their high energy consumption level and the critical role that hydrocarbons play in the structure of their economies (see Figure 1.4). According to Cessar and Pender (2005), there is evidence that climate change is linked to the environmental instability of cultural heritage sites. As they point out, according to heritage specialists, cultural heritage buildings are physically damaged and affected by environmental factors such as changes in temperature, water runoff and erosion, wind, extreme rainfall and river flooding.

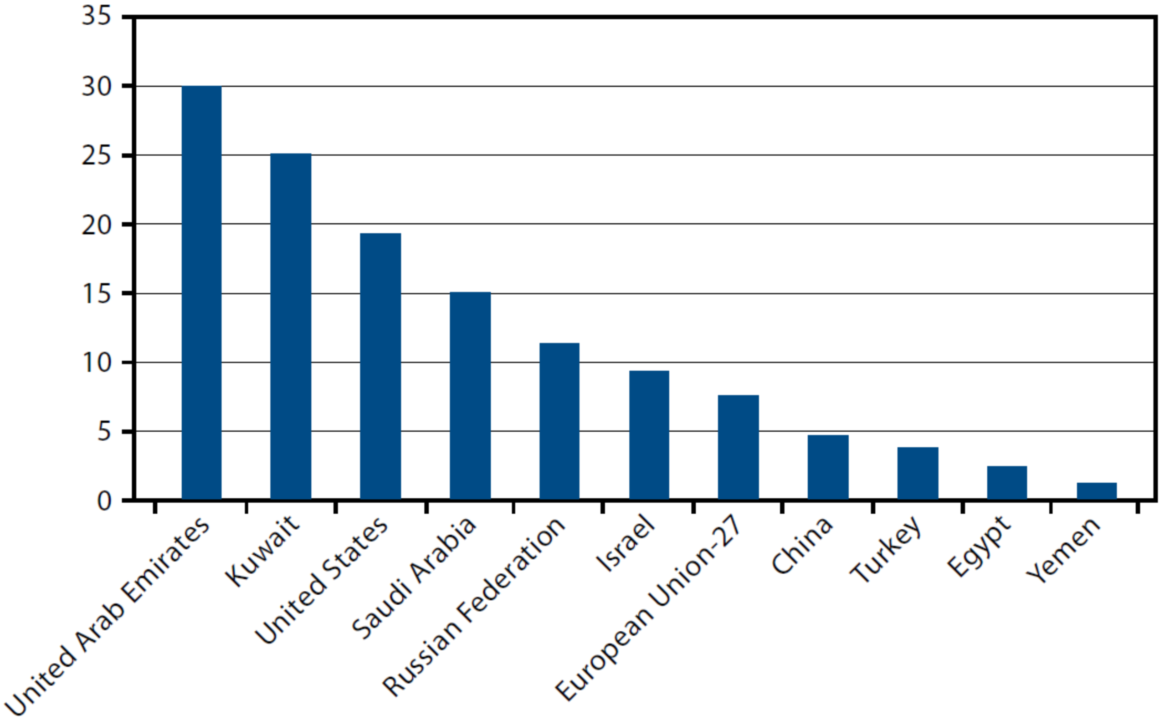


Figure 1-4: Carbon Dioxide Emission Per Capita (Tolba & Saab, 2009)

While the entire Arab region encounters similar environmental threats, other countries will also be impacted by climate change. Countries relying on surface water such as Iraq, Turkey, Syria, Jordan, Egypt and Morocco may face significantly reduced water flow if climate change adversely impacts precipitation patterns in catchment areas that feed rivers upstream (Sowers & Weinthal, 2010). Similarly, sea-level rise is expected to occur and would affect coastal countries such as Egypt, Tunisia and the small Gulf countries, with high population in low altitude areas (see Figure 1.5) (Ghoneim, 2009; Ibrahim, 2012; & Marzouk et al., 2019).

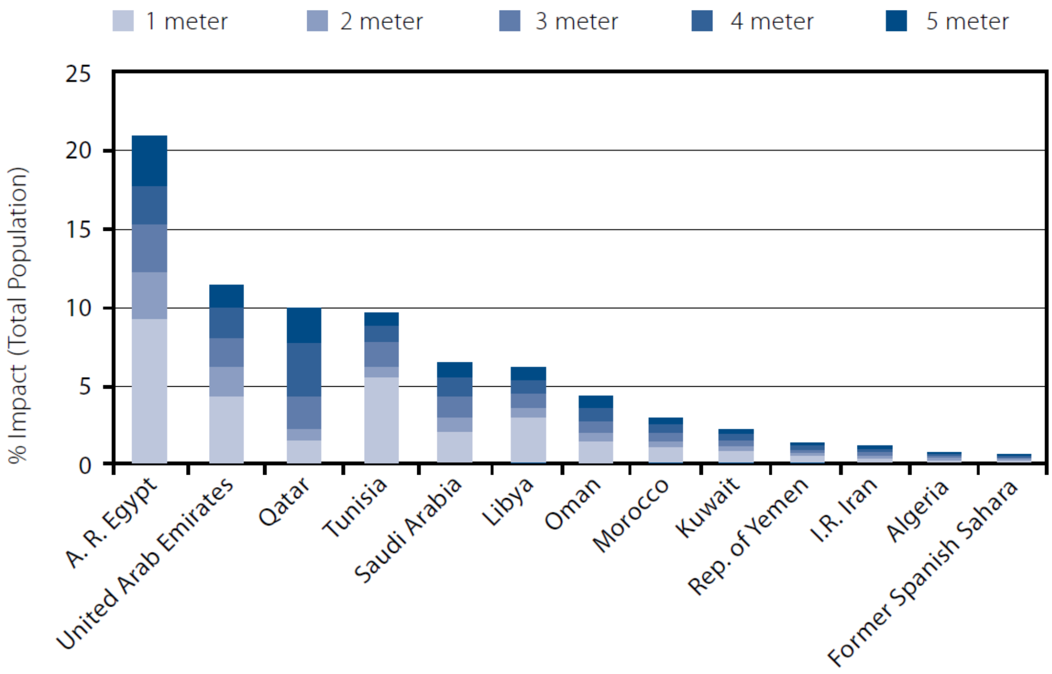


Figure 1-5: The impact of sea level rise on the Arab countries (Tolba & Saab, 2009)

1.1.4 Energy Performance of Heritage Buildings

A building's energy performance is characterized as the energy consumption (actual or estimated) for its proper functioning (Poel et al., 2007, p.395). It is determined by considering parameters such as the surrounding environment, climate, exposure to the sun, energy generation within the building itself, indoor environment, and insulation (Figure 1.6). Modern buildings are designed and built to emit less greenhouse gases and to be more energy efficient (DCLG, 2006).

The authors (Rye 2010; 2011 & Baker, 2011) argued that ArchiCAD and other similar software are characterized by inbuilt inflexibility and their generic treatment predisposes older buildings to less accurate energy efficiency ratings. Meanwhile, Moran et al. (2012) stated that despite government statistics showing higher CO_2 emissions from historic buildings, there are differences in how the energy efficiency of these buildings is viewed. These differences emanate from more recent research that investigate and model the heat and energy use of heritage buildings. This led to an energy efficiency rating for heritage buildings as either good (Wallsgrove, 2008; English Heritage, 2009; Wood, 2009) or weak (DCLG, 2006; EHCS, 2007; Boardman, 2007; DCLG, 2006).

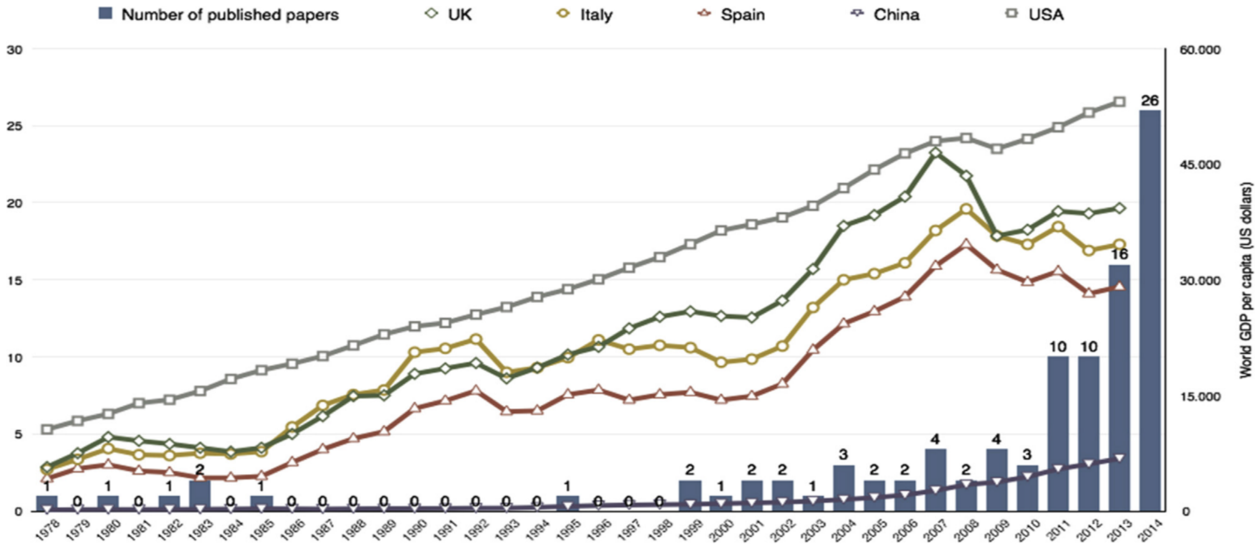


Figure 1-6: Number of publications on energy efficiency and thermal comfort of historic buildings compared to the GDP per capita of the most important countries (Kallakuri et al., 2016)

Residential and commercial buildings are the main contributors to energy consumption in the building sector. As stated in IPCC (2014), residential and commercial buildings account for 24% and 8%, respectively, of the total global energy use. Space heating is the leading consumer of energy in both residential and commercial buildings, with percentages of 32% and 33%, respectively. Cooking as an end use represents 29% of the total global energy consumption in residential buildings while IT equipment represents the second leading energy consumer, with a percentage of 32% (Intergovernmental Panel on Climate Change & Intergovernmental Panel on

Climate Change, 2012). Furthermore, lighting comes in the third place of importance in commercial buildings, representing 16% of energy use, while water heating accounts for 24% of energy use in residential buildings (Figure 1.7). Therefore, a building's function affects its overall energy consumption as well as the end-use activities (Schuck, 2013; & Mahmoud, 2017).

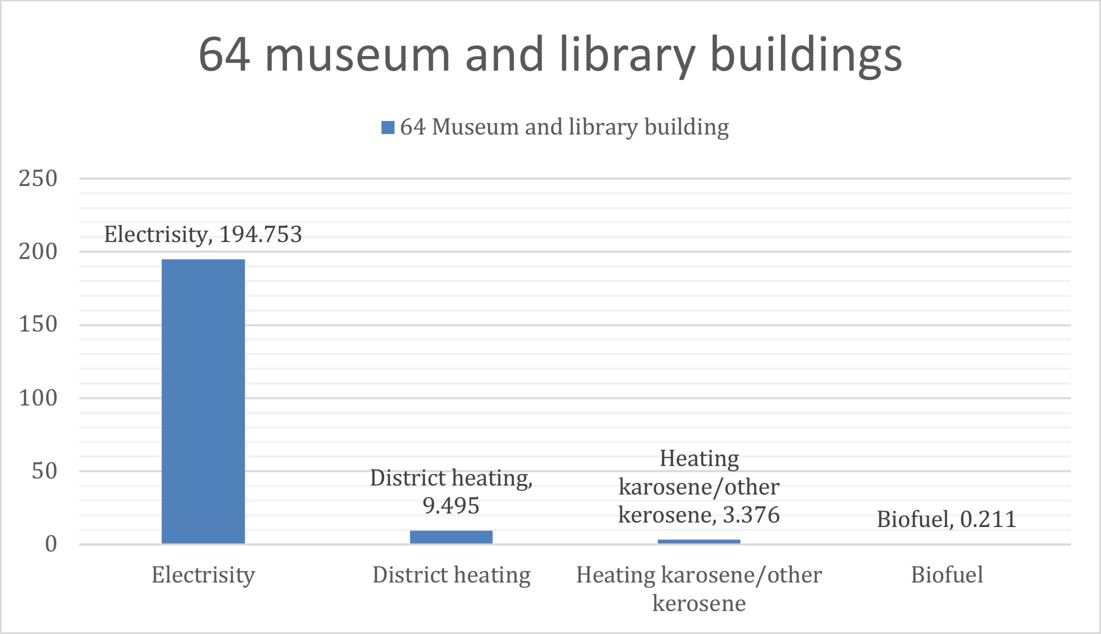


Figure 1-7: Energy consumption of museums and library buildings in Norway (IPCC, 2014)

1.2 Problem Statement and Research Motivation

Although there are several rating tools that assess sustainability of buildings, there is no appropriate rating system for the assessment of the sustainability of heritage buildings. Moreover, there is no unified concept or definition of assessment attributes that express the key aspects of sustainability (Berardinis et al., 2017).

The local context is a fundamental aspect that should be considered when assessing a building. The local context is the region where the building that is subjected to assessment exists. Local parameters and variations significantly affect the performance of the building. Local variations are strictly related to the triple bottom line of sustainability, that is, environment, society and economy. Environmental variations comprise of the local climate (that is, temperature, wind speed and rainfall frequency), location and carbon footprint. Social aspects refer to cultural characteristics, working hours and vacations that affect the building's usage profile. Finally, economic aspects are associated with the currency value, inflation rates, interest rates, building condition, maintenance fees and the availability of an ample budget. Although these variations are correlated, they differ in their importance, weight and impact on the sustainability of buildings from one local context to another. Consequently, sustainability assessment procedures should be site-specific using weight parameters (degree of importance) rather than standardized parameters. This argument leads to the assessment of sustainability of heritage buildings using fixed weight criteria regardless of the variations in local contexts. These criteria should be applicable to several contexts and still preserve the key assessment factors and attributes that maintain its consistency. Therefore, there is need to use Multi Criteria Decision Making (MCDM) process to obtain the index for each criteria, factor and indicator. Fuzzy theory is introduced to handle the uncertainty and vagueness arising from the computation of the factors affecting the performance of the different alternatives.

A significant shortcoming of currently existing rating systems is the absence of a sustainability assessment model that can assist decision makers in upgrading the sustainability of heritage buildings in terms of minimizing energy consumption levels and life cycle costs. The importance of such a model lies in its ability to tackle the economic aspects of sustainability. This means the proposed alternatives to upgrade the sustainability of buildings should be affordable, efficient and economical over their entire life cycle. Thus, the primary purpose of this research is to develop a sustainability rating and rehabilitation tool for heritage buildings through the analysis of case studies of heritage buildings in Canada and Saudi Arabia. Both countries face different problems and challenges in terms of their environment and the standards and protocols of their respective heritage building organizations. In addition, those countries have different type of climate condition. For example, Saudi Arabia represents hot climate while Canada represents cool climate. Also, these two countries have widely different heritage and culture. Consequently, there is a need for the development of a sustainability assessment rating system that is widely and universally applicable and accessible to diverse contexts in order to better ensure practical sustainability efforts and offer an assessment that is geared to the unique demand of heritage buildings.

1.3 Research Objectives

The purpose of this research is to establish a sustainability rating tool for heritage buildings that considers environmental, physical and sustainable aspects. This rating tool will provide decision makers with a tailored holistic evaluation concerning the sustainability performance of their buildings, according to the different local contexts of their assets. This research also focuses on studying the six major phases of a building's life cycle. To achieve this primary objective, the following sub-objectives must also be addressed:

1. Identify and study the criteria, factors, and indicators that impact the sustainability of heritage buildings.
2. Design a hybrid multi-criteria sustainability-rating model and a scale for heritage buildings.
3. Determine sustainability-based energy savings along the life cycle phases of heritage buildings.

4. Design an automated tool and perform sensitivity analysis for the developed models.

1.4 Research Methodology

This research aims to establish a comprehensive sustainability rating tool for heritage buildings that considers the local variations within the environmental, physical and sustainable criteria. The general methodology of this study consists of three phases: (1) *literature review:* the main objective is to compare the criteria, factors and indicators of different rating systems. This comparison will cover the 12 existing rating tools addressed in section 6.2; (2) *identification of the criteria, factors, indicators and sub-indicators:* these sets of attributes collectively reflect the sustainability of heritage buildings and are collected from interviews, heritage organizations and the literature review (see Section 6.2). This section also addresses the impact of the project life cycle phases of heritage buildings; and (3) *data collection and implementation:* this can be found in Chapter 4 of this study. To achieve these objectives, Figure 1.8 summarizes the applied methodology.

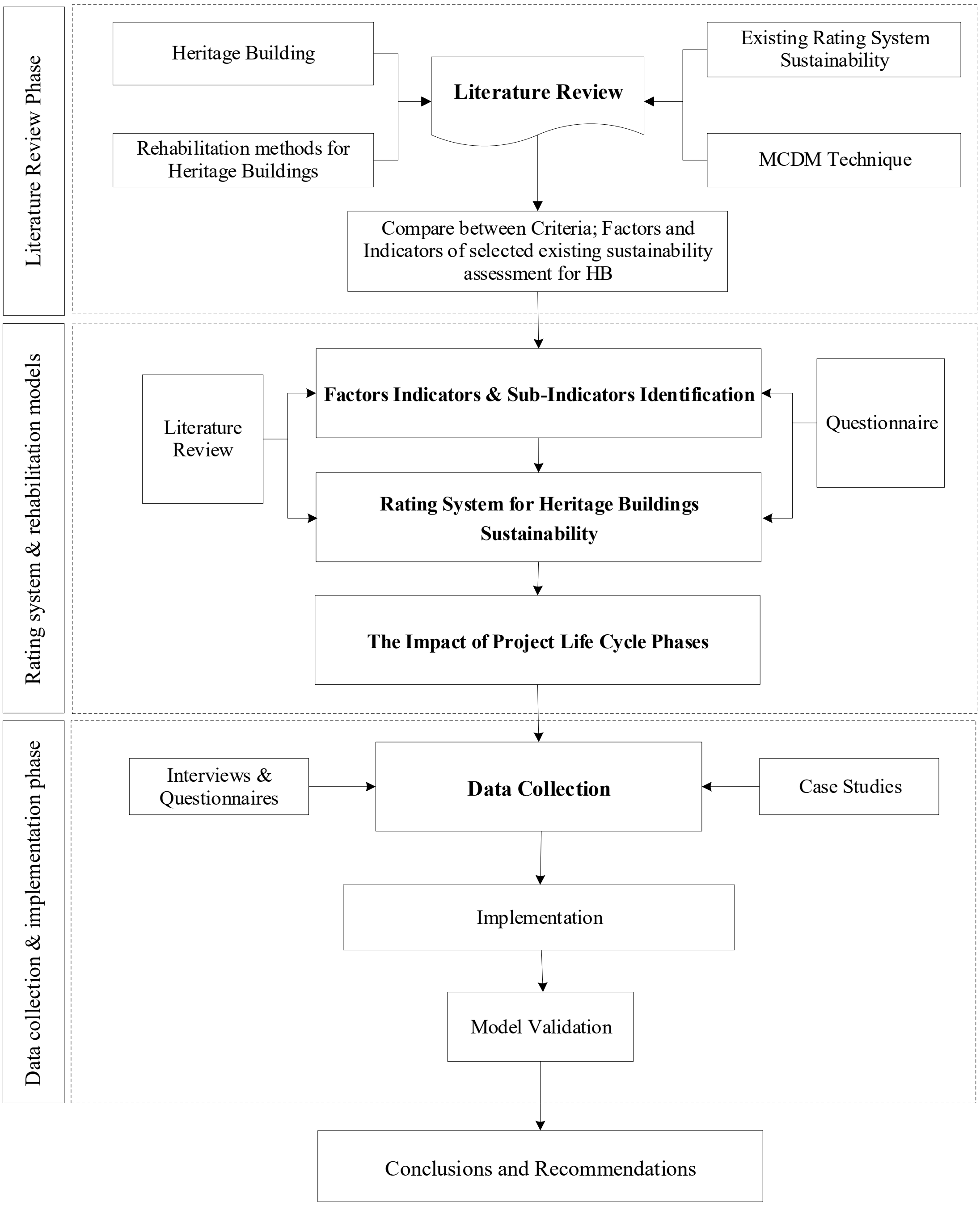


Figure 1-8: Research framework

1.5 Organization of Thesis

This thesis comprises of eight chapters. Chapter One provides an introduction of the research background and describes heritage buildings in terms of sustainability, revenue, the building sector and related environment, and energy performance.

Chapter Two provides detailed review of the state-of-the-art concerning sustainability assessment for generic buildings and in particular, heritage buildings. In essence, it comprises of five main sections: (1) an overview of heritage buildings and the existing rating systems used for sustainability assessment of heritage buildings; (2) definitions, types, and conservation treatments of heritage buildings; (3) an overview of existing rating systems for sustainable heritage buildings; (4) energy performance, embodied energy, modification for reuse of existing heritage building structures and sustainability of heritage buildings; and (5) limitations of existing rating systems with respect to heritage buildings and comparisons between LEED, ITACA and BREEAM.

Chapter Three describes two proposed models for heritage buildings - one for sustainability assessment and the other a rehabilitation model based on sustainability. This chapter also details the methodology for each model's development. It is divided into four main sections: (1) research methodology for the determination and evaluation of appropriate sustainability assessment attributes. This is further sub-divided into four aspects: (a) Identification of sustainability assessment parameters; (b) Weight evaluation by applying the Fuzzy TOPSIS technique; (c) Determination of results for each indicator; and (d) Determination of results for each factor. (2) determination of the total score and sustainability ranking; (3) the Sustainability Based Rehabilitation Model for heritage buildings; and (4) a chapter summary.

Chapter Four depicts the data collection and analysis phase. It includes three sections: (1) criteria and factors that affect sustainability; (2) identification of sustainability assessment attributes; (3) research survey including observation, interviews and questionnaire; (4) weight determination based on the Fuzzy TOPSIS technique for factors and indicators (this relies on the questionnaire responses of experts and a conversion of the linguistic response); (4) determination of a sustainability scale; and (5) chapter summary.

Chapter Five presents: (1) case studies and analytical results for Murabba Palace in Saudi Arabia and Grey Nuns building in Canada; (2) development of AutoCAD® and ArchiCAD® simulation models; and (3) results from questionnaire and an analysis of the chosen attributes for sustainability assessment.

Chapter Six presents analytical results and model implementation phases, which include: 1) data reliability, 2) calculation of the weighted normalized decision matrix; 3) determination of generalized weights; 4) PIS and NIS distance measurements; 5) evaluation of similarity measures (S); 6) calculations of Closeness Coefficient (CC); 7) determination of scores for indicators and sub-indicators; 8) calculation of indicator Sustainability Index (SI); 9) calculation of Heritage Building Index (HBI); and 10) model implementation. The Building Information Model (BIM) simulates energy consumption, emissions analysis, life cycle analysis and Sustainability Assessment (SA) for both case studies.

Chapter Seven presents the automated tool for the proposed assessment model. It comprises of three sections: (1) description of the selected case study; (2) the developed BIM and energy simulation models; (3) the results of the energy simulation model; (4) results of the calculated weights of criteria and factors; and (5) sensitivity analysis.

Finally, Chapter Eight presents conclusions, research limitations and contributions, and recommendations for future research.

CHAPTER 2 : LITERATURE REVIEW

2.1 Chapter Overview

The main aim of this chapter is to provide a comprehensive literature review concerning heritage buildings in relation to the existing worldwide sustainability rating systems. Furthermore, this chapter addresses the main attributes that influence the sustainability of existing projects and sheds light on the shortcomings of some of the existing rating systems by pinpointing the assessment attributes they overlook. Finally, one of the studied decision support techniques will be presented. The primary sources of all the information included in this chapter are journal papers, technical reports, manuals, textbooks, websites, and guides of rating systems, as shown in Figure 2.1.

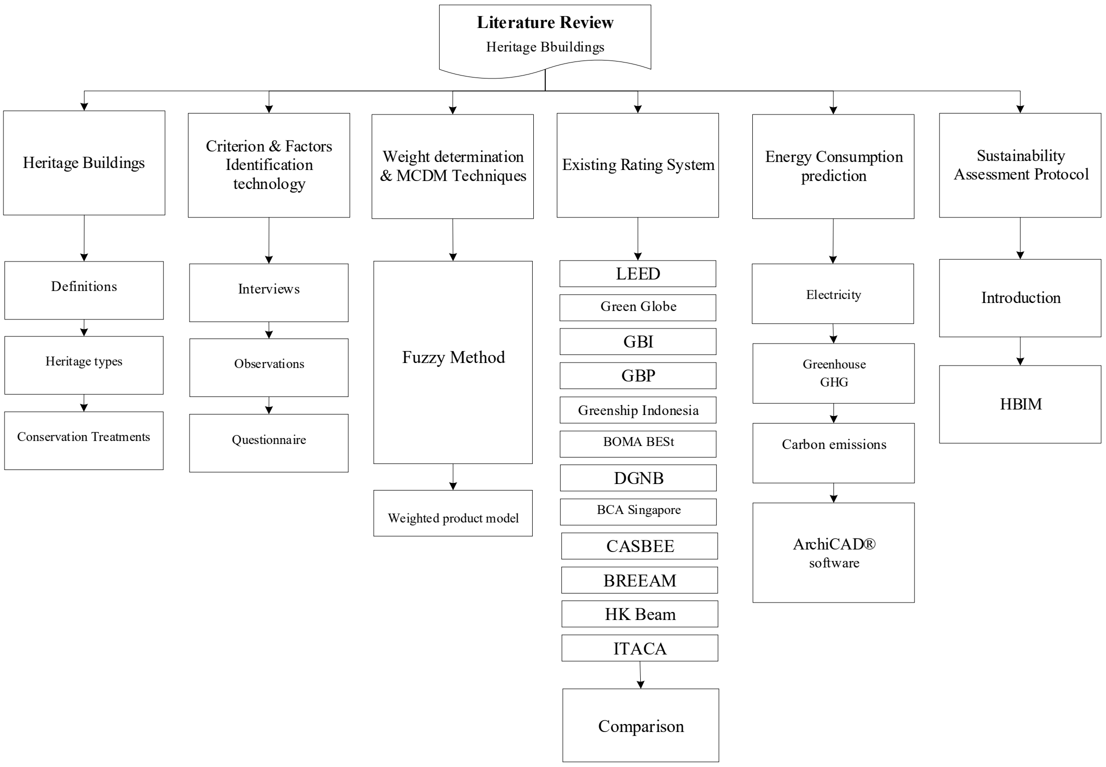


Figure 2-1: Literature Review flowchart

2.2 Systematic review

For the literature search, there is a two-step screening process. Firstly, the number of abstracts that are screened (after duplicates) is reported and then, the number of abstracts whose full-texts are chosen to be read is reported. Secondly, the number of full-text articles that were included in the final review/analysis is reported (Figure 2.2).

After screening, the systematic review process involves five predefined steps. In particular, the systematic review starts with framing questions for a review. This involves defining the problems to be addressed in a clear and structured question format. The relevant work should be surveyed in a comprehensive manner by searching through resources without any language restriction. After compiling the list of relevant work, their quality should be assessed by leveraging assessment criteria. Such criteria would help in identifying the main contribution of the collected studies as well as their strengths and weaknesses. The study characteristics, impacts and contribution are then tabulated and used to summarize each study. The final step of the systematic review involves interpreting the findings in terms of identifying biases, gaps and overlaps among the surveyed studies. In what follows, the systematic review process followed in this research is highlighted. The purpose of this system is to generate data collection from the strongest articles in this field which can help to understand the attributes of sustainability assessment in heritage buildings.

An array of bibliographic databases, including discipline-specific and multi-disciplinary resources, was utilized and publication dates ranged from 1990 to 2020. The following databases were used: Google Scholar, IEEE Xplore, ProQuest Central, Academic Search Complete, Business Source, EconLit, Medline, Geobase, Compendex, GreenFILE, Scopus, ProQuest Dissertations & Theses Global, and Web of Science (Table 2.1). All are common databases employed in research on the sustainability of heritage buildings. In this research, Excel® was employed for data classification for the systematic review analysis.

Search results were required to contain at least one term related to one of the following keywords: (1) Sustainability, (2) Heritage/Cultural Buildings, and (3) Rating Systems/Information Modeling.

For example:

Sustainable* AND *("Heritage Buildings*" OR "architectural heritage" OR "cultural heritage"*) AND *("rating system*" OR classification OR "information modeling" OR Assessment OR "Heritage Buildings Information Modeling" OR HBIM).*

All database search was conducted by a library science expert and followed standards first articulated by Cooper, (1998), and later developed into a set of best practices by the Campbell Collaboration (Kugley et al., 2017; Pickup et al., 2018). Wherever possible, the methodology for database search was modified to suit the requirements of each database by using official controlled vocabulary subject headings or publication type filters (for example, to remove magazine and newspaper articles).

The bibliographic database search was supplemented by a separate strategy to locate grey literature (Farace & Schöpfel, 2010). The primary tool employed was the Google search engine. When scholarly books and conference proceedings were found, their tables of content were scanned for additional relevant information. An exhaustive single search statement is not possible using Google; hence, several search requests were run, varying the keywords employed. For example, sustainability rating system heritage, sustainability rating system, *"Heritage Buildings Information Modeling,"* sustainability *"cultural heritage", "information modeling".* Overall, a total of 1533 results were generated, of which 990 abstracts were retained for review after duplicates were removed (Figure 2.3).

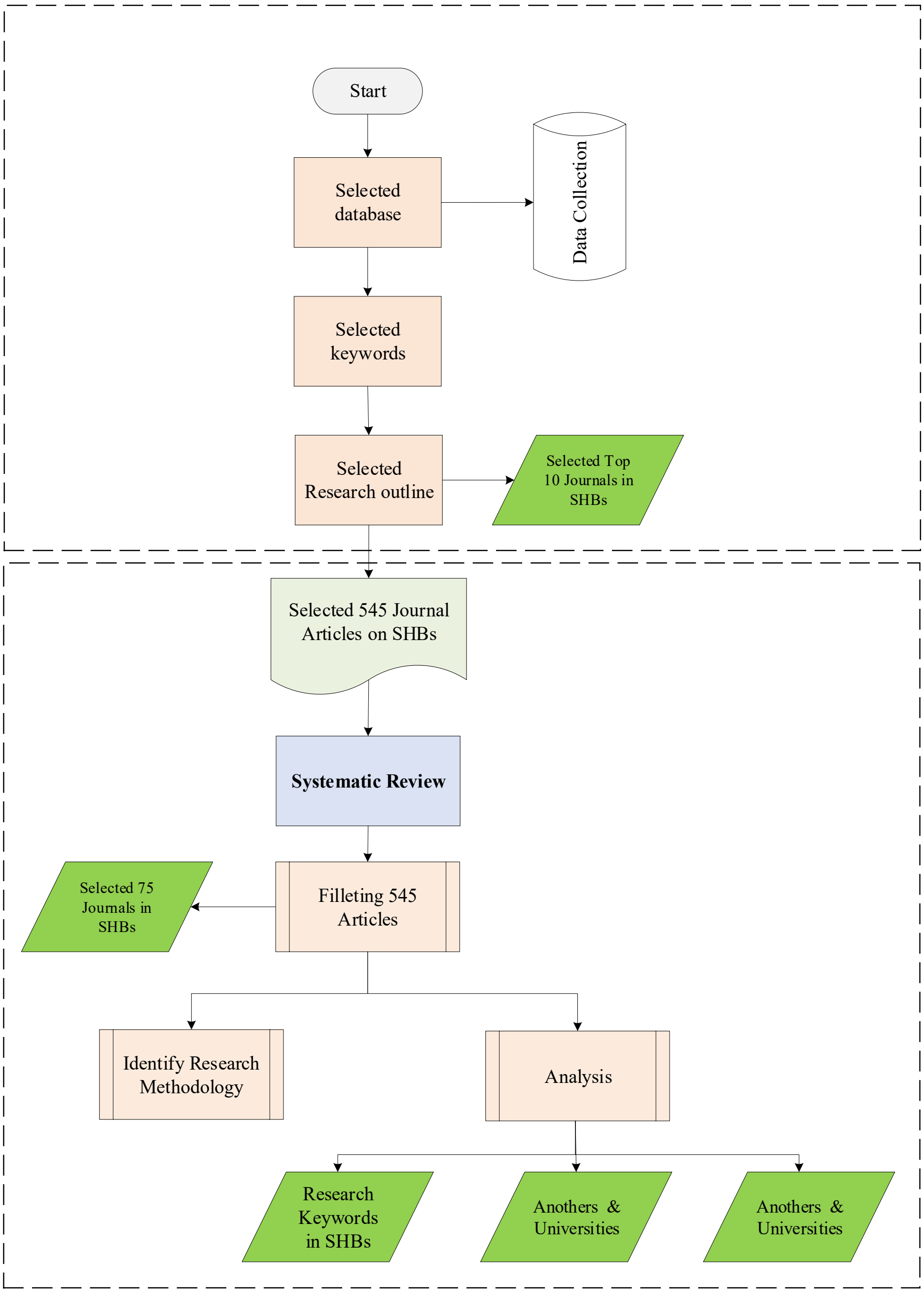


Figure 2-2: Procedure for literature review

Table 2-1: Search History – Overview of Results

Database/Source	Total Results	Results After Duplicates
Academic Search Complete	124	124
Business Source	39	20
GreenFILE	35	16
EconLit	9	9
Medline	11	7
Geobase	135	112
Compendex	240	203
IEEE Xplore	18	17
ProQuest Central	189	147
ProQuest Dissertations	23	20
Web of Science	272	159
Scopus	392	116
Google/Google Scholar	46	40
TOTAL	**1,533**	**990**

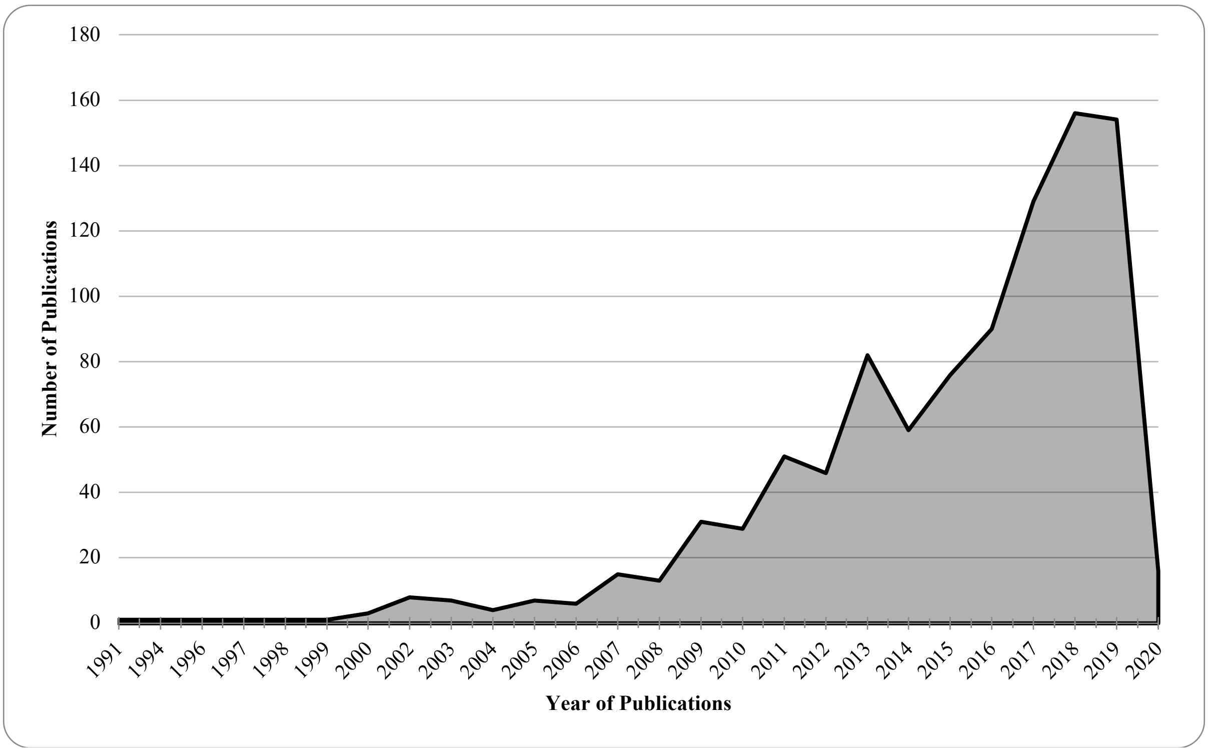


Figure 2-3: Yearly SHBs from all publications (1990 – 2020)

2.2.1 Selection of Database

After selecting the top 10 high-impact factor journals, only 78 papers were found to be published from 1990 to 2020 and were related to SHBs (Figure 2.4). This figure also highlights the procedure of filtering all publications. The different types of publications collected in the systematic review phase included *book, thesis, report, conference paper, and journal paper,* as shown in Figure 2.5.

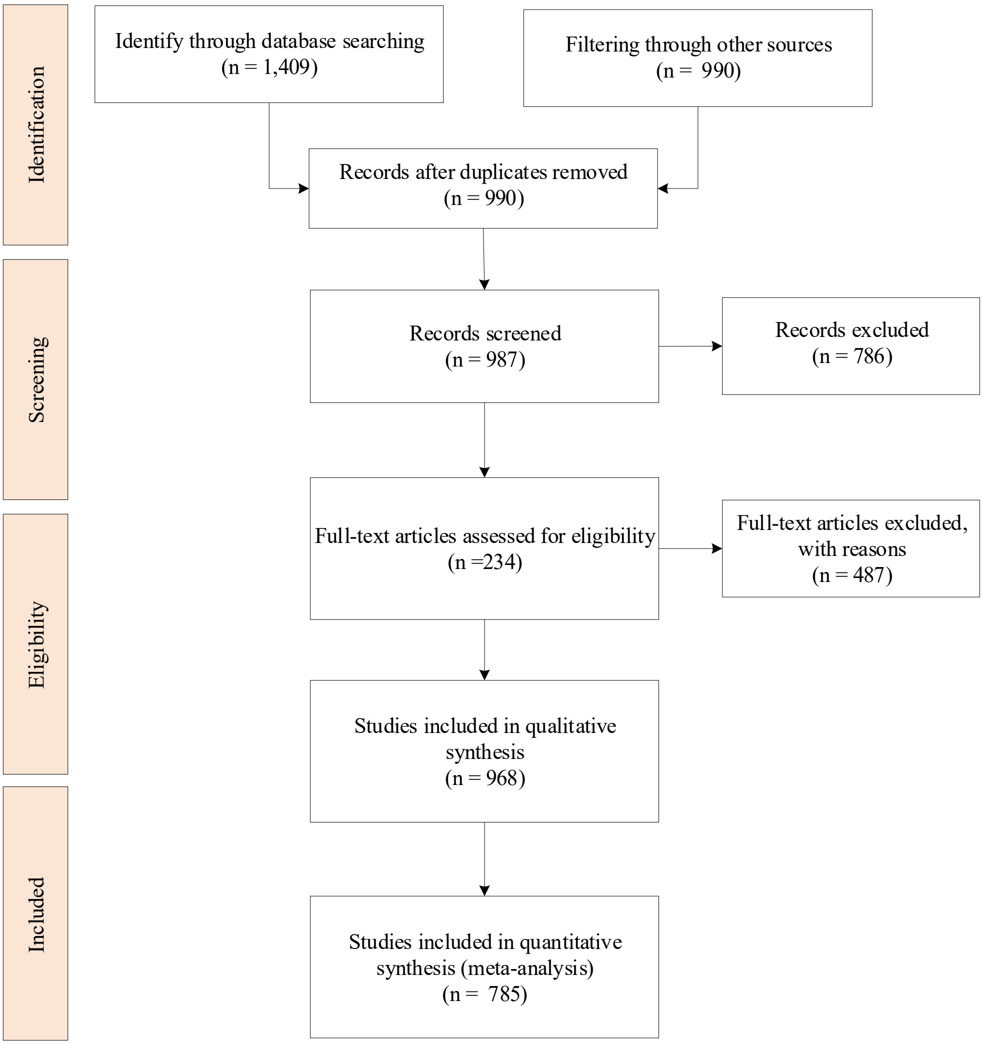


Figure 2-4: PRISMA 2009 Flow Diagram- *Systematic review procedure*

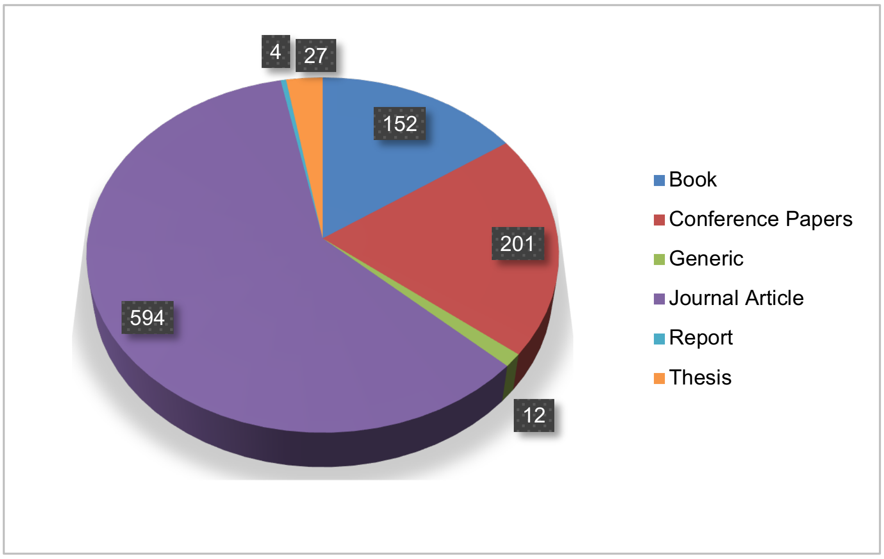


Figure 2-5: Types of (SHBs) publications from 1990 to 2020

2.2.2 Results and Discussion

Based on the systematic review, the analysis and discussion of results encompass yearly publications, the impact of countries on SHBs, publications of universities and authors, top authors and top universities, and institutions in SHBs research. Excel was used to calculate the highest ranking of the year, university, and the author for research in SHBs.

Yearly Publication on SHBs

Figure 2.3 presents the yearly SHBs research publications over the last twenty years. It can be observed that for research on SHBs, between 2000 and 2010, there was, on average, one paper that was published on SHBs yearly. Thus, during the years (2011 to 2016), research on SHBs increased progressively, as seen in the increasing number of research publications per year. From 2017 to 2020, publications in SHBs also increased, as shown in Figure 2.3.

Selected Journals and Keywords

Since keyword search has proven to be an effective means for literature retrieval from various search engines (Deng & Smyth, 2013), the most common and interchangeable keywords related to SHBs were used to extract a more comprehensive set of bibliometric data on SHBs. For instance, the keywords used for the search include *sustainability rating system heritage, sustainability rating system "Heritage Building Information Modeling"* HBIM*, sustainability "cultural heritage", "information modeling",* and "*renovation"*, as shown in Table 2.2. Efforts were made to use keywords which can assist in retrieving almost all the journals and papers on SHBs. Furthermore, only the high-impact journals in the field of sustainability of heritage buildings (SHBs) were retrieved. The top ten journals in SHBs are *Journal of Cultural Heritage, International Journal of Architectural Heritage, Sustainability, Sustainable Cities and Society, Sustainable Development, Engineering Construction, and Architectural Management, Building and Environment, Heritage Science, and International Journal of Heritage Studies*. Only papers in the English language were incorporated, as shown in Table 2.3 and Figure 2.6. Of these journals, *Building and Environment* and *International Journal of Heritage Studies* had the highest and lowest impact factors, respectively. Also, the *Journal of Cultural Heritage* had the highest number of publications while *Sustainable Development* and *Engineering Construction and Architectural Management* had the lowest number of publications. Based on the predefined selection criteria, a total of 78 papers was considered for the systematic analysis review. The abstracts of the 78 papers were examined to compile the top 10 keywords listed in Table 2.2 below.

The Origins of the selected SHBs journal articles

Based on the systematic review, Table 2.4 indicates the countries where SHBs research has been conducted and the total number of involved universities/institutions, authors, and articles from 2000 to 2020 from the selected 78 journal papers. From Table 2.4, Italy had the highest number of relevant articles (20) from 24 universities and 53 authors.

Table 2-2: Top 10 Keywords on SHBs research

Top 10 keywords	
Keyword	**Count**
Cultural Heritage (CH)	17
Sustainability	16
Energy Sustainability (ES)	14
Conservation	13
BIM	12
Heritage	11
Sustainable Development (SD)	9
Management	7
HBIM	6
Heritage Buildings (HBs)	6

Table 2-3: Top 10 Journals on SHBs research

No#	**Top 10 Journal Names**	**Impact Factor**	**No. of Articles**
1	Journal of Cultural Heritage	1.955	15
2	International Journal of Architectural Heritage	1.440	5
3	Sustainability	2.592	41
4	Sustainable Cities and Society	4.624	4
5	Sustainable Development	3.821	1
6	Eng. Construction and Architectural Management	1.561	1
7	Building and Environment	4.820	3
8	Journal of Building Engineering	2.375	2
9	Heritage Science	2.165	4
10	International Journal of Heritage Studies	1.364	2
	Total		78

Research on SHBs: Impacts of Researchers/Universities

The contribution of various researchers and their affiliations are shown in Table 2.5. It is evident that the top 10 researchers in SHBs are from Belgium, Italy, Greece, Iran, and China, respectively. The results also indicate that many researchers dedicated time and effort to conduct SHBs research during the studied period. Litti had the highest number of publications, with seven (7) from the University of Antwerp. It can also be deduced from Table 6 that about 50% of the top researchers are affiliated to institutions in Belgium. For the selected universities and institutions indicated in the systematic review, the top 20 universities and institutions around the globe were found, as shown in Table 2.5.

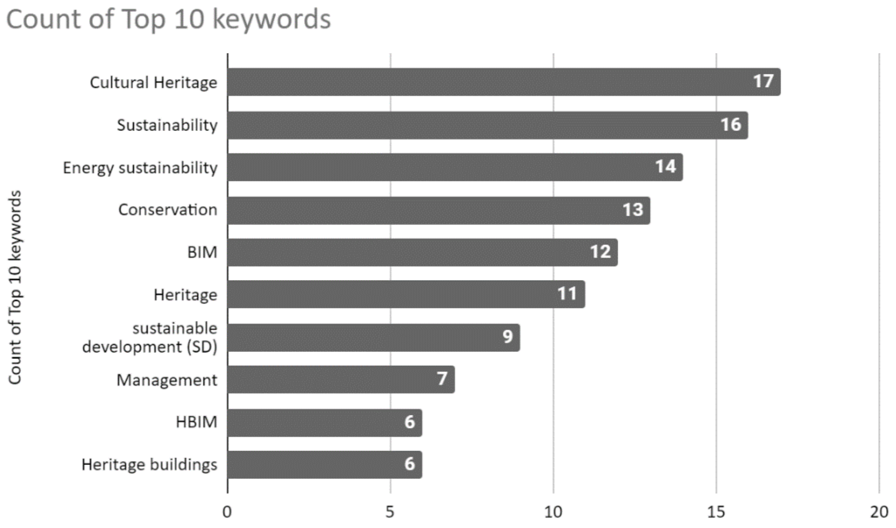


Figure 2-6: Yearly research publications on SHBs (2000 – 2020)

Impacts of countries to SHBs research

After a systematic review, the 78 papers were once again examined to determine the top ten countries involved in SHBs research. For instance, Italy has had ten co-authored research with nine countries: Portugal, Spain, UK, New Zealand, Netherlands, Brazil, Belgium, Germany, and Czech Republic. 2 out of the ten corporations were with Belgium. Also, Canada is seventh on the list, having three co-authored research with three countries: Norway, Egypt, and Romania, as shown in Table 2.6.

Table 2-4: Top countries on SHBs research

County	Uni/Inst.	Authors	Articles
Austria	1	1	1
Australia	1	1	1
Belgium	3	4	2
Canada	2	2	2
China	16	29	9
Cyprus	4	7	3
Czech Republic	1	4	2
Egypt	1	2	1
Germany	4	8	2
Greece	2	10	2
Iran	1	6	2
Italy	24	53	20
Korea	1	1	1
KSA	1	1	1
Malaysia	1	6	1
Mexico	1	1	1
Netherlands	3	9	3
New Zealand	2	5	2
Norway	1	1	1
Poland	1	4	1
Portugal	6	12	5
Qatar	1	2	1
Romania	3	6	2
Spain	12	24	8
Sweden	1	4	1
Taiwan	1	1	1
Turkey	5	16	9
UK	10	29	11
USA	2	3	2

Table 2-5: Top 10 researchers on SHBs research

Researcher	University	Country	Papers
Giovanni Litti	University of Antwerp	Belgium	7
Carla Balocco	University of Florence	Italy	6
Maria Karoglou	National Technical University of Athens	Greece	3
Mostafa Behzadfar	University of Science and Technology	Iran	3
Amaryllis Audenaert	University of Antwerp	Belgium	2
Xilian Luo	Xi’an Jiaotong University	China	2
Weiyao Tang	Sichuan University	China	2
Lisheng Weng	Sun Yat-sen University	China	2

Chengcai Tang	Beijing International Studies University	China	2
Min Yin	Nanjing University	China	2

Table 2-6: Top 10 countries with co-authorship in SHBs research

County	# of Corporations	# of countries
Italy	10	9
UK	6	6
Germany	4	4
Czech Republic	4	4
Netherlands	4	4
Canada	3	3
Spain	3	3
Portugal	2	2
China	2	2
Belgium	2	1

Research Methodologies

In the 78 papers, five methodologies have been applied in SHBs research. These methodologies include simulation, Heritage Building Information Modeling (HBIM), visualization, energy survey, and Multi-Criteria Decision Making (MCDM) methodologies. A summary of research gaps and how each methodology was used to solve problems is presented in Table 2.7.

Table 2-7: Methodologies applied to SHBs research

Methodology	Paper	Technique
Simulation	(Fahmy et al., 2014), (Tiwari, Bhatti, Tiwari, & Al-Helal, 2016), (Pisello et al., 2014)	Software® + SRCs
	(Yildirim & Bilir 2017), (Attar et al., 2013), (Radhi et al., 2013)	TRNSYS+ DesignBuilder®
	(Fumo & Biswas 2015), (Wong et al., 2013), (Hygh et al., 2012),	ArchiCAD® + PVTIGS
HBIM	(Pocobelli, Boehm, Bryan, Still, & Grau-Bové, 2018)	Visualization + BIM
	(Bruno & Fatiguso, 2018), (Hygh et al., 2012), (Kubalikova et al., 2019)	Visualization + Simulation + 3D model
	(Murphy et al., 2013), (Ren & Han, 2018)	Documentation + Simulation
	(Cuperschmid et al., 2019), (Al-Sakkaf et al., 2020)	Simulation + Software®

	(Khodeir et al., 2016), (García-Esparza & Tena, 2018)	3D model + Visualization
Visualization	(Abanda et al., 2013), (Fumo & Biswas 2015), (Khalil & Stravoravdis, 2019)	laser scanner + Virtual prototyping
	(Wong et al., 2013), (Fumo & Biswas 2015), (Di Fazio & Modica, 2018), (Elfadaly & Lasaponara, 2019)	virtual prototyping + BIM model + GIS
	(Khalil & Stravoravdis, 2019), (Abdelmonem et al., 2017)	3D printing + laser scanner
Energy Survey	(Tiwariet et al., 2016), (Attar et al., 2013)	Energy analysis + SWHS
	(Attar et al., 2013), (Naamandadin, Sapian, Mazlina, & Khuzzan, 2018)	GHG + Software
	(Kehinde, 2015), (Yildirim & Bilir 2017), (Günçe & Misirlisoy, 2019)	Documentation + Simulation + Software®
	(Yildirim & Bilir 2017), (Shamseldin, 2018)	SRCs + PVTIGS
MCDM	(Prieto et al., 2017), (Sanna et al., 2008)	Fuzzy logic + AHP
	(Sanna et al., 2008), (Bottero, D'Alpaos, & Oppio, 2019)	Visualization + ANP
	(Alireza et al., 2018), (De Rosa & Di Palma, 2013)	Simulation + Fuzzy logic
	(Tupenaite et al., 2017), (Matute et al., 2014)	BIM + AHP

2.3 Heritage Buildings

2.3.1 Definitions

This section reviews three main aspects of heritage buildings: definitions, types and treatments. Each aspect helped draw a different picture with some general trends. However, none of these definitions, types or treatments stands out as the most suitable in terms of the sustainability of heritage buildings. In terms of definition, each country defines heritage based on its own local geographic or policy context, leaving no exact or explicit definition that can be applied globally. Regarding the type, four distinct categories can be identified: archaeological, built, landscape, movable/collection, and conservation area. Four key conservation strategies have been pointed out: preservation, restoration, recreation and rehabilitation. Each of these could be leveraged based on the condition of the building and the availability of materials. To conclude, this review explores the variability of definitions, types, and treatments of heritage buildings among different organizations where collaboration between academic institutions and other organizations such as UNESCO and ICOMOS has led to the development of a standard definition of heritage buildings. Heritage buildings were classified into different types and the most appropriate strategy for conservation treatment was selected. Many studies have been conducted to effectively develop the sustainability assessment of heritage buildings for large public organizations.

Tangible and Intangible buildings:

Heritage buildings have been associated with the term cultural heritage. In 1972, UNESCO elaborated on this term by referring to buildings, artworks, structures, or monuments that have a significant artistic, historical, or scientific value (Ahmad, 2006). Furthermore, heritage buildings can exist as a stand-alone building, that is, single or a group of connected buildings that share the same architectural elements or located in the same place on the landscape. Concerning heritage sites, some of them are man-made; however, others are just as a result of climate and environmental changes. In addition, some heritage areas can include more than one archaeological site (UNESCO, 1972). Version 7 of the UNESCO document refers to heritage mainly from a horizontal perspective, as being handed down from generation to generation, and patrimonies describe heritage from a social context. To account for the overall reality, the definition of heritage should also include a vertical perspective (Bree, 2010; UNESCO, 2009; Zancheti & Similä, 2012).

For Blake and Forrest, the concept of 'heritage' includes a vision that is vertical but limited to what is being transmitted, while that of 'patrimonies' has a more social meaning, where the vision is horizontal in the sense that it can be of a much larger dimension and is able to encompass more than just the simple concept of inheritance (Blake, 2001; Forrest, 2010).

The heritage of directives, charters, and international resolutions:

The first text that gives a definition of the concept of 'heritage' is the International Charter of Venice (1964). In its introduction, the first definition of heritage is given: "Imbued with a message from the past, the historic monuments of generations of people remain to the present day as living witnesses of their age-old traditions" (Gruzinski, 1993).

The Scope and Definitions of Heritage: From Tangible to Intangible:

Although the scope of heritage, in general, is now agreed internationally to include 'tangibles' and 'intangibles,' as well as 'environments,' the finer terminology of 'heritage' has not been streamlined or standardized, and thus no uniformity exists between countries (Ahmad, 2006). *Heritage was then defined as 'monuments' and 'sites':*

The term 'monument' includes all real property, whether they contain buildings or not, having archaeological, architectural, historical, or ethnographical interest and may include besides the furnishing preserved within them. The term 'site' is defined as a group of elements, either natural or human-made, or a combination of the two, which is in the interest of the public to conserve (Koeman, 1990).

'Cultural property' was regrouped and defined in 1968 as 'movable' and 'immovable.' 'Movable cultural property' was referred to as 'museum collections' while 'immovable cultural property' was referred to as 'architectural heritage' and was defined to include not only historical sites and features, but also, more importantly, groups of traditional structures and historic quarters in urban and rural areas (Nilson & Thorell, 2018).

The scope of heritage generally remained the same as that introduced by the Council of Europe in 1975, but the Burra Charter introduced three new terms: 1) *Place*: referring to site, area, building or other work, group of buildings or other works together with pertinent contents and surroundings; 2) *Cultural significance*: referring to aesthetic, historic, scientific or social value; and 3) *Fabric*: meaning all the physical material of the place. (The Burra Charter, 1979).

Countries like Australia and New Zealand have limited their definition of heritage to include places. However, China describes its concept of places designated as heritage as: "the immovable physical remains where they have been created during the history of humankind, and this has significance". In this context, immovable remains comprise of historic ancient towns, debris, sepulchers and structures (Ahmad, 2006). Other Southeast Asian countries described the term cultural heritage by referring to “structures and artifacts, sites and human habitats, oral or folk heritage, written heritage, and popular cultural heritage” (Museums, 2001). Specifically, in Vietnam, heritage consists of “tangible and intangible cultural heritage” while the country, Philippines, includes both “movable and immovable” heritage (Ahmad, 2006).

In the 1964 Venice charter, a number of recommendations were proposed to aid the definition of the scope of the term heritage, but there still lacks a consensus in the definition for all countries (Inventory, 2004). Although these two organizations, International Council on Monuments and Sites (ICOMOS) and UNESCO, both acknowledge that heritage must include ‘cultural’ (that is, structures or buildings) and ‘natural’ heritage (Göttler & Ripp, 2017), this remains yet to be accepted internationally. For example, in Australia, heritage includes “place, cultural significance, and fabric”; in Canada, it includes “material culture, geographic environments, and human environments”; in New Zealand, it includes “place”; and in China, it includes “immovable physical remains” (Ahmad, 2006). Countries have the liberty to define several terms, but it is necessary that a uniform norm is developed. Hence, UNESCO and ICOMOS were advised to discuss the establishment of scope and standard terminologies and definitions, which countries are requested to implement (Göttler & Ripp, 2017) later.

2.3.2 Heritage Classification:

This section highlights different classifications of heritage buildings based on physical, environmental, sustainable, and economic value. There are five main distinguished types of heritage buildings, as shown in Figure 2.7.

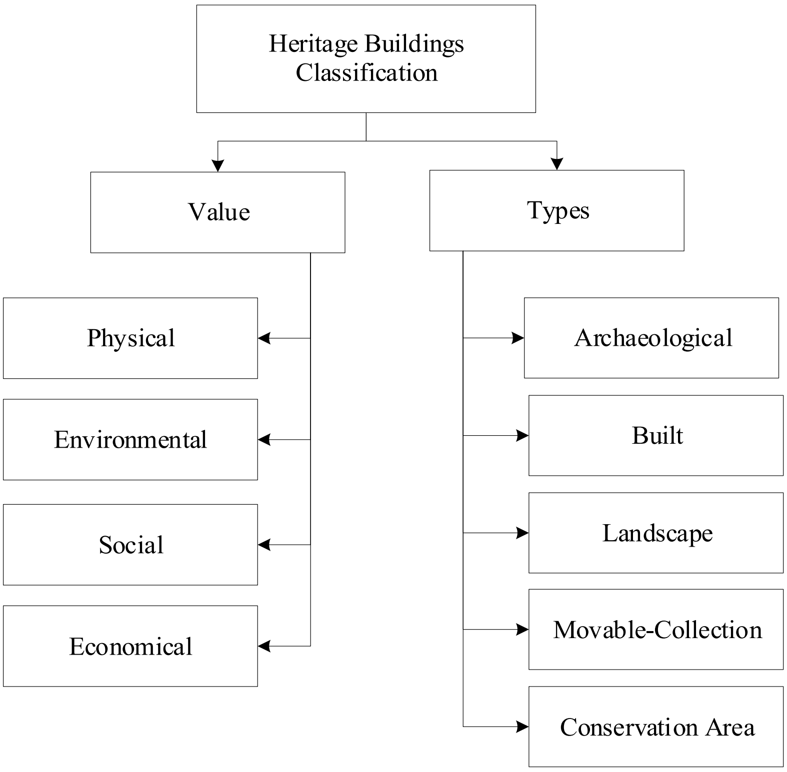


Figure 2-7: Classification of Heritage

1. ***Archaeological***

Archaeology employs physical proofs and historical knowledge to understand the past (Piero Gazzola, 1964). ‘Historical archaeological sites’ are culturally significant in that they enlighten our knowledge of man’s lifestyle in history. Note that the age of an archaeological site is not an important indicator of the presence of significant artifacts (Petzet and Michael, 2009; Göttler & Ripp, 2017; Khalaf, 2018).

2. ***Built***

Buildings differ from structures in that buildings are mainly to serve as man’s living and gathering space. Structures, on the other hand, consist of well-assembled elements in order to serve a given purpose (Icomos, 2015).

3. ***Landscape***

Landscapes emphasize the importance of a given space or region. Landscapes do not focus on distinct elements within the space or region and their nature is dependent on the qualities of the said region of space. Landscapes include natural and cultural landscapes with moderate human involvement or interference (Economic Commission for Africa, 2004).

4. ***Movable/Collection***

Movable/collection is related to heritage elements, both natural and man-made, that are inherently movable or that comprise a collection. Some examples are natural relics and artifacts and historical records. Movable items could range from more bulky items to lighter, household objects. (Piero Gazzola, 1964; World Commission on Environment and Development, 1987; & Keeble, 1988 Profile, 2010).

5. ***Conservation Area***

A conservation area is a defined area, according to the State Heritage Register (SHR) or the Local Environmental Plan (LEP), which possesses unique qualities that make this area notable for heritage purposes. Some examples include rural and suburban areas and the landscape of a street or town (Resources, 2013).

2.3.3 Conservation Treatments

The literature review revealed that there had been a great variability with respect to the strategies applied for conservation treatments. Table 2.8 presents a list of the different conservation strategies that can be used for conservation treatments along with their detailed definitions. Preservation includes comprehensively protecting and consistently maintaining the existing form of a historic place. Restoration involves recovering the original condition of a historic place. Recreation refers to the replacement of exterior features that might have been missed during restoration. Building rehabilitation is broader than previous treatments. It involves the reuse, repair or maintenance of existing features that cannot be restored through renovation (Garner, 1983; Caccia & Charles, 2001; Francioni, 2003; Akande et al., 2016).

Table 2-8: Conservation Treatments (Vecco, 2010)

Conservation Treatment	Definition
Preservation	involves the protection, maintenance, and stabilization of the existing form, material, and integrity of a historic place.
Restoration	involves the accurate revealing, recovering, or representing the state of a historical place as it appeared at a period in its history.
Recreating	missing features of the exterior form that existed during the restoration period, based on physical or documentary evidence; for example, duplicating a dormer or restoring a carport that was later enclosed.
Rehabilitation	involves the sensitive adaptation of a historic place or individual component for a continuing or compatible new use. Rehabilitation is the process that would be used when the repair or replacement of materials and features is necessary. It is the only process that allows for additions.

2.4 Existing Rating Systems for Sustainable Facility Management

2.4.1 Leadership in Energy and Environmental Design (LEED)

Founded in 1998 in the United States, the LEED system for buildings serves as a guideline for rating sustainability (Bernardi et al., 2017). LEED is applicable to both residential and commercial or newer and older buildings. Its accreditation system can be summarized as Certified (40 – 49), Silver (50 – 59), Gold (60 – 79), or Platinum (80+) (Table 8). This accreditation is fulfilled when a new or remodeled building covers the following eight criteria: "Location and Transportation (LT),Supportable Site (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR), Indoor Environment Quality (IEQ), Innovation in Outline (ID), and Regional Priority (RP)"(Canada Green Building Council, 2009; Andrade & Bragança, 2010; Ho et al., 2013; Robar, 2018).

2.4.2 Green Globe

An online rating system, Green Globe provides a framework for sustainability assessment of buildings from its design to its operational phase. It provides information to the public through a system similar to customer reviews for a commercial product. Green Globe is part of Green Building Index (GBI). The American National Standards Institute (ANSI) adopted the Green Building Index (GBI) in 2005, with the first of its merger accreditation standard published in 2010. The Federal Government of Canada is one of the many that employs this rating system (GBI, 2018; & Robar, 2018).

2.4.3 Green Building Index (GBI)

The Malaysian Institute of Architects (MIA) originally presented GBI in 2009, which is privately used to survey the execution of the green structures. GBI contains six appraisal criteria: 1) supportable arranging and administration of rooms, 2) quality of the indoor ecology, 3) energy performance, 4) availability of resources or materials and assets, 5) quality of the indoor environment, and 6) level of sustainability of the organization and management of the building location. GBI uses four fundamental ratings to express sustainability: Certified (50 – 65), Silver (66 – 75), Gold (76 – 85), and Platinum (86 – 100) (Nizarudin et al., 2011; Green Building Index, 2016).

2.4.4 Green Building Program (GBP)

The Green Building Program (GBP) was developed to enhance energy efficiency performance by raising awareness and improving its recognition in the public sector. An energy review, action and execution plans, and commitment to reporting energy consumption on a regular basis need to be provided by the building management. GBP provides modules that characterize the technical nature of an appropriate committee for each energy service provided by GBP. Such modules are supplemented by guidelines on relevant issues such as financing, energy audits, and energy management (Green Building Council, 2012; Siemens, 2018; Al-Sakkaf et al., 2019).

2.4.5 Greenship Indonesia

Indonesia's Green Building Council announced the rating framework, Greenship, in 2010 and 2011. The framework assesses existing structures for: 1) water management, 2) the availability and lifecycle of resources, 3) the building's location, 4) energy performance, 5) indoor environmental quality, and 6) management of the building's environment. Results are embedded into four fundamental evaluations/levels: Bronze (min. of 35%), Silver (min. of 46%), Gold (min. of 57%), and Platinum (min. of 73%) (GBC Indonesia, 2011; GBC Indonesia, 2012; Green Building Council Indonesia, 2018).

2.4.6 Green Globes (BOMA BESt)

Building Owners and Management Association (BOMA) founded an initiative called the Building Environmental Standard (BESt) in 2005. This initiative mainly serves to offer a structure or guideline for the assessment of existing buildings with respect to their management and influence on the environment. This system reviews three areas: 1) energy and site emissions and water and waste effluents, 2) quality of the indoor environment, and 3) environmental management. Five attainable levels are possible, which include Certified (min. of 59%), Bronze (60-69%), Silver (70-79%), Gold (80-89%) and Platinum (90-100%) (BOMA Canada, 2013; Smiciklas, 2016; Inc., 2013; BOMA Canada, 2011; GBI, 2018).

2.4.7 German Sustainable Building Council (DGNB)

The DGNB relies on regular improvements of its baseline certification framework, which makes it one of the most crucial frameworks around the world. The DGNB accreditation framework tends to touch on financial matters, ecological, and socio-cultural perspectives. The framework covers all building perspectives through their whole lifecycle, which provides decision-makers with information to characterize their sustainability targets at the planning stage. Furthermore, the DGNB gives a scoring framework covering six criteria and sixty-four subtopics. The accreditation framework given by DGNB involves four levels: Certified (underneath 35), Bronze (35 - 50), Silver (50 - 65), Gold (65 - 80) (Hamedani & Huber, 2012).

2.4.8 BCA Green Mark Singapore

In 2005, Singapore's BCA Green Mark was established to not only ensure sustainability in new building projects, but also maintain sustainability during and after the accomplishment of the projects. It involves five assessment criteria: 1) water conservation, 2) energy performance, 3) quality of the indoor environment, 4) environmental conservation, and 5) supplementary sustainability criteria. BCA Green Mark applies the following benchmark scheme: Green Mark Certified (50–74), Green Mark Gold (75–84), Green Mark Gold Plus (85–89), and Green Mark Platinum (90+) (BCA, 2012; Ministry of Finance Singapore (MOF), 2016).

2.4.9 CASBEE Japan

CASBEE, Comprehensive Assessment System for Building Environmental Efficiency, was established in Japan in 2001. It relies on two factors: 1) the quality of the building's environment (both indoor and outdoor), and 2) the load reduction (LR) of the building's environment (includes energy and other resources). In order to assign an accreditation, the Building and Environment Efficiency Ratio (BEER) is calculated as follows: 1) determine a total score; 2) approximate the final category, and 3) classify into the appropriate level (Naamandadin et al., 2018); (JaGBC, 2008; Baker, 2011; Shamseldin, 2018).

Figure 2-8: CASBEE ranking Benchmark (JaGBC, 2008)

$$(SQ) = (Q1 \times 0.4) + (Q2 \ \times 0.3) + (Q3 \ \times 0.3) \qquad (2.1)$$

$$(SLR) = (LR1 \times 0.4) + (LR2 \ \times 0.3) + (LR3 \ \times 0.3) \qquad (2.2)$$

$$BEE = \frac{Q}{LR}, = \frac{25 \ \times (SQ - 1)}{25 \times (5 - SLR)} \qquad (2.3)$$

Where:

Q = the environmental quality of the building

LR = the environmental load reduction of the building

SQ = the score of building’s environmental quality

SLR = the score of building’s environmental load reduction

BEE = the building and environmental efficiency ratio

Table 2-9: Sustainability scale for CASBEE (JaGBC, 2008)

Ranks	Assessment	BEE value, etc.	Expression
S	Excellent	BEE = 3.0 or more, Q=50 or more	5 star *****
A	Very Good	BEE = 1.5 ~3.0	4 star ****
B^+	Good	BEE = 1.0 ~ 1.5	3 star ***
B^-	Fairly Poor	BEE = 0.5 ~ 1.0	2 star **
C	Poor	BEE= less than 0.5	1 star *

2.4.10 BREEAM

In the UK in 1990, the Building Research Establishment Environmental Assessment Method (BREEAM) was introduced in order to rate sustainable or environmentally friendly buildings. The benchmark rating system that is employed can be easily calculated. To determine a building's sustainability, BREEAM analyzes ten factors, which contain 50 sub-criteria. The following score levels are possible: Outstanding (above 85), Excellent (70-84), Very Good (55-69), Good (45-54), Pass (30-44) and Unclassified (below 30). Known for its reliable standards, BREEAM assesses nine criteria: pollution, management, energy, transport, water, material, land use, health and wellbeing and ecology. Accreditation is determined according to the 1) calculated ratio, from each criterion, between the attained and attainable points; 2) multiplication of the attained points (in percent) by the weight of each criterion; and 3) addition of the all the results from (2) for each criterion. The possible scores are: Outstanding (+85%), Excellent (70%-84%), Very Good (55%-69%), Good (45%- 54%), Pass (30%-44%), and Unclassified (below 30%) (Table 4) (BREEAM, 2012; BRE, 2015; & Bernardi et al., 2017).

$$Category\ Score\ percentage\ (Sc)\% = \frac{Credit\ acheive}{available\ credits} \times 100 \qquad (2.4)$$

$$Total\ Category\ score\ (Sc\ total) = Category\ weight\ \times (Sc) \qquad (2.5)$$

$$Total\ score\ (S\ total) = \sum Sc\ total \tag{2.6}$$

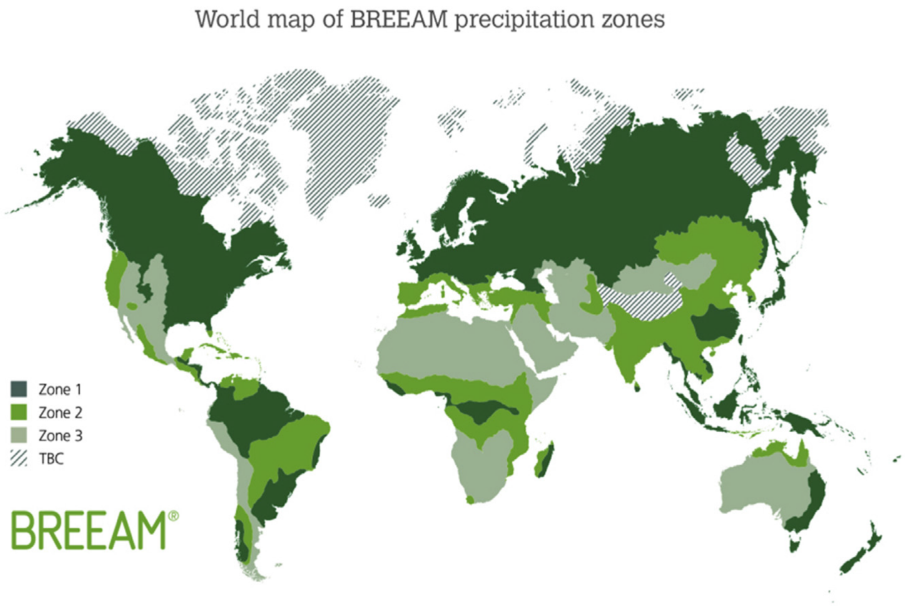


Figure 2-9: BREEAM Domestic Refurbishment scoring methodology (BREEAM, 2018)

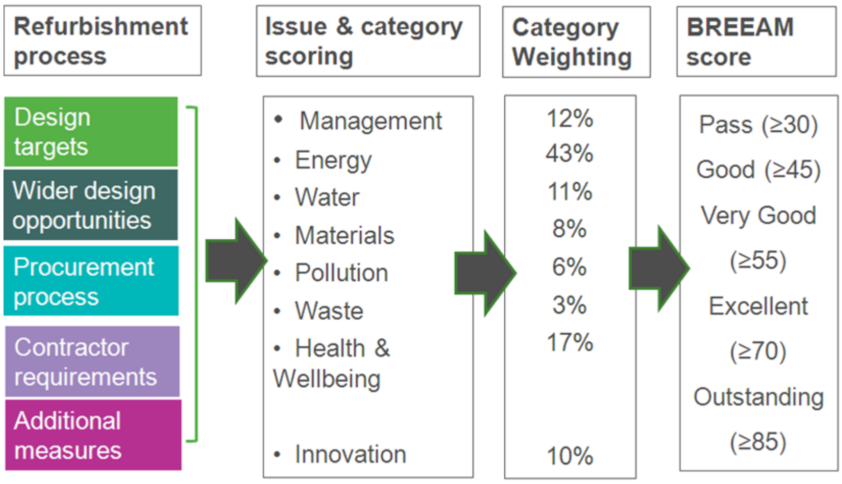


Figure 2-10: World map of BREEAM precipitation zones (BRE Global, 2013)

2.4.11 HK Beam

The Building Environmental Assessment Method (BEAM) was established in 1996 in

Hong Kong as a tool for assessing the sustainability of buildings. It is a modification of the BREEAM and its goal is mainly to enhance the quality and environmental impacts of buildings throughout the period of their existence. It evaluates the existence span of a building and analyzes the quality of the building location, its water and energy consumption, waste generation, quality of the indoor environment, and the management and modernization associated with the building. Possible scores include: Bronze (equivalent to Above Average or 40%) , Silver (equivalent to Good or 55%), Gold (equivalent to Very Good or 65%), and Platinum (equivalent to Excellent or 70%) (Ho et al., 2013; Mahmoud et al., 2019; Al-Sakkaf et al., 2019).

2.4.12 ITACA

In Italy, in 2001, the ITACA system was founded as a nationally accepted accreditation system for environmental sustainability. It is based on the worldwide norm (that is, the SB-method) and has, since 2002, been adopted by the International Initiative for Sustainable Built Environment (IISBE). The Italian National Standards Institute UNI recently drafted a document, "*Environmental sustainability in construction tools for the sustainability assessment"*, to enable a building's sustainability assessment. This document incorporates both the ITACA system and other European rating tools (Bragança et al., 2010; Principi et al., 2015; Asdrubali et al., 2015; Al-Sakkaf et al., 2019), as shown in Table 2.10 and Table 2.11.

Table 2-10: Areas and scores of ITACA certification (Asdrubali et al., 2015)

ITACS areas	**Maximum Score**
Site quality	4.0%
Resource consumption	53.6%
Environmental loads	17.5%
Indoor environmental quality	18.2%
Service quality	6.7%
Total	**100.0%**

Table 2-11: Areas and score of LEED certification (Asdrubali et al., 2015)

LEED areas	**Maximum Score**
Sustainable sites	25
Water efficiency	10
Energy and atmosphere	30
Materials and resources	15
Indoor environmental quality	20
Innovation in design	**10**
Total	**100.0%**

Methodology for the comparison between LEED and ITACA

Both building environmental assessment tools are primarily analyzed while pinpointing the main differences and similarities. By subdividing and adding up credits (for LEED) and sheets (for ITACA), it was possible to define five new categories (site, water, energy, materials and indoor environmental quality) to compare the two methods and their scores, as shown in Table 2.12 and Table 2.13.

The comparison shows that LEED focuses more on the site choice and materials while ITACA considers more energy and water management aspects, as shown in Table 2.14. Moreover, the indoor environmental quality is equally important in both LEED and ITACA to guarantee a satisfactory quality in the confined spaces of the building, as presented in Figures 2.11 and 2.12 (Asdrubali et al., 2015).

Table 2-12: Levels of certification for LEED (Asdrubali et al., 2015)

Level of certification	Score
Not certified	0-39
Certified	40-49
Silver	50-59
Gold	60-79
Platinum	80+

Table 2-13: Levels of certification for ITACA (Asdrubali et al., 2015)

Level of certification	Score
D (not certified)	<40
C	40—<55
B	55—<70
A	70—<85
A+	85—100

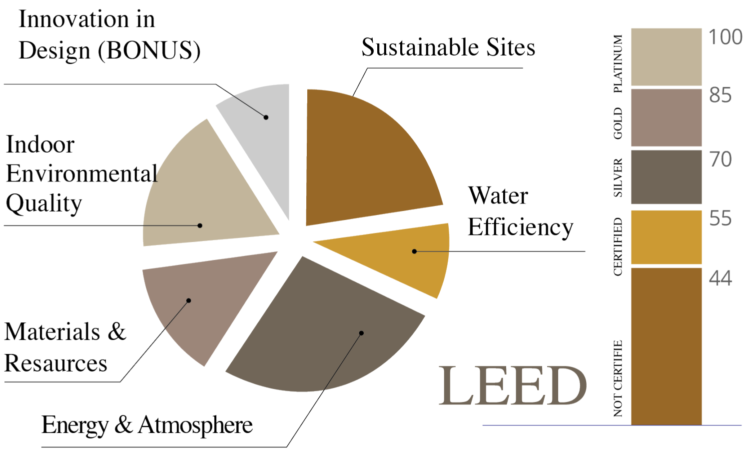


Figure 2-11: Areas and levels of certification for LEED (Asdrubali et al., 2015)

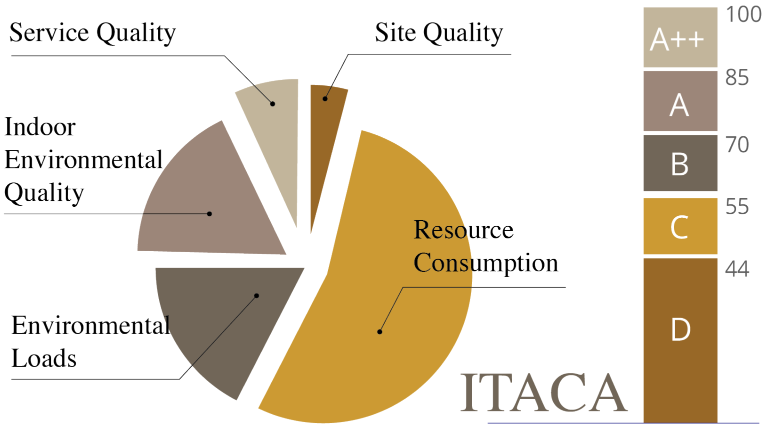
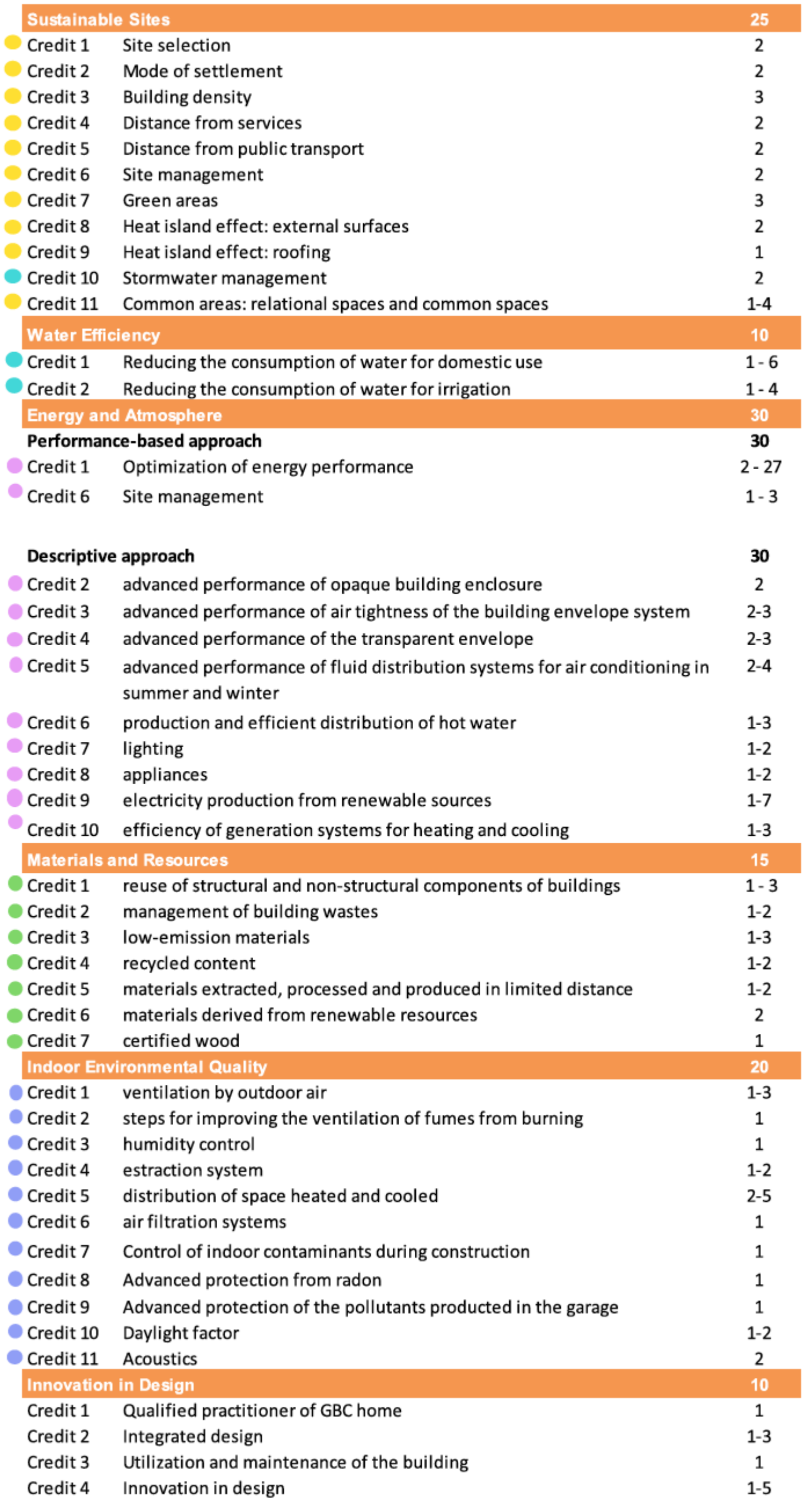


Figure 2-12: Areas and “classes” of certification for ITACA (Asdrubali et al., 2015)

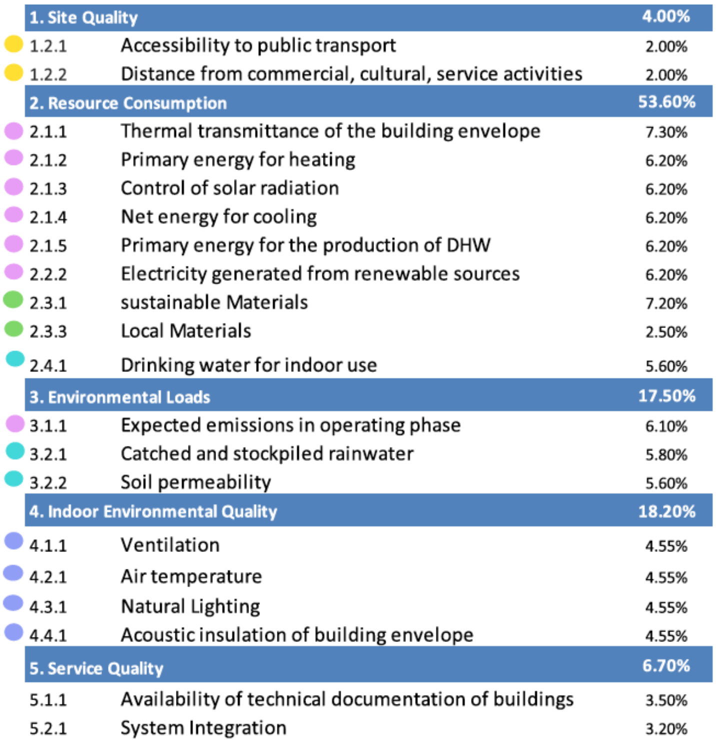
Table 2-14: Combination and association of credits to the new areas for LEED (Asdrubali et al., 2015)



	Sustainable Sites		**25**
●	Credit 1	Site selection	2
●	Credit 2	Mode of settlement	2
●	Credit 3	Building density	3
●	Credit 4	Distance from services	2
●	Credit 5	Distance from public transport	2
●	Credit 6	Site management	2
●	Credit 7	Green areas	3
●	Credit 8	Heat island effect: external surfaces	2
●	Credit 9	Heat island effect: roofing	1
●	Credit 10	Stormwater management	2
●	Credit 11	Common areas: relational spaces and common spaces	1-4
	Water Efficiency		**10**
●	Credit 1	Reducing the consumption of water for domestic use	1 - 6
●	Credit 2	Reducing the consumption of water for irrigation	1 - 4
	Energy and Atmosphere		**30**
	Performance-based approach		**30**
●	Credit 1	Optimization of energy performance	2 - 27
●	Credit 6	Site management	1 - 3
	Descriptive approach		**30**
●	Credit 2	advanced performance of opaque building enclosure	2
●	Credit 3	advanced performance of air tightness of the building envelope system	2-3
●	Credit 4	advanced performance of the transparent envelope	2-3
●	Credit 5	advanced performance of fluid distribution systems for air conditioning in summer and winter	2-4
●	Credit 6	production and efficient distribution of hot water	1-3
●	Credit 7	lighting	1-2
●	Credit 8	appliances	1-2
●	Credit 9	electricity production from renewable sources	1-7
●	Credit 10	efficiency of generation systems for heating and cooling	1-3
	Materials and Resources		**15**
●	Credit 1	reuse of structural and non-structural components of buildings	1 - 3
●	Credit 2	management of building wastes	1-2
●	Credit 3	low-emission materials	1-3
●	Credit 4	recycled content	1-2
●	Credit 5	materials extracted, processed and produced in limited distance	1-2
●	Credit 6	materials derived from renewable resources	2
●	Credit 7	certified wood	1
	Indoor Environmental Quality		**20**
●	Credit 1	ventilation by outdoor air	1-3
●	Credit 2	steps for improving the ventilation of fumes from burning	1
●	Credit 3	humidity control	1
●	Credit 4	estraction system	1-2
●	Credit 5	distribution of space heated and cooled	2-5
●	Credit 6	air filtration systems	1
●	Credit 7	Control of indoor contaminants during construction	1
●	Credit 8	Advanced protection from radon	1
●	Credit 9	Advanced protection of the pollutants producted in the garage	1
●	Credit 10	Daylight factor	1-2
●	Credit 11	Acoustics	2
	Innovation in Design		**10**
	Credit 1	Qualified practitioner of GBC home	1
	Credit 2	Integrated design	1-3
	Credit 3	Utilization and maintenance of the building	1
	Credit 4	Innovation in design	1-5

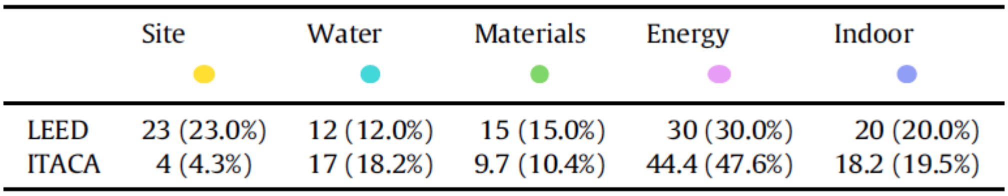
Thus, Table 2.15 presents the combination and association of credits to the new areas for ITACA. Also, Table 2.16 shows the new macro-areas and score for LEED and ITACA. The macro-areas and score for LEED and ITACA, as shown in Figure 2.13.

Table 2-15: : Combination and association of credits to the new areas for ITACA (Asdrubali et al., 2015)



	1. Site Quality		**4.00%**
🟡	1.2.1	Accessibility to public transport	2.00%
🟡	1.2.2	Distance from commercial, cultural, service activities	2.00%
	2. Resource Consumption		**53.60%**
🟣	2.1.1	Thermal transmittance of the building envelope	7.30%
🟣	2.1.2	Primary energy for heating	6.20%
🟣	2.1.3	Control of solar radiation	6.20%
🟣	2.1.4	Net energy for cooling	6.20%
🟣	2.1.5	Primary energy for the production of DHW	6.20%
🟣	2.2.2	Electricity generated from renewable sources	6.20%
🟢	2.3.1	sustainable Materials	7.20%
🟢	2.3.3	Local Materials	2.50%
🔵	2.4.1	Drinking water for indoor use	5.60%
	3. Environmental Loads		**17.50%**
🟣	3.1.1	Expected emissions in operating phase	6.10%
🔵	3.2.1	Catched and stockpiled rainwater	5.80%
🔵	3.2.2	Soil permeability	5.60%
	4. Indoor Environmental Quality		**18.20%**
🔷	4.1.1	Ventilation	4.55%
🔷	4.2.1	Air temperature	4.55%
🔷	4.3.1	Natural Lighting	4.55%
🔷	4.4.1	Acoustic insulation of building envelope	4.55%
	5. Service Quality		**6.70%**
	5.1.1	Availability of technical documentation of buildings	3.50%
	5.2.1	System Integration	3.20%

Table 2-16: New macro-areas and score for LEED and ITACA (Asdrubali et al., 2015)



	Site 🟡	Water 🔵	Materials 🟢	Energy 🟣	Indoor 🔷
LEED	23 (23.0%)	12 (12.0%)	15 (15.0%)	30 (30.0%)	20 (20.0%)
ITACA	4 (4.3%)	17 (18.2%)	9.7 (10.4%)	44.4 (47.6%)	18.2 (19.5%)

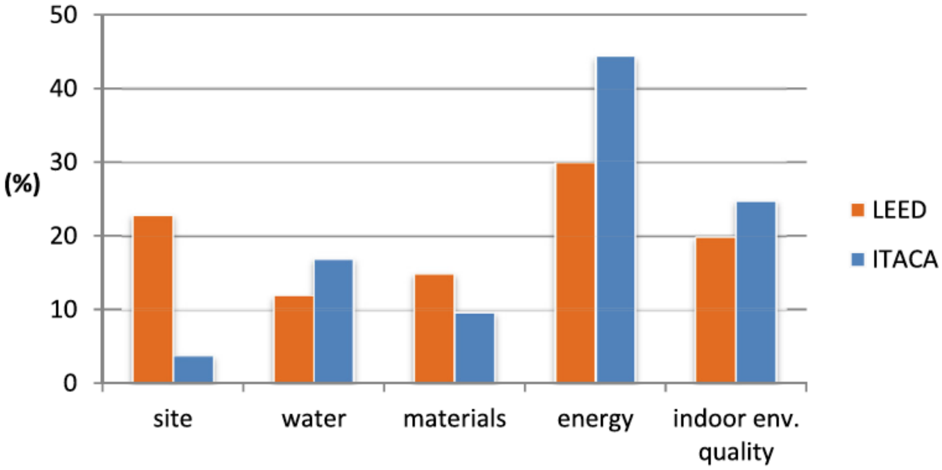


Figure 2-13: Comparison between LEED and ITACA macro-areas (Asdrubali et al., 2015)

Table 2.17 shows a complete comparison of all 12 rating systems per country and the factors that were taken into consideration. For instance, *energy* is considered in BREEAM, GFSH, EPCs, BEAM, CASBEE, DGNB-Seal, Green Star, HQE, Green Globs, LEED and ITACA. Similarly, *Indoor environmental quality* is considered in BREEAM, GFSH, CASBEE, DGNB-Seal, Green Star, HQE, Green Globs, LEED and ITACA. *Economy* is taken into account in DGNB-Seal, HQE, Green Globs, and ITACA. *Management* is considered in BREEAM, GFSH, DGNB-Seal, Green Star, HQE, and ITACA. *Transport* is taken into account in BREEAM, GFSH, DGNB-Seal, Green Star, HQE, Green Globs, LEED and ITACA.

Table 2-17: Comparison of all 12 rating systems per country (Reed et al., 2009)

Country & Assessment Criteria	UK,	UK./EU	UK./EU	UK./EU	Hong Kong	Japan	Germany	Australia	France	Canada /Us	U.S	Italy
	BREEAM	**GFSH***	**EPCs**	**DECs**	**BEAM**	**CASBEE**	**DGNB-Seal**	**Green Star**	**HQE**	**Green Globs**	**LEED**	**Protocol ITACA**
Energy	●	●	●	●	●	●	●	●	●	●	●	●
CO_2	●	●	●	●			●	●	●	●		●
Ecology	●	●			●	●	●	●	●	●	●	●
Economy							●		?	●		●
Health and wellbeing	●	●			●	●	●	●	●	●	●	?
Indoor environmental quality	●	●			●	●	●	●	●	●	●	?
Innovation	●				●		●	●	?		●	?
Land Use	●	●			●		?	●	●	●	●	?
Management	●	●		●	●	●	?	●	?			?
Materials	●	●			●	●	●	?	●			●
Pollution	●	●		●	●	●	●	●	●	●	●	?
Renewable Technologies	●	●	●				?	●	?	●	●	●
Transport	●	●			●		●	●	?	●	●	?
Waste	●	●			●		?		●	●		●
Waste	●	●			●	●	●	●	●	●	●	●

? Date for DGNB-Seal, HQE, and protocol ITACA is not exhaustive and additional criteria may be included in the assessment
* Code for sustainable homes

2.5 Weight determination & MCDM Techniques

Alyami used the Delphi Method and AHP to build a sustainability rating system while Mahmoud employed Fuzzy topics to develop a sustainability assessment-based rehabilitation framework. Tweed & Sutherland designed a novel survey model to assess people's perceptions of the urban historical area (Alyami, 2017; Mahmoud, 2017; Tweed & Sutherland, 2018). Ma (2015) developed the Analytic Hierarchy Process (AHP)-based model to assess how valuable a temple is while Liu el (2016) followed an approach to assess the significance of industrial heritage buildings based on Dempster–Shafer theory and AHP. Finally, Langevine et al. (2006) designed a decision support system to model deterioration rates and prioritize buildings for maintenance (Langevine et al., 2006).

2.6 Energy Performance of Heritage Buildings

The building energy performance is defined by Poel et al. (2007, p. 395) as "the amount of energy actually consumed or estimated to meet the different needs associated with standardized use of the building." According to the authors, this amount is reflected in one or more numeric indicators calculated while considering the following parameters: insulation, technical and installation characteristics, design and positioning in relation to climatic aspects, solar exposure and influence of neighboring structures, a building's own energy production, and other factors affecting energy demand such as indoor climate. With the current efforts towards diminished carbon footprints and enhanced energy performance, new buildings are constructed with energy efficiency in mind (DCLG, 2006, Petrozzi et al., 2014, Preciado et al., 2017).

The UK follows the Standard Assessment Procedure (SAP) to determine the energy performance of buildings. In essence, the SAP measures the thermal and fuel efficiency of the building fabric and heating system, respectively, on a scale of 1 to 100 (Friedman and Cooke, 2012). Based on the SAP results presented by the UK government in 2006, the energy performance of older buildings is much lower than the more recent ones. To put it in perspective, the SAP rating of more than 40% of buildings constructed prior to 1919 was less than 41 while the rating of most buildings built in 1990 was over 70 (DCLG, 2006). Despite the intuitive results, the SAP has been the subject of criticism by several authors (Rye 2010; 2011; Baker, 2011; CITB, 2012), since its inflexibility renders results inaccurate for older buildings.

On a different note, Moran et al. (2012) challenged the government statistics that showed elevated CO_2 emissions from historic buildings and argued about the differences in the energy efficiency of these buildings. In particular, by performing more comprehensive modeling research on the thermal and energy use in heritage buildings, the authors were able to provide a more accurate and detailed assessment of energy efficiency for these buildings rather than the one-word statements such as merely either good (Wallsgrove, 2008; English Heritage, 2009; Wood, 2009) or poor (DCLG, 2006; DCLG, 2007; Boardman, 2007; Berardinis et al., 2017).

2.6.1 Embodied energy and sustainability of Heritage Buildings

The conflicting views on the energy performance of heritage buildings stem from how people perceive their environmental sustainability. To contextualize this, views on modernizing buildings favor upgrading heritage buildings to be more energy-efficient regardless of their embodied energy. On the other hand, views in favor of sustaining heritage buildings strongly believe in the value of their embodied energy; hence, such buildings are far more environmentally friendly than how the opposing views perceive them. According to Pisello et al., (2014), Milani, (2005), and Inc., (2001) the embodied energy of heritage buildings is defined as “the sum of all the energy required for extracting, processing, delivering, and installing the materials needed to construct a building”. Thus, according to their views, the embodied energy of heritage buildings has been expended as part of their construction. This argument is further bolstered by the fact that since the current energy performance and operation cost of the building is not only based on its energy consumption, reusing an existing building implies no waste or generation of additional energy as compared to building a new building.

Further arguments were also based on the fact that many older buildings were constructed using traditional materials (e.g., stone, brick and lime) that will have been subjected to little or no processing or manufacturing, particularly before the Industrial Revolution (Ureche-trifu, 2013). Arguably, the processing that took place would have been achieved without the use of fossil fuels using other sources such as timber (bio-mass). Furthermore, the local and the vernacular origins of most of the materials will have minimized the distance for the transportation of the materials and many materials used for construction would have been close to their natural state. Accordingly, the embodied energy of the fabric used to construct many older buildings is very low in comparison with modern buildings (Pisello et al., 2014). Therefore, from a conservationist point of view, the environmental cost of using energy to demolish or construct a new building is higher. In sustainable terms, it is more realistic to preserve and reuse existing buildings because of their embodied energy; in this way, natural resources are conserved, and long-term energy savings are possible.

2.6.2 Modification of existing Heritage Buildings structure for reuse

Alteration for reuse is part of the conservation process of managing change to culturally significant buildings that could sustain their heritage values while engaging in opportunities to enhance, develop and improve their energy performance (England, 2016). However, according to Oxley (2006), the alteration can interfere with a building's breathing performance. It can lead to a loss of character, distortion of appearance and loss of historic fabric. Therefore, it is important to identify the significance of the building. This, in return, requires an understanding of what the nature of the structure is, who values it and why, how these values relate to the fabric, and how significant are these values compared to the advantages of reuse. The perception of heritage values and the historical significance of heritage buildings is crucial to making appropriate decisions about the required enhancements for better energy efficiency improvement. This is in line with the BS 7913 *(2013, Section 4)*, which states that "understanding the significance of a historic building enables effective decision making about its future" (Hasenfus, 2013).

Thus, the significance of a historic building is closely related to the value that is placed upon it by the people and the wider society and how it continues to be viewed as an asset to them. This value is a combination of its emotional, historical, spiritual and cultural significance. Without these considerations, any good intention and 'reuse' initiative is likely to compromise the building's value for future generations. As a result, it is paramount to understand such building's construction history, its modifications and uses, its cultural significance, and its protected status to make more informed decisions. Besides, the intrinsic values these buildings hold, a clear and structured analysis of their current, intended and proposed performance, is also equally crucial in the repurposing process (Ostrom et al., 2013; UNEP, 2016).

To that end, it is essential to have tools and frameworks that provide a comprehensive analysis of such buildings by considering the economic, ecological, and social aspects. One such tool is the sustainability rating. By observing some of the frameworks that implement such an analysis (for example, BREEAM, LEED and ITACA), it becomes evident that these frameworks fall short in two main categories. The first drawback is that these frameworks analyze buildings within a local context or in other words, analyze in a 'one size fits all' fashion. What this implies is that such tools, when exploited globally on different buildings, would not provide an accurate analysis due to variations in climate, materials and historical significance. As a result, countries repurpose such tools to fit their local context. One example is BREEAM, which was repurposed as HK-BREEAM for China (Crawley and Aho, 1999). The second drawback is that these frameworks overlook the economic and financial aspects, which are usually an essential requirement in such projects. A simple and yet alarming example is that such tools could approve a building project because of its environmental impact (environmentally efficient) regardless of the actual cost to construct it.

2.6.3 Energy Simulation for Heritage Buildings

Fahmy et al. (2014) examined the usage of GRC walls as a new construction method in the housing industry under future climate change. They considered 3-different external wall specifications for three climatic zones scenario in Egypt. They evaluated three different external wall evaluations for energy consumption, energy cost and thermal comfort. Experiments simulated building performance and took into account the thermal nature of the materials. Simulation results confirmed the existence of climatic zones. A recommendation of 10 cm GRC (C2) wall specification was given, as a better alternative to replace the prevalent outer wall specification in Egypt. This prevalent specification is that of a single wall made of half red-brick–Ct, as it is promising for the future in terms of energy performance and will thus minimize energy consumption and cost.

In addition, the authors Radhi et al. (2013) evaluated the impact of climate interactive © systems (CRFS) on cooling energy in fully glazed buildings. This research combined the computational fluid dynamics and the simulation of a building’s energy to determine boundary conditions as well as to generate geometrical models based on a newly constructed multi-story building. According to Hygh et al., (2012), the energy load of a building can be calculated in a precise way by simulating building models. However, these models cannot be manipulated when the building is still in the primary stages of the design process. This is because during the early stages, the availability of an assessment tool that is capable of providing feedback in response to varying the high-level design parameters is required. The authors then proposed a novel modeling strategy in order to determine the energy load of a building during the primary stages of the building design. They indicated that the utilization of standardized regression coefficients (SRCs) can serve as a useful indicator of how the heating and cooling loads are affected by each design variable.

2.6.4 Energy Consumption Prediction

Abanda et al. (2013) reported research gaps in the area of computational modeling with respect to understanding the interrelation between the models themselves and calculations of different parameters such as greenhouse gas emissions, energy and cost. Moreover, understanding this interrelationship between the model and these parameters will enable analysis and design of more energy efficient and sustainable buildings. Wong et al. (2013) described prototype architecture as a means to put in place a system to predict and simulate carbon emission during building projects. This would entail the use of 'virtual prototype technologies', which is an area of study that is lacking in literature. They indicated that the visualization technique, as developed in their study, helps provide an interactive tool for decision-makers to manage a construction project. Also, Fumo & Biswas (2015) presented information on linear regression analysis for residential and whole-building energy consumption in single-family homes. The energy consumption in residential buildings was observed to be higher.

2.6.5 Greenhouse Gas (GHG)

In terms of analyzing GHG systems, Tiwariet et al., (2016) proposed the design of a Photovoltaic Thermal Integrated Greenhouse System (PVTIGS) that could be used for heating a biogas plant within the climatic context of IIT Delhi, India. PVTIGS has various applications. It can be used for generating space heating, enhancing the production of biogas, and various other applications. They point out that the greenhouse room temperature varies between 38 C and 47 C, which is considered to be suitable for biogas production. Additionally, Attar et al., (2013) employed a Transient System Simulation Tool (TRNSYS) to simulate and evaluate the performance of solar water heating systems (SWHS) for a greenhouse, based on the Tunisian weather. They stated that the stored solar energy could not, alone, meet the total requirements of heating. Hence, it is necessary to use an auxiliary heating system such as a fuel boiler or electric energy.

Furthermore, Yildirim & Bilir (2017) discussed the evaluation of the renewable energy option for the required total energy need of a greenhouse. Solar photovoltaic panels were selected and connected on a grid to assist a ground source heat pump in generating enough energy for the lighting. They concluded that the energy payback time of the system was found to be 4.9 years. The authors reported a greenhouse gas payback time of 5.7 years based on natural gas electricity generation as compared to 2.6 years for coal-based electricity generation.

2.7 Project life cycle phases for HBs

A project, by definition, is a set of tasks carried out individually or collaboratively to achieve a specific target. As a result, a project has to go over multiple phases before reaching its complete form, as shown in Figure 2.9. Generally, a project life cycle is divided into six (6) phases, with the last one being the demolition phase. However, since this work focuses on preserving heritage buildings, we consider only six (6) phases of the project life cycle.

2.7.1 Planning phase

A core component of any project is detailing tasks and defining the end goal and milestones. Thus, it is only logical that the initial phase of any project is the planning phase. During this phase, the scope of the project is identified in terms of its end goal, required resources (such as financial costs, manpower, and timeframe), and participating entities (such as stakeholders and investors), in what is called as ‘scope management’ (Baker, 2011). The scope of the project serves as a wide-eyed view of the entire project. The project team would then break down the project into milestones, each with a set of detailed tasks and activities, schedule for start and completion and dependencies such as resources, materials, and costs. With the milestones identified, the project budget is outlined to provide an estimated cost of the operation, labor, and equipment. The milestones and budget provide a guideline that would aid in tracking progress. The last step of this phase is to document the scope and milestones in what is called a quality plan. This plan ensures accurate documentation of the project along with control measures, assurances, and criteria. This would reassure the customer and enable progress tracking within the organization. With that, the project planning is complete and ready to be executed (Di Giovine, 2019).

2.7.2 Manufacturing phase

Execution of the project begins with the manufacturing phase. One crucial task in this phase is to calculate the embodied energy of the manufacturing materials to be used. For this, some data collection on the materials is needed beforehand. Specifically, intensities of the building materials and their prices are retrieved from the bill of materials prepared by the project contractors. After verifying retrieved data, an Economic Input-Output Life Cycle Assessment (EIO-LCA) spreadsheet model (which was developed in this thesis) can be computed to calculate the total initial embodied energy of each material. This calculation is performed by multiplying the national average price and the net quantities (accounting for waste) delivered to the site by the sectoral intensity contributions of the material. Wastage factors were retrieved from Concordia University and the Royal Commission for Riyadh.

2.7.3 Transportation phase

Materials for the implementation of the project need to be transported to the site, marking the start of the transportation phase. Similar to the manufacturing phase, a critical aspect in this phase involves assessing the impact of transportation on the environment. A significant drawback of existing assessment methods is that they consider only emissions from construction and operations. However, one particularly interesting assessment is the Life-Cycle Assessment (LCA). Unlike existing environmental impact assessment methods, LCA provides a more comprehensive assessment framework that considers greenhouse gas emissions, energy use, and overall environmental impact of the transportation phase (Matute et al., 2014).

2.7.4 Construction phase

The construction phase involves several steps including groundwork at the site and equipment installation for mechanical and electrical work. In order to formalize the execution of such activities, process-based LCA can be employed. Data input for the LCA include construction documents drawings, design specifications sheets, live assessments and additional manufacturer information. Information regarding construction, equipment used on-site and distance to the site can be retrieved from the primary contractor and supplier records. Another important information for the LCA is the construction energy, which includes electricity and diesel fuel for lighting and energy supply to construction equipment. For a more holistic energy analysis, energy used for transportation of materials to the site was also compiled.

2.7.5 Operation phase

Energy requirements for a building's operation can also be determined from a process-based LCA. In this thesis, two case studies are evaluated and design specifications of their electrical and mechanical equipment along with each building's forecasted usage pattern per year are exploited in order to determine the operating energy requirements. Electricity is the operating energy for the considered buildings in the case studies and it includes electricity for functions such as cooling, ventilating, lighting, equipment operation and water supply. Finally, the obtained results are cross-validated with available electricity records.

2.7.6 Maintenance phase

Maintenance is the last phase of the project life cycle. Its energy consumption is determined using a similar procedure as that for computing the energy requirement of the building's manufacturing materials. However, the data used here is the estimated life span of the building materials.

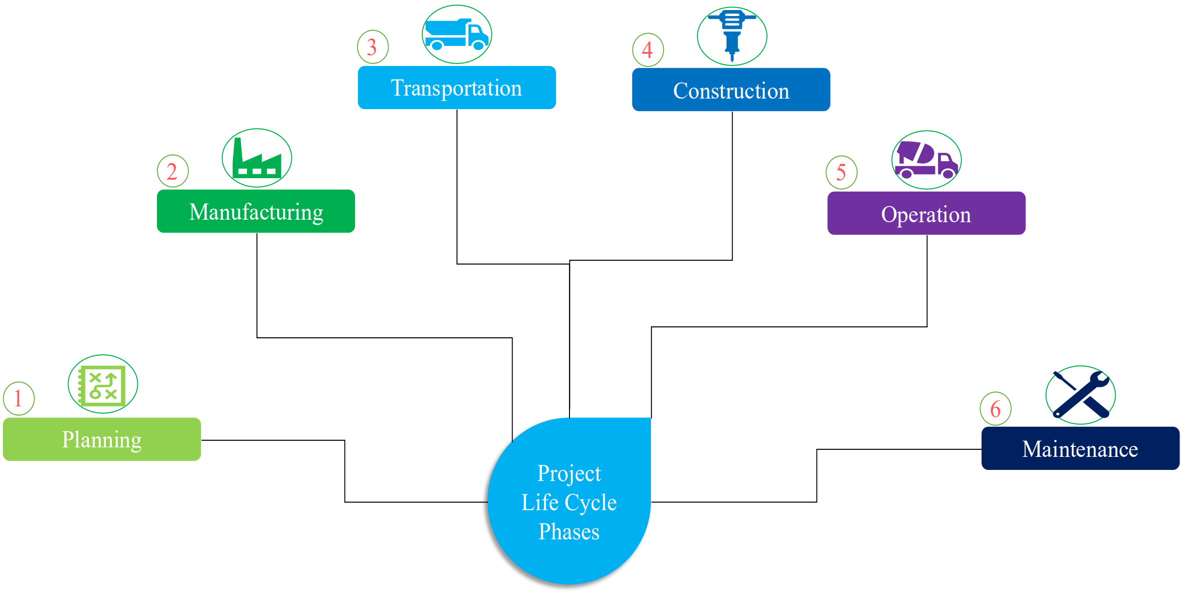


Figure 2-14: Project life cycle phases for Heritage Buildings

2.8 Limitation of the previous studies

Research in existing literature has not proposed a holistic approach for developing the much-needed sustainability assessment for heritage buildings. While there exist some sustainability assessment tools, they still lack the geographical, cultural and economic context awareness. The main limitations of the available tools and frameworks can be summarized into three categories:

2.8.1 Shortcomings in research in existing literature

- **Lack of Standardization**: The standardization of the attributes of sustainability assessment means a homogeneous assessment across the different tools. However, there is a lack of standardization, which implies that different tools would result in different assessments of the same building. This is because the current frameworks leverage different criteria based on specific contexts or settings (one country, for instance).
- **Lack of Inclusion**: Most of the studies do not include heritage buildings in their sustainability assessment process.
- **Lack of Comprehensiveness**: The essence of sustainability is an aura of environmental, economic and sustainable aspects. Thus, a rating tool should assess a building across these different values, as they are equally crucial and result in a far more accurate assessment of the sustainability of a building.

2.8.2 Shortcomings in practices

- **Lack of Inclusion**: No study has explored the design of a rating system to evaluate the sustainability of HBs. Heritage buildings are of an important value to the society and as a result, there should be a rating system that provides a HB-specific sustainability assessment for decision-makers.
- **Lack of understanding of the concept 'heritage'**: The value or worth and the physical state of a heritage site were some of the factors that were not taken into account in some rating systems, making these systems deficient.
- **Lack of Research:** Existing studies do not cover the impact of some factors like heritage value on the sustainability of HBs.

2.8.3 Shortcomings in protocols

- **Lack of consistency**: The criteria considered in the existing rating systems in literature differ, leading to variabilities in the evaluation of sustainability of HBs.
- **Lack of models**: There are no existing models that can provide a system for policy makers to ensure that sustainability is maintained in heritage buildings.

CHAPTER 3 : RESEARCH METHODOLOGY

3.1 Chapter Overview

This chapter covers the research methodology in detail. Four steps are involved in the study of the development of a rating tool for assessing the sustainability of heritage buildings (Figure 3.1). Literature review was first conducted to retrieve relevant information from two main sources - review articles and technical sheets for current global rating tools. The benefits and drawbacks of each rating tool are assessed; the parameters that are employed to evaluate the sustainability of buildings are enumerated; and relevant research is identified. Then, the development of a tool to evaluate sustainability followed. This comprised of two main goals: 1) the identification of criteria, factors and indicators that directly affect heritage buildings; and 2) the design of an integrated weight-based sustainability rating tool for the evaluation of the sustainability of heritage buildings. The latter involves the development of rating scale to categorize the degree of sustainability of heritage buildings and the development of a sensitivity analysis model for the different factors.

The next step involved the validation of the developed model by testing case studies, questionnaire responses and field data. The results from the model are compared to those from the application of some currently used rating systems. When validation was successful, the next and final step was performed. If not, the model was modified and retested. The final step involved the creation of a sustainability-based rehabilitation model for heritage buildings. It includes a project life cycle phase model for simulating energy consumption. It will facilitate decisions for decision-makers who have to choose the most applicable and affordable option to enable the improvement of the sustainability of their buildings. The last step involves the expert validation of the developed rehabilitation model. Given the results of the validation, the conclusion of the research is outlined in terms of novelty, contribution, findings and limitations.

Based on these principles, each rating system tabulates complex arrays of numerical and nonnumerical data to provide a building-performance score, according to the scoring and weighting system built into the method. Indeed, when heritage buildings are adaptively reused, their performance from an “environmental sustainability” aspect is assessed using these very same rating systems.

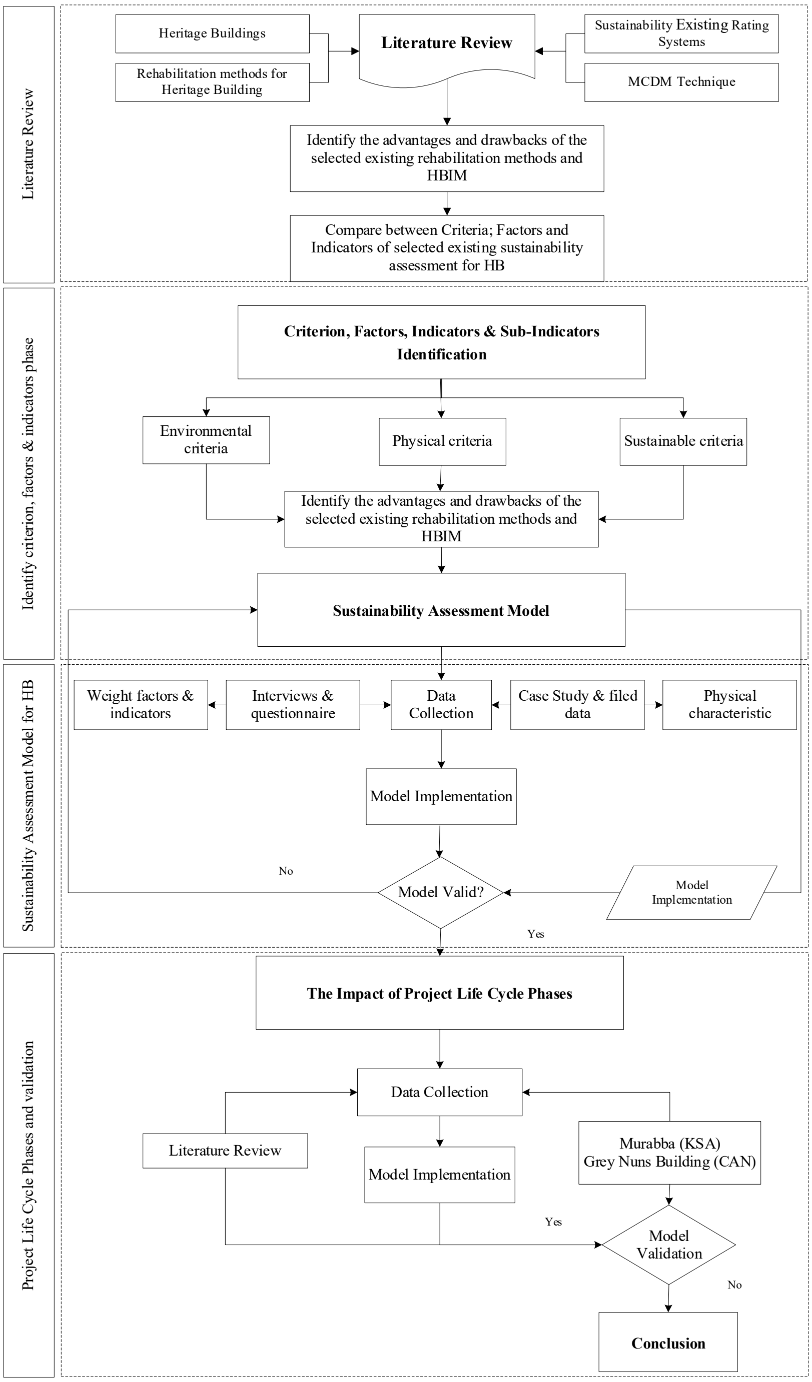


Figure 3-1: Method to develop a rating tool for assessing the sustainability of HBs

3.2 Research Methodology

The first objective is to identify and study criteria, factors, and indicators that impact the sustainability of HBs. This was achieved by:

- Conducting an extensive review of literature, including all publications in English, to identify the main elements of the sustainability assessment (measurable quality criteria).
- Developing a well-structured questionnaire (survey) to assess the identified measurable quality criteria to be used for the maintenance management standards in large public organizations. The questionnaire consisted of two parts: i) a section summarizing the organization, position and years of experience of the maintenance management expert, and ii) a section listing the quality criteria to be assessed by the experts. The quality criteria included compliance with statutory requirements, response time, continuous improvements, and traceability. The experts were expected to express their desirability of each of these aspects using a Likert-type scale. The sample size of the experts was 100 to ensure a more informative representation.
- Analyzing the obtained data statistically.
- Developing maintenance management standards. All assessed measurable quality criteria that are recommended by at least 67% of the survey respondents were included in the standard.

The second objective is to design a hybrid multi-criteria sustainability-rating model and a scale for HBs. This was achieved by:

- Validating the maintenance management standard by three experts in the maintenance management section of large public organizations.
- Applying the developed sustainability assessment for heritage buildings tool (SAHB) on actual case studies of Heritage Buildings in Canada and Saudi Arabia to evaluate

and assess their existing sustainability assessment practices. Moreover, the application of the standards was expected to provide additional validity by checking the consistency between the outcomes of the existing rating systems and the sustainability assessment for heritage buildings.

- Reviewing and updating the proposed heritage building rating tool *SAHB*.

Heritage buildings are in constant need of maintenance and rehabilitation to maintain their cultural value. Similar to other large facilities, heritage buildings require extensive research in order to preserve their legacy and achieve the goals of renovation. The purpose of this study is to provide a procedure for a systematic review that addresses three essential points regarding the sustainability of heritage buildings: (1) the definition of 'Heritage Buildings' and their 'sustainability'; (2) a comparison of different global rating systems that are focused on sustainability in heritage buildings; and (3) an assessment and comparison of the sustainability elements and factors that can be gained from using existing rating systems. Six keywords *(Heritage Buildings, Sustainability, Rating System, Heritage Architecture, Cultural Heritage and HBIM)* were used to cover the three objectives of the review using the following databases: Academic Search Complete, Business Source, GreenFILE, EconLit, Medline, Geobase, Compendex, IEEE Xplore, ProQuest Central, ProQuest Dissertations & Theses Global, Web of Science, Scopus and Google scholar. Articles and reports qualified for this study if they: (1) were published after 1990; (2) were written in English and (3) if they referred to relevant studies, including those focused on practical renovation, rehabilitation and maintenance of heritage buildings. The relevance of titles and abstracts were individually evaluated; the necessary data was extracted; and the biases and overall quality of the studies were assessed. Finally, the results were combined and analyzed using a unique method called Pairwise and Network Meta-Analysis (NMA).

The proposed study will address identified gaps that are present in literature. The literature review comprised of:

a. A review of the definition of Heritage Buildings, types, and conservation treatments.
b. A comprehensive literature review to identify the existing criteria, factors, and indicators for sustainability of HBs.
c. Questionnaires and interviews with architects, engineers, and facility or project managers to identify the importance of each factor, indicator, and sub-indicator.
d. An extensive literature review to examine the existing rating systems used to assess the sustainability of buildings. In addition, a comparison is carried out to pinpoint the various factors affecting sustainability in buildings.
e. An evaluation of the energy consumption prediction of a building, which includes electricity consumption, greenhouse (GHG) emissions and carbon emissions.

The literature review revealed that in the last few decades, many sustainability rating systems have been developed that focus on the sustainability performance of buildings. BREEAM, LEED and ITACA are some examples of these rating systems. However, each has its own assessment attributes based on its local context. Furthermore, none of the rating systems propose a guide for the sustainability assessment of heritage buildings, specifically with respect to energy usage and cost (see Figure 3.1).

3.3 Criteria & Factors that effect on Sustainability of HBs

Various criteria and factors affect the sustainability performance of heritage buildings. The first challenge is to identify all the criteria, factors and indicators that affect the sustainability assessment procedure of heritage buildings such as performance energy efficiency, heritage value and structural condition. Three criteria have been identified and grouped under:

1) Environmental;

2) Physical; and

3) Sustainable Criteria

12 rating systems were chosen based on the member list of the World Green Building Council and compared (WorldGBC, 2016; Petrullo et al., 2018). The most important factors as well as the least considered factors that influence the sustainability of an existing building were identified through this comparative study. These were then incorporated in the newly developed rating system (Figure 20). Three criteria and nine factors were identified to have a major effect on a building's sustainability: **A- Environmental criteria**: 1) site and ecology; 2) material and waste reduction; 3) transportation; **B- Physical criteria**: 4) energy efficiency; 5) water use; 6) heritage value; 7) structural condition; **C- Sustainable criteria**: 8) indoor environmental quality (IEQ); and 9) building management (Al-Sakkaf et al., 2019) (Figure 3.5). For each factor, there are set indicators and sub-indicators. This hierarchy reflects the different categories related to the same criteria and thus, helps build a detailed assessment for a building. Furthermore, the indicators are classified into two types: quantitative and qualitative. Quantitative indicators are design-oriented and focus on fulfilling the design requirements by setting thresholds and identifying quantity constraints. On the other hand, qualitative indicators are an abstraction of the project in terms of its long-term plans and policies.

Figures 3.2, 3.3 and 3.4 show the hierarchical structure of sustainability performance in heritage buildings for all criteria. This hierarchy illustrates the criteria that affect heritage buildings with respect to the nine factors (that is, group of factors). Considering this structure, the sustainable heritage buildings represent a single objective (that is, goal).

In order to better identify the attributes to be used in the sustainability assessment, it is crucial to examine literature for the existing tools and methodologies used to perform sustainability assessment. Such a review would help identify previous studies on sustainability assessment and identify gaps and possible areas of improvement. In particular, the following areas were reviewed:

1) Research work and studies that focused on developing novel tools for sustainability assessment or adding improvements to existing ones (Alyami, 2017; Bragan.a et al., 2010; Chandratilake & Dias, 2013; Gething & Bordass, 2006; Malmqvist et al., 2011; Nguyen & Altan, 2011);
2) Some of the most common sustainability assessment systems like LEED, BREEAM, CASBEE, HK-BEAM, Green Mark, Green Building Index, and Greenhip (BCA, 2012; BRE, 2015; GBC Indonesia, 2012; GBI, 2011; HK GBC, 2012; JaGBC, 2008; USGBC, 2009).
3) Comparative studies that explored different tools and analyzed the differences and similarities among them (Abd'razack & Ludin, 2013; Al-Waer & Sibley, 2005; Banani et al., 2013; Berardi, 2012; Bunz et al., 2006; Crawley & Aho, 1999; Dimitrijevic & Langford, 2007; Fenner & Ryce, 2008; Forsberg & Malmborg, 2004; Haapio & Viitaniemi, 2008; Nguyen & Altan, 2011; Reed et al., 2009; Xiaoping et al., 2009).

While previous studies offered some insights on sustainability assessment tools, the most informative source was the structured and unstructured interviews, in the form of informal meetings and questionnaires, with engineers, architects and sustainability experts. Such interviews helped to identify the most crucial attributes for suitability assessment from a more practical perspective and hence gave more realism to the proposed tool.

The rating tools selected for analysis in this study were chosen if:

- They are present in the list of building rating systems on World Green Building Council.
- They are widely utilized.

- Their technical datasheets are available.

Based on these criteria, most of the chosen tools were either pioneers in the sustainability assessment field or served as a benchmark for the development of other rating tools in different countries. For example, BREEAM has been adopted by Canada and Australia (Berardi, 2012; Ding, 2008; Fenner & Ryce, 2008; Haapio & Viitaniemi, 2008; McArthur et al., 2014). Those are material and waste, site and ecology, transportation, water use, heritage value, structural condition, energy efficiency, indoor environmental quality, and building management (Al-Sakkaf et al., 2019). Further, each criterion consists of nine factors, and for each factor, there are set indicators and sub-indicators. This hierarchy reflects the different categories related to the same criteria, and thus, help build a detailed assessment for a building. The different criteria and factors are shown in Figure 3.2.

Further, we classify the indicators into two types: quantitative and qualitative. The quantitative indicators are design-oriented that focus on fulfilling the design requirements by setting thresholds and identifying quantity constraints. On the other hand, qualitative indicators are an abstraction of the project in terms of its long-term plans and policies. In addition, for each indicator, there is a number of allocated points that reflect the degree of fulfillment of each of the requirements of the indicators.

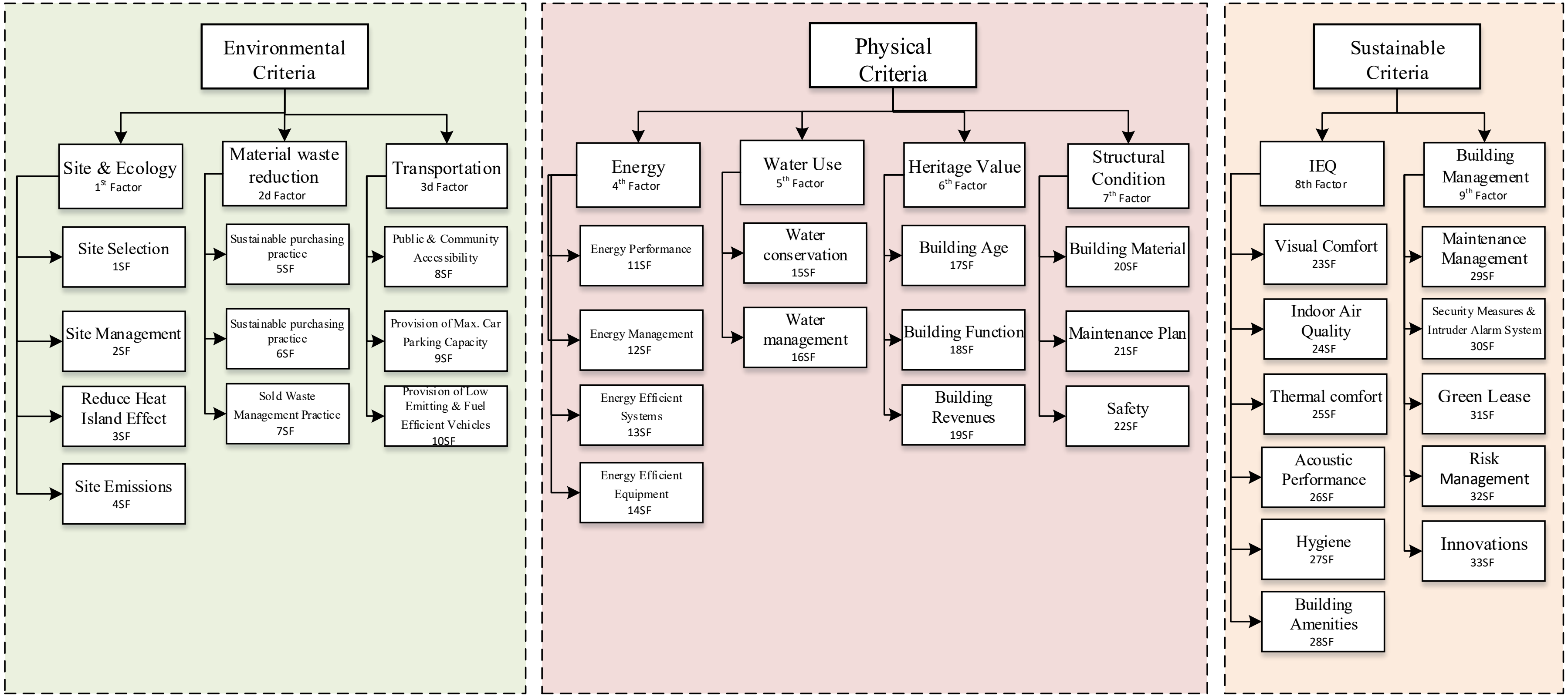


Figure 3-2: Sustainability assessment attributes (criteria, factors & factor indicators) of (HBs)

Site and Ecology Factor

The Site and Ecology factor corresponds to the site in question and all its related perspectives and it includes four indicators (Figure 3.3). These indicators are:

1) **Site selection** demonstrates whether the building is already certified under any rating framework during the phases of design, construction or the conservation of a site after construction.
2) **Site management** assesses the presence of the following:
    a. The ecological strategy and purchasing schema
    b. The practices of purchasing all the required materials on the site
    c. The green cleaning products
    d. The operation, maintenance, and exterior of the site
    e. The past administration and landscape management
3) **The reduction of the heat island effect** has an impact on the assessment of the practices used to limit the heat effect arising from the building materials, which contributes to an increase in temperature of the surrounding environment.
4) **Site emissions** survey the methodology used to reduce the pollution impact due to the building surroundings, which may include noise and light pollution (Mahmoud, 2017).

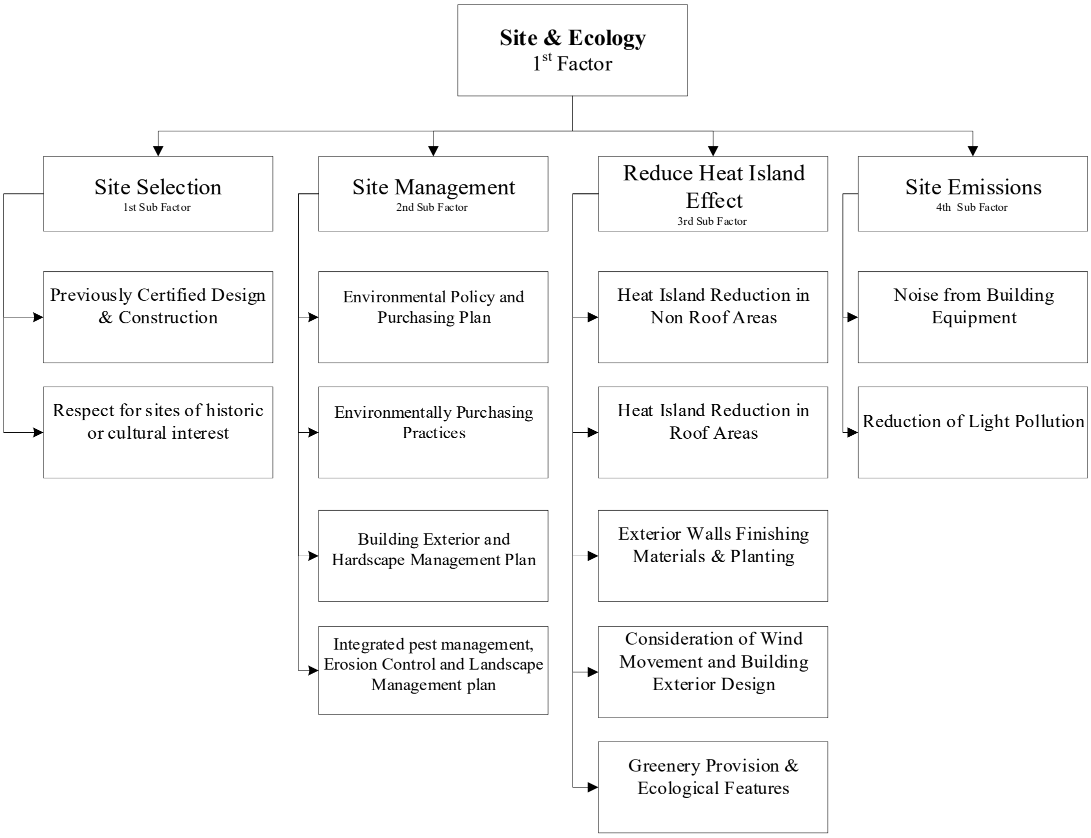


Figure 3-3: Site and Ecology Factor and its related factor indicators

Material Waste Reduction Factor

This factor examines the environment-friendly usage of substances and the sustainable solid waste management techniques utilized. Three indicators are involved (Figure 3.4):

1) **The availability of green materials** assesses the quantity of ozone layer-friendly substances that are used. It also examines the leak control of fluids like refrigerants;

2) **Efficiency in material usage** evaluates the reuse of building parts and supports the standardized building design that allows for vastness and flexibility in the building and landscape design;
3) **Solid waste management** examines the presence of a policy for the management of generated solid waste, hazardous waste management, and waste stream audit. It addresses the waste of consumable and durable goods. In addition, it involves providing a policy on how to treat the waste that results from facility alternation and addition. It evaluates the existence of collection, storage and disposal of recyclables as well as the provision of installed equipment for waste reduction such as compaction or composting.

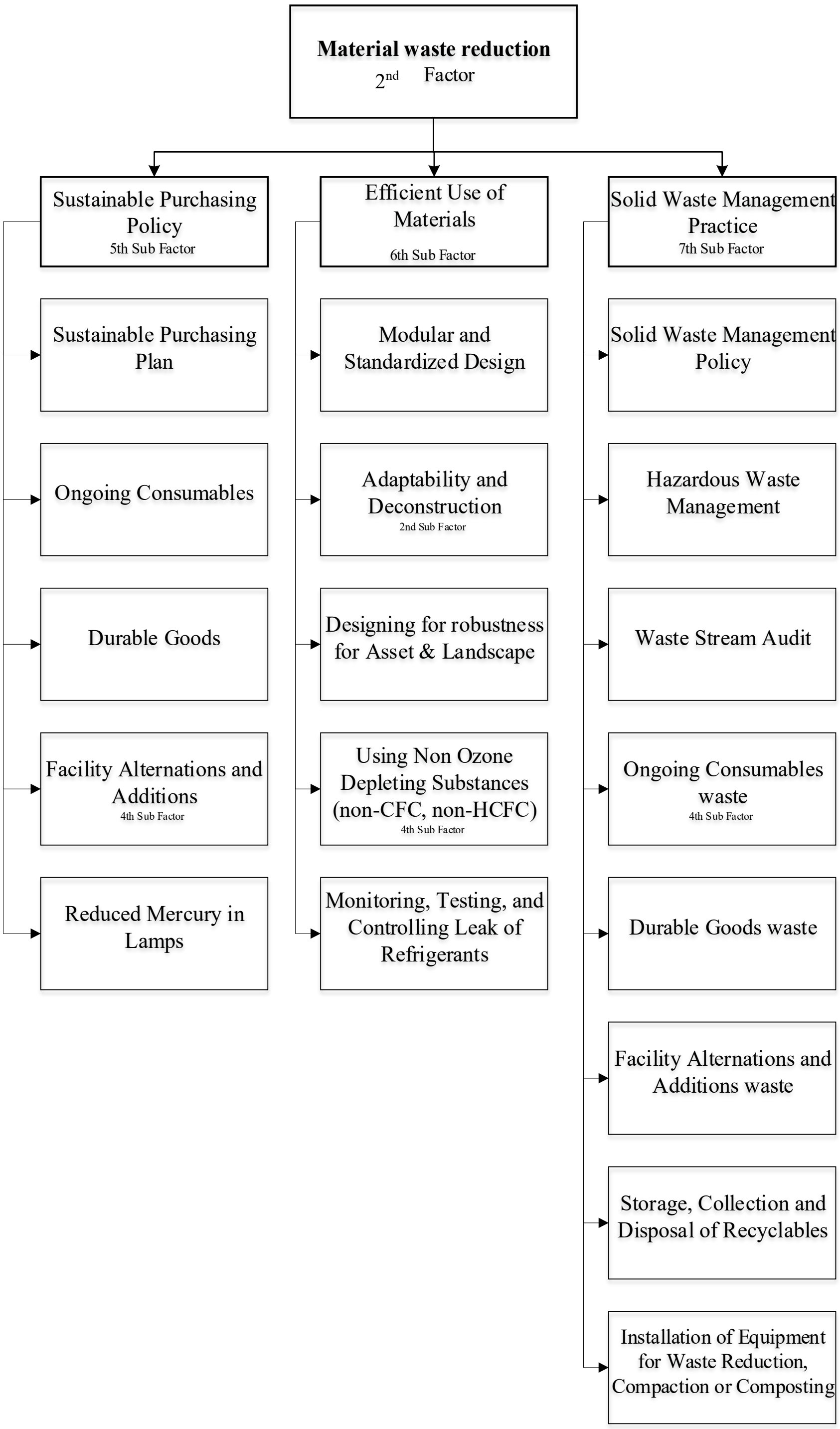


Figure 3-4: Material waste reduction factor and its related factor indicators

Transportation Factor

It promotes the usage of public transportation in commuting. It consists of three indicators (Figure 3.5):

1) **Adequate access to public transport** focuses on the presence of nearby public transportation to the building;
2) **Availability of ''maximum parking capacity''** leads to a decrease in the number of private cars that are used in commuting;
3) **Priority parking for sustainable vehicles** promotes their usage.

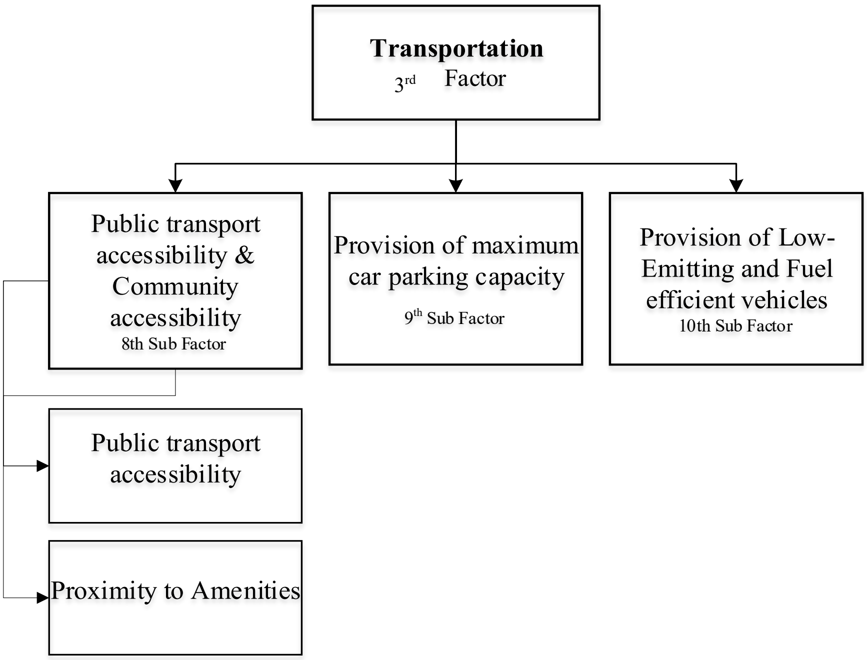


Figure 3-5: Transportation factor and its indicators

Energy Factor

Energy factor is a very important one when accessing a building's sustainability. It aims to reduce energy usage and its corresponding negative effects on the life cycle of a building. It comprises of four indicators (Figure 3.6):

1) **Energy performance** analyzes the percent decrease in energy usage for a building in terms of the lowest energy needed and energy optimization;
2) **The provision of energy management** evaluates the presence of operating plans for energy management and for building and energy audit, energy monitoring and metering for the operated equipment. This, in turn, facilitates auditing, commissioning and testing for the analyzed in-demand energy and end-uses. In addition, it contributes to the development of an automated system that monitors and controls all the building's systems and emissions reduction. These allow the identification of the building's performance parameters, which are essential to reduce conventional energy consumption and quantify any reductions. Sustainable maintenance ensures that all systems will perform in an efficient way according to the designed building maintenance;
3) **The availability of energy-efficient systems** estimates using of energy-saving systems for lighting, air circulation and energy generation;
4) **The availability of energy-saving amenities** assesses the presence of energy-saving amenities such as washing and drying machines within the building.

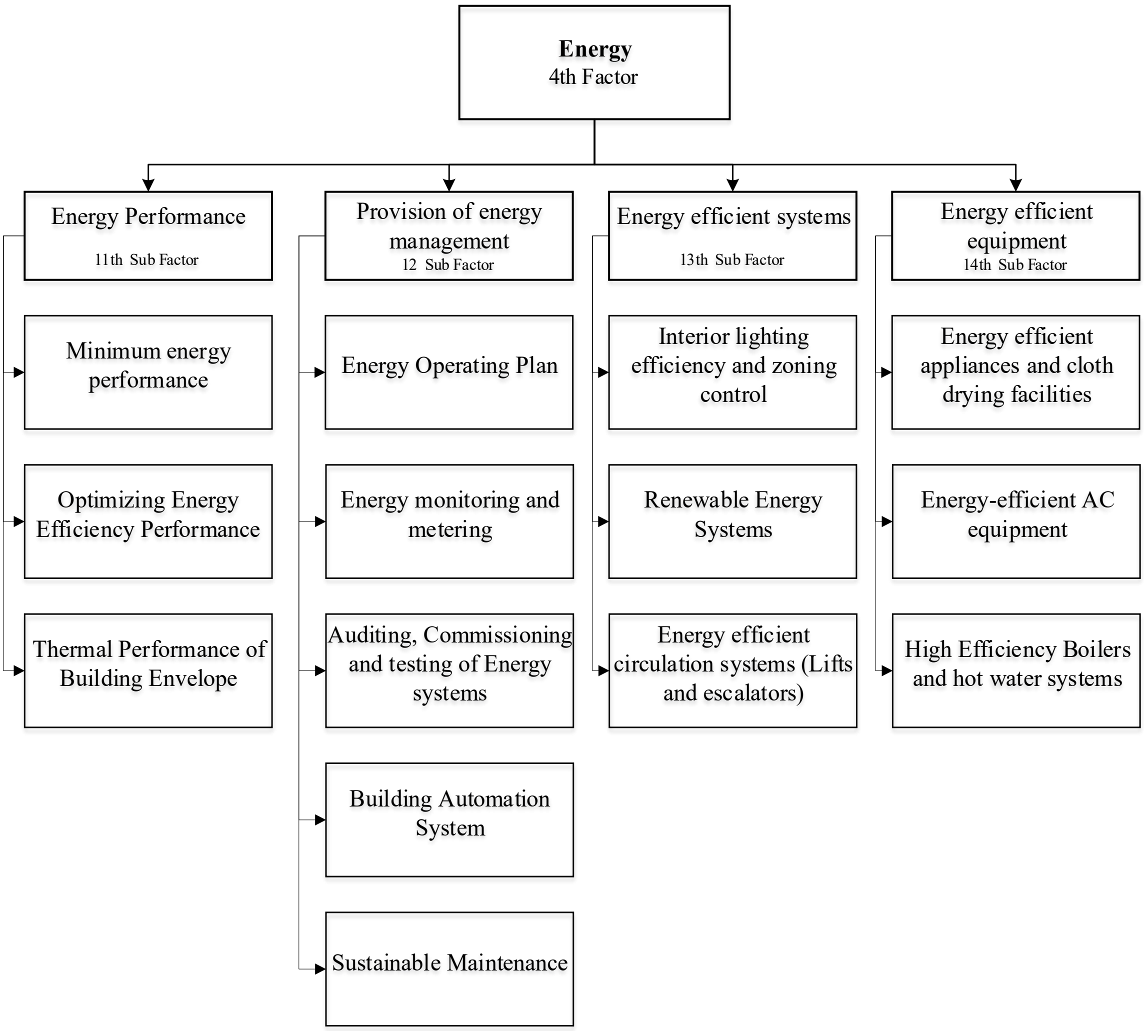


Figure 3-6: Energy factor and its related factor indicators

Water Use Factor

This factor aims at assessing the best and most efficient practices to be used to conserve water. It is comprised of two indicators (Figure 3.7):

1) **Efficient water use**, which evaluates the following:
    a. The efficiency of the minimal interior plumbing systems
    b. The efficiency of supplementary indoor plumbing features
    c. Recycling of water and rainwater collection
    d. The efficient use of water for lawns
    e. Efficiency of water usage in communal spaces
2) **Water use management** deals with the different techniques that could be used to better manage water use in terms of its conservation while meeting the building's water demand. It evaluates the different procedures taken to perform water quality and quantity measurement, and leak detection and repair. In addition, this indicator also involves water performance monitoring, cooling tower water management, storm-water quantity control, and surface water runoff.

Indicator Calculating Methodology

Water consumption per sector is calculated as follows:

$$Water\ comsuptiom = \frac{Quantity\ of\ consumption\ by\ sector}{Total\ of\ consumption\ of\ freshwater} \times 100 \qquad 3.1$$

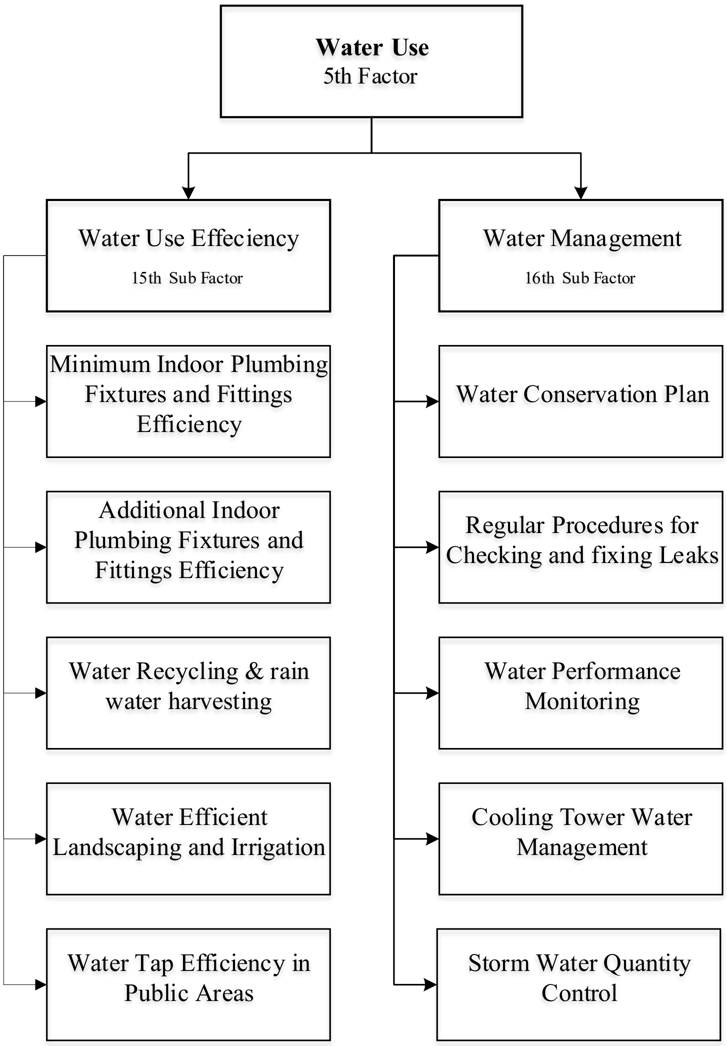


Figure 3-7: Water Use factor and its related factor indicators

Heritage Value Factor

This is a major factor when studying the sustainability of Heritage Buildings. It comprises of the following three indicators (Figure 3.8). All these factors are based on observations.

1) **Building age**: there is significant debate as to what age a building should be in order to be historically valued. According to SCTNH (2012), 100 years is the least age. Thus, in the questionnaire, the minimum building age was chosen to be 100 years.

2) **Function of the building** for touristic, commercial or residential use;

3) **Building revenue** (Canadian Heritage, 2018).

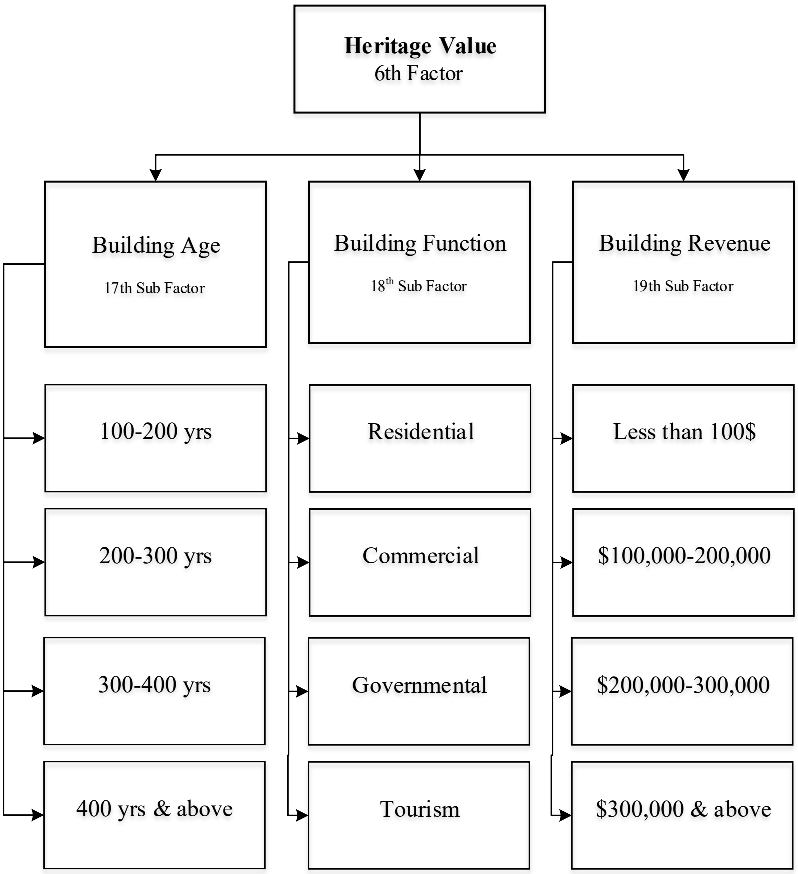


Figure 3-8: Heritage Value factor and its related factor indicators

Structural Condition Factor

This factor emphasizes the structural conditions of the buildings and it is an important factor to consider in the sustainability of heritage buildings. It comprises of three indicators (Figure 3.9):

1) **Building materials** such as mud, stone, concrete, and cast iron.

2) **Maintenance plan** which is focused on:

   a- Maintenance frequency (once a year if is quantitative) b- Inspection frequency

c- Minor Intervention

d- Major Intervention

3) **Safety**:

This indicator aims to assess the safety of the building. It deals with the structural integrity of the building and evaluates its condition as excellent, good or bad. It assesses the probability of building failure and evaluates how safe the building is for undertaking different activities.

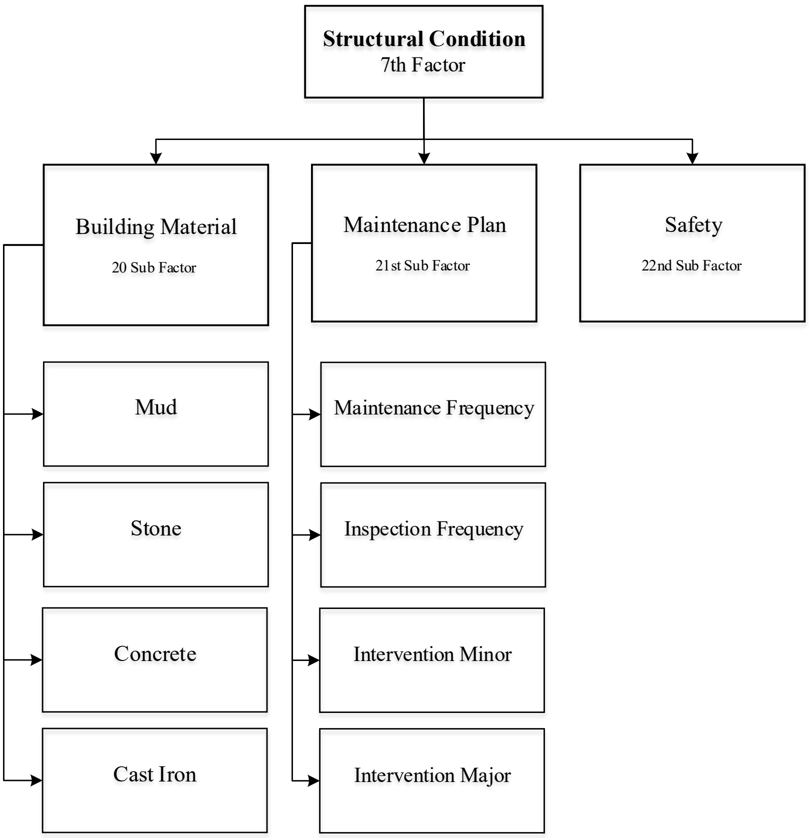


Figure 3-9: Structural Condition factor and its related factor indicators

Indoor Environmental Quality Factor

It promotes practices that are geared to enhancing the quality of the indoor environment, encouraging the well-being of the building residents and minimizing possibly detrimental environmental risks. It consists of six indicators (Figure 3.10):

1) **Visual comfort** assesses the following:
    a. The quantity of incoming sunlight
    b. The control measures for incoming sunlight
    c. The presence of the right amount of lighting in the building's occupied and non-occupied spaces;
    d. The availability of control systems and high-frequency ballasts for man-made lighting in the buildings
2) **Quality of the indoor air** examines the:
    a. Maintenance of the imposed minimum quality of indoor air
    b. Control measure for cigarette smoke in the building environment
    c. Performance and management of indoor air quality that evaluates auditing, management plan and greenhouse gas monitoring.
    d. Pollution monitoring and sustainable policies for cleaning indoor air evaluate the upkeep and cleaning protocol in place
3) **Thermal comfort** examines the:
    a. Design and reduction of thermal loads
    b. Observation and analysis of the ''airspeed and radiant temperature''
    c. Presence of a control system for temperature in naturally-ventilated and air-conditioned sections in the building;
4) **Acoustic performance** evaluates all sound-related issues in the building including efficiency of noise

5) **Hygiene** assesses the following:

   a. Plumbing and drainage systems to confirm the absence of contaminants

   b. Minimal effects arising from leakage of chemicals in the storage area

   c. Reduction and control of biological contaminants such as Legionella

   d. Presence of an air-freshener in garbage collection rooms

6) **Building facilities** assess the availability of in-door facilities for disabled people.

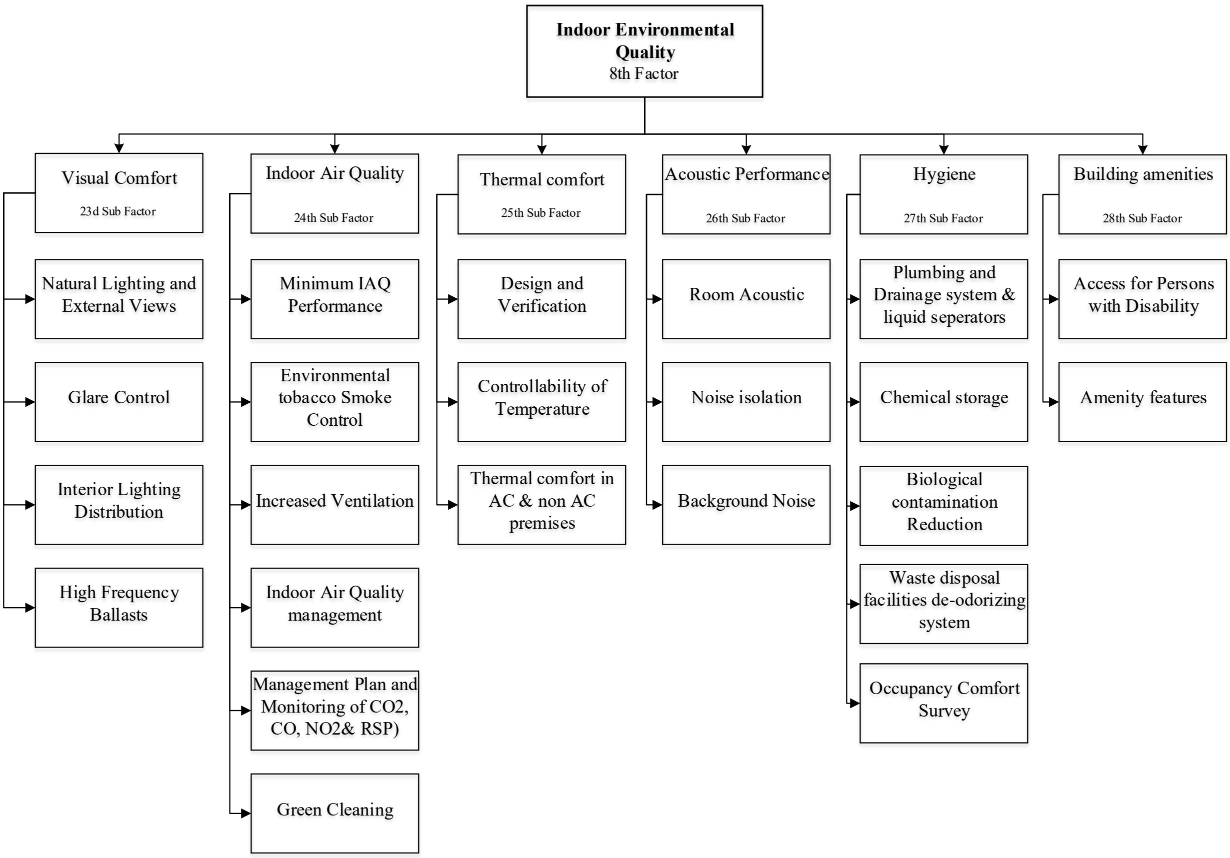


Figure 3-10: IEQ factor and its related factor indicators

Building Environmental Management Factor

It consists of five indicators (Figure 3.11):

1) **Management of building maintenance** evaluates the following:
    a. Investigation of the building condition
    b. The quality of the staff on the maintenance team
    c. The availability of materials such as building plans needed to carry out maintenance work
    d. The availability of documents such as the building user guide, maintenance policies and protocols for building operation and maintenance
2) **The presence of security measures and intruder alarm** to hinder any harm to the building and unwanted usage of building materials;
3) **The availability of green lease** enables building residents to lead a sustainability-minded lifestyle by signing lease agreements to reduce energy and water usage and waste generation;
4) **Risk management** has to do with the managing the risk of fire and the occurrence of other natural disasters;
5) **Innovations** assess the application and degree of efficiency of the applied innovative ideas.

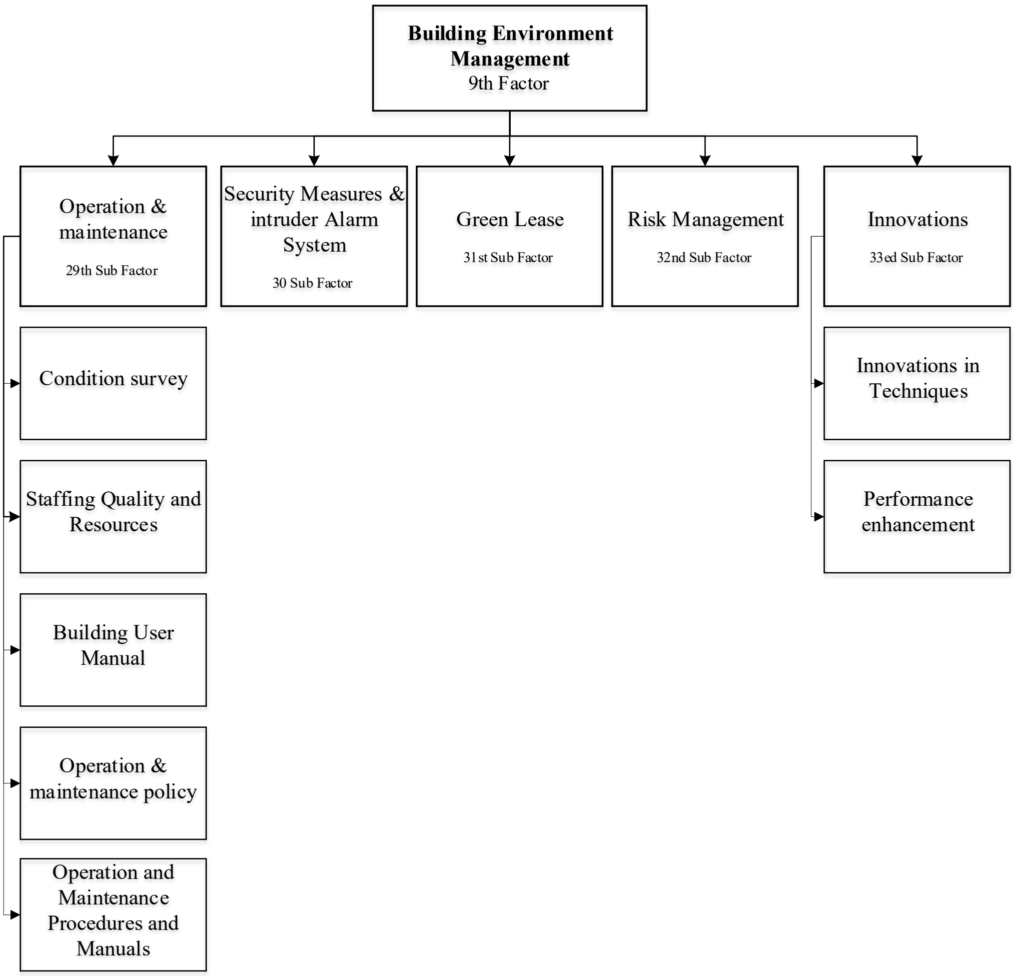


Figure 3-11: Building Environmental Management factor and its related factor indicators

Table 3.1 indicates the scoring system for Sustainability Assessment of Heritage Buildings (SAHB). For each factor and indicator, points are allocated to reflect the degree of fulfillment of each of the requirements. The scoring system is discussed in more detail in the following subsections. Calculations are based on the results of the questionnaire, observations and the existing rating systems.

Each factor consists of indicators and each indicator has sub indicators. The weight of each sub-indicator is allocated based on the results of the questionnaire, observations and the existing rating systems. The weight is represented by points. For example, the maximum points for the *site and ecology* factor is 18 points that are distributed among its indicators as follows:

Site Selection – 2 points, *Site Management* – 6 points, *Reduce Heat Island* effect- 8 points, and *Site Emissions* – 2 points. In a similar manner, points are allocated for other factors (Table 3.1). The maximum achievable points for all factors sum up to 269. The factor with the greatest number of points is *energy* with 78 points while *transportation* accounts for only 12 points.

This scoring system is applied to both case studies, MP and GN. MP achieved total points (score) of 117 compared to 162 points for GN. For MP, the achieved scores for *energy* and *transportation* factors are 51 out of 78 and 2 out of 12, respectively. For GN, the achieved scores for the *energy* and *transportation* factors are 45 out of 78 and 7 out of 12, respectively. The automated tool SAHB, as illustrated in chapter 7, is built based on this scoring system.

Table 3-1: Scoring Schema for Sustainability Assessment for Heritage Buildings (SAHB)

Factors	**Indicators and Sub-Indicators**	**Max. Score**	**MP**	**GN**
Site and Ecology – 18 Points	***Site Selection***	***2***	***2***	***2***
	Previously Certified Design & Construction	1	1	1
	Respect for sites of historical or cultural interest	1	1	1
	Site Management	***6***	***4***	***2***
	Environmental Policy & Purchasing Plan	3	1	1
	Environmentally Purchasing Practices (HK Beam)	1	1	1
	Building Exterior and Hardscape Management Plan	1	1	0
	Integrated pest management, Erosion Control	1	1	0
	Reduce Heat island effect	***8***	***2***	***4***
	Heat Island Reduction in Non-Roof Areas	1	0	1
	Heat Island Reduction in Roof Areas	1	0	1
	Exterior Walls Finishing Materials & Planting	1	1	1
	Consideration of Wind Movement	1	0	0
	Greenery Provision & Ecological	4	1	1
	Site Emissions	***2***	***2***	***1***
	Noise from Building Equipment	1	1	1
	Reduction of Light Pollution	1	1	0
Transportation - 12 Points	***Public transport accessibility & Community accessibility***	***10***	***0***	***5***
	Public transport accessibility	1-7	0	4
	Proximity to Amenities	1-3	0	1
	Provision of maximum car parking capacity	***1***	***1***	***1***
	Provision of Low-Emitting & Fuel-Efficient Vehicles	***1***	***1***	***1***
Ene	***Energy Performance***	***28***	***20***	***20***

	Minimum Energy Performance	**	**	**
	Optimizing Energy Efficiency Performance	1-18	14	10
	Thermal Performance Reduction of Building Envelope	1-10	6	10
	Provision of Energy Management	***15***	***10***	***15***
	Energy Operating Plan	1	1	1
	Energy Monitoring and metering	1	1	1
	Metering of Electrical loads	1	0	1
	Monitoring of Central HVAC plant	1	1	1
	Monitoring record	1	1	1
	Public Display of Energy use	1	1	1
	Auditing, Commissioning, and testing of Energy systems	2	0	2
	Energy Auditing	1	1	1
	Emissions reduction reporting	1	1	1
	Investigation and Analysis	1	1	1
	Implementation	1	1	1
	Ongoing Commissioning	1	0	1
	Building Automation System	1	1	1
	Sustainable Maintenance	1	0	1
	Energy Efficient Systems	***24***	***17***	***17***
	Interior Lighting Efficiency and Zoning Control	10	10	10
	Energy efficient lighting	8	5	5
	Zoning Control	1-3	2	1
	Renewable Energy Systems	2	0	1
	Energy-Efficient Circulation Systems (Lifts and Escalators)	1	0	0
	Energy Efficient Equipment	***11***	***4***	***8***
	Energy Efficient Appliances and Cloth Drying Facilities	1-2	2	2
	Energy-Efficient AC equipment	8	2	5
	High-Efficiency Boilers and hot water systems	1	0	1
Water Use 31- Points	***Water Conservation***	***14***	***10***	***2***
	Minimum Indoor Plumbing Fixtures and Fittings Efficiency	**	**	**
	Additional Indoor Plumbing Fixtures and Fittings Efficiency	1	0	1
	Water Recycling & Rain Water Harvesting	5	5	0
	Water Efficient Landscaping and Irrigation	5	5	0
	Water Tap Efficiency in Public Areas	3	0	1
	Water Management	***17***	***6***	***4***
	Water Conservation Plan	**	**	**
	Regular Procedures for Checking and Fixing Leaks	1	1	0
	Detection system	1	1	1
	Leak Prevention	1	1	0
	Isolation Valves	1	1	1
	Water Performance Monitoring	2	0	0
	Permanently installed water metering	1-2	1	1
	Monitoring & Reporting	1-3	1	1
	Cooling Tower Water Management	2	0	0
	Chemical Management (1) Non potable Water Source Use (1)	1-2	0	0
	Storm Water Quantity Control & Surface Water run off	1	0	0

	Storm Water Management Plan	1	0	0
Material Waste -25 Points	***Sustainable Purchasing Practice***	***5***	***0***	***0***
	Sustainable Purchasing Policy	**	**	**
	Ongoing Consumables	1	0	0
	Durable Goods	2	0	0
	Facility Alternations and Additions	1	0	0
	Reduced Mercury in Lamps	1	0	0
	Efficient Use & Selection of Materials	***7***	***0***	***5***
	Modular and Standardized Design	1	0	1
	Adaptability and Deconstruction	1	0	0
	Interior elements and building services components	1	0	1
	Flexible engineering services	1	0	1
	Structural adaptability	1	0	1
	Designing for robustness for Asset & Landscape	1	0	1
	Using Non Ozone	1	0	0
	Solid Waste Management Practice	***13***	***3***	***6***
	Solid Waste Management Policy	**	**	**
	Hazardous Waste Management	1	0	1
	Waste Stream Audit (HK BEAM)	1	1	1
	Ongoing Consumables	1	0	1
	Durable Goods	1	0	1
	Facility Alternations and Additions	1	1	1
	Storage, Collection and Disposal	4	1	1
	Installation of Equipment	2	0	0
	For Organic Waste	1	0	0
	For Non-Organic Waste	1	0	0
IEQ - 48 Pts	***Visual Comfort***	***11***	***4***	***11***
	Natural Lighting and External Views	1	1	1
	Glare Control	4	0	4
Indoor Environment Quality - 48 Points	Interior Lighting	2	2	2
	Lighting in normally occupied	1	0	1
	Lighting in Non-normally occupied	1	1	1
	High-Frequency Ballasts (Green ship)	2	0	2
	Indoor Air Quality	***19***	***2***	***11***
	Minimum IAQ Performance	**	**	**
	Environmental tobacco Smoke Control	**	**	**
	Increased Ventilation Performance, Localized Ventilation	1	0	1
	Indoor Air Quality Performance & management	1	0	1
	IAQ Audit (GM Singapore)	1	0	0
	Construction management plan	1	1	0
	Monitoring CO2	1	0	0
	Monitoring CO	1	0	0
	Monitoring Nox	1	0	0
	Respirable suspended particulate	1	0	0
	Indoor Air Quality Pollutant monitoring	2	1	1
	Volatile organic compounds (VOC)	1	0	1

	Urea Formaldehyde	1	0	1
	Chemicals	1	0	1
	Green Cleaning	1	0	0
	Purchase sustainable cleaning products and materials	1	0	1
	Sustainable Cleaning Equipment (LEED)	1	0	1
	Indoor Chemical and Pollutant Source Control (LEED)	1	0	1
	Indoor Integrated Pest Management (LEED)	1	0	1
	Deep Cleaning Policy	1	0	1
	Thermal comfort	*5*	*3*	*3*
	Design and Verification (LEED)	1	1	0
	Design	1	1	1
	Controllability of Temperature (GBI)	1	0	1
	Control	1	1	1
	Thermal comfort in air-conditioned (HK BEAM)	1	0	0
	Acoustic Performance	*3*	*1*	*3*
	Room Acoustic (HK BEAM)	1	0	1
	Noise isolation	1	1	1
	Background Noise	1	0	1
	Hygiene	*7*	*2*	*6*
	Plumbing, Drainage system and Light Liquid Separators	1	1	1
	The system design	1	0	1
	Light Liquid Separators	1	0	1
	Chemical Storage	1	1	1
	Biological contamination Reduction	1	0	0
	Waste disposal facilities de-odorizing system	1	0	1
	Occupancy Comfort Survey	1	0	1
	Building amenities	*3*	*1*	*2*
	Access for Persons with Disability (HK BEAM)	1	1	0
	Amenity features (HK BEAM)	2	0	2
Bldg Mgmt - 36 Pts	*Operation and Maintenance Management*	*17*	*5*	*10*
	Condition Survey	4	0	4
	Staffing Quality and Resources	1	1	1
Building Management – 36 Points	Building User Manual and Information (HK BEAM)	2	0	2
	Instructions and guidance materials	1	1	1
	Building User Information	1	1	0
	Operation & Maintenance policy	1-2	1	0
	Operation and Maintenance Procedures and Manuals	1	1	1
	Maintenance Procedures:	1	0	0
	Inspections, cleaning, maintenance and general repairs systems	1	0	0
	Operation Procedures (BREAM)	1-2	0	0
	Operation and maintenance manuals (BREAM)	1	1	1
	Security Measures & intruder Alarm System	*4*	*2*	*4*
	Security Measures	1-3	1	3
	Intruder Alarm System	1	1	1
	Green lease (BREAM)	*2*	*0*	*2*
	Risk Management	*3*	*1*	*2*

	Fire Risk Management	1	1	1
	Fire Risk Assessment	1	0	1
	Fire Risk Manager & Natural Hazard	1	0	1
	Innovations	*10*	*2*	*2*
	Innovations in Techniques	1-5	2	2
	Performance enhancement	1-5	0	0
Heritage value -12 Points	*Building age*	*4*	*2*	*4*
	100-200 years	1	1	1
	200-300 years	1	1	1
	300-400 years	1	0	1
	400- above	1	0	1
	Building function	*4*	*4*	*2*
	Residential only	1	1	1
	Commercial only	1	1	1
	Governmental only	1	1	0
	Tourism only	1	1	0
	Building revenue	*4*	*2*	*2*
	Less 100k	1	1	1
	Between 100-200k	3	1	1
	Between 200-300k	3	0	0
	Between 300k & above	4	0	0
Structural condition- 12 Points	*Building material*	*4*	*4*	*3*
	Mud	1	1	0
	Concrete	1	1	1
	Stone	1	1	1
	Cast Iron	1	1	1
	Maintenance plan	*4*	*0*	*1*
	Maintenance frequency	1	0	1
	Inspection frequency	1	0	0
	Intervention major	1	0	0
	Intervention minor	1	0	1
	Safety	*1*	*0*	*1*
	Labour training & Equipment safety	1	0	1
Total		**269**	**117**	**162**

** indicates a prerequisite indicator

3.4 The Sustainability Assessment Model for HBs

After the criteria, factors and indicators that affect the sustainability of heritage buildings were identified (Figure 3.15), data collection followed, which included the expert responses from the questionnaire. Then, the sustainability and rehabilitation models for heritage buildings were implemented. Each of these models requires a different type of data. Both models require the identification of the criteria, factors and indicators to evaluate the current sustainability performance of the building and the sustainability index needed to upgrade the building. Furthermore, the weight of each of the criteria, factors and indicators was required in order to determine its significance based on the local context. After the model development phase, the validation phase followed.

Each factor has its set of indicators and sub-indicators, with their respective attainable points. Therefore, in order to calculate each indicator's score, the sum of all the points from its corresponding sub-indicators is computed (Equation 3.1). In addition, the result of each factor is calculated by multiplying the corresponding weight of this factor that will have been calculated in the previous stage, and the score of the factor as in Equation 3.2.

$$SC\,f_j = \sum_{i=1}^{l} I \times f_i \qquad 3.2$$

Where:

$SC\ f_j$ = the score of the j^{th} factor

I = the weight of the i^{th} indicator

f_i = the number of indicators under each j^{th} factor

$$R\,f_j = W\,f_j \times SC\,f_j \qquad 3.3$$

Where:

$R\ f_j$ = the result of the j^{th} factor

$W\ f_j$ = the weight of the i^{th} indicator

3.4.1 Important Factors in the Sustainability of HBs

As will be presented in the next chapter, the literature review led to the identification of nine factors, which affect a building's sustainability. These factors include: 1) site and ecology; 2) transportation; 3) energy efficiency; 4) water use; 5) material and waste reduction; 6) heritage value; 7) structural condition; 8) indoor environmental quality (IEQ); 9) building management. Each factor comprises of indicators and sub-indicators. Figure 3.12 shows the methodology of the comparative analysis based on the systematic reviews and the 12 existing rating systems.

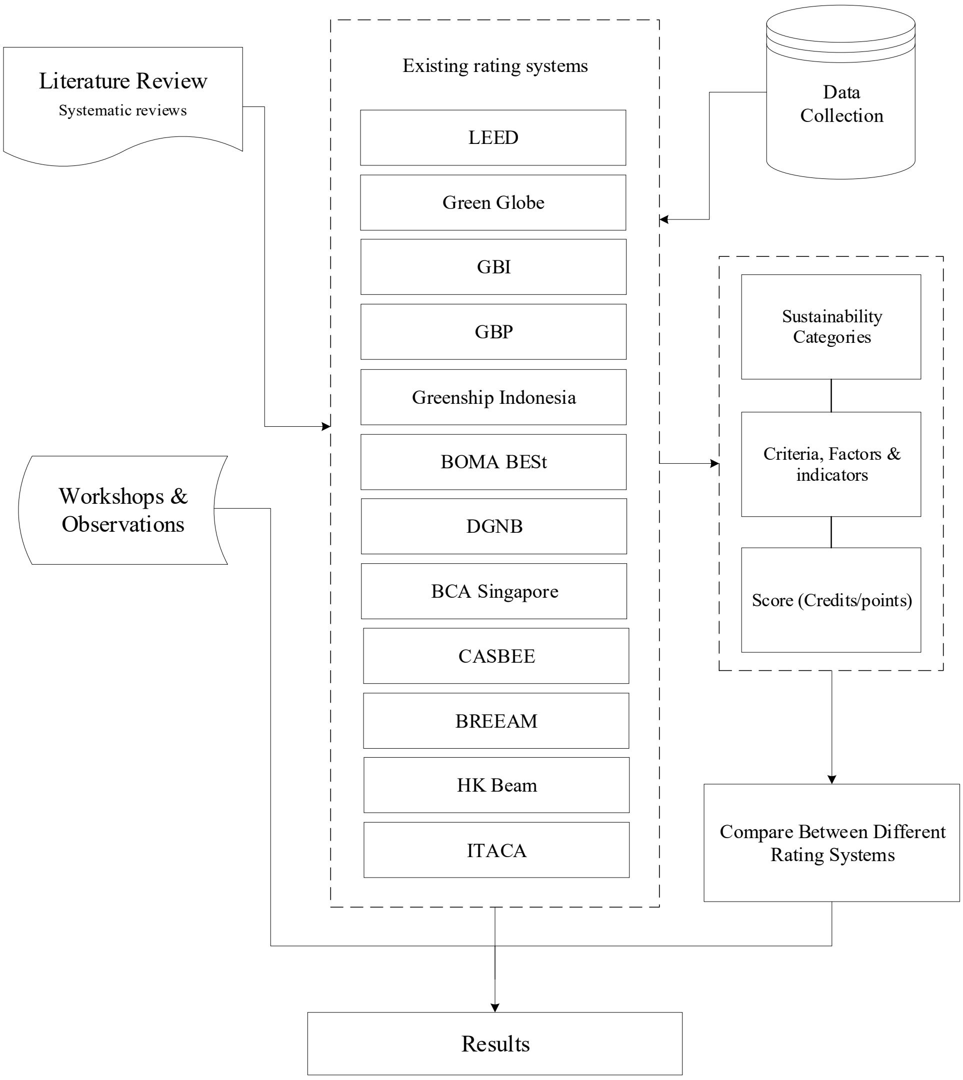


Figure 3-12: Procedure of the comparison flowchart

The comparison aims to highlight the percent contribution of each rating system to each factor (Equations 3.3, 3.4 and 3.5)

$$\sum S_{max,f} = \sum S_{max,i} \qquad 3.4$$

Where:

$S_{max,f}$: The maximum score a system rating can achieve with respect to a factor $_f$

$S_{max,i}$: The maximum score a system rating can achieve with respect to an indicator i

$$\sum S_{max\ i} = \sum S_{max\ s} \qquad 3.5$$

Where:

$S_{max\ i}$ = The maximum score a system rating can achieve with respect to an indicator $_i$

$S_{max\ s}$ = The maximum score a system rating can achieve with respect to sub-indicators

$$Coverage\ percentage = \frac{\sum S_i}{\sum S_{max\ i}} \qquad 3.6$$

Where:

Coverage percentage = The reflected values to each rating system

$S_{max\ s}$ = The maximum score a system rating can achieve with respect to sub-indicators

S_i = The score that rating achieved with respect to an indicator

$S_{max\ i}$ = The maximum score with respect to an indicator

The results obtained from the implementation of this comparison are further illustrated in Chapter 5.

3.4.2 Weight Evaluation applying Fuzzy TOPSIS Technique

The Fuzzy TOPSIS technique, together with expert responses on the questionnaire, was applied to determine the weight of each factor and indicator. The experts were required to answer the five parts of the questionnaire in order to determine the significance of the listed criteria, factors and indicators with respect to sustainability assessment of heritage buildings.

3.4.3 Normalized decision matrix

Tables C-22-26, available in Appendix C, depict the detailed steps for the weight determination of each of the indicators for the two case studies. In particular, the weight determination is divided into three main stages: 1) Creation of the decision matrix, 2) Normalization of the decision matrix, and 3) Creation of the weighted normalized decision matrix. The first step involved the creation of the decision matrix, which embeds the linguistic variables of each of the respondents. These linguistic variables are based on the perspective of each of the respondents regarding the weight of each indicator relative to the whole usability assessment. In addition, fuzzification was applied to these linguistic variables following the scale presented in the prior section. This step resulted in the formation of the decision matrix for each of the nine factors (Table 7.2). The linguistic decision is represented in terms of the TFN. Thus, the combination of all TFNs represents the decision matrix. The next step was to normalize the decision matrix by normalizing the respondents' decisions to make it unitless. To accomplish this, values of all TFNs across one row (representing a single respondent) was divided by the third-largest FTN value in the same row (Equation 3.3) (Ertuğrul & Karakaşoğlu, 2008; Pramanik et al., 2016; Yong, 2006). The last step was to transform the normalized matrix into a weighted normalized matrix. Each row representing the decision of one respondent was multiplied by the reliability weight of those respondents (Equations 3.7 and 3.8). The reliability weight is a measure of how reliable the respondents' decisions are.

Accordingly, a uniform reliability weight of 0.025 was assigned to each of the 40 correspondents to prevent bias and simplify calculations.

$$\widetilde{r_{ij}} = \begin{cases} \frac{a_{ij}}{c_j^*}, \quad \frac{b_{ij}}{c_j^*}, \quad \frac{c_{ij}}{c_j^*} \ for\ benfit\ attibute \\ \frac{a_j^-}{c_{ij}}, \quad \frac{b_j^-}{b_{ij}}, \quad \frac{c_j^-}{c_{ij}} \ for\ sustainibility\ attribute \end{cases} \qquad 3.7$$

$$\widetilde{V_{ij}} = \widetilde{r_{ij}} \, . \widetilde{W_{ij}} \qquad 3.8$$

Where:

a_{ij}, b_{ij}, c_{ij} = three values of a TFN with the highest-ranking.

V = Weighted normalized decision matrix;
W_{ij} = Weight of each attribute.
$\widetilde{r_{ij}}$ = Ranking each alternative with respect to one attribute (j).

3.4.4 Determination of Results for Each Indicator

Based on the aforementioned discussion, each factor comprises of a set of indicators and sub-indicators, which have associated attainable points. Therefore, in order to calculate each indicator's score, the sum of all the points from its corresponding sub-indicators is computed (Equation 3.9). Furthermore, each indicator's score is used to calculate the result of the indicator (Equation 3.10)

$$SC\ f_j = \sum_{i=1}^{l} Sub\ f_i \qquad 3.9$$

Where:

$SC\ f_j$ = the score of the jth indicator
$Sub\ f_i$ = the weight of the ith sub-indicator
l = the number of sub-indicators under each jth indicator

$$R\ f_j = W\ f_j \times SC\ f_j \qquad 3.10$$

Where:

$R\ f_j$ = the result of the jth indicator

$W\ f_j$ = the weight of the ith sub-indicator

3.4.5 Determination of Results for Each Factor

Similar to the calculation of the scores of the indicators, the score of the factors is detailed in this section. Essentially, each factor's score is the sum of all the results of its corresponding indicators (Equations 3.11 and 3.12). Furthermore, the result of each is calculated by multiplying the corresponding weight ($W\ c_k$) of the required factor, as calculated in Section 3.3.1, and the score of the factors, as shown in equation 3.5. The Fuzzy TOPSIS technique, together with expert responses on the questionnaire, was employed to determine the weight of each factor. Such responses would quantify the significance of each factor with respect to the building's sustainability as a whole. In addition, the global weight (WG) of the indicator is determined by multiplying the local weight of the factor by the weight of the factor (Equation 3.13).

$$SC\ c_k = \sum_{j=1}^{m} R\ f_j \qquad 3.11$$

Where:

$SC\ c_k$ = the score of the kth factor

m = the number of indicators under each kth factor

$$R\ c_k = W\ c_k \times SC\ c_k \qquad 3.12$$

Where:

$R\ c_k$ =the result of the kth factor

$W\ c_k$ = the weight of the kth factor

$$WGj_k = Wc_k \times WLc_j \tag{3.13}$$

Where:

WGj_k =the corresponding global weight of the jth indicator

Wc_k =the corresponding weight of kth factor

WLc_j =the corresponding local weight of the kth indicator

3.5 Generalized Weights Determination

In order to differentiate between the Positive Ideal Solution (PIS) and the Negative Ideal Solution (NIS), the generalized mean should be calculated. Essentially, PIS has the highest generalized mean while NIS has the lowest. A defuzzification process was leveraged to convert the fuzzy triangular numbers to a crisp value, as shown in Equation 3.14 (Kahraman et al., 2008).

$$M(v_{ij}) = \frac{\left(-a_{ij}^2 + c_{ij}^2 - a_{ij}b_{ij} + a_{ij}b_{ij}\right)}{[3(-a_{ij} + c_{ij})]} \tag{3.14}$$

Where:

vj* = positive ideal solution concerning a particular attribute

vj = negative ideal solution concerning a particular attribute

M(vij): = generalized mean for each solution; and a, b, c: three values of the fuzzy

3.6 PIS and NIS Distances Measurements

After determining the generalized mean, the distance between two TFNs were calculated using the Euclidean distance (Equation 3.15) (Byun & Lee, 2005; Ertuğrul & Karakaşoğlu, 2008; Pramanik et al., 2016; Yong, 2006, Mahmoud, 2017). The results are shown in Table 6.3, which represents each factor as three columns. The first column represents the generalized mean and the second and the third columns depict the distances from the PIS (D+) and NIS (D-), respectively. For instance, the first row in the table shows D+ values of 0 for the energy and water use indicators. This implies that the first respondent ranked these two factors as the highest among the other factors and thus, they represent the PIS. On the other hand, the Site and Indoor Environmental Quality factors had a D- of 0, which means that they represent the NIS.

$$d(\widetilde{M_1}, \widetilde{M_2}) = \sqrt{\frac{1}{3}[(a_1 - a_2) + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \qquad 3.15$$

Where:

d (M1, M2) = the distance between two fuzzy triangular numbers.
a1, b1, c1 = three values of the first triangular fuzzy numbers; and
a2, b2, c2 = three values of the second triangular fuzzy numbers.

3.6.1 Similarity Measures Evaluation (S)

The positive similarity (S+) is the summation of the D+ values of each of the nine factors across all the respondents. Similarly, the negative similarity (S-) is the summation of all D- values of each factor across all respondents (Byun & Lee, 2005; Ertuğrul & Karakaşoğlu, 2008; Kahraman et al., 2008; Doan et al., 2012; Pramanik et al., 2016, Mahmoud, 2017).

3.6.2 Closeness Coefficient (CC) Calculations

The Closeness Coefficient (CC) is a measure of how similar the values are and it would be used to determine the final weight of each factor (Byun & Lee, 2005; Ertuğrul & Karakaşoğlu, 2008; Kahraman et al., 2008; Pramanik et al., 2016, Mahmoud, 2017). Particularly, the CC is calculated as the ratio between the negative similarity S- and the summation of both negative and positive similarity (Equation 3.16). Furthermore, the final weight of the factors is determined by the normalization of all the calculated CC. The CC values are shown in Table 4. It is evident that the Energy factor was ranked the highest among all the other factors, with a CC value of 0.738 and a weight of 0.2. Conversely, the Transportation factor had the lowest weight.

$$CC_i = \frac{S_i^-}{S_i^- + S_i^*} \qquad 3.16$$

Where:

S_i = score of the ith indicator in each factor,

S_i^*: = score of the ith indicator in each factor, and

CC_i = score of the ith sub-indicator in each indicator

3.6.3 Determination of the Scores of Indicators and Sub-Indicators

The proposed factors in this research comprise of indicators and sub-indicators; hence, a score should be attributed to each. In essence, the score of the indicator is the aggregation of the score of all of its sub-indicators (Equation 3.17).

$$SC_j = \sum_{i=1}^{1} SC_{indi} \qquad 3.17$$

Where:

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

SC_{indi} = score of the ith sub-indicator in each indicator.

3.6.4 Indicator Sustainability Index (SI) Calculation

Appendix C.2 depicts the weights of all factors and indicators. By closely observing the values, the weights can be categorized intoW_f, W_L, which represents the weight of the factors and indicators, respectively. The global weight W_G was then calculated, which is the product of both the factor and indicator weight (Equation 3.18). The global weight represents the overall weight of each indicator with respect to the whole sustainability assessment tool. Furthermore, the summation of all the global weights should amount to one. The Indicator

Sustainability Index (SI) is calculated as the product of the indicator score (SC) and its global weight (W_G) (Equation 3.19).

$$WG_J = W_K \times WL_j \tag{3.18}$$

$$SI_j = SC_j \times WG_j \tag{3.19}$$

Where:

WG_j	= the corresponding global weight of the j^{th} indicator;
W_k	= the corresponding weight of the kth factor
WL_j	= corresponding local weight of the j^{th} indicator; and
SI_j	= sustainability index of the j^{th} indicator.

3.6.5 Heritage Buildings Index (HBI) Calculation

In order to determine the Building Sustainability Assessment Ratio (SAHB), the Heritage Building Index (HBI) should first be calculated. The HBI is calculated as the summation of Sustainability Indices (SI) of all indicators (Equation 3.20). The SAHB is the percentage ratio between the HBI and the maximum HBI (Equation 3.21) or a more generalized form in Equation 3.22. The maximum HBI is calculated following the same procedures described above. However, instead of using the actual scores based on the respondents' answers, the maximum allowable score per indicator is used.

$$HBI = \sum_{j=1}^{m} SCF_i \times W_{gj} = \sum_{j=1}^{m} SI_j \tag{3.20}$$

$$SAHB = \frac{HBI}{HBI_{max}} \times 100 \tag{3.21}$$

$$SAHB = \frac{\sum_{j=1}^{m} SC_i \times W_{gj}}{\sum_{j=1}^{m} \left(SC_j\right)_{max} \times WG_j} \times 100 \tag{3.22}$$

Where:

HBI = Heritage Buildings Index; and
SAHB = Sustainability Assessment for Heritage Buildings.

3.6.6 Model Implementation

The sustainability assessment (SA) model was developed by applying the same pre-defined framework to the two case studies (see Figures. 3.13 and 3.14). The proposed framework involved four steps:

1) compiling case study data (documentation phase) using AutoCAD®; 2) utilizing the building information model (BIM) using Revit®; 3) producing the energy simulation model using ArchiCAD®; and 4) conducting Sustainability Assessment (SA) using SAHB model. This model was tested on Murabba Palace (MP), KSA and Grey Nuns (GN), Canada.

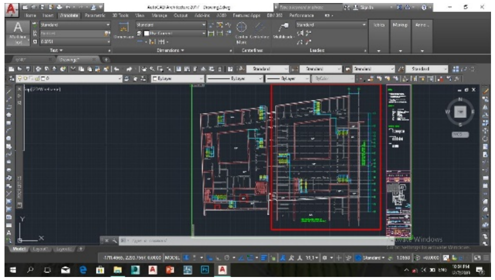
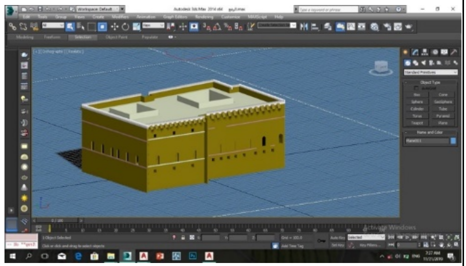
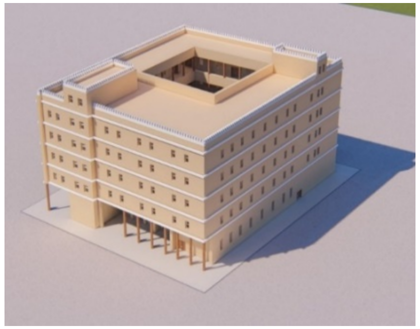
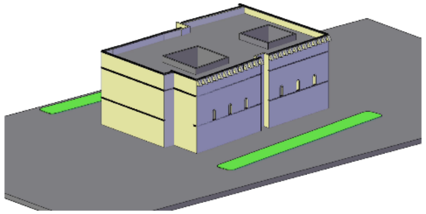
AutoCAD® drawing	Revit® drawing	ArchiCAD®	Simulation model
			
Documentation phase	BIM model phase	Testing phase	Validation phase

Figure 3-13: Different phases of study Murabba Palace, KSA

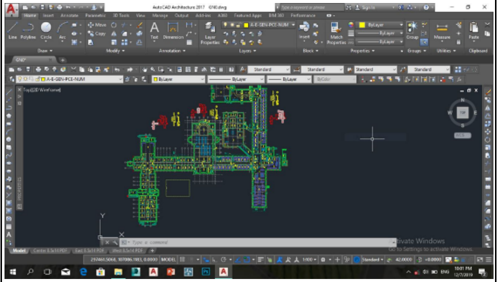
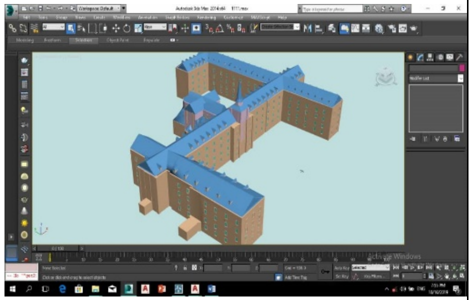
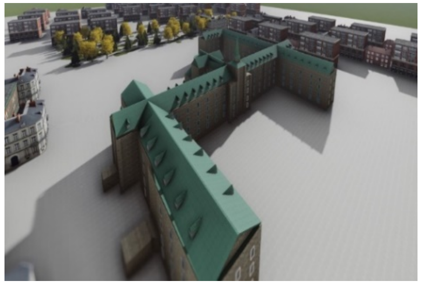
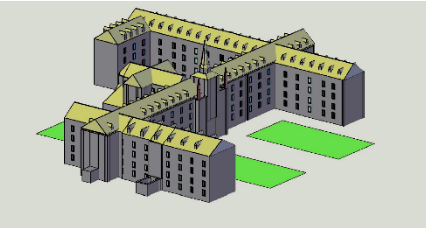
AutoCAD® drawing	Revit® drawing	ArchiCAD®	Simulation model
			
Documentation phase	BIM model phase	Testing phase	Validation phase

Figure 3-14: Different phases of study Grey Nuns Building, Canada

3.7 Total Score Determination and Sustainability Ranking

The final total score is the summation of the results of all factors, from (1) to (n) factors, as shown in Equation 3.23. The total sustainability assessment for heritage buildings (SAHB) is the ratio between the total score and the maximum allowable score that assigns the same weights, as shown in Equation 3.24. The advantage of this formula is to get relative sustainability based on each country's local settings. Furthermore, the building is ranked according to its total sustainability and according to the developed scale.

$$SC\ \ total = \sum_{k=1}^{n} R\ c_k \tag{3.23}$$

Where:

$SC\ \ total$ = the total score

n = the total number of the factor

$$SAHB\ = \frac{SC\ total}{Max\ available\ score} \times 100 \tag{3.24}$$

Where:

$SAHB$ = sustainability assessment for Heritage Buildings

3.8 Data Validation and Verification

3.8.1 Data reliability

Statistical analysis and data collection require that the results be both representative of the targeted population and informative about the subject. In essence, the degree of representativeness of the data is referred to as data reliability. Examining data reliability is essential to make sure that data is authentic for further computational or analytical use. In this work, two data reliability evaluation frameworks were employed. In particular, the coefficient of variance (Chandratilake and Dias, 2013) and Cronbach's alpha (Cronbach, 1951; Cronbach,

2004) were leveraged. The coefficient of variance is computed using Equation 3.25. The coefficient of variance provides excellent insights into the reliability of the data. Lee Cronbach in 1951 developed the Cronbach's alpha, which proved to be efficient in measuring the degree of reliability of data. The Cronbach's alpha ranges from 0 to 1, with negative values indicating a negative correlation between the examined data (Vaske et al., 2017). Among many other equations, Equation 3.16 is the most prevalent to calculate the Cronbach's alpha. A 0.7 alpha value has been agreed to demonstrate adequate data reliability (Bhatnagar et al., 2014; Ver Hoef et al., 2004; Vaske et al., 2017).

There are different ways to calculate Cronbach's alpha, for example, the ANOVA method. First, the *Anova: Two Factor without Replication* tool in Excel® has been used on the raw data. Then, the following formula was applied to get the Cronbach's alpha (Zaiontz, 2015):

$$\propto = 1 - \frac{MS_E}{MS_R} \qquad 3.25$$

Where:

MS_E = Mean Squares Error

MS_R =Mean Squares Rows

Given that some commercially available software like Minitab® has built-in functions to calculate the Cronbach's alpha, this software was used as a second-stage validation process of the collected data.

3.8.2 Sensitivity analysis

Sensitivity analysis is a measure of how robust the developed model is. In essence, sensitivity analysis tests the model under varying weights and observes the impact on the overall condition of the infrastructure. Thus, in a sense, it helps in understanding the degree of significance of the weights and factors.

For the sensitivity analysis, nine factors were considered, namely, Site and Ecology, Material Waste Reduction, Transportation, Energy, Water Use, Heritage Value, Structural Condition, IEQ, and Building Management, for the two case studies - Murabba Palace, Saudi Arabia, and Grey Nuns Building, Canada. For each factor, its weight was increased by 50% and the effect on the overall performance of the model was studied. The sensitivity analysis was performed by increasing one of the factor's weights by 50% and reducing the weights of the other factors by 50% in order to ensure a total weight of 1, as shown in Equations 3.26 and 3.27.

$$W_{i(new)} = W_{i(old)} + (W_{i(old)} * 0.50) \tag{3.26}$$

$$W_{j(new)} = W_{j(old)} - [(W_{i(new)} + \sum W_{j(old)}) - 1] \tag{3.27}$$

3.8.3 Model validation

Weighted sum is calculated to evaluate the sustainability assessment index for HBs. For validation, multi-criteria decision-making methods, *Fuzzy TOPSIS*, Simple Additive Weight *SAW*, Weighted Sum Model *WSM*, Weighted Product Model *WPM,* and *OCRA,* were applied to evaluate sustainability of heritage buildings.

Simple Additive Weight (*SAW)* is the simplest and most popular MCDM method (MohammadSadegh et al., 2014; Salehi & Izadikhah, 2014). Its simplicity favors its use as a benchmark to evaluate other MCDM methods. Its formula is shown in Equation 3.28 (Alireza et al., 2018).

$$S_i = \sum_{j-1}^{n} w_j r_{ij} \tag{3.28}$$

Where:

S_i: = Sustainability index.

w_j = total local weight for each factor.

r_{ij} = total global weight for each factor

Weighted Sum Model *(WSM)* assigns, for each alternative, a weight calculated using Equation 3.29 (Budiharjo et al., 2017). Thus, in the case of minimization, the more preferable alternatives would be the ones with higher weights and vice versa.

$$P_i = \sum_{j-1}^{n} f_{ij} \times w_j \qquad 3.29$$

Where:

P_i = represents the performance of each alternative.

f_{ij} = represents a measure of performance in the normalized matrix.

w_j = represents the weight of each factor.

The Weighted Product Model *(WPM)* is an accessible multi-criteria decision analysis (MCDA) or Multi-Criteria Decision Making (MCDM) method. Despite its similarity to the WSM method, it applies multiplication instead of addition, as shown in Equation 3.30 (Mingxi et al., 2010).

$$S\ (p, q_1, \ldots, q_m) = p + \sum_{j=1}^{m} w_j\ \sqrt{q_j} \qquad 3.30$$

Where:

S = Sustainability index

P = Total achieved score for all factors

q_j = The total score for all factors.

Operational Competitiveness Rating Analysis (OCRA) is one of the less common MCDM techniques. It relies on independently evaluating both the relative cost and benefit of alternatives, both of which provide decision-makers with a holistic evaluation. The formula used is shown in Equation 3.31 (Danuta et al., 2013)

$$Y = \frac{w_g}{\sum w_l} \times 100 \qquad 3.31$$

Where:

Y = Total index.

w_g = Global weight of factors.

w_l = Local weight of factors

3.9 The Sustainability Based Current Condition Model for HBs

The sustainability-based current condition model for heritage buildings is demonstrated in Figure 3.2 below. It is essentially comprised of three main modules. The first module is the input module, where the documentation of the heritage buildings is compiled and transformed into AutoCAD® and ArchiCAD® models for both case studies Murabba Palace (MP), KSA and Grey Nuns (GN), Canada. The next module is the sustainability assessment module, which evaluates the model in terms of a calculation of the sustainability index. In this phase, the sustainability model allows experts to demonstrate ideal sustainability options that are needed to redesign the assessment of their buildings while in its current condition. As a result, through-put of the model for sustainability assessment of HBs indicated the different weights for all attributes based on the optimal set of alternatives.

This model provides three main modules:

1) For every sustainability option, a corresponding score that relies on the fulfillment of the constraints of sustainability performance,

2) The conditions associated with every sustainability option, and

3) The scope of sustainability index constraint.

The last module exploits the model's results to provide a list of various sustainability options that are expected to improve the building's sustainability while in its current condition (see Figure 3.15).

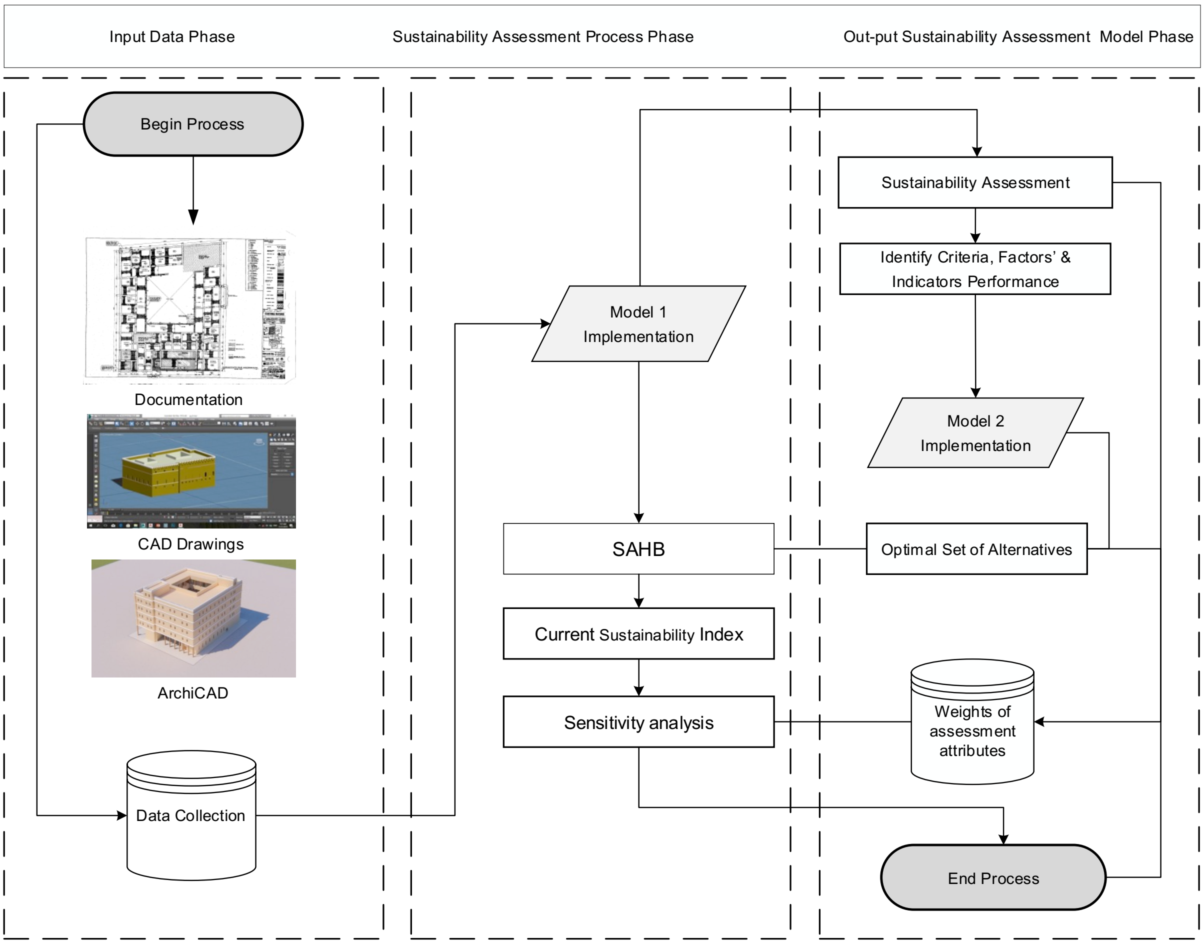


Figure 3-15: Sustainability assessment framework for (HBs)

3.10 Building Energy Analysis

From Figure 3.16, the described building energy analysis consist of three main stages, each modeled as a system of input, process, and output. Six phases that affect heritage buildings are considered in the project LCC of energy and two case studies are evaluated - Murabba Palace (MP), Saudi Arabia, and Grey Nuns Building (GN), Canada. The steps for model development are summarized as follows:

1) ***Identification*** of the criteria, factors, and indicators: The main objective is to identify quantitative and qualitative factors and indicators. Literature review and answers from the questionnaires were compiled and processed. Different percentages for each life cycle phase were identified, which were then applied to real electricity and gas consumption data as well as to the actual energy consumption cost data.
2) ***Survey analysis:*** Based on the building energy analysis, the goal of this step is to evaluate the life cycle phases with respect to their significance and rankings. For this, answers from the questionnaires were used to validate the proposed model of the LCC of energy for HBs. Also, for model validation, sensitivity analysis was used to confirm the impact on the energy consumption, gas consumption and cost of heritage buildings. Then, calculation of Energy (Electricity + Gas) Consumption: Here, energy consumption of heritage buildings in both case studies was calculated. A model for each building was built and energy consumption was calculated and cross-validated with the actual energy consumption data, obtained from the Royal Commission of Riyadh and Concordia University's Facility Management Department.
3) ***Sensitivity analysis*** measures the robustness of a model by observing the impact of varied weights of an attribute on the model output. Robustness of a model is evaluated based on the ability of the model to withstand significant changes in its input parameters. Since each sensitivity analysis simulation involves a specific change in the weight of an attribute, sensitivity analysis can serve to identify relevant attributes and weights for a given model. In this study, attributes include the planning phase, manufacturing phase, transportation phase, construction phase, operation phase, and maintenance phase. The two case studies that are analyzed are Murabba Palace, Saudi Arabia, and Grey Nuns Building, Canada. The weight of each attribute, that is one of the six project life cycle phases, was increased by +15% and the performance of the life

cycle assessment model was evaluated. For example, the weight of an attribute w_2 is increased by Δ. Thus, its resulting weight ${w_2}'$ will be $w_2 + \Delta$. For each weight change, the weights of other attributes can be calculated from Equations 3.32 and 3.33 and the total weight of all attributed must equal 100%. Note that the number of simulations for each attribute must be equal.

$$W_{i(new)} = W_{i(old)} + (W_{i(old)} * 0.15) \qquad 3.32$$

$$w'_j = \frac{1 - w'_c}{1 - w_c} * w_j \qquad 3.33$$

Where,

w_c, w'_c represent the original and modified weights of the main attribute, respectively.

w_j, w'_j represent the original and modified weights of other attributes, respectively.

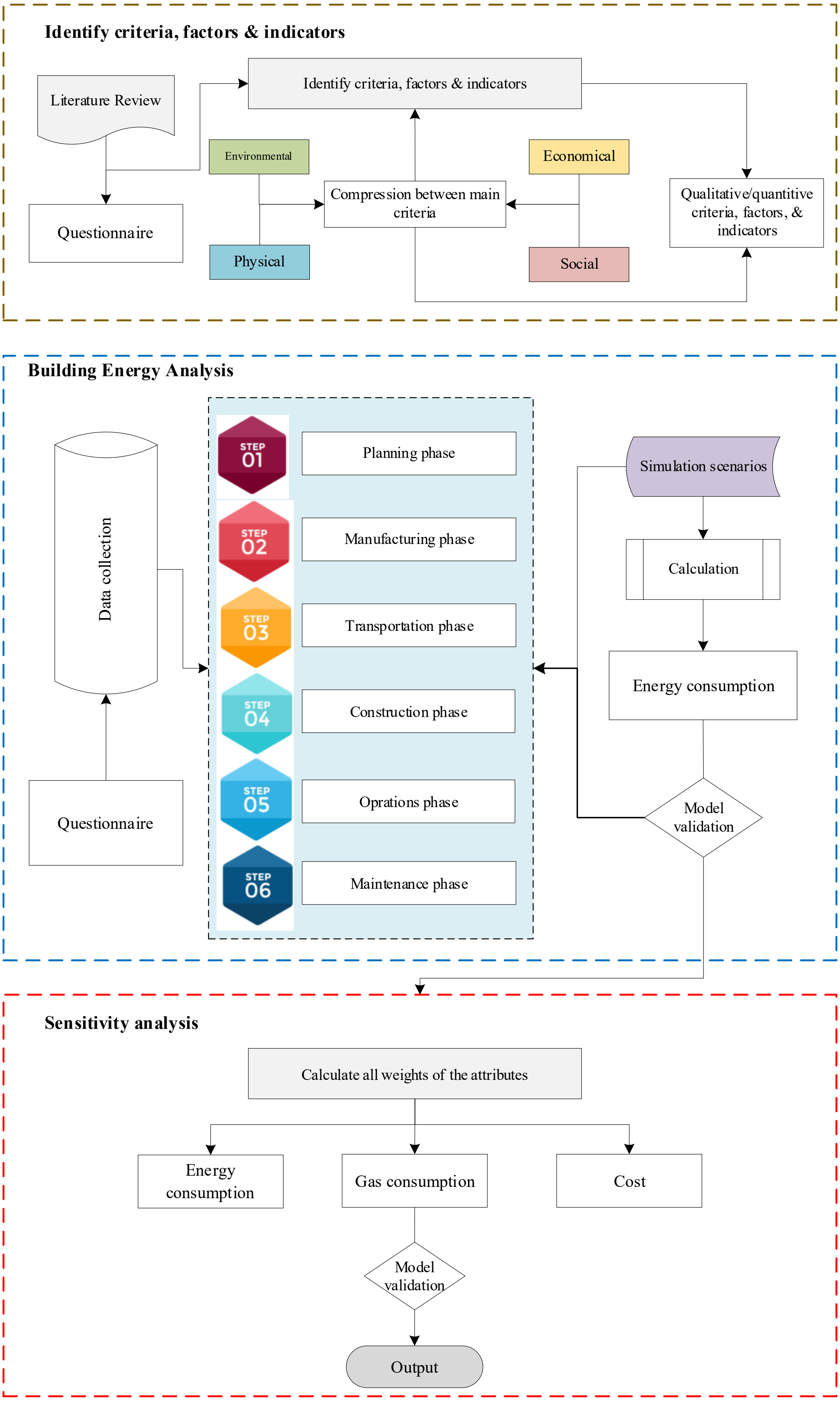


Figure 3-16: Framework of building energy analysis for HBs

3.11 Overview of an automated tool (SAHB)

The performance level of a rating system relies on: (a) how suitable or applicable the process of developing the SAHB is and what impact the model has on sustainable development; (b) the climatic condition of the studied country and its influence on the building sector; and (c) the design of energy-efficient buildings that reduce greenhouse gas emissions and minimize cost, among other benefits. Every city or country has its own associated climatic condition (microclimate) (Al-Homoud, 2009). Classification of climatic zones can be done based on certain factors (Yang et al., 2008). To improve the accuracy of the SAHB model, meteorological data of Riyadh and Montreal cities should be analyzed. The reason for suggesting the investigation of the weather data of the capital of Saudi Arabia (Riyadh) is because this region will represent the hottest climatic region and as a result, it would require and emit a variable amount of energy and greenhouse gas, respectively. The applicability of SAHB can be verified for regions with varying climates and that have similar economic and sustainable situations. For this, some available meteorological data and building modeling tools were retrieved for the two cities (Ryan and Campbell, 2012).

BREEAM led to the development of a one-word ranking accreditation statement for sustainability assessments. Other rating systems such as LEED, CASBEE and ITACA follow the same path. For example, the rating score is calculated on a 100% basis in BREEAM and LEED, leading to a one-word certification result. ITACA and CASBEE employ a linear rating system from -2 to +5 and 0 to 3, respectively.

SAHB also applies a rating system in which the final score is calculated out of 100 like other rating systems such as BREEAM and LEED. The rating scale comprises of six possible levels; that is, *Unsatisfied* – < 49%, *Pass* – 50-59%, *Satisfied* – 60-69%, *Bronze* – 70-79%, *Silver* – 80-89%, and *Gold* - >90%. Gold-certified buildings fulfill the requirements of most of the factors in SAHB and employ novel sustainable ideas.

Figure 3.17 shows the different levels for the proposed scale of the sustainability model for heritage buildings.

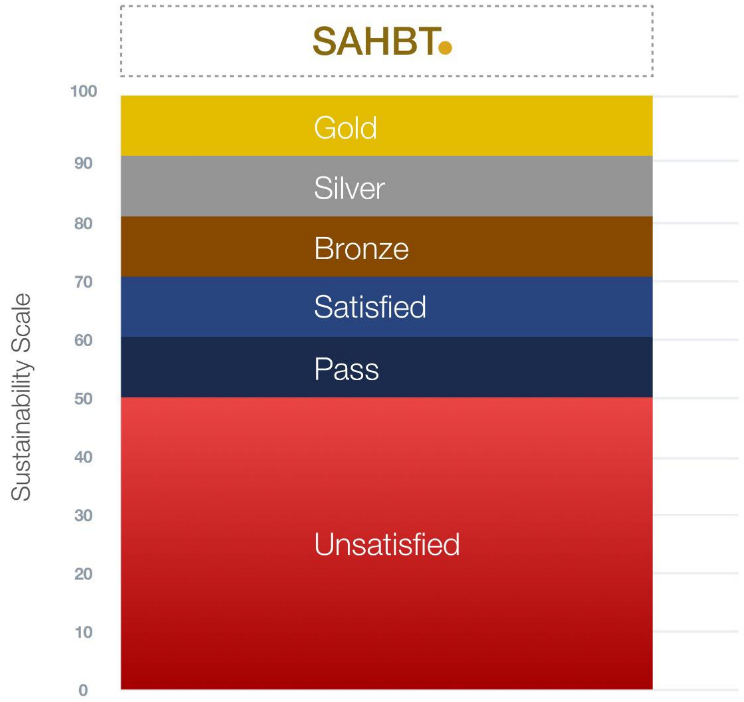


Figure 3-17: Scale for sustainability assessment for heritage buildings model

With the detailed model and final assessment scale described above, the last step is to compile the different stages into an automated system that provides the decision-maker with an easy-to-use and intuitive interface. The design of an automated system is a crucial step that would affect the adaptability of the proposed model in both academia and industry. To this end, web-based automated software is built and designed, as depicted in Figure 3.18. Particularly, the software is composed of two main modules:

Front end (GlassoryTech, 2017) is the main webpage a user would use and its goal is allow the user to input the weights of the different factor, send it to the SAHBT engine (backend), and display the results and overall sustainability rating to a user. It is built based on the following languages:

- HTML (Hypertext Markup Language): is the document standard of the World Wide Web for creating web pages and applications.
- CSS: A stylesheet language that is used for presenting and formatting content on the webpages, including font, size, color, spacing, border and location of HTML information.
- JavaScript: client-side scripting language used to make web pages interactive. It is also responsible for exchanging data with the backend.

Backend: The backend is where the equations, thresholds and scales are embedded. The main objective of the backend is to receive user input from the frontend, process it, and output the scores for the different criteria, the total SAHB score and the overall sustainability level of the building. The technology used in the backend is Ruby on Rails (Vyas, 2019) . It is a framework that is used on top of ruby language to build websites and apps by abstracting and simplifying most of the repetitive tasks. The advantages of this framework are as following:

- Provides faster programming, as it is dynamic
- Uses object-oriented scripting
- Is a full-stack structure that holds both front and back end

The actual implementation and workflow of this automated tool will be described in more detail in Section 7.6, with results for both case studies (Murabba Palace and Grey Nuns Building).

Server: the application is deployed and hosted in Heroku cloud platform. It has features for developer to build, run, and scale applications. It is owned by Salesforce (Join Extra Crunch, 2010).

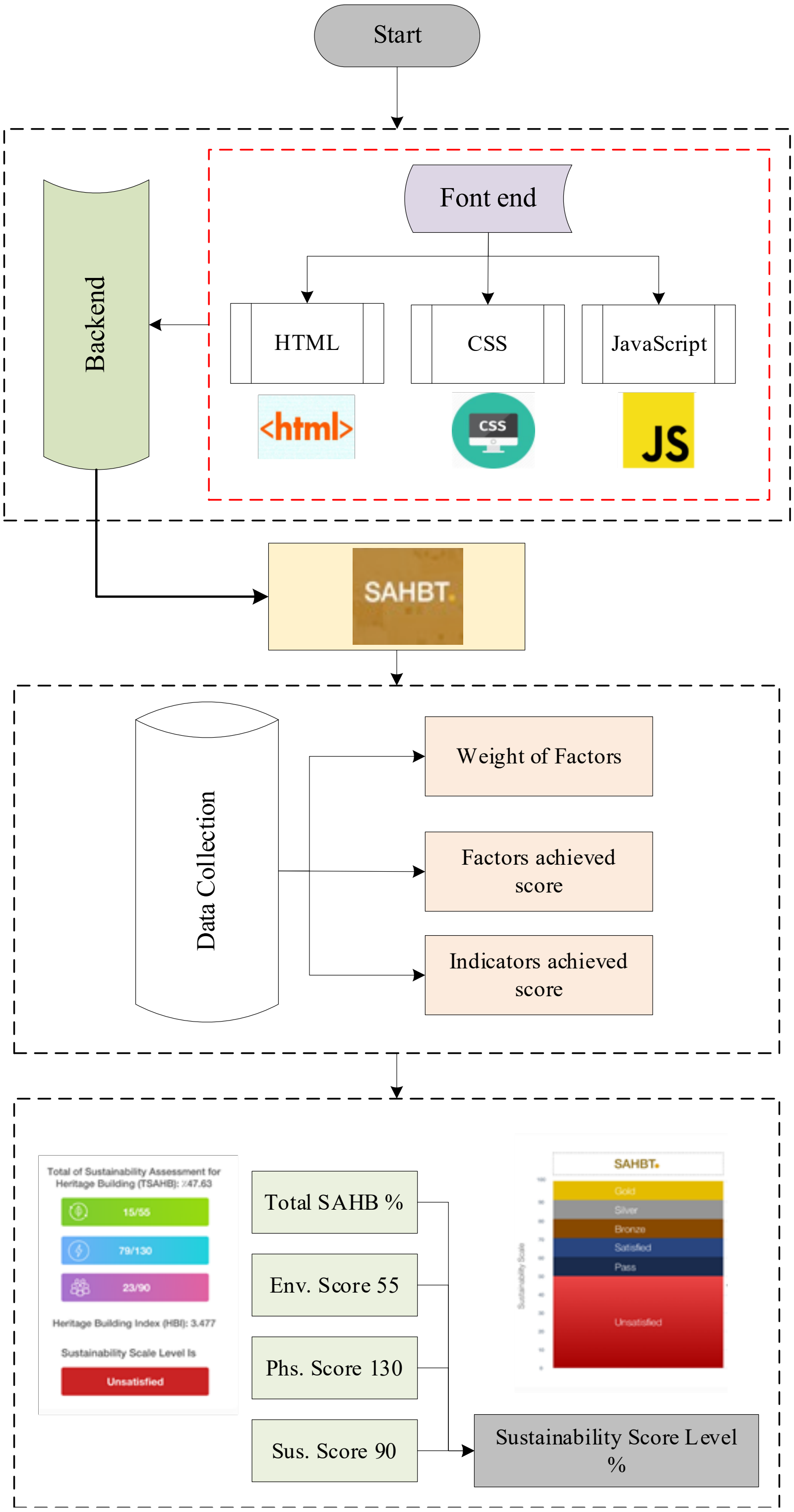


Figure 3-18: An automated tool flowchart (SAHB)

3.12 Summary

The chapter outlined the research methodology used to produce this work. The first part of the chapter of research methodology is exhaustively reviewed literature in terms of sustainability rating systems and their selected criteria and factors. The different environmental, physical and sustainable, indicators were identified based on the missing links of the reviewed tools and frameworks. These factors were then compiled in the sustainability assessment model, which details how the different weights are assigned for the predefined assessment attributes and how the final SAHB score was calculated. The methodology involved in developing the sustainability current-condition model was outlined, illustrating the different phases of model development in terms of model formulation (defining objective, variables, and constraints) and validation. The last part of this chapter detailed the process involved in developing a combined sustainability assessment and rehabilitation system in terms of steps to evaluate a building's sustainability and provide suggested options that would improve the building's sustainability.

CHAPTER 4 : DATA COLLECTION AND CASE STUDY

4.1 Chapter overview

The previous chapter illustrated the research methodology in detail, including sustainable assessment of heritage buildings' overall perspective model. Each of these models requires a different type of data. Both models require the identification of the heritage buildings assessment attributes, such as the criteria, factors, and indicators utilized to evaluate the current heritage buildings sustainable, and rehabilitation methods for heritage buildings index must be utilized to update heritage buildings' sustainability. The weight of each criterion, factors, and the indicators that must be estimated to accurately represent the importance of each of the assessment attribute according to the building type also need to be identified.

This Chapter covers the process involved in the selection of criteria, factors and indicators. This was done through a review of literature and expert-based responses to a questionnaire. This section expounds on each criterion and its corresponding factors, indicators and sub-indicators. This chapter also presents the structure of the questionnaire and the method for calculating weights of factors based on the questionnaire responses. This chapter ends with a description of the methodology used to develop a sustainability scale for heritage buildings.

4.2 Research Survey

4.2.1 Observations and Interviews

Observations were conducted for documentation purposes on the sustainability of heritage buildings. Interviews with experts were carried out for two primary purposes: 1) to help identify the research problems and objectives; and 2) to collect information on the various aspects leveraged to assess the building's sustainability. The conducted interviews fall into two categories, structured and non-structured, based on the purpose they serve. Structured interviews helped identify, through a set of questions, the significance of different sustainability assessment attributes. Such interviews were held with project managers, civil engineers, architects and heritage specialists. On the other hand, the non-structured interviews helped identify the research problems and objectives through meeting with subject-matter experts (project managers, building sustainability experts and heritage specialists) at the early stages of the research.

4.2.2 Questionnaire

The questionnaire was not as straight forward as the interviews. Specifically, it had to be repeatedly adjusted to ensure the feasibility of filling it out within the allocated time frame (15-20 minutes). The wording of the questions had to be changed to avoid confusion and ensure clarity for the targeted audience. The questionnaire was sent to 150 Saudi and Canadian experts who specialize in the fields of heritage buildings, sustainability and construction. Out of the 150 experts, 40 filled the questionnaire. The rationale behind choosing experts from Canada and Saudi Arabia as the candidates for the questionnaire is to allow diversification in terms of the weights of the attributes. Both countries differ with respect to heritage culture and values, energy and water resources, climate and environmental conditions. This variation would result in different weights for the selected assessment attributes. Thus, these weights would provide a context for the sustainability assessment process, as they would account for regional variations.

It would be rather challenging to estimate the exact number of experts in the field of sustainability in both Canada and Saudi Arabia since this number is large. Thus, for the results of the questionnaire to be informative, the chosen sample size of the experts should be representative. The sample size was chosen based on two crucial factors - confidence level and error margin. These two factors will determine how representative the chosen sample of the whole population of experts is. In essence, the confidence level represents the percentage of the results obtained from the questionnaire that could be reproduced from a different sample of the sample population. For instance, a 90% confidence level means that the obtained results from the questionnaire would be the same 90% of the time when tested on a different sample from the same population. The margin of error represents how far the obtained results are from true results. The greater the error, the less the credibility obtained. Results are presented in Table 4.1.

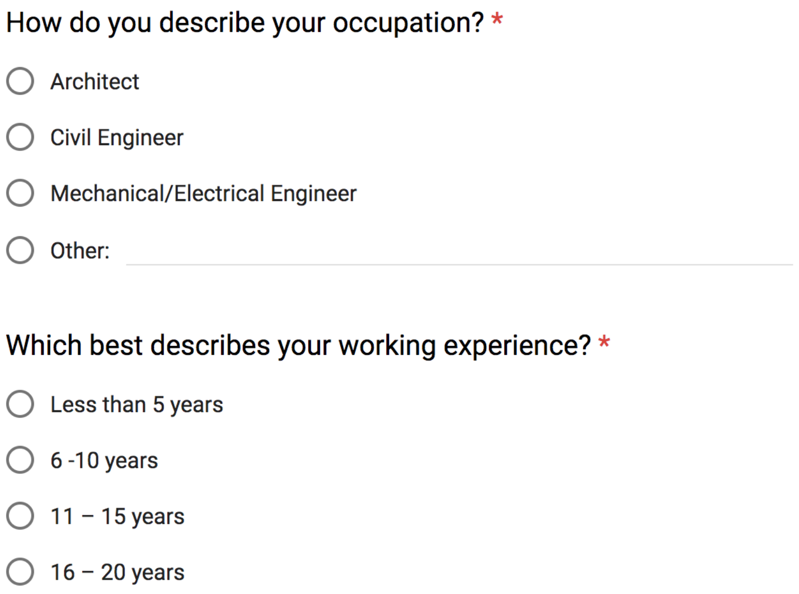
Table 4-1: Frequency of degree of importance for each factor and indicator

Serial	Factors and indicators	Degree of Importance				
		Occurrences (Very High)	Occurrences (High)	Occurrences (Medium)	Occurrences (Low)	Occurrences (Very Low)
F1	Site & Ecology	16	17	7	0	0
S1F1	Site Selection	7	20	12	1	0
S2F1	Site Management	10	18	8	4	0
S3F1	Reduction of Heat Island Effect	10	13	15	2	0
S4F1	Site Emissions	12	15	12	3	0
F2	Material & Waste Reduction	7	12	20	1	0
S1F2	Sustainable Purchasing Practice	10	16	12	2	0
S2F2	Efficient Use of Materials	18	13	7	3	0
S3F2	Solid Waste Management Practice	14	14	10	2	0
F3	Transportation	11	15	11	3	0
S1F3	Public Transport Accessibility & Community Accessibility	16	17	15	1	0
S2F3	Provision of Maximum Car Parking Capacity	14	16	16	1	0
S3F3	Provision of Low-Emitting & Fuel-Efficient Vehicles	11	12	15	1	0
F4	Energy	10	17	13	0	0
S1F4	Energy Performance	18	13	7	3	0
S2F4	Provision of Energy Management	14	17	9	1	0
S3F4	Energy Efficient Systems	8	12	18	3	0
S4F4	Energy Efficient Equipment	14	17	5	4	0
F5	Water Use	11	14	12	3	0
S1F5	Water Conservation	14	10	10	6	0
S2F5	Water Management	11	19	9	1	0
F6	Heritage Value	14	14	7	5	0
S1F6	Building Age	16	10	13	1	0
S2F6	Building Function	11	16	10	3	0
S3F6	Building Revenues	17	12	8	3	0
F7	Structural Condition	11	19	9	1	0
S1F7	Building Material	17	10	12	1	0
S2F7	Maintenance Plan	20	9	8	3	0
S3F7	Safety	10	13	15	2	0
F8	Indoor Environmental Quality	17	14	9	0	0
S1F7	Visual Comfort	11	16	10	3	0
S2F7	Indoor Air Quality	14	15	7	4	0
S3F7	Thermal comfort	18	12	8	3	0

S4F7	Acoustic Performance	14	17	9	1	0
S5F7	Hygiene	13	13	10	4	0
S6F7	Building Amenities	17	10	12	1	0
F9	Building Management	13	15	11	1	0
S1F9	Maintenance Management	19	12	8	1	0
S2F9	Security Measures & Intruder Alarm System	13	18	10	2	0
S3F9	Green Lease	16	12	16	3	0
S4F9	Risk Management	20	10	7	3	0
S5F9	Innovations	10	12	15	3	0

The questionnaire is divided into two main sections: 1) the respondent's self-information; and 2) the degree of importance of factors and indicators. In the respondent's self-information section, the respondents were required to provide their overall background in terms of their profession and years of experience in the given field. The years of experience is assigned a weight value in order to judge the authenticity of the responses for calculation purposes. The section on the degree of importance of factors and indicators highlights the weights of the factors and indicators that will significantly influence the assessment of sustainability of a building. Depending on where the building is located, it is expected that the weights will be different.

Through a period of one year, two hundred experts in the fields of sustainability, building and construction were contacted by emails and interviews to fill out the questionnaire. The respondents include architects, civil engineers, heritage management professionals and sustainability experts in both Saudi Arabia and Canada (Figure 4.2).



How do you describe your occupation? *

○ Architect

○ Civil Engineer

○ Mechanical/Electrical Engineer

○ Other: ______

Which best describes your working experience? *

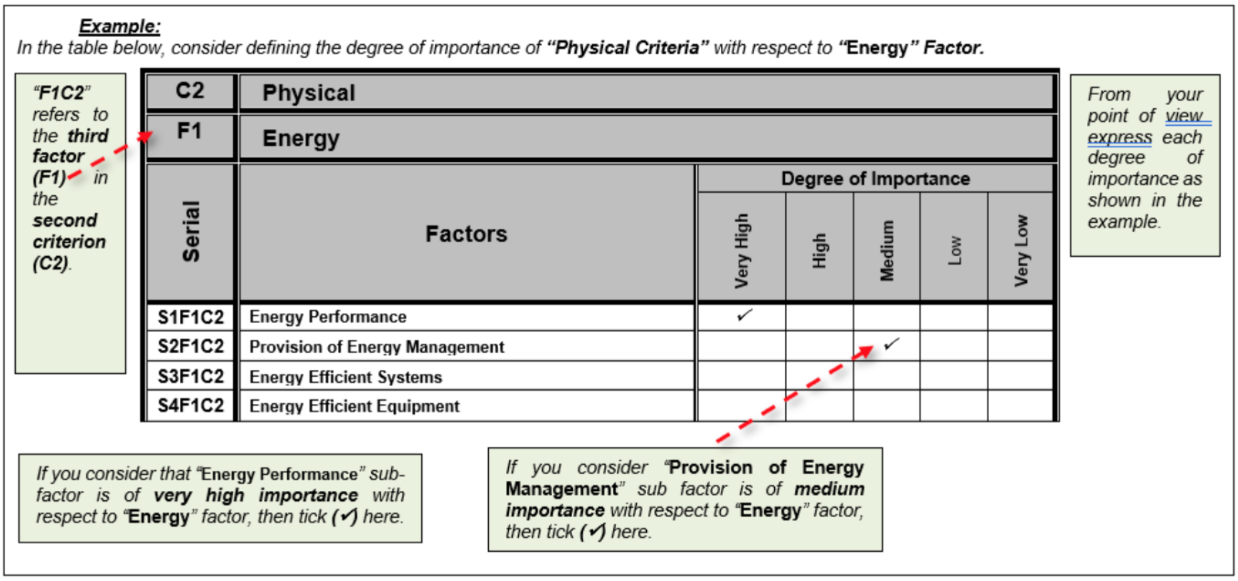
○ Less than 5 years

○ 6 -10 years

○ 11 – 15 years

○ 16 – 20 years

Figure 4-1: Respondent self-information



Example:

*In the table below, consider defining the degree of importance of **"Physical Criteria"** with respect to **"Energy" Factor.***

*"**F1C2**" refers to the **third factor** (**F1**) in the **second criterion** (**C2**).*

C2	**Physical**					
F1	**Energy**					
Serial	**Factors**	**Degree of Importance**				
		Very High	**High**	**Medium**	Low	**Very Low**
S1F1C2	Energy Performance	✓				
S2F1C2	Provision of Energy Management			✓		
S3F1C2	Energy Efficient Systems					
S4F1C2	Energy Efficient Equipment					

From your point of view express each degree of importance as shown in the example.

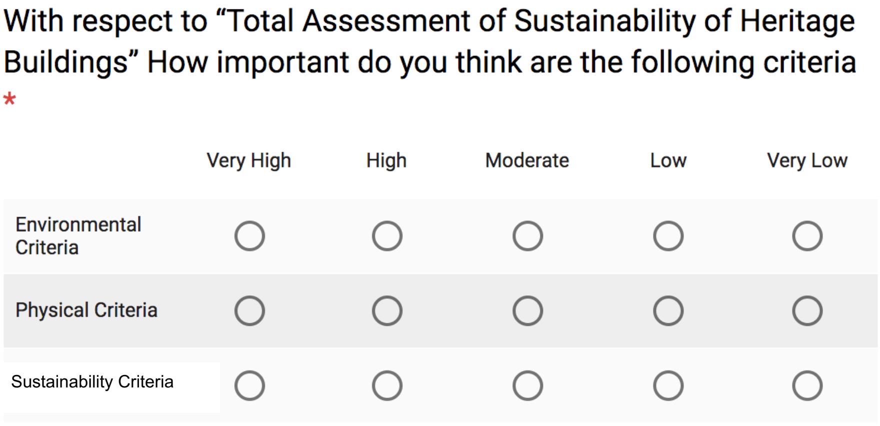
*If you consider that "**Energy Performance**" sub-factor is of **very high importance** with respect to "**Energy**" factor, then tick (✓) here.*

*If you consider "**Provision of Energy Management**" sub factor is of **medium importance** with respect to "**Energy**" factor, then tick (✓) here.*

Figure 4-2: Expressing the linguistic scale in the questionnaire

4.3 Weight Determination

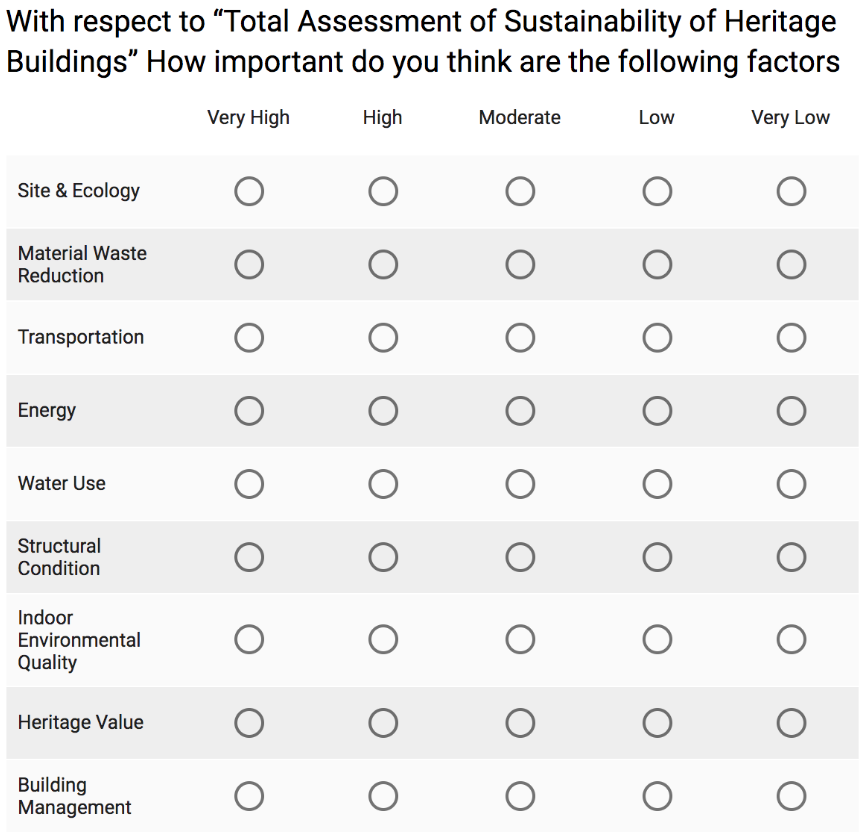
The first part of the questionnaire is shown in Figure 4.1, in which the respondent is required to provide his or her overall background in terms of profession and years of experience in the given field. This helps in assessing the reliability of the answers. In the second part of the questionnaire, shown in Figure 4.2, the respondents are requested to rank the degree of importance of factors and indicators using a range of three numbers to express the five-level scale (very high, high, medium, low, and very low) as a triangular fuzzy number. This part of the questionnaire includes an illustration of an example. Figure 4.3 shows how the respondents were requested to assign a level of importance to each criterion in terms of the assessment of the sustainability of heritage buildings. In the same part of the questionnaire, especially in the second question shown in Figure 4.4, the respondents were requested to assign a level of importance to each criterion, judging from their individual experience. The mean of the responses was then calculated in order to estimate the conversion scale that was later utilized to transform the data from a linguistic scale.



With respect to “Total Assessment of Sustainability of Heritage Buildings” How important do you think are the following criteria
*

	Very High	High	Moderate	Low	Very Low
Environmental Criteria	○	○	○	○	○
Physical Criteria	○	○	○	○	○
Sustainability Criteria	○	○	○	○	○

Figure 4-3: Significance of each criterion



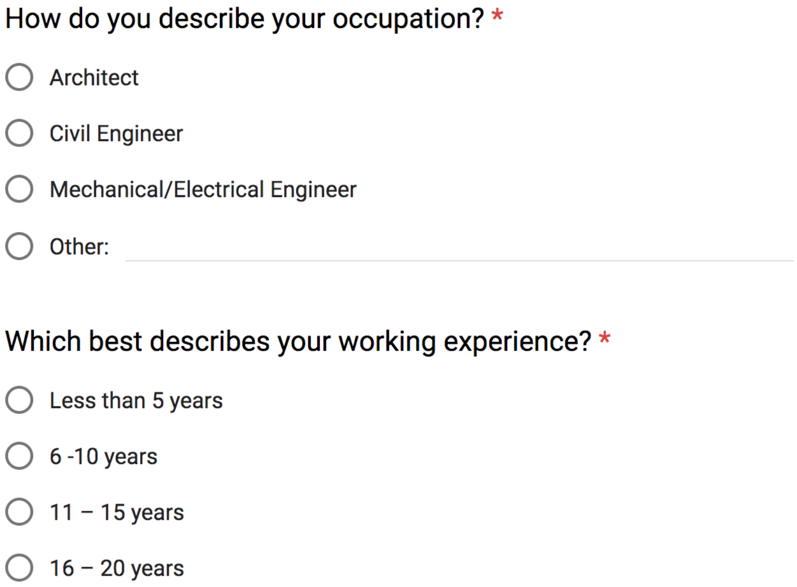
With respect to "Total Assessment of Sustainability of Heritage Buildings" How important do you think are the following factors

	Very High	High	Moderate	Low	Very Low
Site & Ecology	○	○	○	○	○
Material Waste Reduction	○	○	○	○	○
Transportation	○	○	○	○	○
Energy	○	○	○	○	○
Water Use	○	○	○	○	○
Structural Condition	○	○	○	○	○
Indoor Environmental Quality	○	○	○	○	○
Heritage Value	○	○	○	○	○
Building Management	○	○	○	○	○

Figure 4-4: Significance of each factor

4.3.1 Weight Calculation for Factors and Indicators

The first part of the questionnaire is shown below in Figure 4.5, in which the respondent is required to provide his or her overall background in terms of profession and years of experience in the given field. This helps in assessing the reliability of the answers. In the second part of the questionnaire, shown in Figure 4.6, the respondents are requested to rank the degree of importance of factors and indicators using a range of three numbers to express the five-level scale (very high, high, medium, low, and very low) as a triangular fuzzy number. This part of the questionnaire includes an illustration of an example. Figure 4.7 shows how the respondents were requested to assign a level of importance to each criterion in terms of the assessment of the sustainability of heritage buildings. In the same part of the questionnaire, especially in the second question shown in Figure 4.8, the respondents were requested to assign a level of importance to each criterion, judging from their individual experience. The mean of the responses was then calculated in order to estimate the conversion scale that was later utilized to transform the data from a linguistic scale.



How do you describe your occupation? *

○ Architect

○ Civil Engineer

○ Mechanical/Electrical Engineer

○ Other:

Which best describes your working experience? *

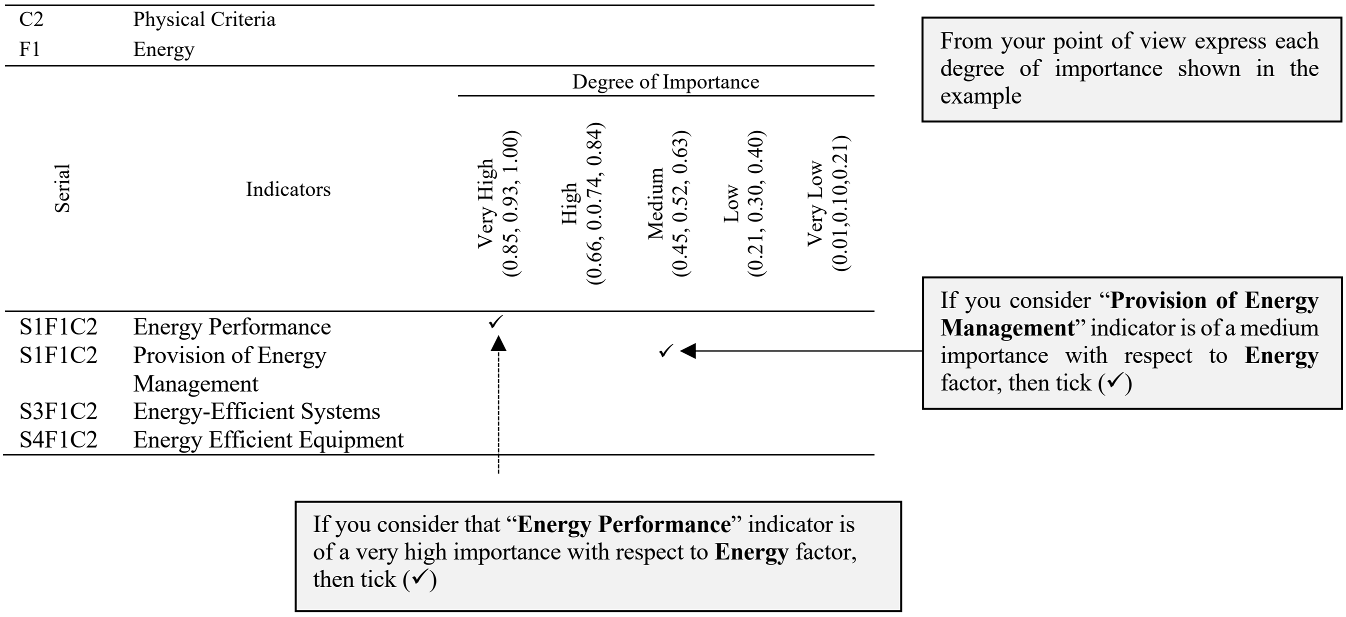
○ Less than 5 years

○ 6 -10 years

○ 11 – 15 years

○ 16 – 20 years

Figure 4-5: Respondent self-information



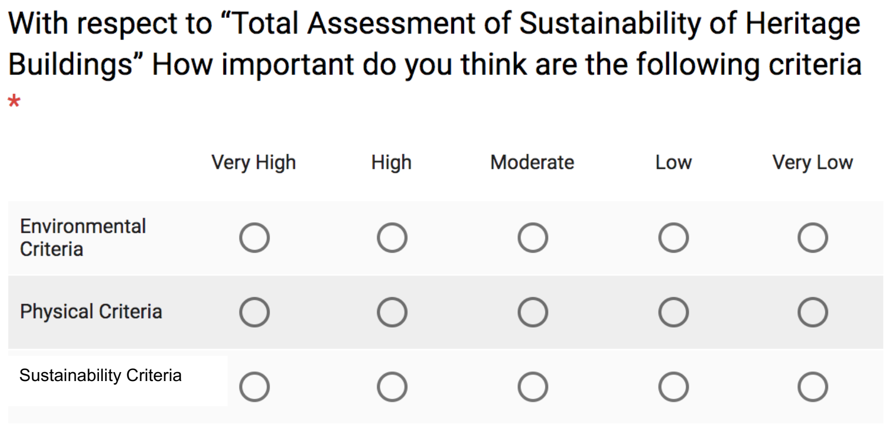
C2	Physical Criteria					
F1	Energy					
		Degree of Importance				
Serial	Indicators	Very High (0.85, 0.93, 1.00)	High (0.66, 0.0.74, 0.84)	Medium (0.45, 0.52, 0.63)	Low (0.21, 0.30, 0.40)	Very Low (0.01,0.10,0.21)
S1F1C2	Energy Performance	✓				
S1F1C2	Provision of Energy Management			✓		
S3F1C2	Energy-Efficient Systems					
S4F1C2	Energy Efficient Equipment					

From your point of view express each degree of importance shown in the example

If you consider "**Provision of Energy Management**" indicator is of a medium importance with respect to **Energy** factor, then tick (✓)

If you consider that "**Energy Performance**" indicator is of a very high importance with respect to **Energy** factor, then tick (✓)

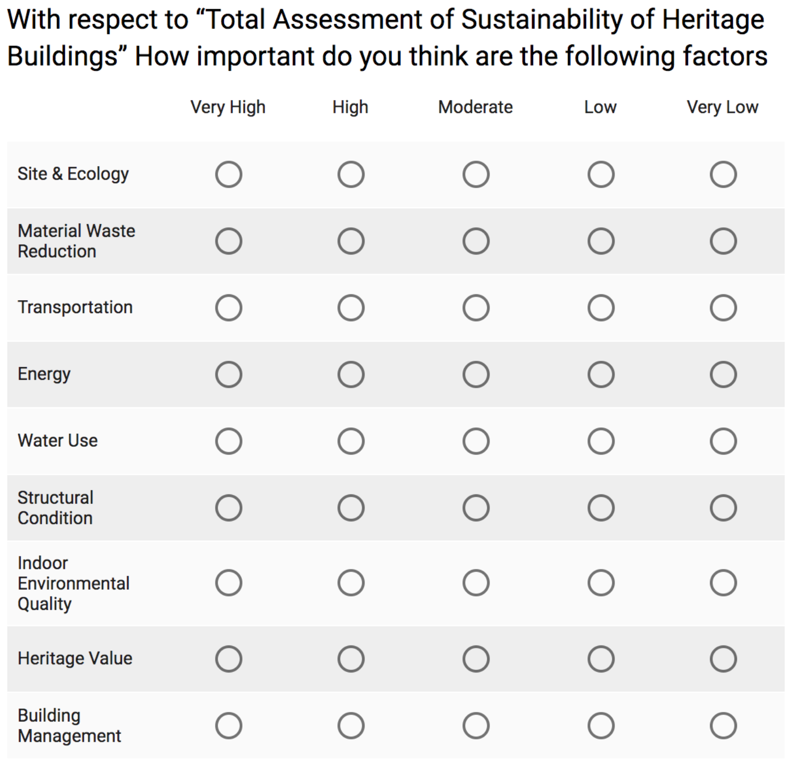
Figure 4-6: Assigning Triangular Fuzzy Numbers to the Linguistic Scale



With respect to “Total Assessment of Sustainability of Heritage Buildings” How important do you think are the following criteria
*

	Very High	High	Moderate	Low	Very Low
Environmental Criteria	○	○	○	○	○
Physical Criteria	○	○	○	○	○
Sustainability Criteria	○	○	○	○	○

Figure 4-7: Significance of each Criteria



With respect to “Total Assessment of Sustainability of Heritage Buildings” How important do you think are the following factors

	Very High	High	Moderate	Low	Very Low
Site & Ecology	○	○	○	○	○
Material Waste Reduction	○	○	○	○	○
Transportation	○	○	○	○	○
Energy	○	○	○	○	○
Water Use	○	○	○	○	○
Structural Condition	○	○	○	○	○
Indoor Environmental Quality	○	○	○	○	○
Heritage Value	○	○	○	○	○
Building Management	○	○	○	○	○

Figure 4-8: Significance of each factor

The weight of each factor and indicator was evaluated by using a fuzzy technique that considers multiple attributes in the decision-making process. This technique is called the technique for Order of Preference (OP) by Similarity to Ideal Solution (TOPSIS). Fuzzy TOPSIS determines the best alternative or to rank a set of alternatives, that involve different factors and attributes. This technique has been proven in its ability to deal with the variability associated with human opinion in the weight determination process. It is also able to convert linguistic data to crisp numerical values (Chu & Lin, 2003; Hwang & Yoon,1981; Kaya et al., 2008; Triantaphyllou & Lin, 1996). This research also seeks to introduce another approach other than AHP, which was used in most of the previous studies that dealt with weight determination. AHP has some limitations: 1) the process is unable to deal with all the assessment attributes at the same time and it focuses on only two attributes (Chandratilake & Dias, 2013); 2) the anomalies that may arise from the weight determination process cannot be tracked and rectified; 3) the result of the same problem may differ when using different problem structures; and 4) some ambiguities can be present when defining the conversion scale from linguistic scale (linguistic variables) to numerical scale that expresses the verbal priorities (Chandratilake & Dias, 2013; Ishizaka & Labib, 2009). Furthermore, the input data for this method is dependent on expert responses to a proposed questionnaire to evaluate the weight of each factor and indicator. In the sub-sections that follow, the eight stages that are involved in the determination of the final weight of the factors and indicators using Fuzzy TOPSIS are discussed in detail.

4.3.2 Fuzzy TOPSIS-based Questionnaire

Data were collected through two groups of questionnaires, which were distributed among architects, engineers and sustainability experts in Saudi Arabia and Canada. The two countries were selected due to apparent variations in their regional contexts such as climate, cultural and social considerations, and economic aspects. The significance of this diversity would be manifested in the weights of the selected attributes and the overall sustainability assessment. More countries could have been utilized in this research to develop a universal rating tool, but KSA has been used as a proof of concept. Although the number of responses (40) was not sufficient, it can serve as a guide for the weight of the proposed factors and indicators in Saudi Arabia. Also, bias in responses may impact results. Therefore, a reliability check was crucial to ensure consistency of the collected answers to be used for further implementation and analysis. The coefficient of variance was utilized as one of the methods to ensure data consistency (Chandratilake & Dias, 2013). Lee Cronbach in 1951 developed the Cronbach's alpha, which proved to be efficient in measuring the degree of reliability of data for one-dimensional aspects (Cronbach, 1951, 2004). The Cronbach's alpha ranges from 0 to 1 and a 0.7 alpha value has been agreed to demonstrate adequate data reliability (Bhatnagar et al., 2014; Pison & Van Aelst, 2004; Vaske, Beaman, & Sponarski, 2017).

In the collected data for this work, the value of Cronbach's alpha was over 0.7 in most of the calculations. The coefficient of variance for the collected data ranged from 5% to 47%. These two factors proved the consistency and reliability of the collected data; hence, the utilization of this data was validated for the determination of the weights of the indicators for Saudi Arabia as well as its implementation within the sustainability assessment model. One issue that needs to be addressed, however, is the sample size. The sample size needs to be increased to represent a more informative evaluation and be used in the formal scheme of the assessment mode. As mentioned earlier, the sample size relies on the confidence level, margin of error and degree of variability, as shown in Figure 4.9. Thus, in order to better determine the right sample size, different formula could be used, one of which is Equation 4.1 (Israel, 1992; Rose, Spinks, & Canhoto, 2015).

$$n = \frac{Z^2 pq}{e^2} \qquad (4.1)$$

Where:

n: Required sample size;

Z: z-score dependent on the confidence level;

p: estimated proportion of an attribute that is present in the population;

q: 1-p; and e: margin of error.

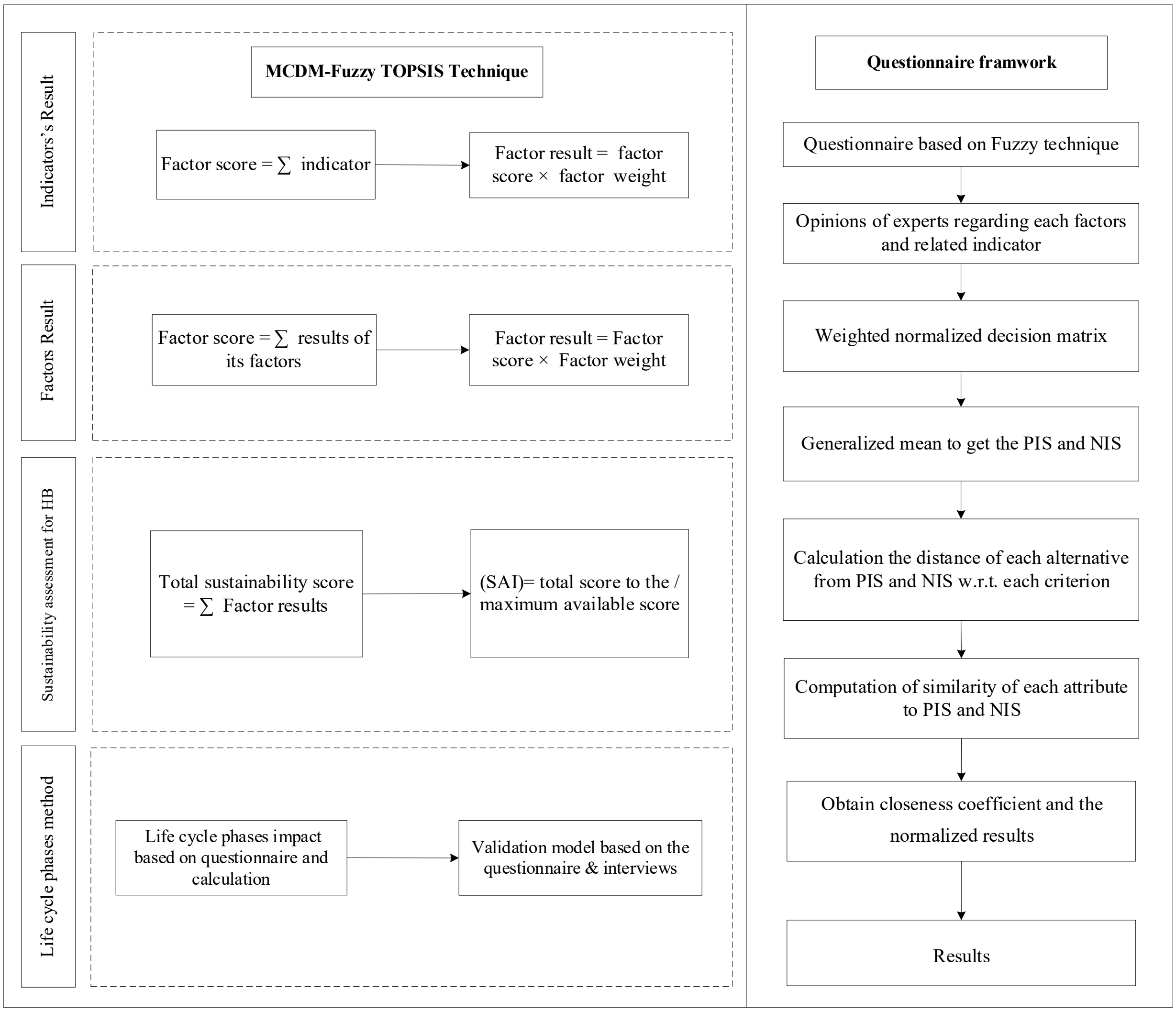


Figure 4-9: Framework of the MCDM model and questionnaire

4.3.3 Expert responses regarding the significance of factors and indicators

In the expert responses, five sets of three numbers were provided to describe five linguistic variables, which are *very low*, *low*, *medium*, *high*, and *very high*. Fuzzification, which generates fuzzy numbers from these variables, could then be applied to generate five “fuzzy triangular numbers”, which are made up of a minimum, center and maximum value. These numbers span from 0 to 1, with (0.01, 0.09, 0.23) for *very low* to (0.82, 0.94, 1.00) for *very high* (see Figure 4.10). 25 out of 40 respondents assigned a numerical value to the worded variables and their answers were averaged and used in the determination of fuzzy numbers (see Figure 4.11). From Figure 4.12, 40% of the respondents were architects, 20% civil engineering and heritage management professionals, and 10% were business development professionals.

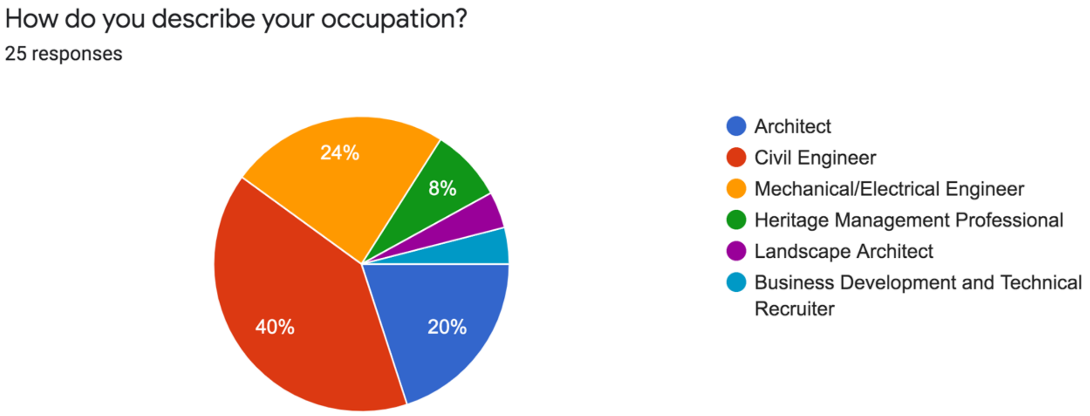


Figure 4-10: Percentage of Respondents' Occupation

Furthermore, Figure 4.11 depicts the results obtained regarding the significance of the specified criteria. The physical criteria scored the highest (80% of the experts rated it as 'very highly important' and 20% as 'highly important'). In addition, the sustainable criteria scored the least (almost 30% of the experts rated it as moderately important).

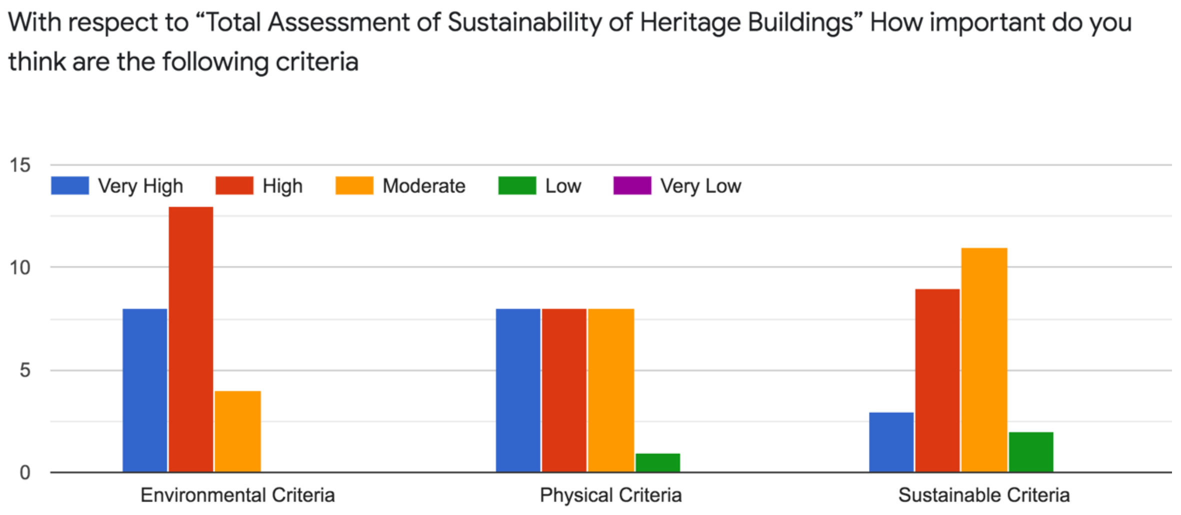


Figure 4-11: Chart for Total Assessment of Sustainably (HB) for each criterion

Similarly, Figure 4.12 illustrates the results of the importance of the factors. Interestingly, the *heritage value* and *site and ecology* factors were ranked the most important. Moreover, *water use* was the least important factor.

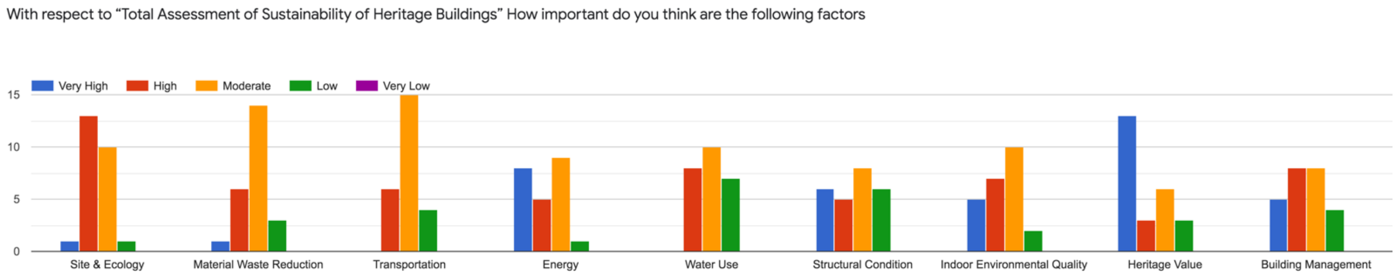


Figure 4-12: Chart for Total Assessment of Sustainably Heritage Buildings for each factor

The most important factor for sustainability in heritage buildings is *indoor environmental quality* while the least important factor is *water use* (Figure 4.13).

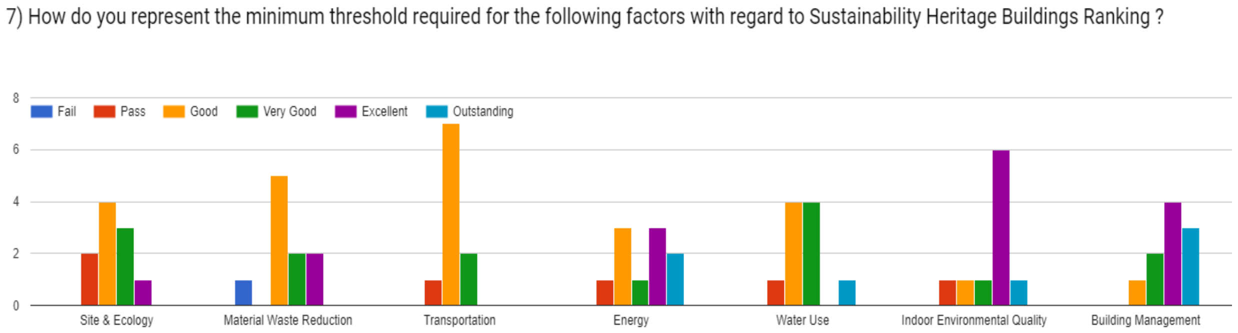


Figure 4-13: Chart for Sustainability Heritage Ranking

Since *heritage value* was one of the most critical factors, Figure 4.14 illustrates the rankings of the indicators for *heritage value*. It can be seen that building revenue was the most important indicator (60% of the experts rated it as very important) while the least important indicator was the building material.

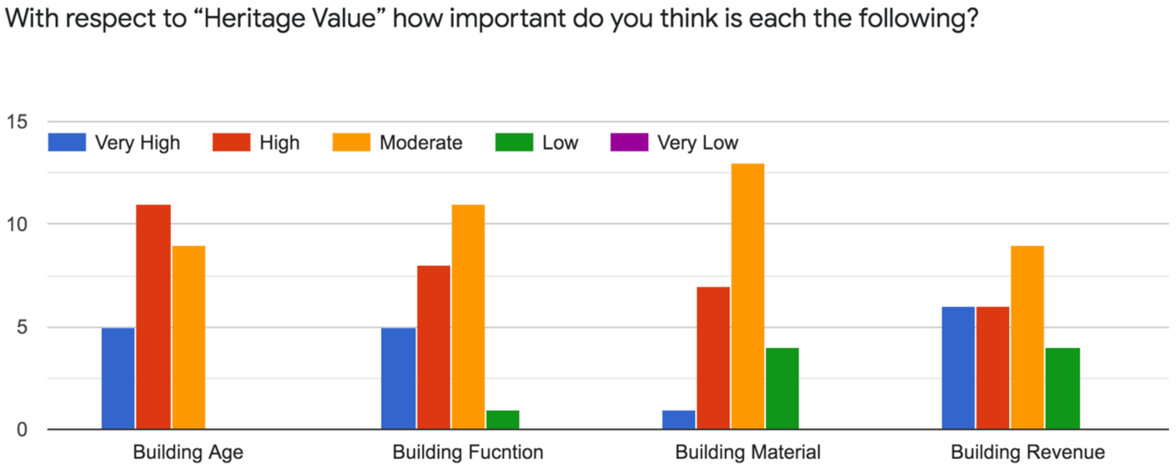


Figure 4-14: Chart for Heritage Value Factor

Similarly, the anticipated *revenues* of heritage buildings are depicted in Figure 4.15. As illustrated, 60% of the experts indicated that revenues of $300,000 and above are the most common revenues for heritage buildings. More interestingly, only 10% of the experts knew heritage buildings with revenues between $200k and $300k.

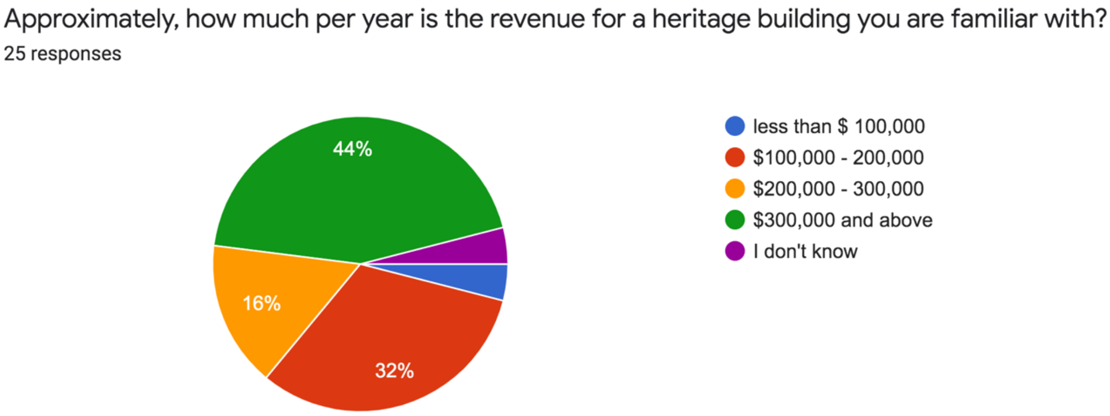


Figure 4-15: Chart for Building Revenue Indicator

4.3.4 Fuzzification of the Obtained Linguistic Responses

Expert responses were used for the fuzzification, that is, the conversion of linguistic variables to fuzzy numbers. In the fuzzification process, a set of three numbers are determined to describe each of the five linguistic variables. In this thesis, 25 of the 40 experts generated sets of three numbers that were used in the calculation of triangular fuzzy numbers (based on an average of all responses) (Table 4.2 and Figure 4.16). The linguistic variables include very low, low, medium, high, and very high and their corresponding fuzzy triangular numbers range from (0.01, 0.09, 0.23) for 'very low' to (0.82, 0.94, 1.00) for 'very high'.

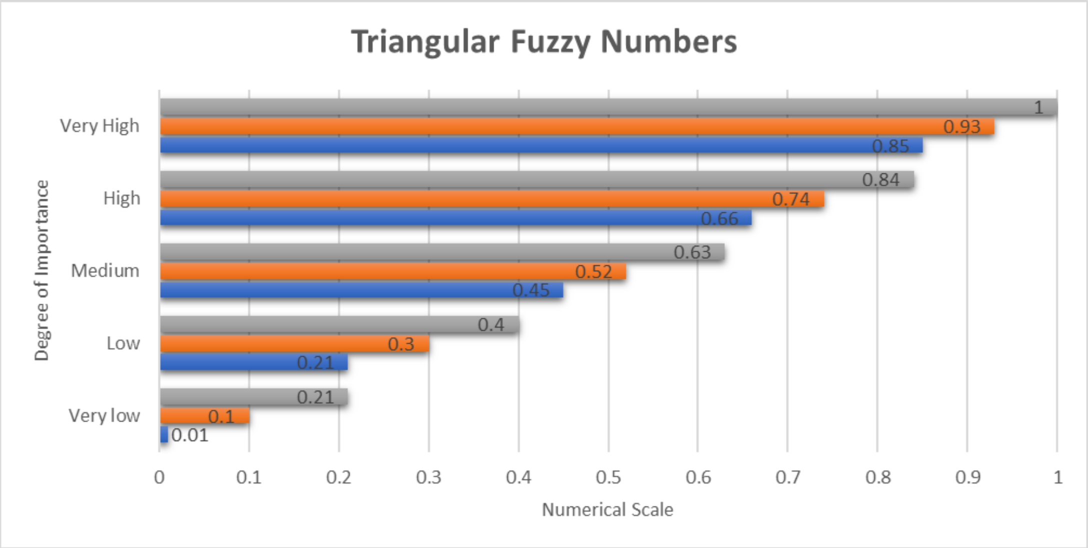


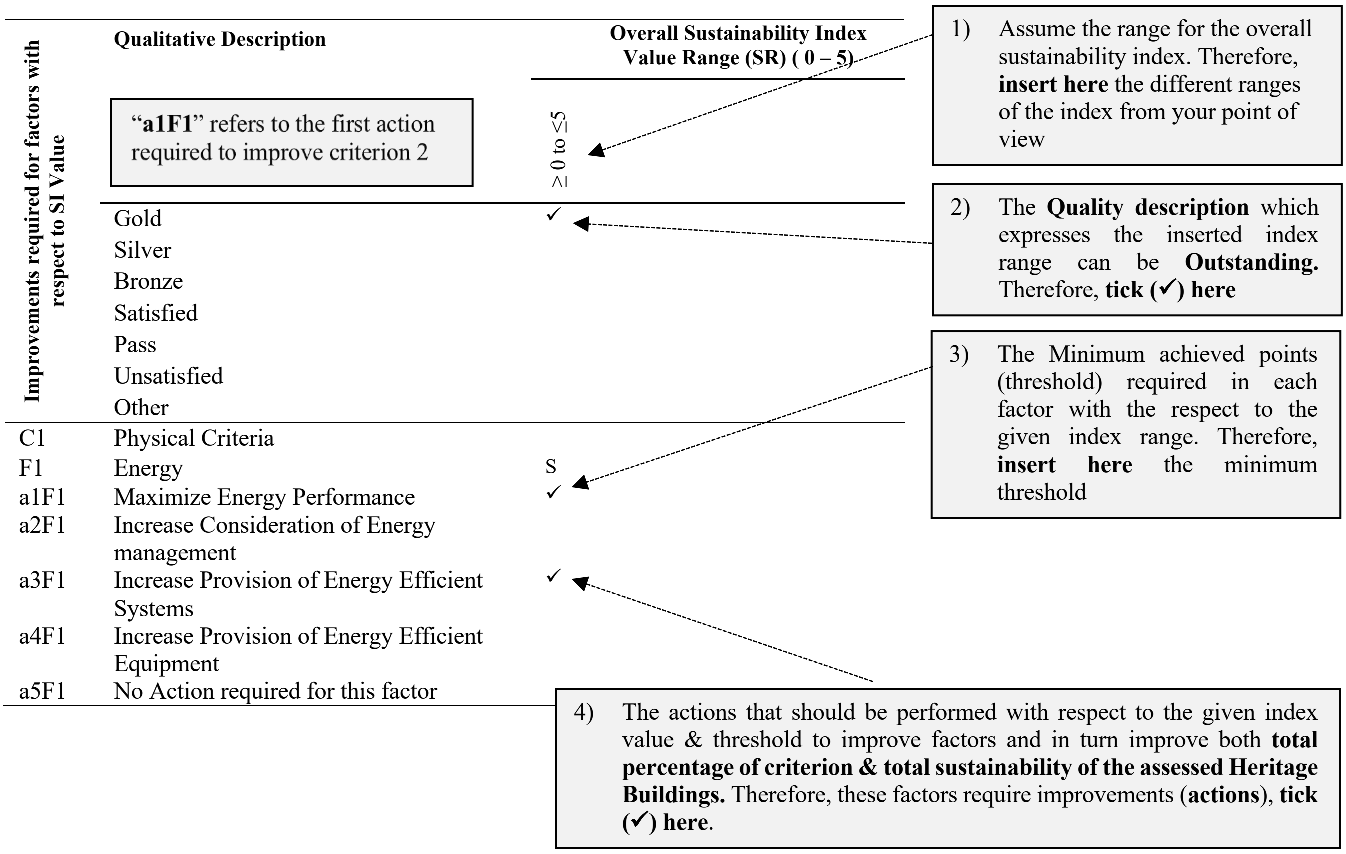
Figure 4-16: Representation of Triangular Fuzzy Numbers

Table 4-2: Calculation of the Triangular Fuzzy Numbers

No	**Very Low**			**Low**			**Medium**			**High**			**Very High**		
1	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
2	0	0.2	0.2	0.3	0.3	0.3	0.4	0.5	0.6	0.6	0.6	0.8	0.8	0.8	1
3	0	0	0	0.1	0.2	0.3	0.4	0.5	0.7	0.7	0.8	1	0.9	0.9	1
4	0	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.7	0.8	0.9	0.9	0.9	1	1
5	0	0.1	0.2	0.3	0.3	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1
6	0	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.9	1
7	0	0.1	0.3	0.3	0.2	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	1	1
8	0	0.2	0.4	0.3	0.3	0.5	0.6	0.6	0.7	0.75	0.8	0.9	0.9	0.95	1
9	0.1	0.1	0.1	0.2	0.4	0.5	0.6	0.6	0.65	0.8	0.85	0.9	0.95	0.95	1
10	0	0.2	0.3	0.3	0.4	0.4	0.5	0.65	0.75	0.8	0.8	1	0.85	0.95	1
11	0	0.1	0.15	0.2	0.3	0.3	0.45	0.5	0.6	0.65	0.7	0.8	0.85	0.9	1
12	0	0	0.1	0.2	0.25	0.3	0.35	0.4	0.55	0.6	0.65	0.7	0.85	0.9	1
13	0	0	0.1	0	0.2	0.3	0.4	0.4	0.6	0.7	0.8	1	0.8	0.9	1
14	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
15	0	0	0.2	0	0.2	0.5	0.5	0.5	0.7	0.6	0.6	0.8	0.8	0.9	1
16	0	0	0.3	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	0.9	0.95	1	1
17	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.6	0.7	0.8	0.85	0.9	1
18	0	0.2	0.5	0.5	0.6	0.65	0.65	0.7	0.75	0.8	0.85	0.85	0.9	0.9	1
19	0	0.1	0.2	0.2	0.3	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.9	1
20	0	0	0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
21	0	0.1	0.2	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.7	0.75	0.8	0.9	1
22	0	0.2	0.3	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
23	0	0	0.1	0	0.1	0.1	0.2	0.4	0.5	0.6	0.7	0.8	0.9	1	1
24	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
25	0	0.1	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1
	0.01	**0.10**	**0.21**	**0.21**	**0.30**	**0.40**	**0.45**	**0.52**	**0.63**	**0.66**	**0.74**	**0.84**	**0.85**	**0.93**	**1.00**

4.4 Sustainability Scale Determination

Two stages are involved in order to develop a sustainability scale: 1) analyzing expert responses to the questionnaire (Figures 4.17 and 4.18); and 2) examining the differences in the selected rating systems (see Figure 3.4). The proposed sustainability scale ranges from 0 to 5 - *Unsatisfied* in sustainability (0 - <1); *Pass* (1 - <2); *Satisfied* (2 - <3); *Bronze* (3 - <4); *Silver* (4 - <4.5); *Gold* (4.5 - <5). The final step in the methodology is the ranking scheme development, which was dependent on two procedures: the expert responses and the review of the widely used sustainability tools. The expert responses were collected through questionnaires that investigated their thoughts on an applicable scale that would demonstrate the level of sustainability in buildings (that is, outstanding, excellent, very good, good, pass and fail). Their responses also covered the threshold for each factor that represents the minimum requirement for each factor in order to attain a given rating (Figure 4.17). The proposed sustainability ranking is a scale from 0% to 100%, which represents six sustainability rankings (*Unsatisfied, Pass, Satisfied, Bronze, Silver, and Gold*). The proposed sustainability scale is *Unsatisfied* (0 - <50%); *Pass* (50% - <60%); *Satisfied* (60% - <70%); *Bronze* (70% - <80%); *Silver* (80% - <90%), *Gold* (90% - <100%).



Improvements required for factors with respect to SI Value	**Qualitative Description**	**Overall Sustainability Index Value Range (SR) (0 – 5)**
	“**a1F1**” refers to the first action required to improve criterion 2	≥ 0 to ≤5
	Gold	✓
	Silver	
	Bronze	
	Satisfied	
	Pass	
	Unsatisfied	
	Other	
C1	Physical Criteria	
F1	Energy	S
a1F1	Maximize Energy Performance	✓
a2F1	Increase Consideration of Energy management	
a3F1	Increase Provision of Energy Efficient Systems	✓
a4F1	Increase Provision of Energy Efficient Equipment	
a5F1	No Action 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 **Quality description** which expresses the inserted index range can be **Outstanding.** Therefore, **tick (✓) here**

3) The Minimum achieved points (threshold) required in each factor with the respect to the given index range. Therefore, **insert here** the minimum threshold

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 Heritage Buildings.** Therefore, these factors require improvements (**actions**), **tick (✓) here**.

Figure 4-17: Sustainability scale in Part Three of the questionnaire

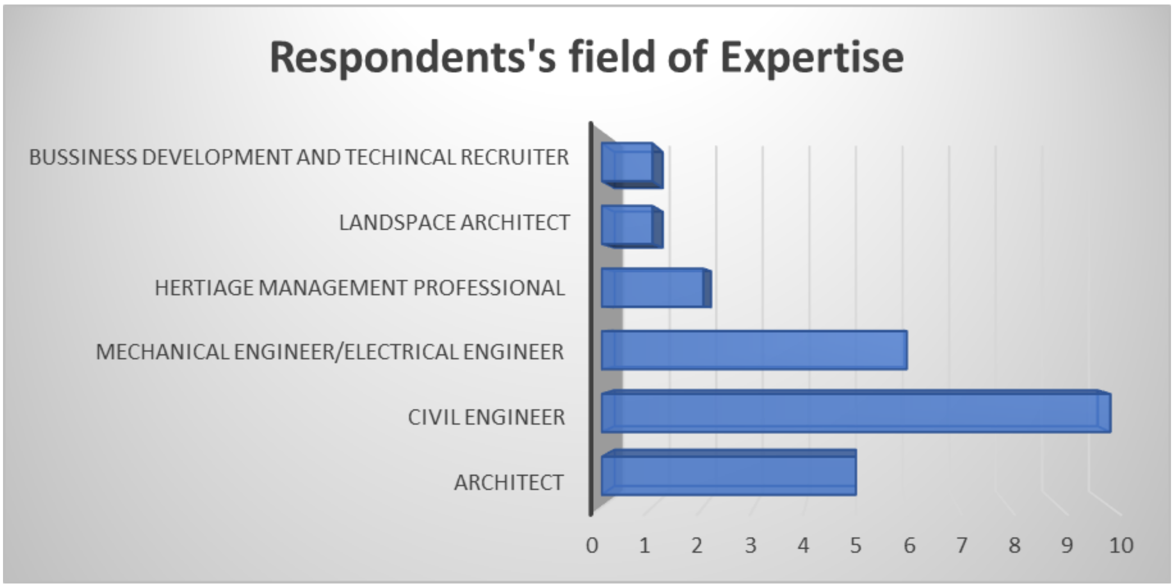
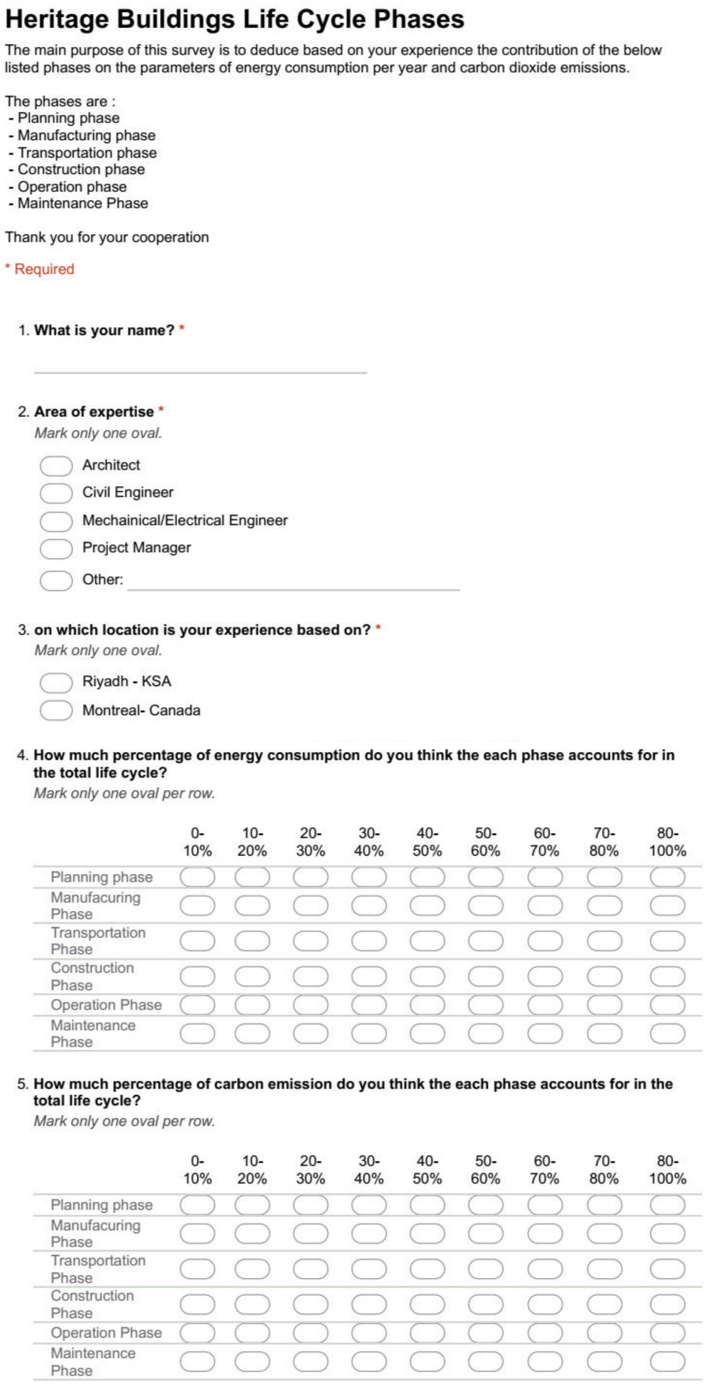


Figure 4-18: Respondents’ field of expertise

4.5 Building Energy Analysis

The questionnaire was divided into four parts: (1) area of expertise; (2) the location of experience based on the KSA or Canada; (3) the percentage of energy consumption in each phase that is accounted for in the total life cycle; and (4) the percentage of carbon emission in each phase that is accounted for in the total life cycle (see Figure 4.19).



Heritage Buildings Life Cycle Phases

The main purpose of this survey is to deduce based on your experience the contribution of the below listed phases on the parameters of energy consumption per year and carbon dioxide emissions.

The phases are :
- Planning phase
- Manufacturing phase
- Transportation phase
- Construction phase
- Operation phase
- Maintenance Phase

Thank you for your cooperation

* Required

1. **What is your name? ***

2. **Area of expertise ***
Mark only one oval.
○ Architect
○ Civil Engineer
○ Mechainical/Electrical Engineer
○ Project Manager
○ Other:

3. **on which location is your experience based on? ***
Mark only one oval.
○ Riyadh - KSA
○ Montreal- Canada

4. **How much percentage of energy consumption do you think the each phase accounts for in the total life cycle?**
Mark only one oval per row.

	0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-100%
Planning phase	○	○	○	○	○	○	○	○	○
Manufacuring Phase	○	○	○	○	○	○	○	○	○
Transportation Phase	○	○	○	○	○	○	○	○	○
Construction Phase	○	○	○	○	○	○	○	○	○
Operation Phase	○	○	○	○	○	○	○	○	○
Maintenance Phase	○	○	○	○	○	○	○	○	○

5. **How much percentage of carbon emission do you think the each phase accounts for in the total life cycle?**
Mark only one oval per row.

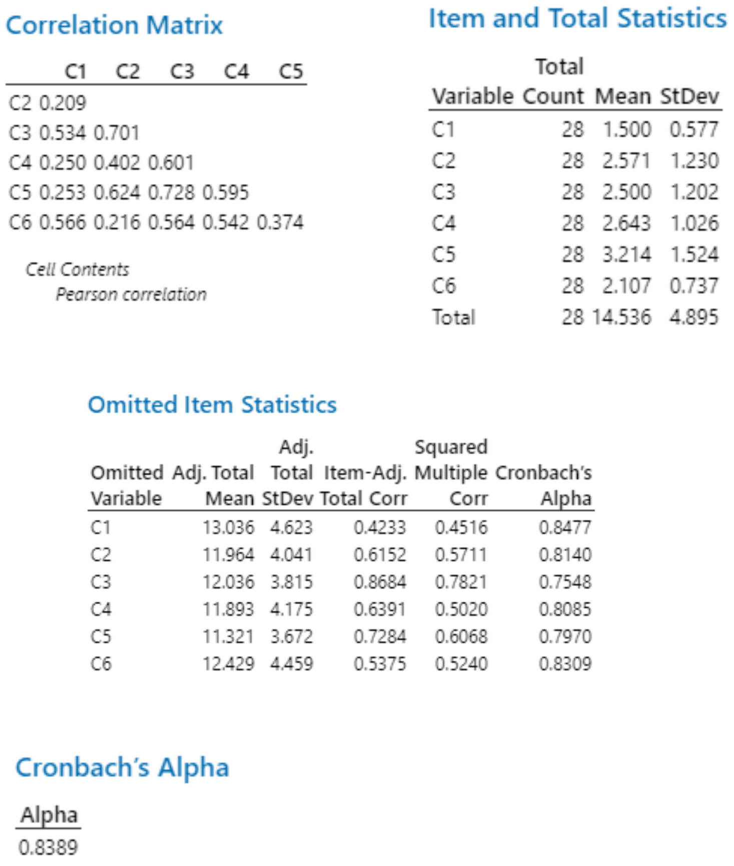
	0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-100%
Planning phase	○	○	○	○	○	○	○	○	○
Manufacuring Phase	○	○	○	○	○	○	○	○	○
Transportation Phase	○	○	○	○	○	○	○	○	○
Construction Phase	○	○	○	○	○	○	○	○	○
Operation Phase	○	○	○	○	○	○	○	○	○
Maintenance Phase	○	○	○	○	○	○	○	○	○

Figure 4-19: Survey of life cycle phases for HBs

Data Reliability results

The reliability of the data and expert preferences collected as part of this model was validated using a similar manner to the methodology implemented in Section 3.6. The tables for inputs, outputs and Cronbach's alpha values calculated using Excel® are available in the Appendix while Minitab® results are presented in Tables 4.3 and 4.4 and Figures 4.20 and 4.21 below.

Table 4-3: Cronbach alpha analysis using Minitab®
(Electricity consumption)



Correlation Matrix

	C1	C2	C3	C4	C5
C2	0.209				
C3	0.534	0.701			
C4	0.250	0.402	0.601		
C5	0.253	0.624	0.728	0.595	
C6	0.566	0.216	0.564	0.542	0.374

Cell Contents
Pearson correlation

Item and Total Statistics

Variable	Total Count	Mean	StDev
C1	28	1.500	0.577
C2	28	2.571	1.230
C3	28	2.500	1.202
C4	28	2.643	1.026
C5	28	3.214	1.524
C6	28	2.107	0.737
Total	28	14.536	4.895

Omitted Item Statistics

Omitted Variable	Adj. Total Mean	Adj. Total StDev	Item-Adj. Total Corr	Squared Multiple Corr	Cronbach's Alpha
C1	13.036	4.623	0.4233	0.4516	0.8477
C2	11.964	4.041	0.6152	0.5711	0.8140
C3	12.036	3.815	0.8684	0.7821	0.7548
C4	11.893	4.175	0.6391	0.5020	0.8085
C5	11.321	3.672	0.7284	0.6068	0.7970
C6	12.429	4.459	0.5375	0.5240	0.8309

Cronbach's Alpha

Alpha
0.8389

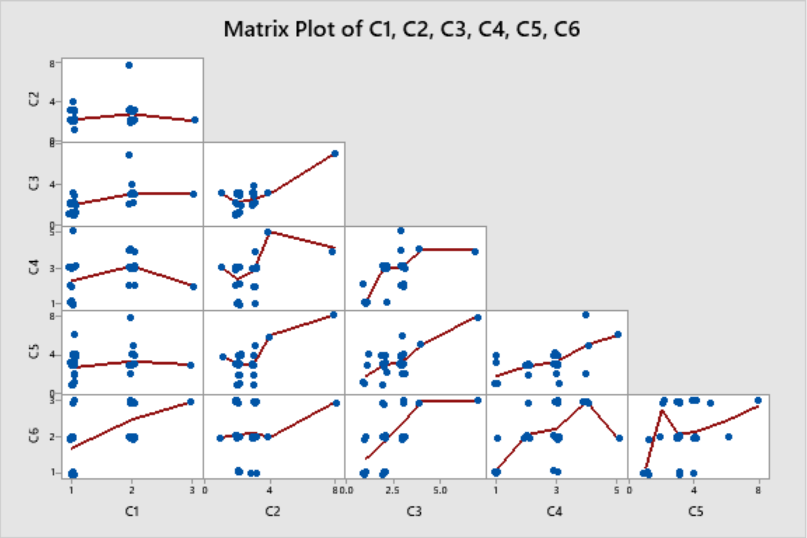
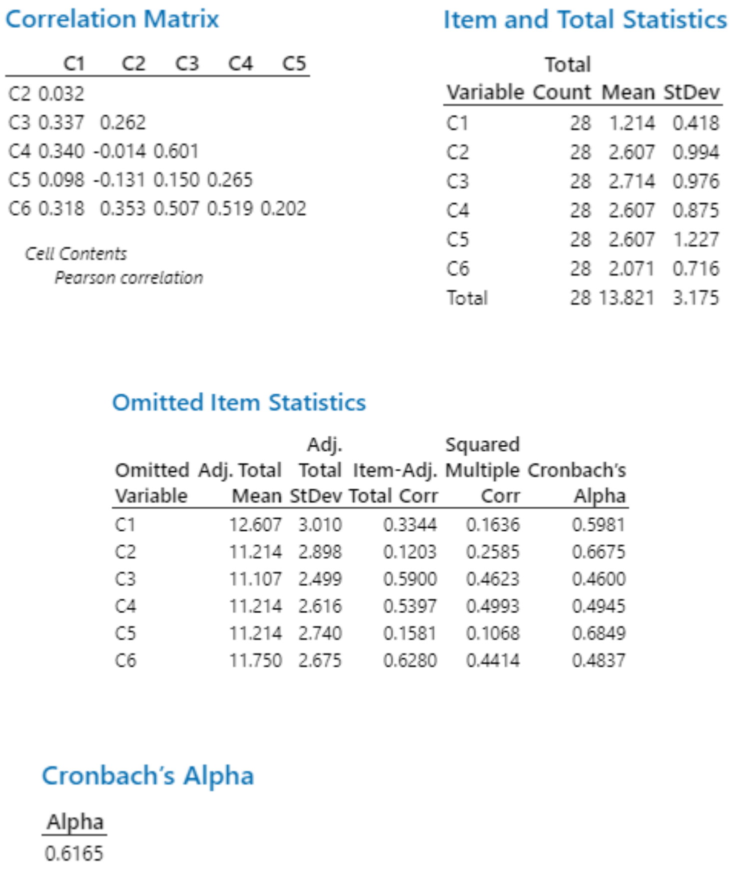


Figure 4-20: The matrix of Cronbach alpha analysis using Minitab® (Electricity consumption)

Table 4-4: Cronbach alpha analysis using Minitab® (Gas consumption)



Correlation Matrix

	C1	C2	C3	C4	C5
C2	0.032				
C3	0.337	0.262			
C4	0.340	-0.014	0.601		
C5	0.098	-0.131	0.150	0.265	
C6	0.318	0.353	0.507	0.519	0.202

Cell Contents
Pearson correlation

Item and Total Statistics

Variable	Total Count	Mean	StDev
C1	28	1.214	0.418
C2	28	2.607	0.994
C3	28	2.714	0.976
C4	28	2.607	0.875
C5	28	2.607	1.227
C6	28	2.071	0.716
Total	28	13.821	3.175

Omitted Item Statistics

Omitted Variable	Adj. Total Mean	Adj. Total StDev	Item-Adj. Total Corr	Squared Multiple Corr	Cronbach's Alpha
C1	12.607	3.010	0.3344	0.1636	0.5981
C2	11.214	2.898	0.1203	0.2585	0.6675
C3	11.107	2.499	0.5900	0.4623	0.4600
C4	11.214	2.616	0.5397	0.4993	0.4945
C5	11.214	2.740	0.1581	0.1068	0.6849
C6	11.750	2.675	0.6280	0.4414	0.4837

Cronbach's Alpha

Alpha
0.6165

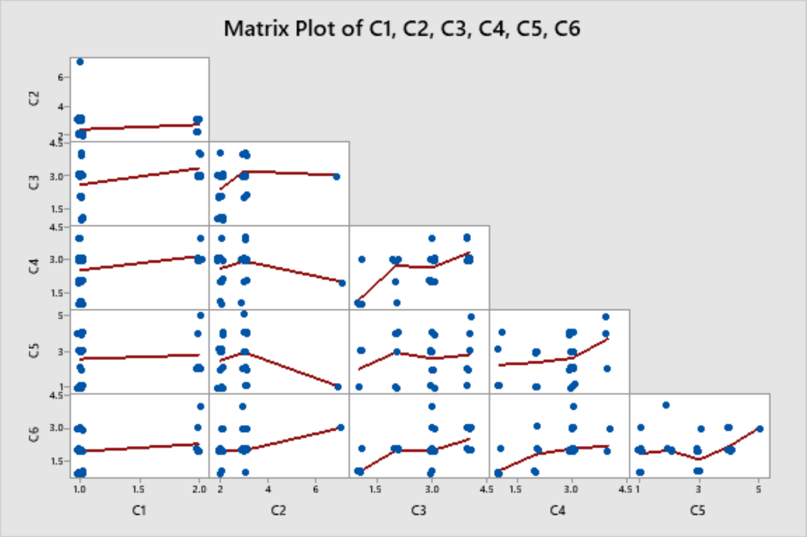


Figure 4-21: The matrix of Cronbach alpha analysis using Minitab® (Gas consumption)

4.6 Summary

This chapter demonstrated the different sustainability attributes proposed in this work. The sustainability rating system is based on selected criteria and their corresponding factors and indicators. The 12 rating systems were compared to exhaustively list the possible attributes and identify those that impact sustainability the most. In addition, to provide more realism to the identified attributes, this chapter highlights details from the questionnaires and interviews conducted with subject-matter experts. Detailed information on the findings was presented. The sections of the questionnaire that were relevant for weight determination of criteria and factors were discussed. Finally, the questionnaire served as a benchmark to enable the development of a scale and thresholds to rank sustainability.

CHAPTER 5 : CASE STUDY AND MODEL IMPLEMENTATIONS

5.1 Chapter Overview

This chapter presents the case studies analysis and results. A complete data related to each criterion is required to achieve results. Unfortunately, some difficulties were encountered due to lack of historical data records related to the following aspects: 1) energy and water consumption during the performance period, especially there were no meters to measure water consumption rate; 2) purchased materials and goods as well as the specification manuals for the devices, equipment and fixtures used in the building.

This chapter evaluated the proposed methodology. It first depicts the different techniques used to evaluate data reliability. Calculation of the weights of the assessment attributes using Fuzzy TOPSIS is detailed as well as the development of the assessment scale and threshold. With the general framework described, the chapter also illustrates the different models used for the two case studies, including BIM and energy simulation models. The chapter also presents results of the emission and life cycle analysis. The last part of the chapter describes the compilation of all elements in order to implement the sustainability assessment model.

5.2 Case Studies

5.2.1 Murabba Palace (Kingdom of Saudi Arabia)

Murabba Palace is in Riyadh, Kingdom of Saudi Arabia. It was built around 150 years ago. Murabba Palace is one of the most popular historic buildings in the Kingdom with an area of $9{,}844.64\ m^2$. The building gets its name from its square shape. It is one of the museums in the city and is comprised of 12 designated areas for administrative purposes. The main materials used in its construction were bricks, indigenous stones, tamarisk trunk and palm-leaf stalks (Arab Newes, 2012). The walls of the building were built using straw reinforced adobe with engraved ornaments on coating (IRCICA, 2017). Available data include the total annual energy consumption, a five-year record of energy proficiency, all the architectural plans (which are necessary for the Revit model and the energy simulation model using ArchiCAD® software) and the electrical plans. Moreover, data such as energy consumption, water use, and material use have been provided by the Riyadh Development Authority (see Figures 5.1, 5.2, 5.3 and 5.4).

Figure 5-1: Manual Murabba Palace plan, KSA (Riyadh Development Authority, 2018)

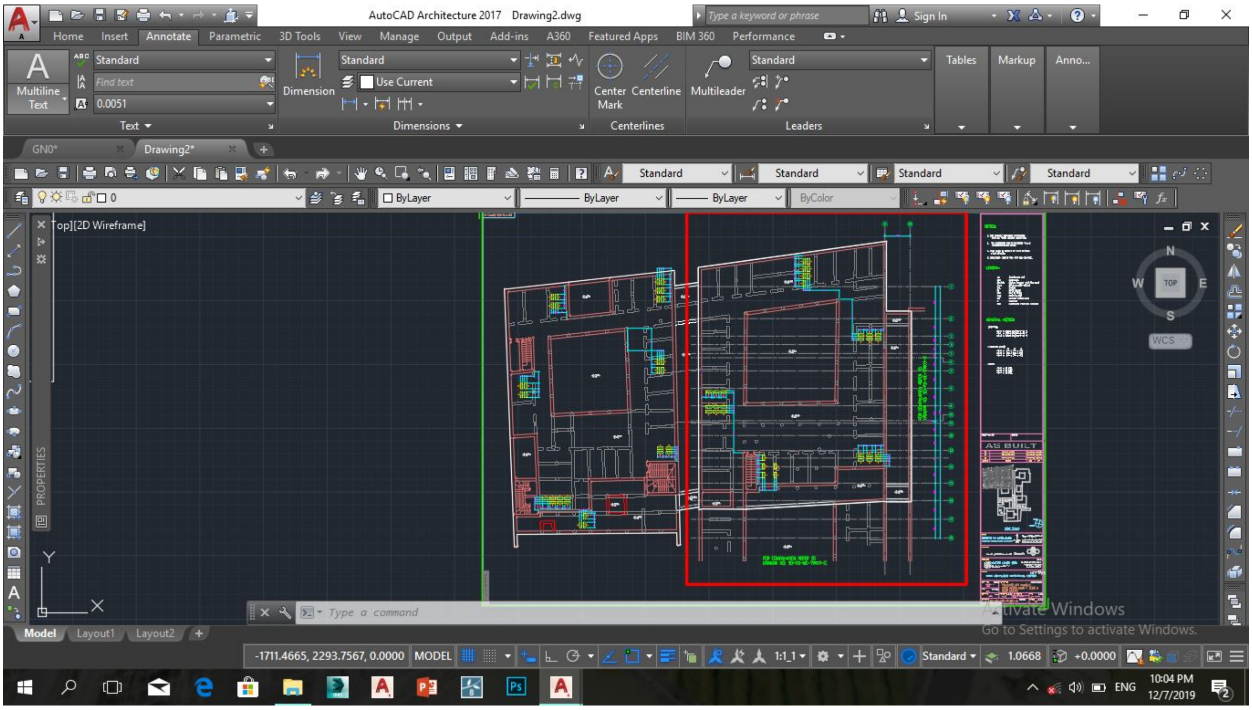


Figure 5-2: Murabba Palace AutoCAD drawing first-floor plan (details)

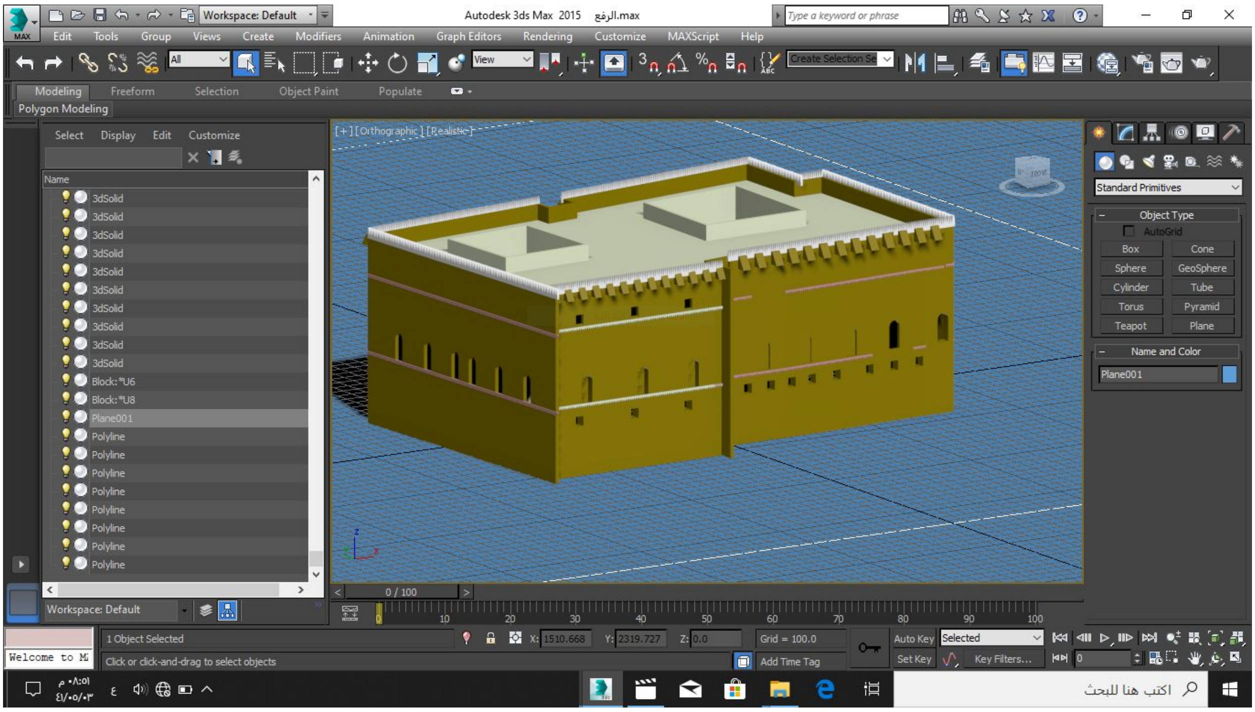


Figure 5-3: Murabba Palace BIM model details

Figure 5-4: A 3D model for Murabba Palace

Grey Nuns building- Concordia University (Canada)

Grey Nuns Motherhouse, which is known today as the Grey Nuns Building, is located at 1190 Guy Street, Montreal, Quebec, Canada with an area of $15{,}175.75\ m^2$. It was the former motherhouse of the Grey Nuns and was renamed as Grey Nuns Hospital of Montreal. It is however different from the Grey Nun's hospital located in the south of place d'Youvill. construction work on the building was finished in 1871 (Concordia University, 2014) and the building was acquired and renovated by Concordia University in 2007. The building currently functions as a co-ed residence for 598 undergraduate students on Concordia's Sir George Williams Campus (Federal Heritage Designations, 2011). The graves of 276 nuns and other individuals can be found in the basement of the building. While this in itself speaks of the cultural value of the building, one of these nuns was a native Canadian, *Mother Marie-Marguerite d'Youvill*. Her remains were, however, transferred to her birthplace in Varennes, Quebec (Concordia Journal, 2009).

Grey Nuns Building was declared as one of the National Historic Sites of Canada in 2011. Available data include the total annual energy consumption, a five-year record of energy proficiency, all the architectural plans (which are necessary for the Revit model and the energy simulation model using ArchiCAD® software) and the electrical plans. Moreover, Concordia University's Facility Management Department provided data such as energy consumption, water use, and material use (see Figures 5.5, 5.6 and 5.7).

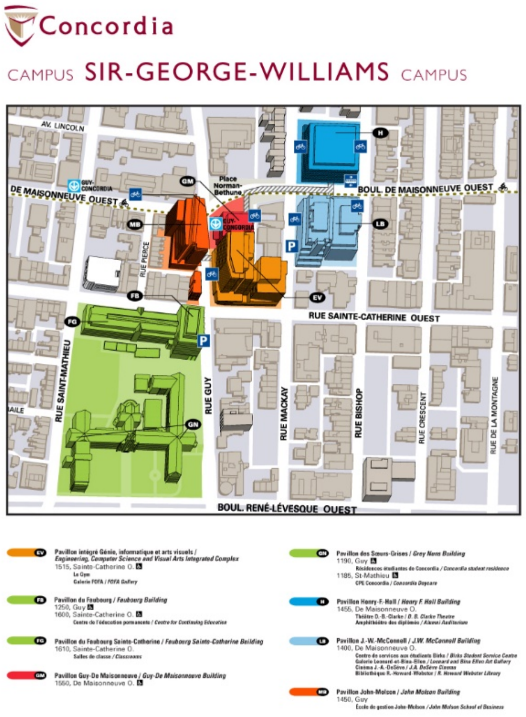


Figure 5-5: Concordia University master plan, Canada (Facility management department, 2019)

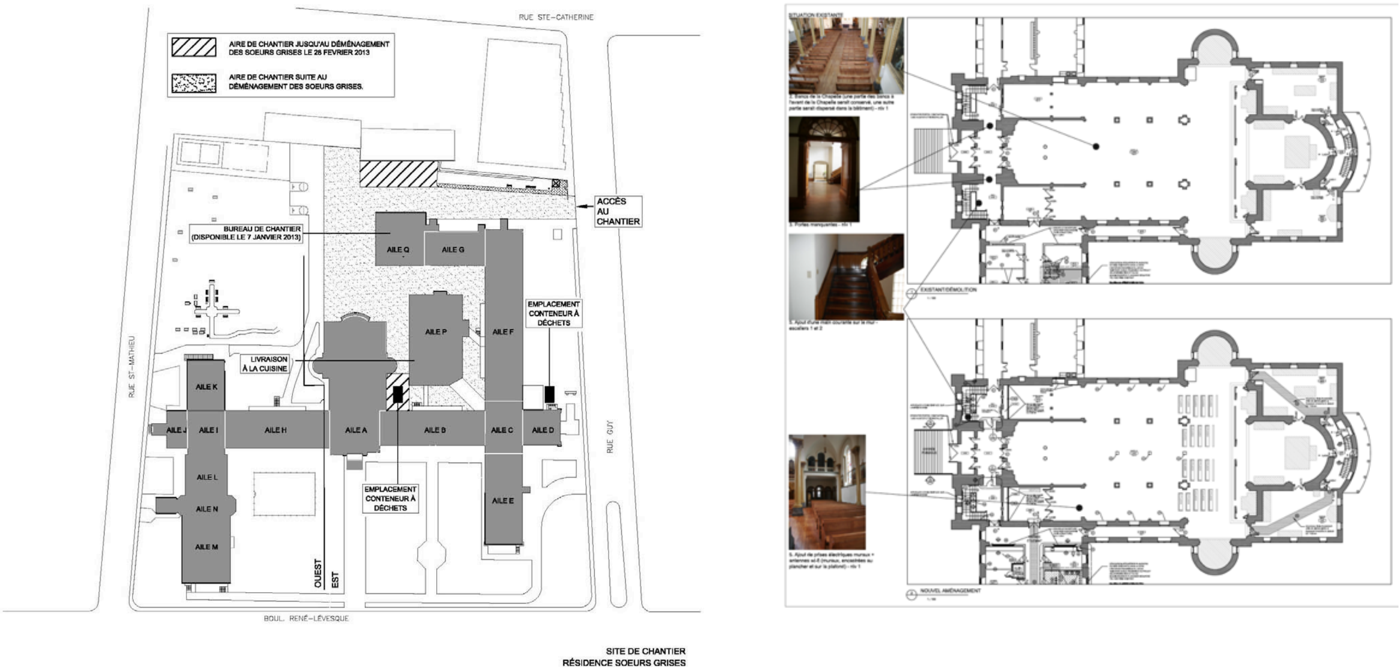


Figure 5-6: Grey Nuns Building, Canada (Facility Management Department, 2019)

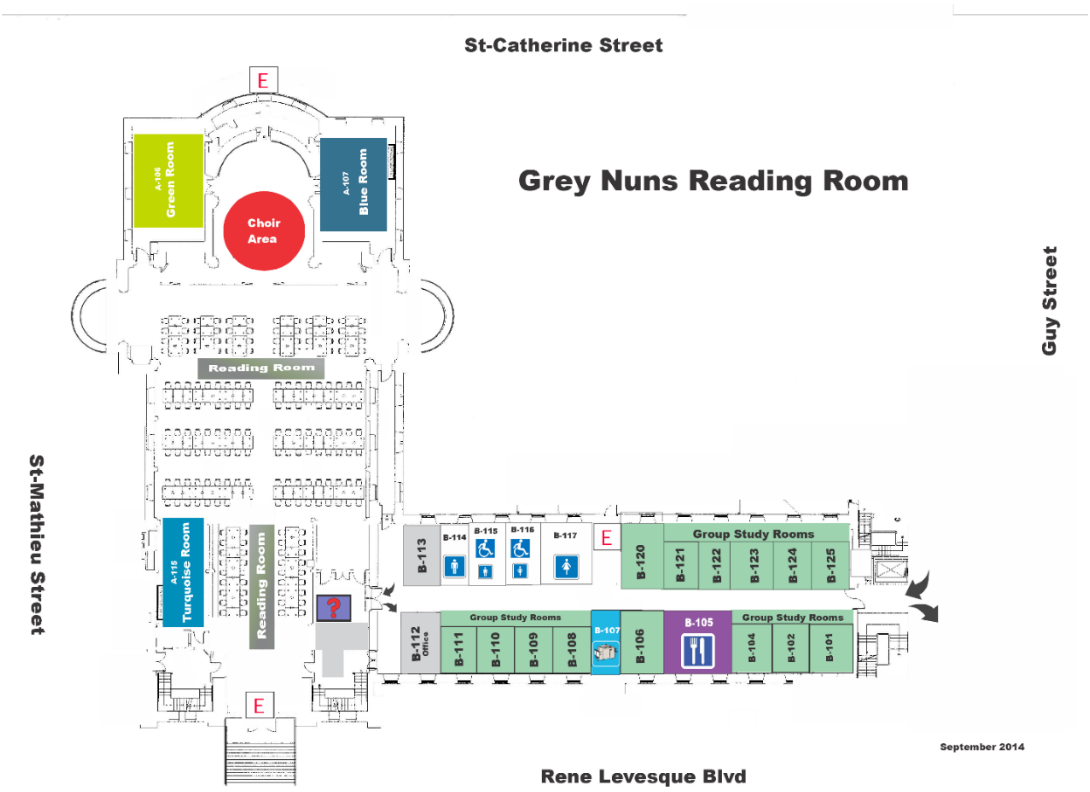


Figure 5-7: Details of the Grey Nuns first-floor plan (Facility management department, 2019)

5.3 Development of AutoCAD® and ArchiCAD® simulation models

The ArchiCAD® model is developed by leveraging the AutoCAD® drawings of the six-story floor plans, as shown in Figure 5.8, 5.9 and 5.10. The ArchiCAD® model enabled the extraction of data such as the floor area of each room, the gross area of each floor, the gross area of the entire building, the area and material of walls and partitions, the cladding area and type, number of fixtures in each bathroom, the height of each floor, and the generation of the AutoCAD® file (Alwan et al., 2015).

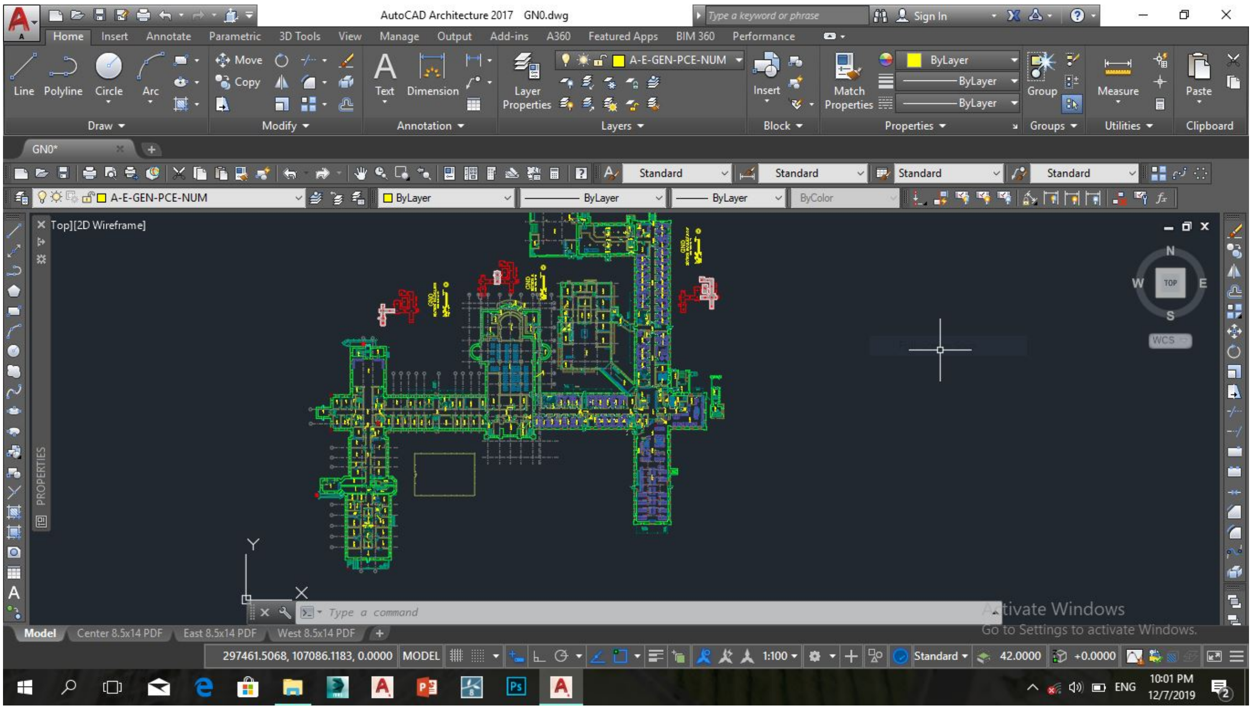


Figure 5-8: Developed AutoCAD® Model for Grey Nuns Building

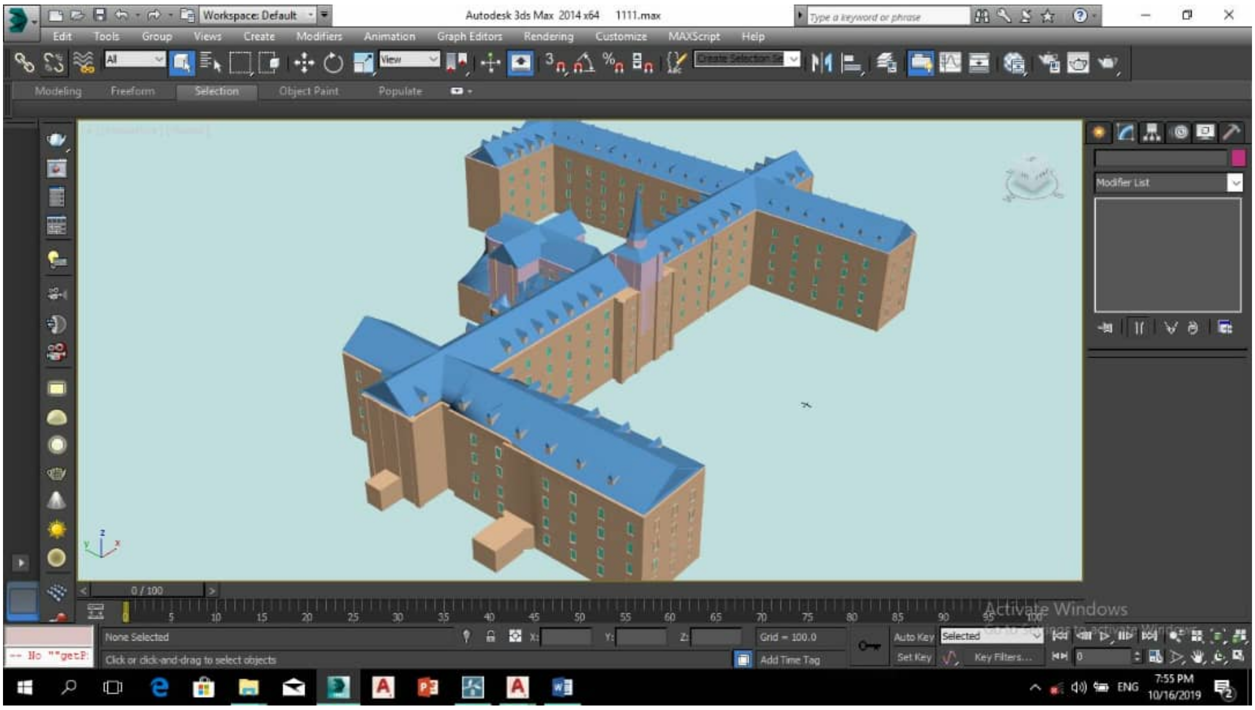


Figure 5-9: Grey Nuns Building BIM model I (details)

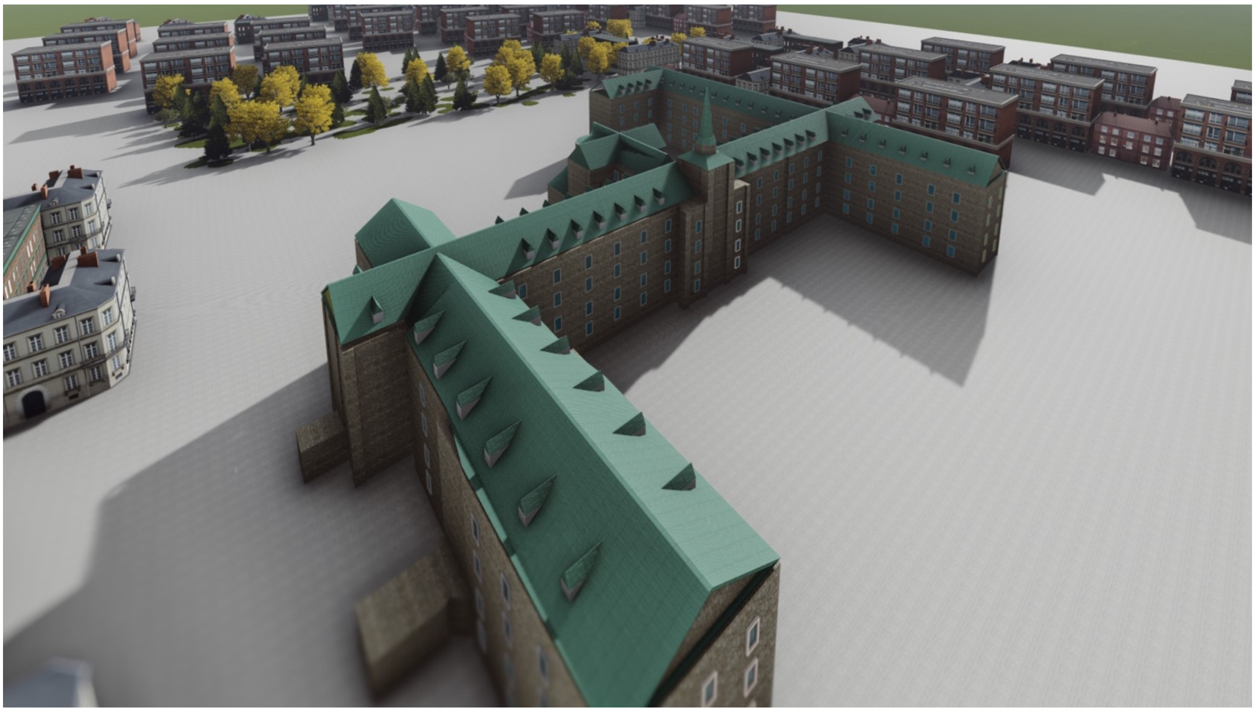


Figure 5-10: A 3D model for the Grey Nuns Building

In order to perform energy simulation, AutoCAD® was exported to Rivet®, which performs the simulation based on the building size and materials used, as shown in Figure 5.11. The ArchiCAD® model can provide the daily, monthly and yearly energy consumption of the building, as shown in Figure 5.12. Furthermore, it can perform a comparison of the energy consumption in different countries with varying energy demands. Such data is leveraged in the calculation of the Energy factor and accounts for the observed percent improvements from varying input parameters.

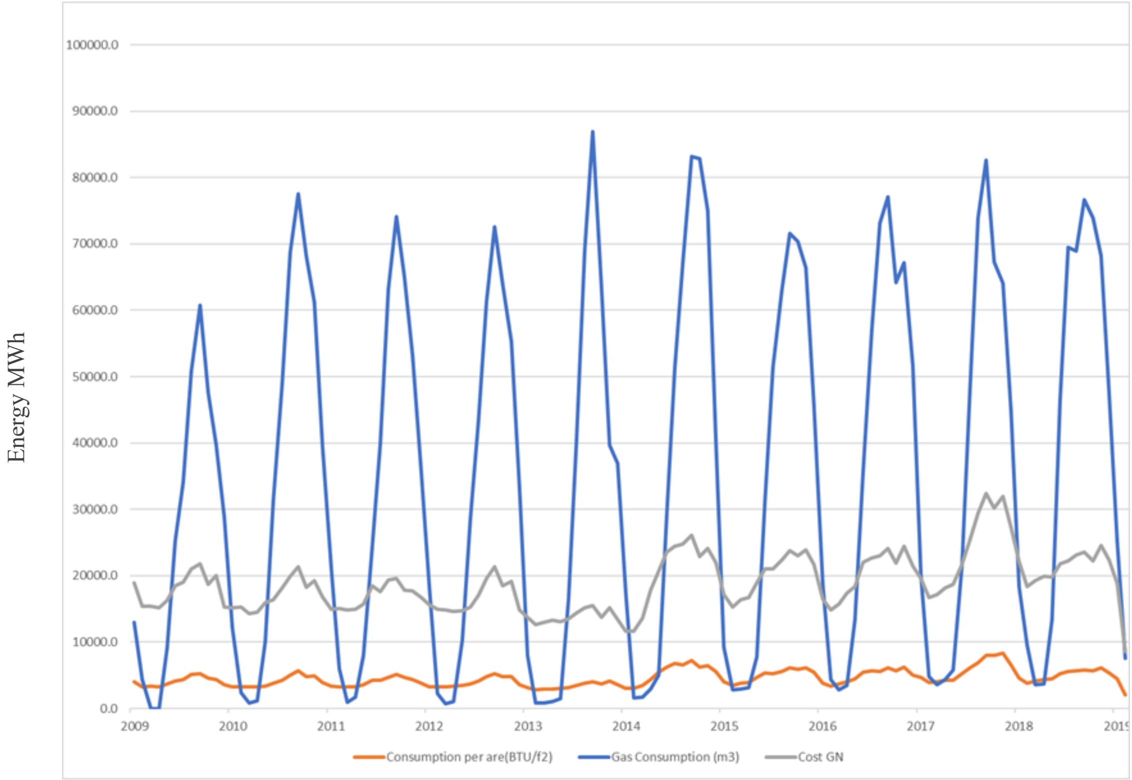


Figure 5-11: Chart for the total energy consumption of the Grey Nuns Building

Simulation results were observed to be accurate from a comparison with the building's actual energy consumption. For instance, the total energy consumption in Montreal was 23,000 MWh while simulation results showed a value of 23,656 MWh (Table 5.1). An error of 2.58% was calculated, which is within the accepted range. In addition, since the goal of this rating system is to provide an accurate and context-aware assessment of buildings in different countries, a simulation of the two cities, namely Riyadh (Saudi Arabia) and Montreal (Canada), is performed. The results are depicted in Tables 5.1-5.6. It can be observed that the total energy consumption in cold cities (Montreal) is much higher than in warm cities (Riyadh). This is due to the fact that in cold cities, there is a much higher need for heating and hot water. This also leads to higher greenhouse gas emissions. There is a positive correlation between energy consumption and GHG emission (Figures 5.12-5.14). Surprisingly, both buildings had a very significant, but of the similar order of magnitude of the carbon footprint.

Table 5-1: Total energy consumption for Riyadh and Montreal in MWh

Month	**Riyadh** (MWh)	**Montreal** (MWh)
Jan	720.5857	4178.4438
Feb	607.9359	3545.4973
Mar	591.3252	3101.4517
Apr	621.7115	1775.0482
May	771.3423	908.2664
Jun	828.7534	539.2683
Jul	920.3878	628.6202
Aug	929.0263	587.1654
Sep	818.5269	728.4873
Oct	682.3896	1579.0417
Nov	496.7218	2370.8779
Dec	650.6226	3714.6084
Total	8639.33	23656.78

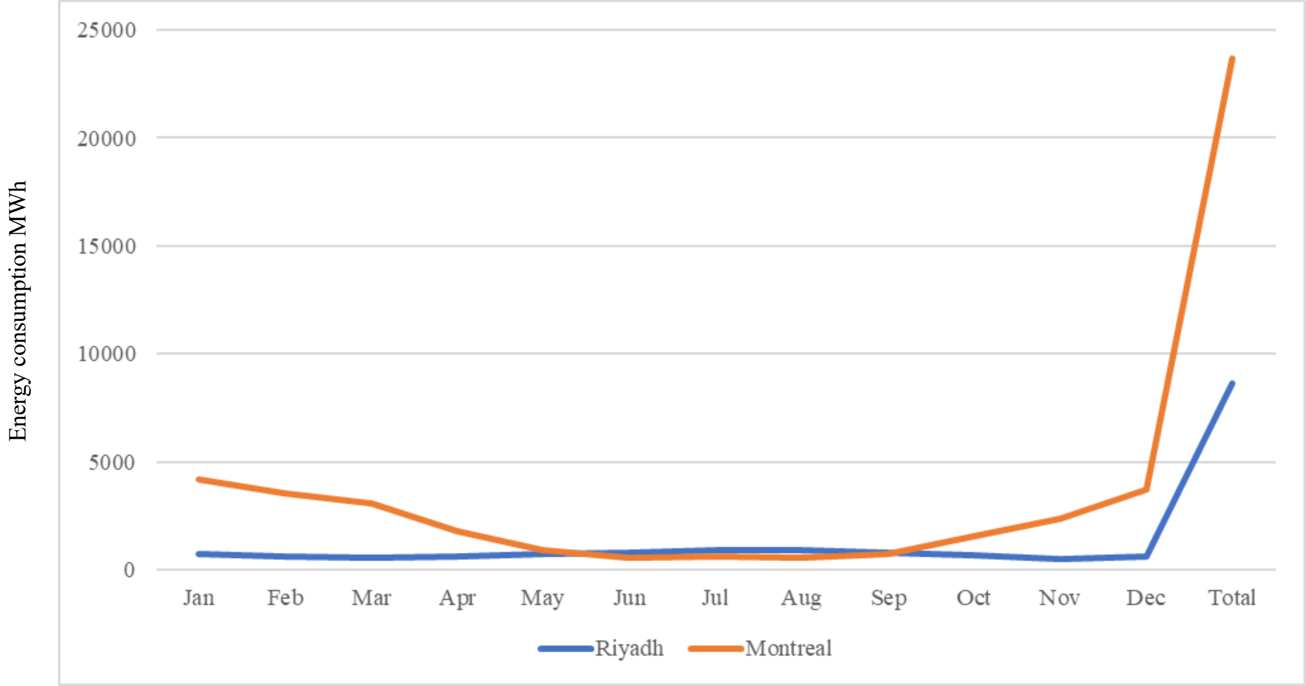


Figure 5-12: Chart for total energy consumption for Riyadh and Montreal in MWh

Table 5-2: Total carbon emissions in Riyadh and Montreal in $kgCO_2$

Month	**Riyadh** $kgCO_2$	**Montreal** $kgCO_2$
Jan	259879	1000932
Feb	228141	854803
Mar	251276	768365
Apr	307812	480563
May	392125	303896
Jun	423391	250204
Jul	470734	308587
Aug	475218	281585
Sep	418093	267572
Oct	346989	442903
Nov	238024	607297
Dec	249650	900591
Carbon emissions	4061332	6467297

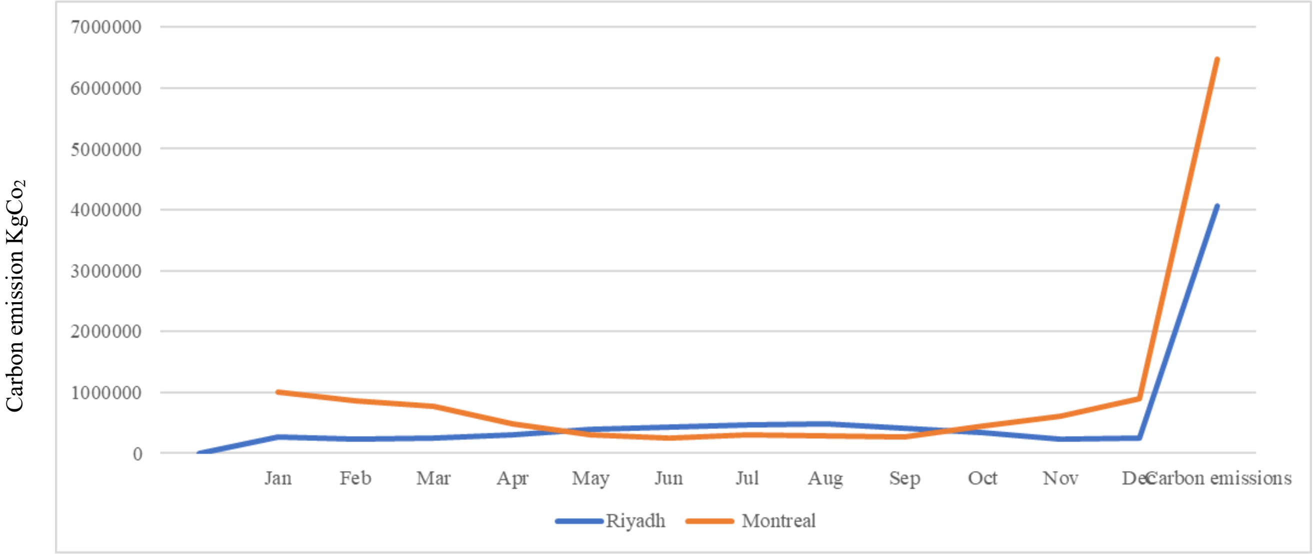


Figure 5-13: Chart for total carbon emissions in Riyadh and Montreal cities in $KgCO_2$

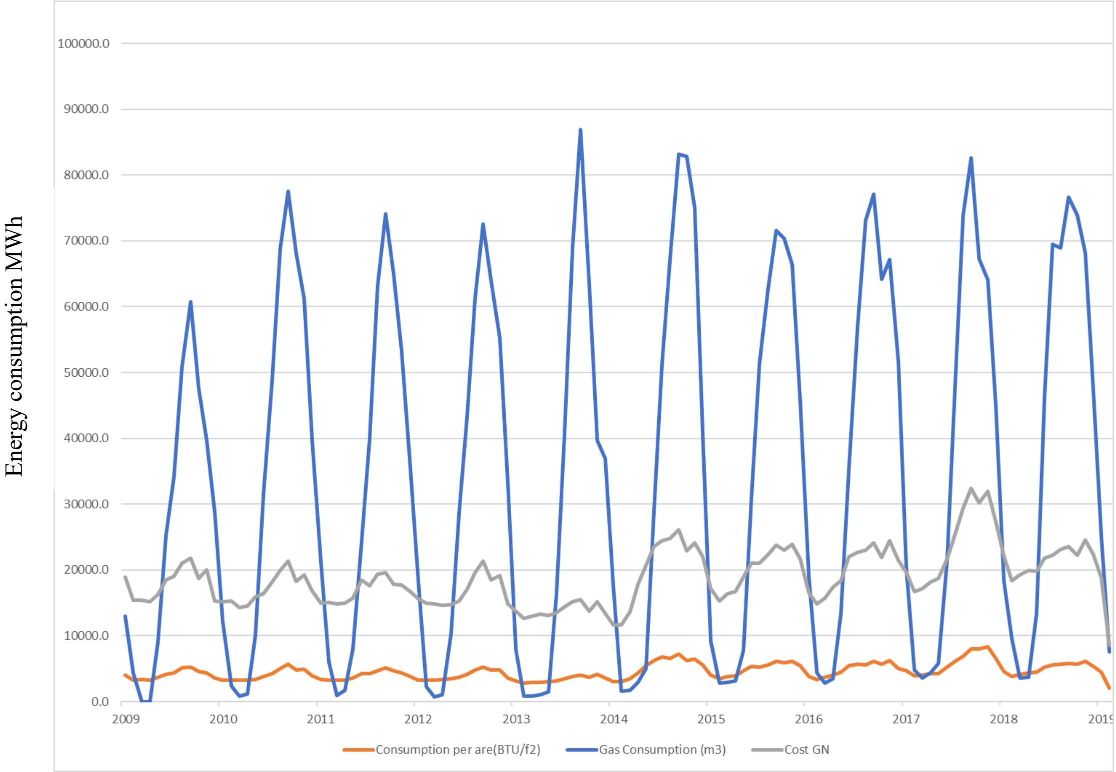


Figure 5-14: Chart for total energy consumption for Murabba Palace

Table 5-3: The monthly energy consumption of Murabba Palace

Date	Consumption per unit area (BTU/ft^2)	Cost $
Jan 01-31	12412.0	$ 20,708.25
Feb 01-28	12335.9	$ 19,355.58
Mar 01-31	12905.8	$ 20,442.74
Apr 01-30	10114.7	$ 17,482.62
May 01-31	7111.2	$ 14,134.54
Jun 01-30	5953.7	$ 11,734.33
Jul 01-31	6409.9	$ 12,322.16
Aug 01-31	6764.4	$ 12,726.32
Sep 01-30	6929.5	$ 12,673.15
Oct 01-31	8075.0	$ 13,926.57
Nov 01-30	8590.3	$ 14,252.04
Dec 01-31	8757.8	$ 14,831.83
Summed total	106360.2	$ 184,590.13

Table 5-4: The monthly energy consumption of Grey Nuns

Date	Consumption per unit area (BTU/ft^2)	Cost $
Jan 01-31	8051.8	$ 32,356.64
Feb 01-28	8002.4	$ 30,243.09
Mar 01-31	8372.1	$ 31,941.78
Apr 01-30	6561.5	$ 27,316.60
May 01-31	4613.1	$ 22,085.22
Jun 01-30	3862.2	$ 18,334.89
Jul 01-31	4158.2	$ 19,253.38
Aug 01-31	4388.1	$ 19,884.88
Sep 01-30	4495.2	$ 19,801.79
Oct 01-31	5238.3	$ 21,760.26
Nov 01-30	5572.6	$ 22,268.82
Dec 01-31	5681.3	$ 23,174.74
Summed total	68996.8	$ 288,422.09

Table 5-5: Total energy consumption for Riyadh and Montreal in MWh

Date	Murabba Riyadh	Grey Nuns Montreal
Jan	246.7	385.5
Feb	245.2	383.1
Mar	256.5	400.8
Apr	201.0	314.1
May	141.3	220.8
Jun	118.3	184.9
Jul	127.4	199.1
Aug	134.4	210.1
Sep	137.7	215.2
Oct	160.5	250.8
Nov	170.7	266.8
Dec	174.1	272.0
Total	2113.8	3303.2

Table 5-6: Carbon emissions for the two case studies

Date	Murabba Riyadh (kgCO$_2$)	Grey Nuns Montreal (kgCO$_2$)
Jan	52886.3	82634.8
Feb	43061.0	67282.9
Mar	40992.0	64050.0
Apr	28710.9	44860.8
May	11733.5	18333.7
Jun	6081.3	9502.0
Jul	2284.6	3569.7
Aug	2340.3	3656.7
Sep	8594.3	13428.5
Oct	29699.5	46405.5
Nov	44449.6	69452.4
Dec	44091.5	68892.9
Carbon emissions(m^3)	314924.8	492069.9

5.4 Results

In this part, results of a survey on experts' feedback were analyzed. These results comprised of three main modules. A comparative analysis of selected global sustainability rating systems is also presented.

5.4.1 Assigning Weights for Each Factor and Indicator

As detailed in the previous chapters, the Fuzzy TOPSIS Technique was applied to estimate the weight of each criterion and factor. Questionnaires and interviews were also conducted in order to determine the significance of each factor. Two sets of forty questionnaires were given to building stakeholders such as architects, civil engineers, project managers, sustainability experts and users.

Seventeen responses and the calculations are tabulated and presented in this section. In Appendix C.1, the weights of the nine criteria are estimated. The highest weight is *energy*, with a weight of 0.215 out of 1. The weights decreased in the following order: *IEQ*, *heritage value, structural condition, building management*, *water use*, *material and waste reduction*, *transportation* and lastly, *site and ecology* factor of weight 0.098 out of 1.

In Appendix C.2, for the *site and ecology* factor, *reduced heat island effect* indicator possesses the highest weight (0.4087) while the second and the third indicators, in decreasing order, are *site emissions* and *site management.* The indicator with the lowest weight is *site selection* of weight 0.152 out of 1. Appendix C.3 presents the weights of the indicators included in the *transportation* factor. It illustrates that the *fuel-efficient vehicles* indicator has the highest weight (0.348), followed by *alternative transportation means* and *public transportation accessibility* and lastly, the *car parking capacity* indicator (0.096). In Appendix C.4, for the *energy* factor, the *energy performance* factor has the highest weight (0.403), followed by *energy-efficient systems* and *provision of energy management* and lastly, *energy-efficient equipment* of weight 0.184. Appendix C.5 illustrates the distribution of weights for *water use*. The *water management* indicator has the highest weight of value 0.487 while the lowest value is seen for the *efficient discharge in the foul sewer* indicator (0.109). Furthermore, for the *material and waste reduction* factor as shown in Appendix C.6, the *efficient use of material* indicator has the highest weight (0.584), followed by *solid waste management* (0.318) and *sustainable purchasing practices* (0.101). Appendix C.7 illustrates the weights for the *indoor environmental quality* factor. *Indoor Air Quality* indicator has the highest weight (0.272) while *building amenities* indicator has the lowest weight (0.051). The four other indicators in descending order are *thermal comfort*, *hygiene*, *visual comfort*, and *acoustic performance* of weight values 0.237, 0.196, 0.124, and 0.119, respectively. Appendix C.8 demonstrates the weights of the *building managemen*t factor. The *maintenance management* indicator has the highest weight (0.303) while the *security measures* indicator has the lowest weight (0.125). Besides, the three other indicators in descending order are *risk management*, green lease, and *innovations* of weight values 0.217, 0.188, and 0.166, respectively.

5.4.2 Comparison of the Sustainability Assessment Attributes

A comparative study was implemented to document the similarities among the well-established sustainability rating tools and the developed tool. In this section, conclusions are drawn on the contribution of each tool to the overall rating process.

First, for the *site and ecology* factor, it can be noted that LEED and HK BEAM rating tools have the highest influence percentage of 70% while the GSBC had no contribution from this factor. A sample comparison is shown in Table 5.7, which identifies the similarities between the SAHB and LEED US rating systems. It also presents the shortcomings of the LEED US rating system with respect to the *site and ecology* factor.

Table 5-7: The scores of LEED US rating system for Site & Ecology Factor

	Factors, indicators, and sub-indicators of the proposed system	Overall Score	LEED US
Site & Ecology Factor	**Site Selection Indicator**	2	1
	Previously Certified Design & Construction	1	1
	Respect for Sites of Historical or Cultural Interest	1	
	Site Management Indicator	4	2
	Environmentally Purchasing Plan	1	0
	Environmentally Purchasing Practices & Green Cleaning	1	0
	Building Exterior and Hardscape Management Plan	1	1
	Integrated Pest Management Erosion Control and Landscape Management	1	1
	Reduction of Heat Island Effect Indicator	5	2
	Heat Island Reduction in Not Roofed Areas	1	1
	Heat Island Reduction in Roof Areas	1	1
	Exterior Walls Finishing Materials & Planting	1	0
	Consideration of Wind Movement and Building Exterior Design	1	0
	Greenery Provision & Ecological Features	1	0
	Site Emission Indicator	4	1
	Noise from Building Equipment	1	0
	Light Pollution Reduction	1	1
	Boiler Emission	1	0
	Asbestos Management Plan	1	0
	Total	15	6
	Coverage percentage	40.0%	

Regarding the *transportation* factor, BCA GM, BREEAM UK and Greenship Indonesia rating tools take the lead with a contribution percentage of 43%. Rating tools such as Green Globe, Green Building Index, BOMA BESt, GSBC and CASBEE do not cover any indicator in this factor. For the *energy* factor, the rating tools with the highest contribution or coverage are Green Building Index and HK BEAM with a contribution percentage of 63%. The lowest coverage is seen in CASBEE with a value of only 19%. BOMA BESt has a strong consideration for *water use* factor, with a contribution percentage of 90% while CASBEE shows only 20%. For *material and waste reduction* factor, the LEED rating tool shows the highest contribution (61%) while the lowest contribution is seen in Green Globe, Green Building Index, GSBC and ITACA. Figure 5.15 summarizes the comparison of the nine selected factors for the twelve popular rating systems.

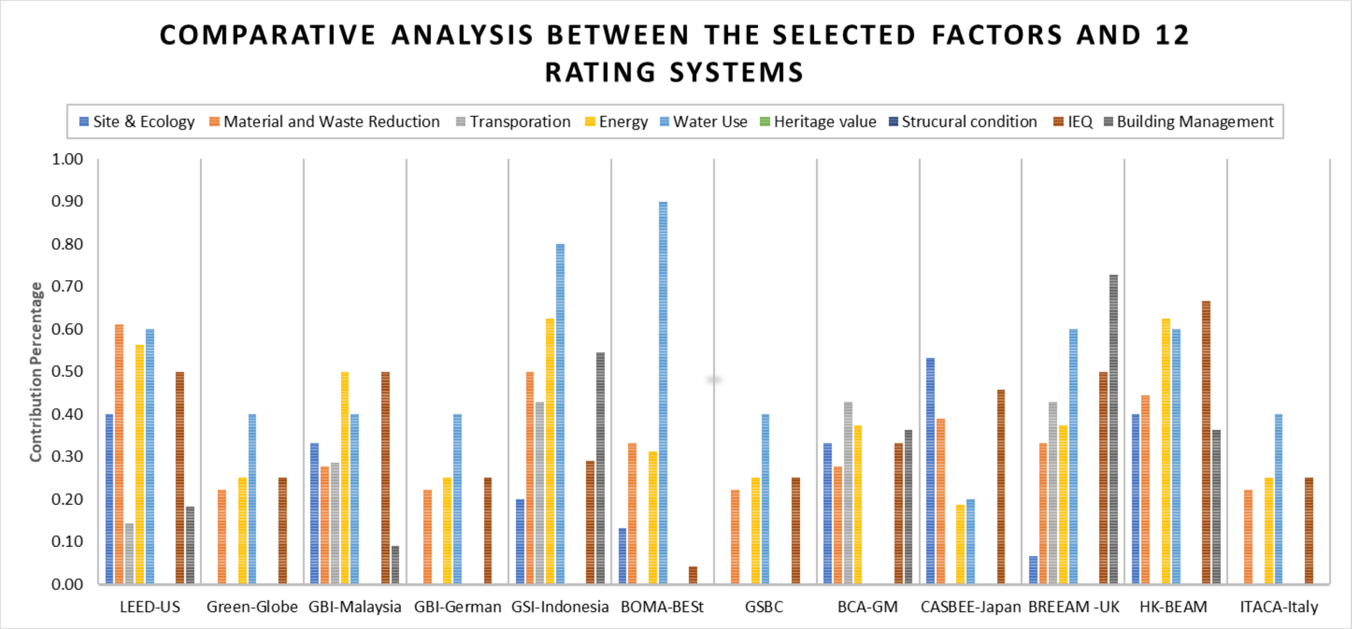


Figure 5-15: Comparative analysis between the selected factors and 12 rating systems

12 global rating systems were chosen based on the green building tool and the member list of the World Green Building Council (Worldgbc, 2016). The 12 rating systems include LEED, GL, GBI, GBP, GSI, BOMA, GSBC, BCA GM, CASBEE, BREEAM HK, BEAM and ITACA. A compilation of all the factors or attributes that influence a building's sustainability is highlighted and it is necessary that this compilation be considered in the development of the rating system (Figures 5.16 and 5.17).

Table 5-8: Comparison of the 12 rating systems of Building Sustainability (Al-Sakkaf, et al., 2019)

Rating systems	Fail	1st rating	2nd rating	3rd rating	4th rating	5th rating	6th rating
LEED	< 40 credits	Certified	Silver	Gold	Platinum	Certified	
		40-49	50-59	60-79	80-116	40-49	
Green Globes	< 15 %	1 Globe	2 Globes	3 Globes	4 Globes	5 Globes	
		15% - 34%	35% - 54%	55% - 69%	70%-84%	85%-100%	
Green Building Index	< 50 points	Certified	Silver	Gold	Platinum		
		50-65	66-75	76-85	86-100		
Green Building Program (GBP)	< 35 %	Bronze	Silver	Gold	Platinum		
		≥60% - <70%	≥70% - <80%	≥80% - <90%	≥90% - <100%		
Green ship Indonesia	< 35 %	Bronze	Silver	Gold	Platinum		
		≥35% - <46%	≥46% - <57%	≥57% - <73%	≥73% - <100%		
Green Globes (BOMA BESt)	< 30%	1 Globe	2 Globes	3 Globes	4 Globes	5 Globes	
		30% - 39%	39% - 59%	60% - 79%	80%-89%	90-100%	
German Sustainable Building Council (DGNB)	< 50 points	Certified	Silver	Gold	Platinum		
		50-65	66-75	76-85	86-100		
BCA Green Mark	< 50 points	Certified	Gold	Gold Plus	Platinum		
		50-74	75-84	85-89	90-180		
CASBEE (Japan)	< 50 points	1 star (Fairy Poor)	2 stars (Poor)	3 stars (Good)	4 stars (Very Good)		
		BEE<0. 5	BEE=0.5-1.0	BEE=1.0-1.5	BEE=1.5-3.0		
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%
HK BEAM	< 40 credits points	Bronze (Above average)	Silver (Good)	Gold (Very Good)	Platinum (Excellent)		
		≥40% - <50%	≥50% - <65%	≥65% - <75%	≥75% - <100%		
		50-65	66-75	76-85	86-100		
ITACA	< 40 credits points	D	C	B	A	A++	
		44	55	70	85	100	

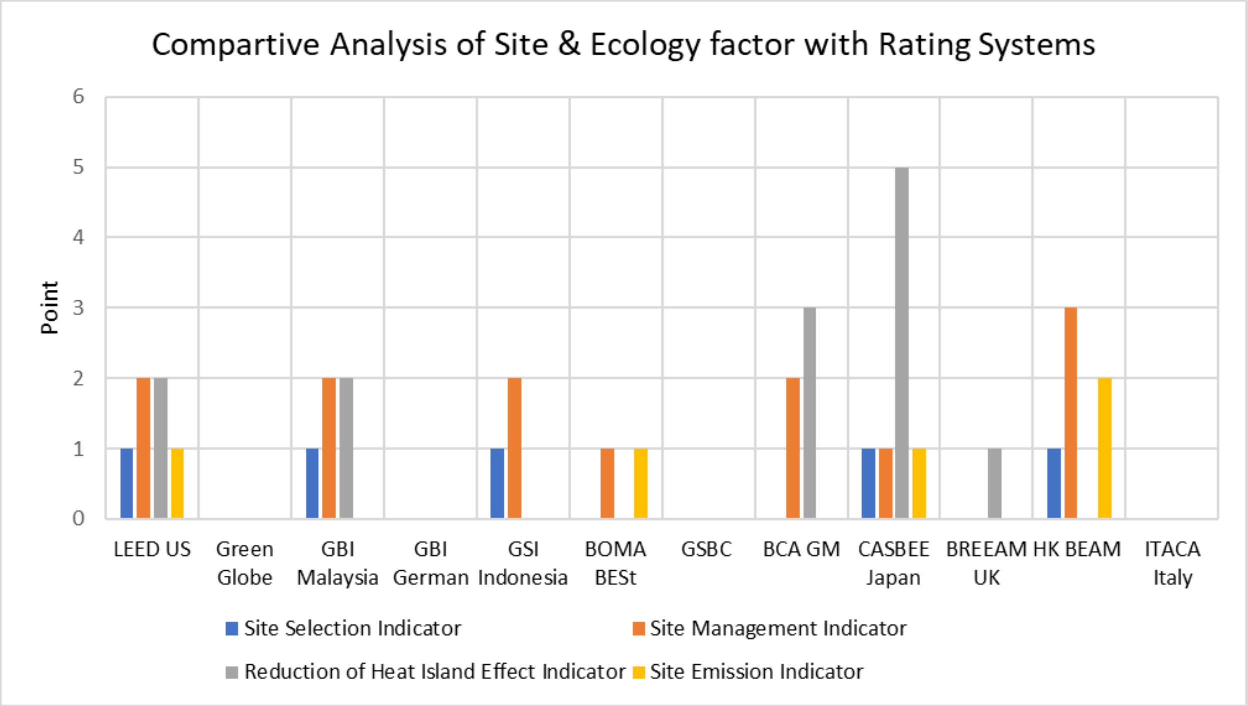


Figure 5-16: Comparative analysis of site & ecology factor for the 12 rating systems

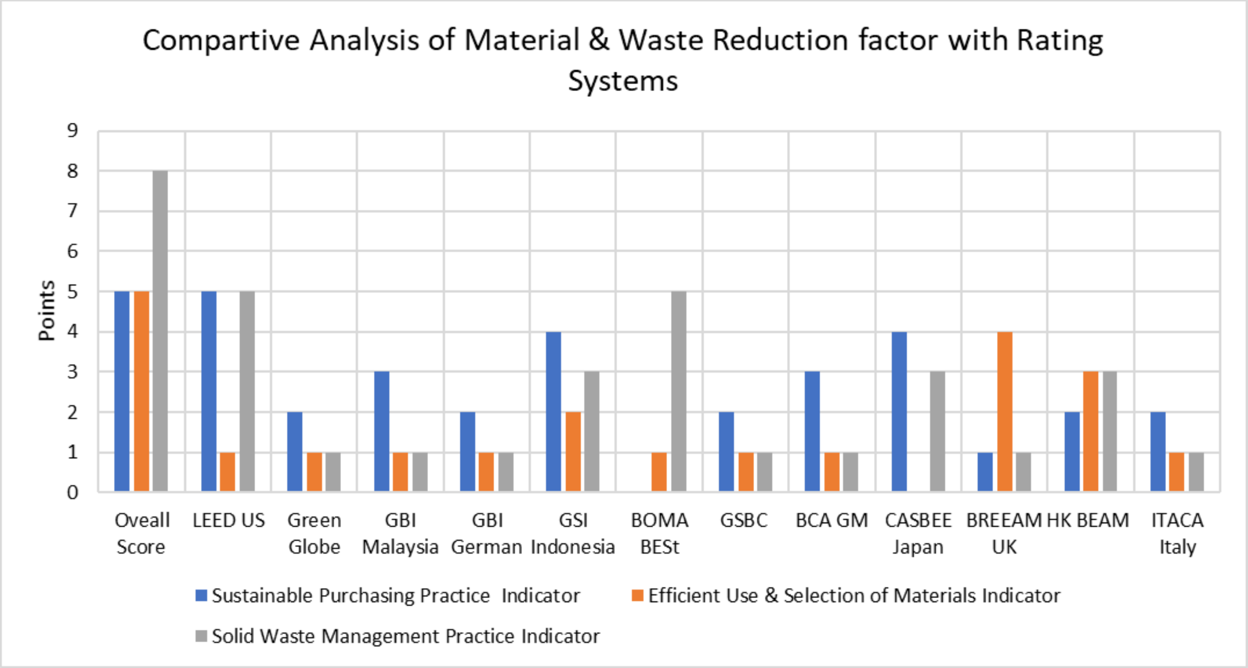


Figure 5-17: Comparative analysis of material and waste reduction factor for the 12 rating systems

Table 5.9 compares the selected rating systems based on the *site and ecology*, *transportation*, and *energy use* factors. For the *site and ecology* factor, site management indicator and reduced heat island effect indicators are considered in all twelve rating systems. The site selection and site emissions indicators are considered the least. Table 5.10 shows that the *transportation* factor is the least considered factor in all the selected rating systems. For the *energy* factor, energy performance indicator, availability of energy management, and energy-efficient systems indicators are considered in all rating tools. The availability of energy-efficient equipment indicator is however only considered in all but LEED (Figures 5.18 and 5.19).

Table 5-9: Comparison of the 12 rating systems of Building Sustainability (environmental criteria)

Criteria, factors, indicators and sub-indicators of the proposed system		Oveall Score	LEED US	Green Globe	GBI Malaysia	GBI German	GSI Indonesia	BOMA BESt	GSBC	BCA GM	CASBEE Japan	BREEAM UK	HK BEAM	ITACA Italy
Environmental Criteria														
Site & Ecology Factor	Site Selection Indicator	2	1	0	1	0	1	0	0	0	1	0	1	0
	Previously Certified Design & Construction	1	1	0	1	0	0	0	0	0	0	0	1	0
	Respect for Sites of Historic or Cultural Interest	1	0	0	0	0	1	0	0	0	1	0	0	0
	Site Management Indicator	4	2	0	2	0	2	1	0	2	1	0	3	0
	Environmentally Purchasing Plan	1	0	0	0	0	0	0	0	1	0	0	1	0
	Environmentally Purchasing Practices & Green Cleaning	1	0	0	0	0	0	0	0	1	0	0	1	0
	Building Exterior and Hardscape Management Plan	1	1	0	1	0	1	0	0	0	1	0	1	0
	Integrated Pest Management Erosion Control and Landscape Management	1	1	0	1	0	1	1	0	0	0	0	0	0
	Reduction of Heat Island Effect Indicator	5	2	0	2	0	0	0	0	3	5	1	0	0
	Heat Island Reduction in Not Roofed Areas	1	1	0	1	0	0	0	0	0	1	0	0	0
	Heat Island Reduction in Roof Areas	1	1	0	1	0	0	0	0	1	1	0	0	0
	Exterior Walls Finishing Materials & Planting	1	0	0	0	0	0	0	0	1	1	0	0	0
	Design	1	0	0	0	0	0	0	0	0	1	0	0	0
	Greenery Provision & Ecological Features	1	0	0	0	0	0	0	0	1	1	1	0	0
	Site Emission Indicator	4	1	0	0	0	0	1	0	0	1	0	2	0
	Noise from Building Equipment	1	0	0	0	0	0	0	0	0	0	0	1	0
	Light Pollution Reduction	1	1	0	0	0	0	0	0	0	1	0	1	0
	Boiler Emission	1	0	0	0	0	0	1	0	0	0	0	0	0
	Asbestos Management Plan	1	0	0	0	0	0	0	0	0	0	0	0	0
	Total	15	6	0	5	0	3	2	0	5	8	1	6	0
	Coverage percentag		40%	0%	33%	0%	20%	13%	0%	33%	53%	7%	40%	0%
Material & Waste Reduction Factor	Sustainable Purchasing Practice Indicator	5	5	2	3	2	4	0	2	3	4	1	2	2
	Sustainable Purchasing Policy	1	1	0	1	0	1	0	0	0	0	0	0	0
	Ongoing Consumables	1	1	0	0	0	0	0	0	1	1	0	0	0
	Durable Goods & Sustainable Forest Products	1	1	1	1	1	1	0	1	1	1	1	1	1
	Facility Alternations and Additions & Reuse	1	1	1	1	1	1	0	1	1	1	0	1	1
	Reduced Mercury in Lamps	1	1	0	0	0	1	0	0	0	1	0	0	0
	Efficient Use & Selection of Materials Indicator	5	1	1	1	1	2	1	1	1	0	4	3	1
	Modular and Standardized Design	1	0	0	0	0	0	0	0	0	0	0	1	0
	Adaptability and Deconstruction	1	0	0	0	0	0	0	0	0	0	1	1	0
	Designing for robustness for Asset & Landscape	1	0	0	0	0	0	0	0	0	0	1	0	0
	Using Non-Ozone Depleting Substances	1	1	1	1	1	1	1	1	1		1	1	1
	Monitoring, Testing, and Controlling Leak of Refrigerants	1	0	0	0	0	1	0	0	0	0	1	0	0
	Solid Waste Management Practice Indicator	8	5	1	1	1	3	5	1	1	3	1	3	1
	Solid Waste Management Policy	1	1	0	0	0	1	1	0	0	0	0	1	0
	Hazardous Waste Management	1		0	0	0	1	1	0	0	0	0	0	0
	Waste Stream Audit	1	1	0	0	0	1	1	0	0	1	0	1	0
	Ongoing Consumables	1	1	0	0	0	0	0	0	0	0	0	0	0
	Durable Goods	1	1	0	0	0	0	0	0	0	0	0	0	0
	Facility Alternations and Additions	1	1	0	0	0	0	0	0	0	0	0	0	0
	tenants	1	0	1	1	1	0	1	1	1	1	1	1	1
	Compaction or Composting	1	0	0	0	0	0	1	0	0	1	0	0	0
	Total	18	11	4	5	4	9	6	4	5	7	6	8	4
	Coverage percentag		61%	22%	28%	22%	50%	33%	22%	28%	39%	33%	44%	36%
Transportation Factor	Provision of Max. Car Parking Capacity Indicator	1	0	0	1	0	0	0	0	0	0	0	0	0
	Indicator	3	1	0	0	0	2	0	0	1	0	1	0	0
	Cyclist Facilities	1	0	0	0	0	1	0	0	1	0	1	0	0
	Carpooling & Vanpooling	1	0	0	0	0	1	0	0	0	0	0	0	0
	Reduction in Conventional Commuting Trips	1	1	0	0	0	0	0	0	0	0	0	0	0
	Public & Community Accessibility Indicator	2	0	0	0	0	1	0	0	1	0	2	0	0
	Public Transport Accessibility	1	0	0	0	0	0	0	0	1	0	1	0	0
	Proximity to Amenities	1	0	0	0	0	1	0	0	0	0	1	0	0
	Provision of Low Emitting & Fuel Efficient Vehicles	1	0	0	1	0	0	0	0	1	0	0	0	0
	Total	7	1	0	2	0	3	0	0	3	0	3	0	0
	Coverage percentag		14%	0%	29%	0%	43%	0%	0%	43%	0%	43%	0%	0%

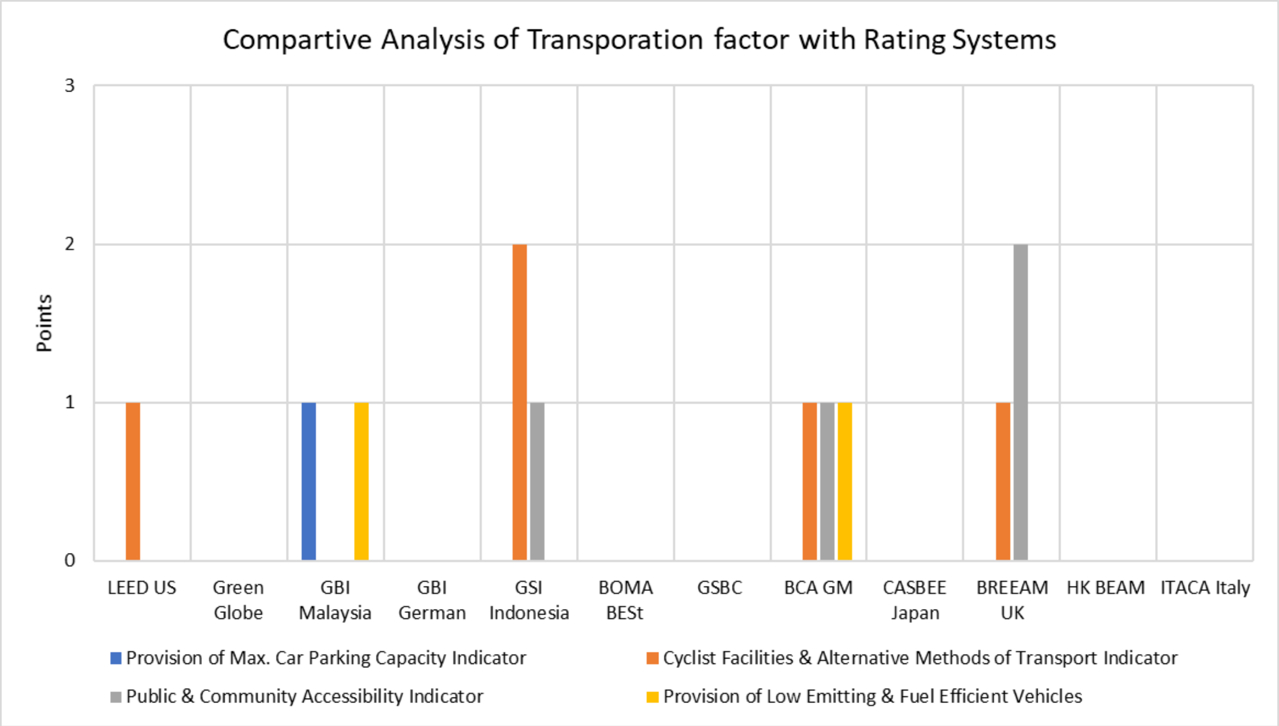


Figure 5-18: Comparative analysis of the transportation factor for the 12rating systems

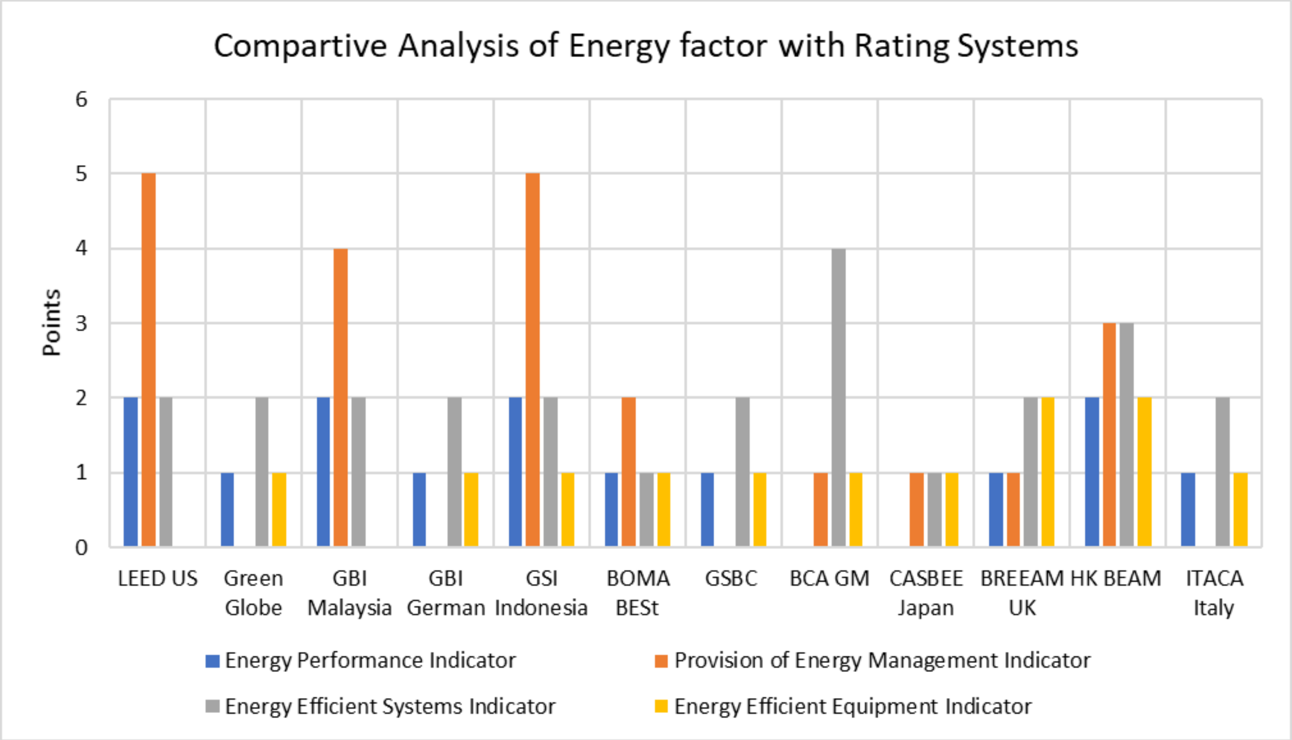


Figure 5-19: Comparative analysis of energy factor for the 12 rating systems

Table 5.10 demonstrates the comparison between rating tools based on the *water use* factor. The water conservation and water management indicators are mainly considered in all the rating tools. The water conservation indicator is considered by all rating tools except BCA GM. The water management indicator is considered by all tools except BAC GM and CASBEE. Regarding the *material and waste reduction* factor, all rating systems consider efficient use and selection of materials indicator and solid waste management practice indicator. The sustainable purchasing practice indicator is considered by all rating systems except GSI and BOMA. Singapore's BCA Green Mark rating tool does not take this indicator into account. All indicators for this factor are considered in all 12 rating systems; thus, this factor is very important in sustainability assessment (Figures 5.20 and 5.21).

Table 5-10: Comparison of the 12 rating systems of Building Sustainability (physical criteria)

Criteria, factors, indicators and sub-indicators of the proposed system		Ovell Score	LEED US	Green Globe	GBI Malaysia	GBI German	GSI Indonesia	BOMA BESt	GSBC	BCA GM	CASBEE Japan	BREEAM UK	HK BEAM	ITACA Italy
Physical Criteria														
Energy Factor	Energy Performance Indicator	3	2	1	2	1	2	1	1	0	0	1	2	1
	Minimum Energy Performance	1	1	0	1	0	1	0	0	0	0	0	1	0
	Optimizing Energy Efficiency	1	1	1	1	1	1	1	1	0	0	1	1	1
	Evaluation of Thermal Performance	1	0	0	0	0	0	1	0	1	0	0	0	0
	Indicator	6	5	0	4	0	5	2	0	1	1	1	3	0
	Energy Operating Plan	1	1	0		0	1	1	0	1	0	0	1	0
	Energy Monitoring and Metering	1	1	0	1	0	1	1	0	0	1	0	1	0
	Commissioning and Testing Energy	1	1	0	1	0	1	0	0	0	0	1	1	0
	Energy Management System (EMS)	1	1	0	1	0	0	0	0	0	0	0	0	0
	Emission Reduction Reporting	1	1	0	0	0	1	0	0	0	0	0	0	0
	Sustainable Maintenance	1	0	0	1	0	1	0	0	0		0	0	0
	Energy Efficient Systems Indicator	4	2	2	2	2	2	1	2	4	1	2	3	2
	Interior Lighting Efficiency and	1	1	1	1	1	1	0	1	1	0	1	1	1
	Renewable Energy Systems	1	1	1	1	1	1	1	1	1	1	1	1	1
	Energy Efficient Circulation Systems	1	0	0	0	0	0	0	0	1	0	0	0	0
	Efficient Ventilation System in Car	1	0	0	0	0	0	0	0	1	0	0	1	0
	Energy Efficient Equipment Indicator	3	0	1	0	1	1	1	1	1	1	2	2	1
	Energy Efficient Appliances and	1	0	0	0	0	0	0	0	0	0	0	1	0
	Energy Efficient AC Equipment	1	0	1	0	1	1	0	1	1	1	1	1	1
	High Efficiency Boilers	1	0	0	0	0	0	1	0	0	0	1	0	0
Total		16	9	4	8	4	10	5	4	6	3	6	10	4
Coverage percentag			56%	25%	50%	25%	63%	31%	25%	38%	19%	38%	63%	25%
Water Use	Water Conservation Indicator	5	3	3	3	3	4	4	3	0	2	3	4	3
	Minimum Indoor Plumbing Fixtures	1	1	1	0	1	1	1	1	0	0	1	1	1
	Additional Indoor Plumbing Fixtures	1	1	1	1	1	1	1	1	0	1	1	1	1
	Water Recycling & Rain Water	1	0	1	1	1	1	1	1	0	1	1	1	1
	Water Efficient Landscaping and	1	1	0	1	0	0	1	0	0	0	0	1	0
	Water Tap Efficiency in Public Areas	1	0	0	0	0	1	0	0	0	0	0	0	0
	Water Management Indicator	5	3	1	1	1	4	5	1	0	0	3	2	1
	Water Conservation Plan	1	0	0	0	0	1	1	0	0	0	0	1	0
	Regular Procedures for Checking and	1	0	0	0	0	1	1	0	0	0	1	0	0
	Water Performance monitoring	1	1	1	1	1	1	1	1	0	0	1	1	1
	Cooling Tower Water Management	1	1	0	0	0	0	1	0	0	0	0	0	0
	Storm Water Quantity Control &	1	1	0	0	0	1	1	0	0	0	1	0	0
Total		10	6	4	4	4	8	9	4	0	2	6	6	4
Coverage percentag			60%	40%	40%	40%	80%	90%	40%	0%	20%	60%	60%	40%
Heritage Value Factor	Building Age Indicator	4	0	0	0	0	0	0	0	0	0	0	0	0
	100-200 yrs.	1	0	0	0	0	0	0	0	0	0	0	0	0
	200-300 yrs.	1	0	0	0	0	0	0	0	0	0	0	0	0
	300-400 yrs.	1	0	0	0	0	0	0	0	0	0	0	0	0
	400 yrs. & above	1	0	0	0	0	0	0	0	0	0	0	0	0
	Building Function Indicator	4	0	0	0	0	0	0	0	0	0	0	0	0
	Residential	1	0	0	0	0	0	0	0	0	0	0	0	0
	Commercial	1	0	0	0	0	0	0	0	0	0	0	0	0
	Governmental	1	0	0	0	0	0	0	0	0	0	0	0	0
	Tourism	1	0	0	0	0	0	0	0	0	0	0	0	0
	Building Revenue Indicator	4	0	0	0	0	0	0	0	0	0	0	0	0
	Less than $100 K	1	0	0	0	0	0	0	0	0	0	0	0	0
	$100,000-200,000	1	0	0	0	0	0	0	0	0	0	0	0	0
	$200,000-300,000	1	0	0	0	0	0	0	0	0	0	0	0	0
	$300,000 & above	1	0	0	0	0	0	0	0	0	0	0	0	0
Total		12	0	0	0	0	0	0	0	0	0	0	0	0
Coverage percentag			0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Structural Condition Factor	Building Material Indicator	4	0	0	0	0	0	0	0	0	0	0	0	0
	Mud	1	0	0	0	0	0	0	0	0	0	0	0	0
	Stone	1	0	0	0	0	0	0	0	0	0	0	0	0
	Concrete	1	0	0	0	0	0	0	0	0	0	0	0	0
	Cast Iron	1	0	0	0	0	0	0	0	0	0	0	0	0
	Maintenance Plan Indicator	4	0	0	0	0	0	0	0	0	0	0	0	0
	Maintenance Frequency	1	0	0	0	0	0	0	0	0	0	0	0	0
	Inspection Frequency	1	0	0	0	0	0	0	0	0	0	0	0	0
	Intervention Minor	1	0	0	0	0	0	0	0	0	0	0	0	0
	Intervention Major	1	0	0	0	0	0	0	0	0	0	0	0	0
	Safety Indicator	1	0	0	0	0	0	0	0	0	0	0	0	0
Total		9	0	0	0	0	0	0	0	0	0	0	0	0
Coverage percentag			0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

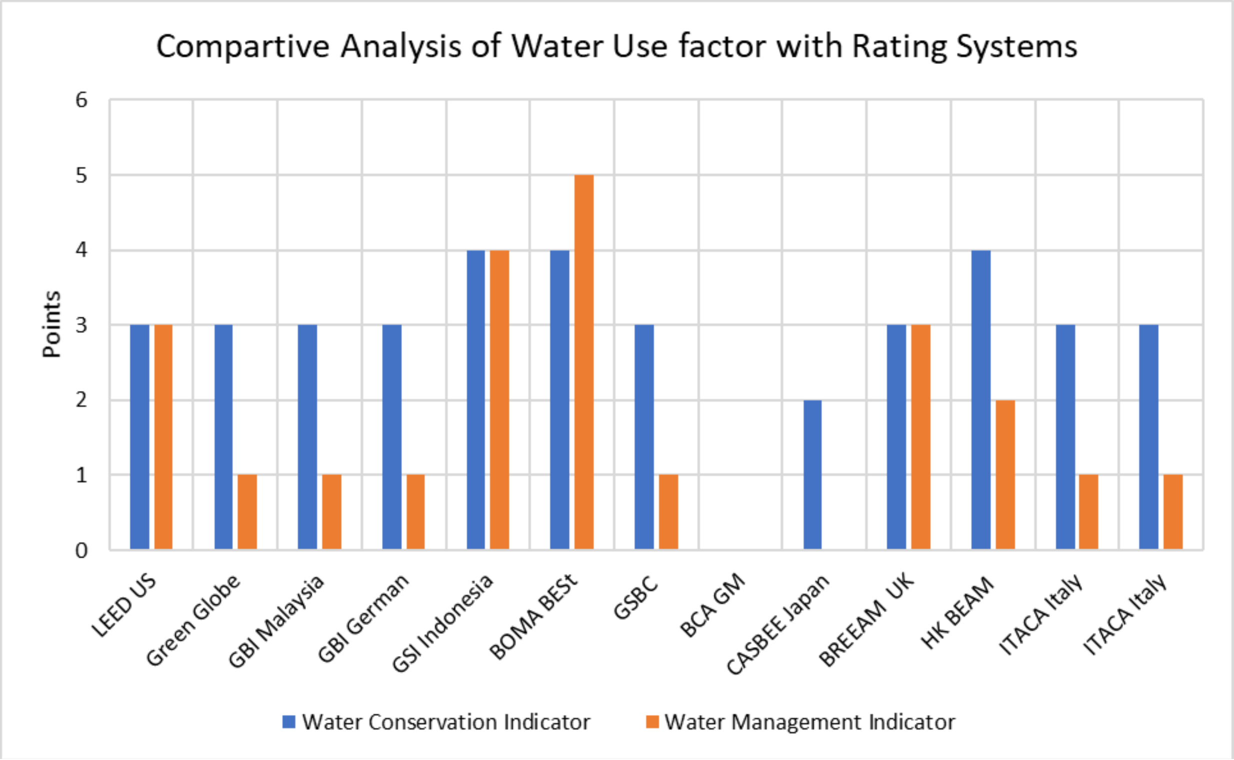


Figure 5-20: Comparative analysis of water use factor for the 12 rating systems

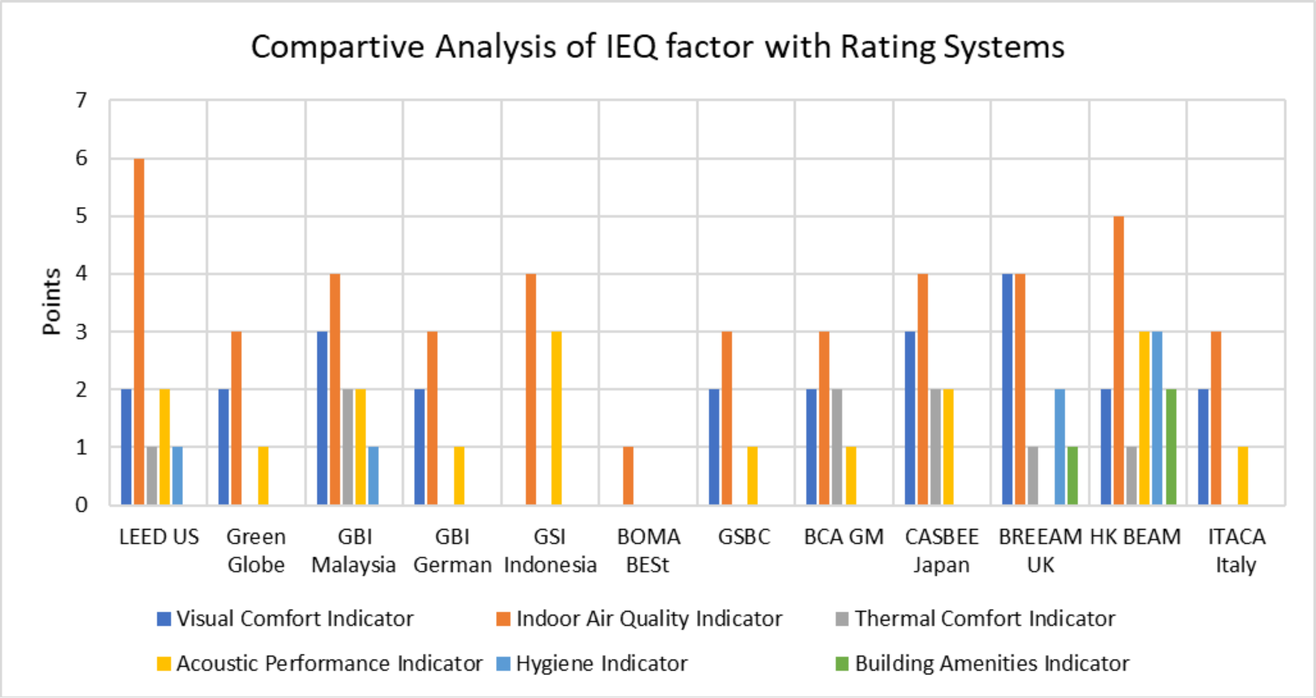


Figure 5-21: Comparative analysis of IEQ factor for the 12 rating systems

Table 5.11 shows that the *heritage value* factor is not considered by any of the rating tools except ITACA. The ITACA rating tool considers only the building function indicator. For the *indoor environmental quality* factor (Table 5.11), the following components are included in the rating systems: indoor air quality, visual comfort, thermal comfort, acoustic performance, hygiene, and building amenities. Their corresponding percentages are as follows: 100%, 87.5%, 75%, 62.5%, 50%, and 25%, respectively. In terms of the *building management* factor, the percentages that correspond to management of the building's functioning and upkeep, level of security, risk and remodeling management are 62.5%, 37.5%, 37.5%, and 12.5%, respectively

Table 5-11: Comparison of the 12 rating systems for Building Sustainability (sustainable criteria)

Criteria, factors, indicators and sub-indicators of the proposed system		OvealI Score	LEED US	Green Globe	GBI Malaysia	GBI German	GSI Indonesia	BOMA BESt	GSBC	BCA GM	CASBEE Japan	BREEAM UK	HK BEAM	ITACA Italy
Sustainable Criteria														
Indoor Environment Quality Factor	Visual Comfort Indicator	4	2	2	3	2	0	0	2	2	3	4	2	2
	Natural Lighting and External Views	1	1	0	1	0	0	0	0	0	1	1	1	0
	Glare Control	1	0	0	1	0	0	0	0	0	0	1	0	0
	Interior Lighting Distribution in	1	0	1	1	1	0	0	1	1	1	1	1	1
	Controllability of Lighting System	1	1	1	0	1	0	0	1	1	1	1	0	1
	Hight Frequency Ballasts	1	0	0	1	0	1	0	0	0	0	1	0	0
	Indoor Air Quality Indicator	7	6	3	4	3	4	1	3	3	4	4	5	3
	Minimum IAQ Performance	1	1	0	1	0	0	0	0	0	0	0	0	0
	Environmental Tobacco Smoke	1	1	0	0	0	1	0	0	0	1	0	1	0
	Increased Ventilation Performance,	1	1	0	0	0	0	0	0	0	1	1	1	0
	Indoor Air Quality Performance &	1	1	1	1	1	1	1	1	1	1	1	1	1
	Indoor Air Quality Pollutant	1	1	1	1	1	1	0	1	1	1	1	1	1
	Green Cleaning Policy	1	1	1	0	1	1	0	1	1		1	1	1
	IAQ Verification Before/ During	1	0	0	1	0	0	0	0	0	0	0	0	0
	Thermal Comfort Indicator	3	1	0	2	0	0	0	0	2	2	1	1	0
	Design, Verification	1	1	0	1	0	0	0	0	0	1	0	0	0
	Controllability of Temperature	1	0	0	1	0	0	0	0	1	0	1	0	0
	Thermal Comfort in Air-Conditioned	1	0	0	0	0	0	0	0	1	1	0	1	0
	Acoustic Performance Indicator	3	2	1	2	1	3	0	1	1	2	0	3	1
	Room Acoustic	1	1	0	1	0	1	0	0	0	0	0	1	0
	Noise Isolation	1	0	0	0	0	1	0	0	0	1	0	1	0
	Background Noise	1	1	1	1	1	1	0	1	1	1	0	1	1
	Hygiene Indicator	5	1	0	1	0	0	0	0	0	0	2	3	0
	Plumbing and Drainage	1	0	0	0	0	0	0	0	0	0	0	1	0
	Chemical Storage	1	0	0	0	0	0	0	0	0	0	1	0	0
	Biological Contamination Reduction	1	0	0	0	0	0	0	0	0	0	1	1	0
	Waste Disposal facilities de-odorizing	1	0	0	0	0	0	0	0	0	0	0	1	0
	Occupancy Comfort Survey	1	1	0	1	0	0	0	0	0	0	0		0
	Building Amenities Indicator	2	0	0	0	0	0	0	0	0	0	1	2	0
	Access for Persons with Disability	1	0	0	0	0	0	0	0	0	0	1	1	0
	Amenity Features	1	0	0	0	0	0	0	0	0	0	0	1	0
Total		24	12	6	12	6	7	1	6	8	11	12	16	6
Coverage percentag			50%	25%	50%	25%	29%	4%	25%	33%	46%	50%	67%	25%
Building Management Factor	Operation and Maintenance	5	0	0	1	0	2	0	0	2	0	4	2	0
	Condition Survey	1	0	0	0	0	0	0	0	0	0	1	0	0
	Staffing Quality and Resources	1	0	0	0	0	0	0	0	1	0	0	1	0
	Building User Manual and	1	0	0	1	0	0	0	0	1	0	1	1	0
	Operation & Maintenance Policy	1	0	0	0	0	1	0	0	0	0	1	0	0
	Operation & maintenance Procedures	1	0	0	0	0	1	0	0	0	0	1	0	0
	Security Measures & Intruder Alarm System Indicator	1	0	0	0	0	1	0	0	1	0	1	0	0
	Green Lease Indicator	1	0	0	0	0	1	0	0	1	0	1	0	0
	Risk Management Indicator	2	2	0	0	0	0	0	0	0	0	0	0	0
	Fire Risk Assessment, Fire Risk	1	1	0	0	0	0	0	0	0	0	0	0	0
	Natural Hazards	1	1	0	0	0	0	0	0	0	0	0	0	0
	Innovations Indicator	2	0	0	0	0	2	0	0	0	0	2	2	0
	Innovations in Techniques	1	0	0	0	0	1	0	0	0	0	1	1	0
	Performance Enhancement	1	0	0	0	0	1	0	0	0	0	1	1	0
Total		11	2	0	1	0	6	0	0	4	0	8	4	0
Coverage percentag			18%	0%	9%	0%	55%	0%	0%	36%	0%	73%	36%	0%

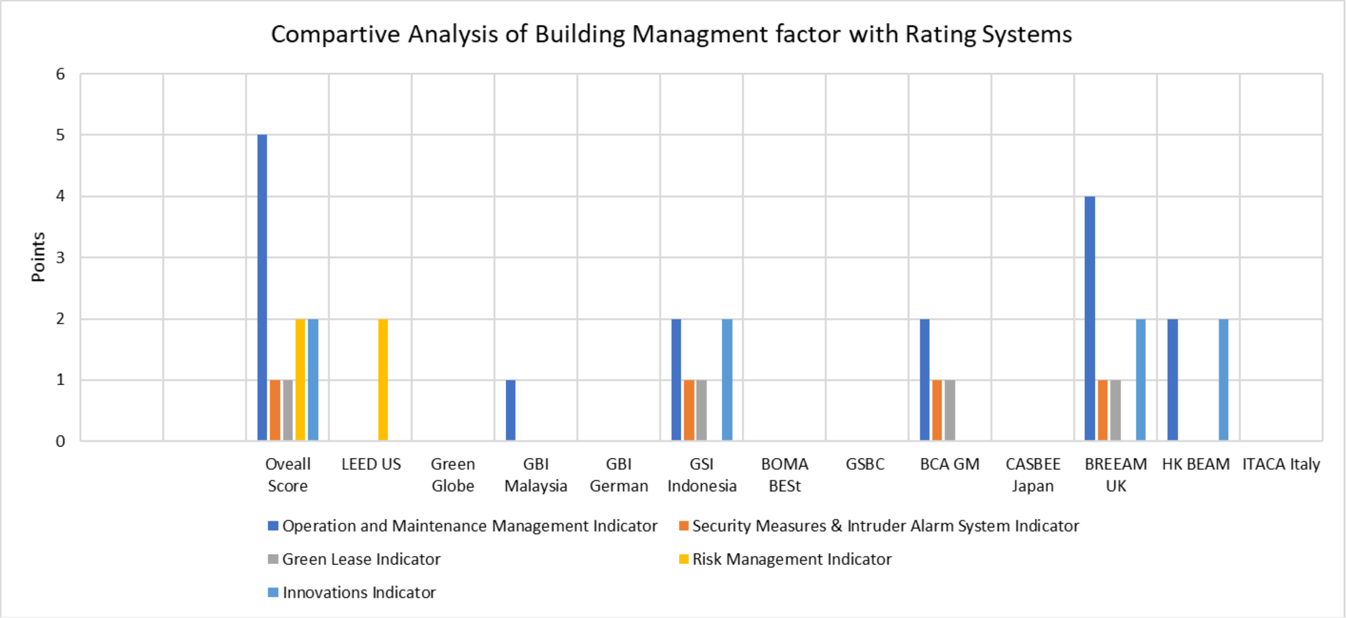


Figure 5-22: Comparative analysis of building management factor for the 12 rating systems

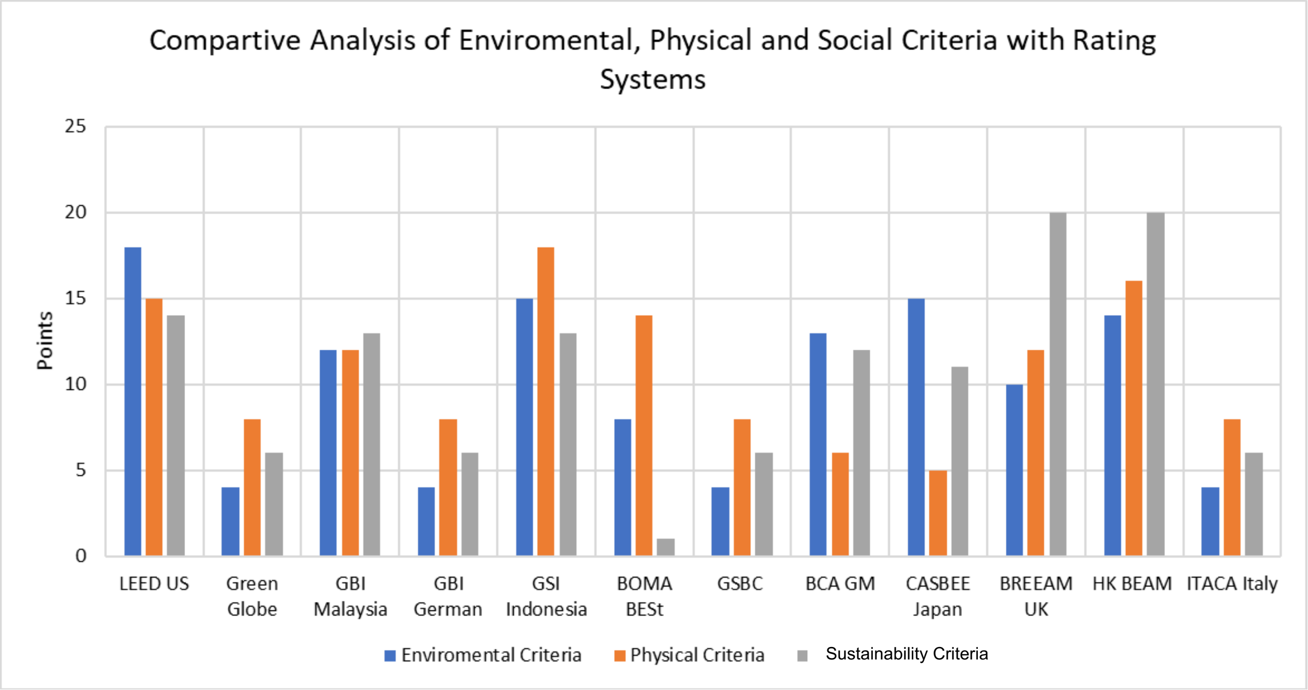


Figure 5-23: Comparative analysis of environmental, physical and sustainable criteria for the 12 rating systems

5.5 Data Reliability

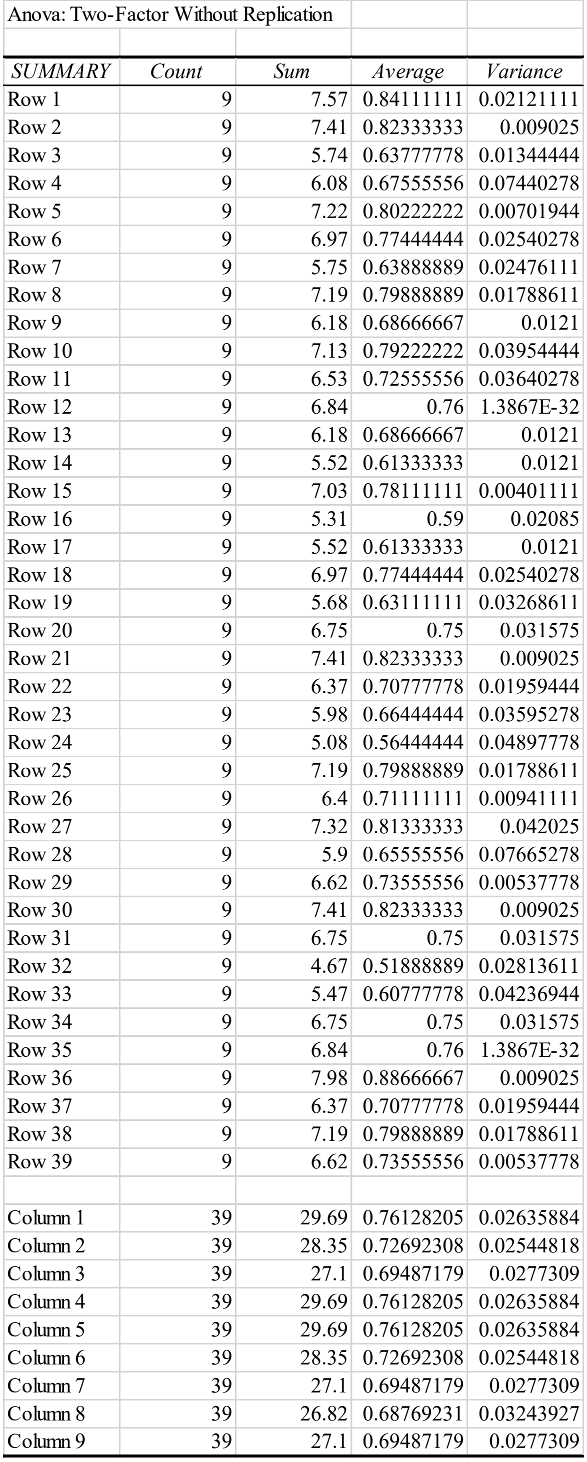
A two-stage verification methodology was followed to indicate the confidence level in the expert responses gathered. First, the *Anova: Two Factor without Replication* tool in Excel® was utilized to display the reliability level in the respondents' decisions, as shown in Table 5.12. Another validation procedure was undertaken to calculate the reliability level in the gathered responses using Minitab®, as shown in Table 5.13.

The result of this validation procedure was extremely promising, as the values of the Cronbach's alpha derived from the two methodologies were similar (0.9342). This value exceeded the acceptable benchmark of 0.7 that was identified in the literature review. In Table 5.12, the inputs and outputs for the calculation are shown.

Table 5-12: Statistical Analysis of SAHB Factors and Indicators of Relative Weight

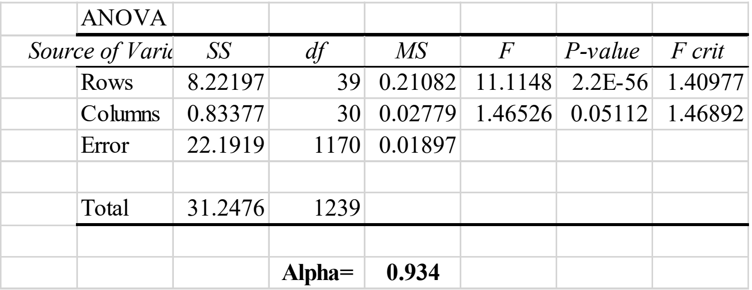
Statistical Analysis of (SAHB) Factors Relative Weight Data									
Q	F1	F2	F3	F4	F5	F6	F7	F8	F9
1	0.54	0.76	0.76	0.95	0.95	0.76	0.54	0.76	0.76
2	0.76	0.95	0.95	0.76	0.76	0.95	0.95	0.54	0.95
3	0.95	0.76	0.76	0.95	0.95	0.76	0.76	0.76	0.76
4	0.54	0.54	0.76	0.54	0.54	0.54	0.76	0.76	0.76
5	0.95	0.54	0.54	0.95	0.95	0.33	0.54	0.95	0.54
6	0.76	0.95	0.76	0.76	0.76	0.95	0.76	0.76	0.76
7	0.95	0.54	0.76	0.95	0.95	0.54	0.76	0.76	0.76
8	0.76	0.76	0.54	0.76	0.76	0.76	0.54	0.54	0.54
9	0.76	0.76	0.76	0.76	0.76	0.76	0.95	0.54	0.95
10	0.76	0.76	0.54	0.76	0.76	0.76	0.54	0.76	0.54
11	0.76	0.95	0.76	0.76	0.95	0.95	0.54	0.76	0.54
12	0.95	0.76	0.54	0.95	0.95	0.76	0.54	0.54	0.54
13	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
14	0.54	0.76	0.76	0.54	0.54	0.76	0.76	0.76	0.76
15	0.54	0.54	0.76	0.54	0.76	0.54	0.76	0.54	0.95
16	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.95	0.76
17	0.54	0.54	0.76	0.54	0.54	0.54	0.76	0.33	0.76
18	0.54	0.76	0.54	0.54	0.54	0.76	0.54	0.76	0.54
19	0.76	0.54	0.95	0.76	0.76	0.54	0.95	0.76	0.95
20	0.54	0.95	0.54	0.54	0.54	0.95	0.54	0.54	0.54
21	0.95	0.76	0.54	0.95	0.95	0.76	0.54	0.76	0.54
22	0.76	0.76	0.95	0.76	0.76	0.76	0.95	0.76	0.95
23	0.76	0.76	0.54	0.76	0.76	0.76	0.54	0.95	0.54
24	0.76	0.33	0.76	0.76	0.76	0.33	0.76	0.76	0.76
25	0.54	0.76	0.95	0.54	0.54	0.76	0.33	0.95	0.54
26	0.95	0.76	0.95	0.95	0.95	0.76	0.76	0.54	0.76
27	0.76	0.54	0.76	0.76	0.76	0.54	0.76	0.76	0.76
28	0.54	0.95	0.95	0.54	0.54	0.95	0.95	0.95	0.95
29	0.95	0.76	0.76	0.95	0.95	0.76	0.76	0.54	0.33
30	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.54	0.76
31	0.95	0.76	0.76	0.95	0.76	0.76	0.76	0.76	0.76
32	0.95	0.54	0.76	0.95	0.95	0.54	0.76	0.54	0.76
33	0.54	0.76	0.33	0.54	0.54	0.76	0.33	0.54	0.33
34	0.54	0.95	0.54	0.54	0.54	0.95	0.54	0.33	0.54
35	0.95	0.54	0.76	0.95	0.95	0.54	0.76	0.54	0.76
36	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
37	0.54	0.54	0.76	0.95	0.54	0.95	0.76	0.95	0.54
38	0.54	0.76	0.76	0.54	0.54	0.76	0.95	0.95	0.54
39	0.76	0.76	0.76	0.95	0.95	0.76	0.76	0.54	0.76
40	0.54	0.95	0.76	0.76	0.76	0.54	0.76	0.54	0.76

Table 5-13: ANOVA analysis method in Excel®

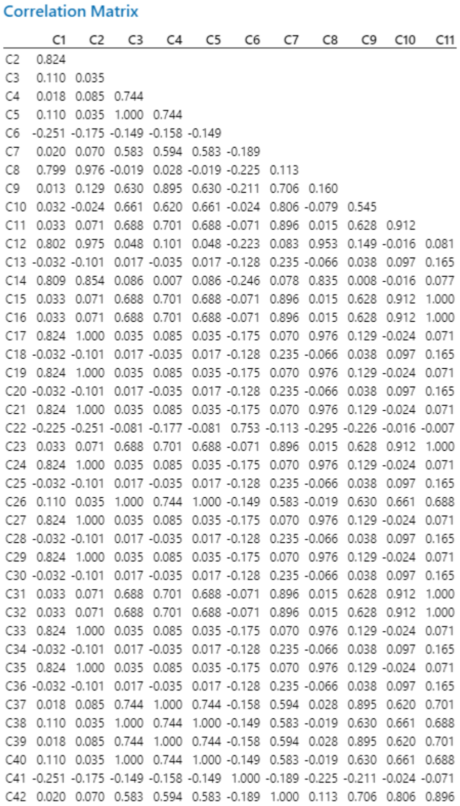


Anova: Two-Factor Without Replication				
SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	9	7.57	0.84111111	0.02121111
Row 2	9	7.41	0.82333333	0.009025
Row 3	9	5.74	0.63777778	0.01344444
Row 4	9	6.08	0.67555556	0.07440278
Row 5	9	7.22	0.80222222	0.00701944
Row 6	9	6.97	0.77444444	0.02540278
Row 7	9	5.75	0.63888889	0.02476111
Row 8	9	7.19	0.79888889	0.01788611
Row 9	9	6.18	0.68666667	0.0121
Row 10	9	7.13	0.79222222	0.03954444
Row 11	9	6.53	0.72555556	0.03640278
Row 12	9	6.84	0.76	1.3867E-32
Row 13	9	6.18	0.68666667	0.0121
Row 14	9	5.52	0.61333333	0.0121
Row 15	9	7.03	0.78111111	0.00401111
Row 16	9	5.31	0.59	0.02085
Row 17	9	5.52	0.61333333	0.0121
Row 18	9	6.97	0.77444444	0.02540278
Row 19	9	5.68	0.63111111	0.03268611
Row 20	9	6.75	0.75	0.031575
Row 21	9	7.41	0.82333333	0.009025
Row 22	9	6.37	0.70777778	0.01959444
Row 23	9	5.98	0.66444444	0.03595278
Row 24	9	5.08	0.56444444	0.04897778
Row 25	9	7.19	0.79888889	0.01788611
Row 26	9	6.4	0.71111111	0.00941111
Row 27	9	7.32	0.81333333	0.042025
Row 28	9	5.9	0.65555556	0.07665278
Row 29	9	6.62	0.73555556	0.00537778
Row 30	9	7.41	0.82333333	0.009025
Row 31	9	6.75	0.75	0.031575
Row 32	9	4.67	0.51888889	0.02813611
Row 33	9	5.47	0.60777778	0.04236944
Row 34	9	6.75	0.75	0.031575
Row 35	9	6.84	0.76	1.3867E-32
Row 36	9	7.98	0.88666667	0.009025
Row 37	9	6.37	0.70777778	0.01959444
Row 38	9	7.19	0.79888889	0.01788611
Row 39	9	6.62	0.73555556	0.00537778
Column 1	39	29.69	0.76128205	0.02635884
Column 2	39	28.35	0.72692308	0.02544818
Column 3	39	27.1	0.69487179	0.0277309
Column 4	39	29.69	0.76128205	0.02635884
Column 5	39	29.69	0.76128205	0.02635884
Column 6	39	28.35	0.72692308	0.02544818
Column 7	39	27.1	0.69487179	0.0277309
Column 8	39	26.82	0.68769231	0.03243927
Column 9	39	27.1	0.69487179	0.0277309

Table 5-14: Cronbach's alpha analysis in Minitab®

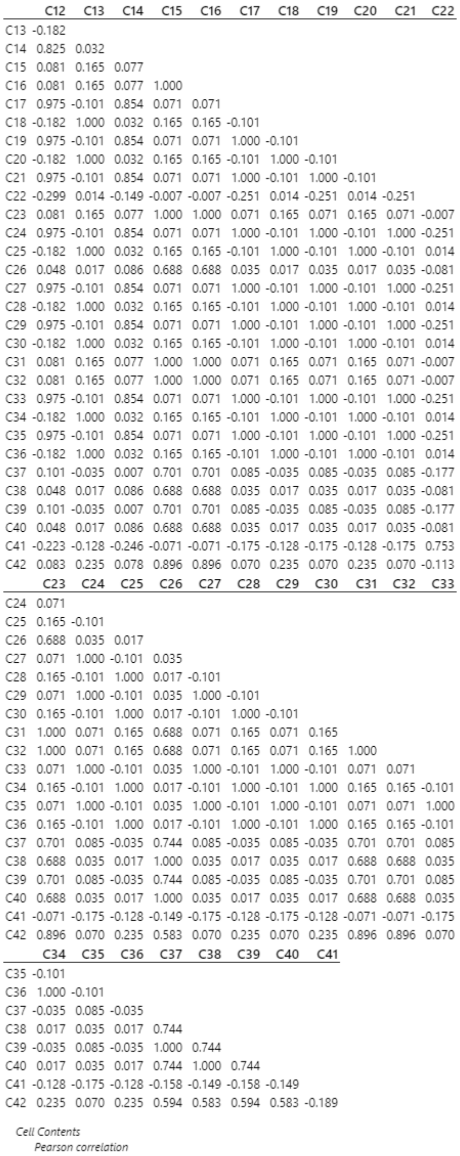


ANOVA						
Source of Vari	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	8.22197	39	0.21082	11.1148	2.2E-56	1.40977
Columns	0.83377	30	0.02779	1.46526	0.05112	1.46892
Error	22.1919	1170	0.01897			
Total	31.2476	1239				
		Alpha=	**0.934**			



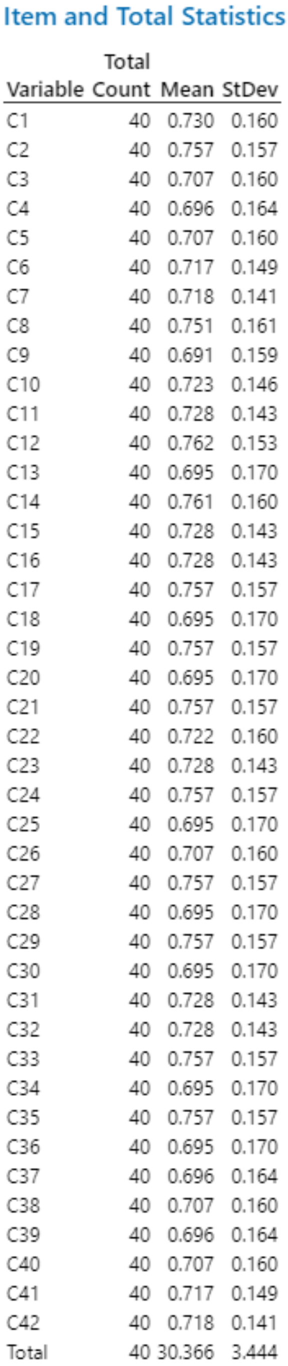
Correlation Matrix

```
        C1     C2     C3     C4     C5     C6     C7     C8     C9    C10    C11
C2   0.824
C3   0.110  0.035
C4   0.018  0.085  0.744
C5   0.110  0.035  1.000  0.744
C6  -0.251 -0.175 -0.149 -0.158 -0.149
C7   0.020  0.070  0.583  0.594  0.583 -0.189
C8   0.799  0.976 -0.019  0.028 -0.019 -0.225  0.113
C9   0.013  0.129  0.630  0.895  0.630 -0.211  0.706  0.160
C10  0.032 -0.024  0.661  0.620  0.661 -0.024  0.806 -0.079  0.545
C11  0.033  0.071  0.688  0.701  0.688 -0.071  0.896  0.015  0.628  0.912
C12  0.802  0.975  0.048  0.101  0.048 -0.223  0.083  0.953  0.149 -0.016  0.081
C13 -0.032 -0.101  0.017 -0.035  0.017 -0.128  0.235 -0.066  0.038  0.097  0.165
C14  0.809  0.854  0.086  0.007  0.086 -0.246  0.078  0.835  0.008 -0.016  0.077
C15  0.033  0.071  0.688  0.701  0.688 -0.071  0.896  0.015  0.628  0.912  1.000
C16  0.033  0.071  0.688  0.701  0.688 -0.071  0.896  0.015  0.628  0.912  1.000
C17  0.824  1.000  0.035  0.085  0.035 -0.175  0.070  0.976  0.129 -0.024  0.071
C18 -0.032 -0.101  0.017 -0.035  0.017 -0.128  0.235 -0.066  0.038  0.097  0.165
C19  0.824  1.000  0.035  0.085  0.035 -0.175  0.070  0.976  0.129 -0.024  0.071
C20 -0.032 -0.101  0.017 -0.035  0.017 -0.128  0.235 -0.066  0.038  0.097  0.165
C21  0.824  1.000  0.035  0.085  0.035 -0.175  0.070  0.976  0.129 -0.024  0.071
C22 -0.225 -0.251 -0.081 -0.177 -0.081  0.753 -0.113 -0.295 -0.226 -0.016 -0.007
C23  0.033  0.071  0.688  0.701  0.688 -0.071  0.896  0.015  0.628  0.912  1.000
C24  0.824  1.000  0.035  0.085  0.035 -0.175  0.070  0.976  0.129 -0.024  0.071
C25 -0.032 -0.101  0.017 -0.035  0.017 -0.128  0.235 -0.066  0.038  0.097  0.165
C26  0.110  0.035  1.000  0.744  1.000 -0.149  0.583 -0.019  0.630  0.661  0.688
C27  0.824  1.000  0.035  0.085  0.035 -0.175  0.070  0.976  0.129 -0.024  0.071
C28 -0.032 -0.101  0.017 -0.035  0.017 -0.128  0.235 -0.066  0.038  0.097  0.165
C29  0.824  1.000  0.035  0.085  0.035 -0.175  0.070  0.976  0.129 -0.024  0.071
C30 -0.032 -0.101  0.017 -0.035  0.017 -0.128  0.235 -0.066  0.038  0.097  0.165
C31  0.033  0.071  0.688  0.701  0.688 -0.071  0.896  0.015  0.628  0.912  1.000
C32  0.033  0.071  0.688  0.701  0.688 -0.071  0.896  0.015  0.628  0.912  1.000
C33  0.824  1.000  0.035  0.085  0.035 -0.175  0.070  0.976  0.129 -0.024  0.071
C34 -0.032 -0.101  0.017 -0.035  0.017 -0.128  0.235 -0.066  0.038  0.097  0.165
C35  0.824  1.000  0.035  0.085  0.035 -0.175  0.070  0.976  0.129 -0.024  0.071
C36 -0.032 -0.101  0.017 -0.035  0.017 -0.128  0.235 -0.066  0.038  0.097  0.165
C37  0.018  0.085  0.744  1.000  0.744 -0.158  0.594  0.028  0.895  0.620  0.701
C38  0.110  0.035  1.000  0.744  1.000 -0.149  0.583 -0.019  0.630  0.661  0.688
C39  0.018  0.085  0.744  1.000  0.744 -0.158  0.594  0.028  0.895  0.620  0.701
C40  0.110  0.035  1.000  0.744  1.000 -0.149  0.583 -0.019  0.630  0.661  0.688
C41 -0.251 -0.175 -0.149 -0.158 -0.149  1.000 -0.189 -0.225 -0.211 -0.024 -0.071
C42  0.020  0.070  0.583  0.594  0.583 -0.189  1.000  0.113  0.706  0.806  0.896
```



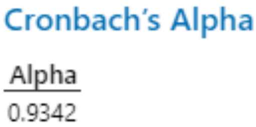
```
       C12    C13    C14    C15    C16    C17    C18    C19    C20    C21    C22
C13 -0.182
C14  0.825  0.032
C15  0.081  0.165  0.077
C16  0.081  0.165  0.077  1.000
C17  0.975 -0.101  0.854  0.071  0.071
C18 -0.182  1.000  0.032  0.165  0.165 -0.101
C19  0.975 -0.101  0.854  0.071  0.071  1.000 -0.101
C20 -0.182  1.000  0.032  0.165  0.165 -0.101  1.000 -0.101
C21  0.975 -0.101  0.854  0.071  0.071  1.000 -0.101  1.000 -0.101
C22 -0.299  0.014 -0.149 -0.007 -0.007 -0.251  0.014 -0.251  0.014 -0.251
C23  0.081  0.165  0.077  1.000  1.000  0.071  0.165  0.071  0.165  0.071 -0.007
C24  0.975 -0.101  0.854  0.071  0.071  1.000 -0.101  1.000 -0.101  1.000 -0.251
C25 -0.182  1.000  0.032  0.165  0.165 -0.101  1.000 -0.101  1.000 -0.101  0.014
C26  0.048  0.017  0.086  0.688  0.688  0.035  0.017  0.035  0.017  0.035 -0.081
C27  0.975 -0.101  0.854  0.071  0.071  1.000 -0.101  1.000 -0.101  1.000 -0.251
C28 -0.182  1.000  0.032  0.165  0.165 -0.101  1.000 -0.101  1.000 -0.101  0.014
C29  0.975 -0.101  0.854  0.071  0.071  1.000 -0.101  1.000 -0.101  1.000 -0.251
C30 -0.182  1.000  0.032  0.165  0.165 -0.101  1.000 -0.101  1.000 -0.101  0.014
C31  0.081  0.165  0.077  1.000  1.000  0.071  0.165  0.071  0.165  0.071 -0.007
C32  0.081  0.165  0.077  1.000  1.000  0.071  0.165  0.071  0.165  0.071 -0.007
C33  0.975 -0.101  0.854  0.071  0.071  1.000 -0.101  1.000 -0.101  1.000 -0.251
C34 -0.182  1.000  0.032  0.165  0.165 -0.101  1.000 -0.101  1.000 -0.101  0.014
C35  0.975 -0.101  0.854  0.071  0.071  1.000 -0.101  1.000 -0.101  1.000 -0.251
C36 -0.182  1.000  0.032  0.165  0.165 -0.101  1.000 -0.101  1.000 -0.101  0.014
C37  0.101 -0.035  0.007  0.701  0.701  0.085 -0.035  0.085 -0.035  0.085 -0.177
C38  0.048  0.017  0.086  0.688  0.688  0.035  0.017  0.035  0.017  0.035 -0.081
C39  0.101 -0.035  0.007  0.701  0.701  0.085 -0.035  0.085 -0.035  0.085 -0.177
C40  0.048  0.017  0.086  0.688  0.688  0.035  0.017  0.035  0.017  0.035 -0.081
C41 -0.223 -0.128 -0.246 -0.071 -0.071 -0.175 -0.128 -0.175 -0.128 -0.175  0.753
C42  0.083  0.235  0.078  0.896  0.896  0.070  0.235  0.070  0.235  0.070 -0.113
       C23    C24    C25    C26    C27    C28    C29    C30    C31    C32    C33
C24  0.071
C25  0.165 -0.101
C26  0.688  0.035  0.017
C27  0.071  1.000 -0.101  0.035
C28  0.165 -0.101  1.000  0.017 -0.101
C29  0.071  1.000 -0.101  0.035  1.000 -0.101
C30  0.165 -0.101  1.000  0.017 -0.101  1.000 -0.101
C31  1.000  0.071  0.165  0.688  0.071  0.165  0.071  0.165
C32  1.000  0.071  0.165  0.688  0.071  0.165  0.071  0.165  1.000
C33  0.071  1.000 -0.101  0.035  1.000 -0.101  1.000 -0.101  0.071  0.071
C34  0.165 -0.101  1.000  0.017 -0.101  1.000 -0.101  1.000  0.165  0.165 -0.101
C35  0.071  1.000 -0.101  0.035  1.000 -0.101  1.000 -0.101  0.071  0.071  1.000
C36  0.165 -0.101  1.000  0.017 -0.101  1.000 -0.101  1.000  0.165  0.165 -0.101
C37  0.701  0.085 -0.035  0.744  0.085 -0.035  0.085 -0.035  0.701  0.701  0.085
C38  0.688  0.035  0.017  1.000  0.035  0.017  0.035  0.017  0.688  0.688  0.035
C39  0.701  0.085 -0.035  0.744  0.085 -0.035  0.085 -0.035  0.701  0.701  0.085
C40  0.688  0.035  0.017  1.000  0.035  0.017  0.035  0.017  0.688  0.688  0.035
C41 -0.071 -0.175 -0.128 -0.149 -0.175 -0.128 -0.175 -0.128 -0.071 -0.071 -0.175
C42  0.896  0.070  0.235  0.583  0.070  0.235  0.070  0.235  0.896  0.896  0.070
       C34    C35    C36    C37    C38    C39    C40    C41
C35 -0.101
C36  1.000 -0.101
C37 -0.035  0.085 -0.035
C38  0.017  0.035  0.017  0.744
C39 -0.035  0.085 -0.035  1.000  0.744
C40  0.017  0.035  0.017  0.744  1.000  0.744
C41 -0.128 -0.175 -0.128 -0.158 -0.149 -0.158 -0.149
C42  0.235  0.070  0.235  0.594  0.583  0.594  0.583 -0.189

  Cell Contents
     Pearson correlation
```



Item and Total Statistics

```
                 Total
Variable Count  Mean  StDev
C1          40  0.730  0.160
C2          40  0.757  0.157
C3          40  0.707  0.160
C4          40  0.696  0.164
C5          40  0.707  0.160
C6          40  0.717  0.149
C7          40  0.718  0.141
C8          40  0.751  0.161
C9          40  0.691  0.159
C10         40  0.723  0.146
C11         40  0.728  0.143
C12         40  0.762  0.153
C13         40  0.695  0.170
C14         40  0.761  0.160
C15         40  0.728  0.143
C16         40  0.728  0.143
C17         40  0.757  0.157
C18         40  0.695  0.170
C19         40  0.757  0.157
C20         40  0.695  0.170
C21         40  0.757  0.157
C22         40  0.722  0.160
C23         40  0.728  0.143
C24         40  0.757  0.157
C25         40  0.695  0.170
C26         40  0.707  0.160
C27         40  0.757  0.157
C28         40  0.695  0.170
C29         40  0.757  0.157
C30         40  0.695  0.170
C31         40  0.728  0.143
C32         40  0.728  0.143
C33         40  0.757  0.157
C34         40  0.695  0.170
C35         40  0.757  0.157
C36         40  0.695  0.170
C37         40  0.696  0.164
C38         40  0.707  0.160
C39         40  0.696  0.164
C40         40  0.707  0.160
C41         40  0.717  0.149
C42         40  0.718  0.141
Total       40 30.366  3.444
```



Cronbach's Alpha

```
Alpha
0.9342
```

Table 5.14 depicts results from the statistical analysis and data reliability of the questionnaire conducted in Saudi Arabia and Canada. It is evident that the Cronbach's alpha values were greater than 0.7 for a majority of the indicators. However, exceptions were present for the Site and Ecology and Energy indicators. Similarly, the coefficient of variance values for a majority of the indicators ranged from 5% to 43%. The similarity between the obtained results of the Cronbach's alpha and the coefficient of variance proves the high reliability of the collected data. Furthermore, the calculated mean, median and mode are listed in the Appendix. The values of the median and mode fall close to the mean, which is a further indication of the reliability of the collected data. All the statistical results demonstrate the robustness of the collected data and support its applicability in the implementation of the heritage building assessment tool as a whole and specifically, the determination of the weights of the indicators.

5.6 Weighted Normalized Decision matrix calculation

As presented in Chapter 3, a decision matrix is formulated to identify the expert preferences with respect to each of the identified factors by means of a Triangular Fuzzy Number (TFN) that converts the linguistic terms representing the experts' decisions into a tri-component set to be used in the Fuzzy TOPSIS analysis procedure. Results are displayed in Table 5.13, where the first column represents the number of respondents, and the respondents' preferences with respect to each of the nine factors are further shown in each succeeding row.

5.7 The BIM model for MP in the KSA and GN in Canada

The BIM modeling was carried out using Autodesk's Revit® software. The AutoCAD® drawings (provided by the Riyadh Development Authority) were used as the primary input for the Revit model. The model further demonstrated the properties of both the external façade and the internal spaces with the purpose of collecting data for the *SA* model and acting as a base model for the energy simulation model. Further outputs of this step included:

1) The effective area of the ground floor used in the energy consumption calculations and to estimate the greenery provision value and the reduction value of the heat island effect of the non-roofed area.
2) The area of the external walls included in the assessment of the building's envelope.
3) The area of the roof to be included in the heat island effect assessment.
4) The area of the building envelope exposed to the prevailing wind, which was used as an input figure for the wind movement analysis of the building.
5) The total count of the interior spaces that determine the score of some indicators in the energy, water use, and indoor environmental quality factors (see Figures 5.24 & 5.25).

5.8 Energy simulation model

Energy simulation is a tool for analyzing and understanding the complex behavior of energy, which is used in construction, analytical building energy surveys, and evaluation of architectural design. They are also based on traditional methods of calculating energy loads in heating, ventilation, refrigeration and air conditioning (Sousa, 2012). The construction power simulation was performed to analyze building energy performance in order to understand the relationship between the transient factor design and the properties of the building's energy consumption (Coakley et al., 2014). Building energy modeling also helps to study the scenarios of the buildings interims of electricity and gas consumption. As a result, the fit solution for the building can be given to minimize energy consumption.

The energy simulation model was developed using ArchiCAD® software. It simulated the building's daily, monthly, and yearly energy consumption. Connected with Rhino and Grasshopper, ArchiCAD® was the software of choice due to its seamless workflow (Enzyme, 2016).

The significance of weather conditions on a building's performance mandates the use of reliable climate data for energy modeling. To understand the significance of reliable weather data and the different dynamics related to energy simulation, a study is highlighted that performed energy simulations for different envelopes. Weather data was also integrated on one of the Shibam city buildings (registered as a UNESCO world heritage site). In the preliminary simulations, three different weather files were tested and surprisingly, all three produced very similar and accurate results. Further analysis showed that the files contained data on locations that were in close vicinity to one other (within a few kilometers). Although there were significant discrepancies in the wind conditions among the different files, this did not affect the result since the building is not very susceptible to wind. The findings from this study showed that a design team should use a weather file that is representative of the local context of the building. The design team has the freedom to use a ready-made weather file or create a weather file from scratch by either collecting data from local sources (EPW1) or mine their own data (EPW2). Interestingly, the second option proved more lucrative for the design team in the study. The total cost for setting up an independent weather station for the building was about $2,500. After running the data logger for several months, very close measurements were generated, similar to those of MIT and UMASS weather stations, which could be seamlessly converted into -1257 -EPW formats. This implies that in a situation where climate data is not available, design teams should collect their own weather data over a period of at least a few months in order to have a clearer image of the weather conditions of the building site. In addition, the data collected should reflect normal weather conditions. This means that data collected in abnormal years or months would be of limited use. Collecting data using the EPW1 approach proved to be extremely time-consuming, as it required a significant amount of manual labor to merge, synchronize, and input the data sources.

For the case studies in this thesis, two different weather files were obtained from the Climate Consultant® software. These files were then imported to ArchiCAD® to perform energy simulation with the local climate data of both considered buildings.

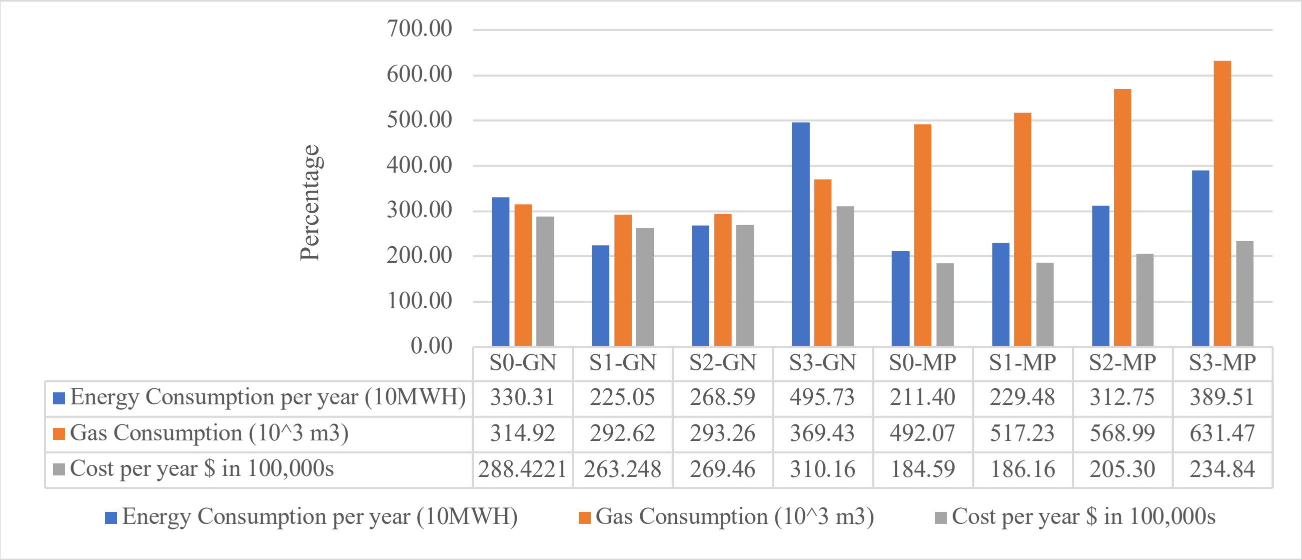
In order to evaluate energy-efficiency for each building, information on the shape of the building, wall thickness, direction, openings percentage, and orientation were required. In other words, it can be represented as scenarios: construction material. For example,

(Scenario No. 1: Mud; Scenario No. 1: Stone; and Scenario No. 1: Concreate)

As a result, six scenarios were analyzed, for both Murabba Palace and Grey Nuns Building, and an attempt was made to simulate each scenario for each building. One drawback, however, is the lack of support of curves in ArchiCAD®; hence, all openings were modeled as straight lines. The data for each case comprised:

1. The simulation was done for all months of the year
2. Reflection of each was 20 % and solid resistance was 1.87 k/s
3. Brick thinness in the ceiling was 30 cm
4. Single glass type with a thinness of 6 mm was used
5. Residential building type was considered, and the model was treated as one mass
6. The area of a model for each case was between 10-15 km^2
7. Results were recorded for the average energy consumption per year.

To begin simulation, the construction material (e.g. mud) and other materials for the next scenario were defined, as shown in Figure 5.26.



	S0-GN	S1-GN	S2-GN	S3-GN	S0-MP	S1-MP	S2-MP	S3-MP
■ Energy Consumption per year (10MWH)	330.31	225.05	268.59	495.73	211.40	229.48	312.75	389.51
■ Gas Consumption (10^3 m3)	314.92	292.62	293.26	369.43	492.07	517.23	568.99	631.47
■ Cost per year $ in 100,000s	288.4221	263.248	269.46	310.16	184.59	186.16	205.30	234.84

Figure 5-24: : Comparison between real and simulated scenarios of GN & MP

Several options were assumed for each building in the case study and the walls were considered as external (“envelope construction material’’). Alternatives of different component assemblies are depicted in Tables 5.15, 5.16 and 5.17.

Table 5-15: Available scenarios for Murabba Palace, KSA

Building assemblies	**Scenarios No.**	**Scenarios description**
External walls	1	Mud bricks envelope construction material which is the actual used material
External walls	2	Stone envelope construction material which is assumed material
External walls	3	Concrete bricks envelope construction material which is assumed material

Table 5-16: Available scenarios for Grey Nuns Building, Canada

Building assemblies	Scenarios No.	Scenarios description
External walls	1	Stone bricks envelope construction material which is the actual used material
External walls	2	Mud envelope construction material which is assumed material
External walls	3	Concrete bricks envelope construction material which is assumed material

Table 5-17: Available scenarios for GN & MP

Scenario No.	Energy Consumption per year (KWH)	Gas Consumption (m^3)	Cost per year $
Grey Nuns Actual	3,303,099.00	208,564.80	253,098.23
S1-GN	2,250,501.00	197,491.80	203,621.05
S2-GN	2,685,890.00	198,686.80	224,830.13
S3-GN	4,957,290.00	314,927.80	288,425.09
Murabba Palace Actual	2,113,983.44	492,070.00	184,590.14
S1-MP	2,294,780.00	517,230.00	186,164.92
S2-MP	3,127,450.00	568,991.00	205,297.57
S3-MP	3,895,130.00	631,468.00	234,843.76

5.9 Emissions Analysis

Three simulations were performed using ArchiCAD® software for Murabba Palace and Grey Nuns Building, respectively. Each simulation covered different envelope material (mud, stone and concrete). Each had different energy conditions and consequently, resulted in different Energy factor scores. These simulations would provide envelope material contexts. The simulated data was compared to the actual energy consumption data and the results are shown in Figures 5.25, 5.26 and 5.27 and Tables 5.18 and 5.19. For instance, the actual energy consumption of the Grey Nuns Building is 3,303,099 kWh while simulation results showed a yearly energy consumption of 2,250,501 kWh. Furthermore, concrete buildings consumed the highest amount of energy for both the Grey Nuns Building and Murabba Palace. Mud building in the case of the Grey Nuns Building and stone building in the case of the Murabba Palace showed the lowest energy consumption. Similarly, the highest gas consumption in the case of the Murabba Palace was that of the concrete building while the lowest was that of the stone building. The values of energy and gas consumption are reflected directly in the yearly cost. For instance, the stone material in the case of the Murabba Palace had the highest energy and gas consumption across the different material envelopes and as a result, the stone material yielded the highest cost.

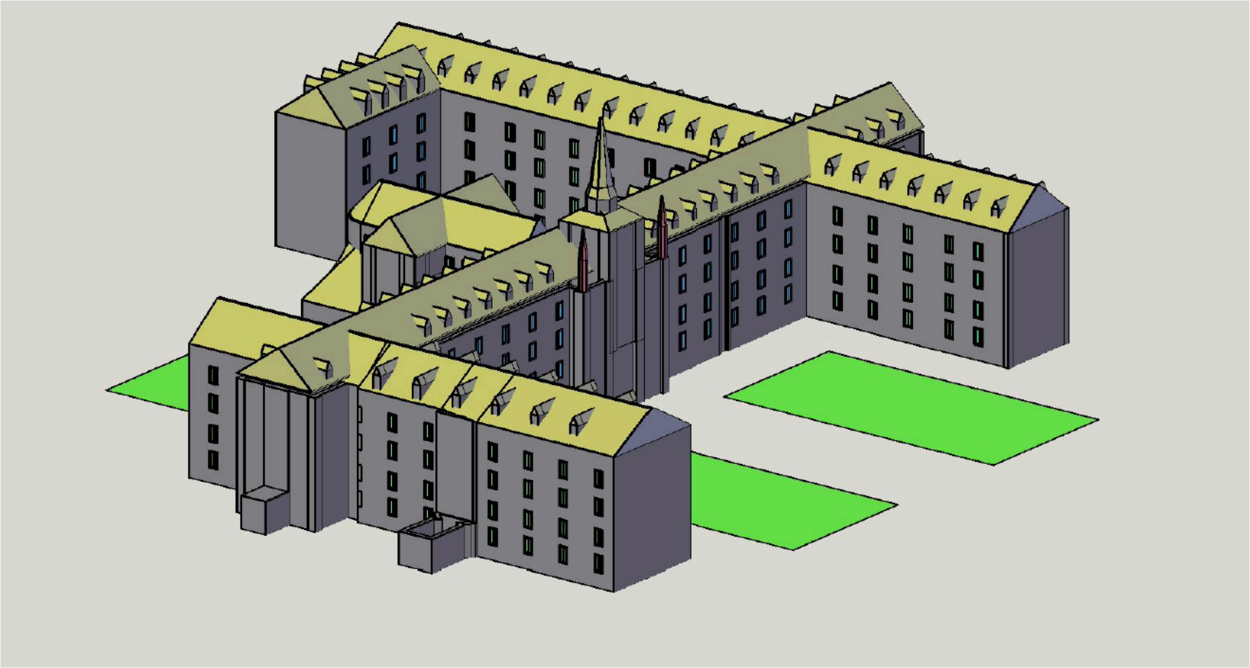


Figure 5-25: BIM model of Grey Nuns Building, Canada using ArchiCAD®

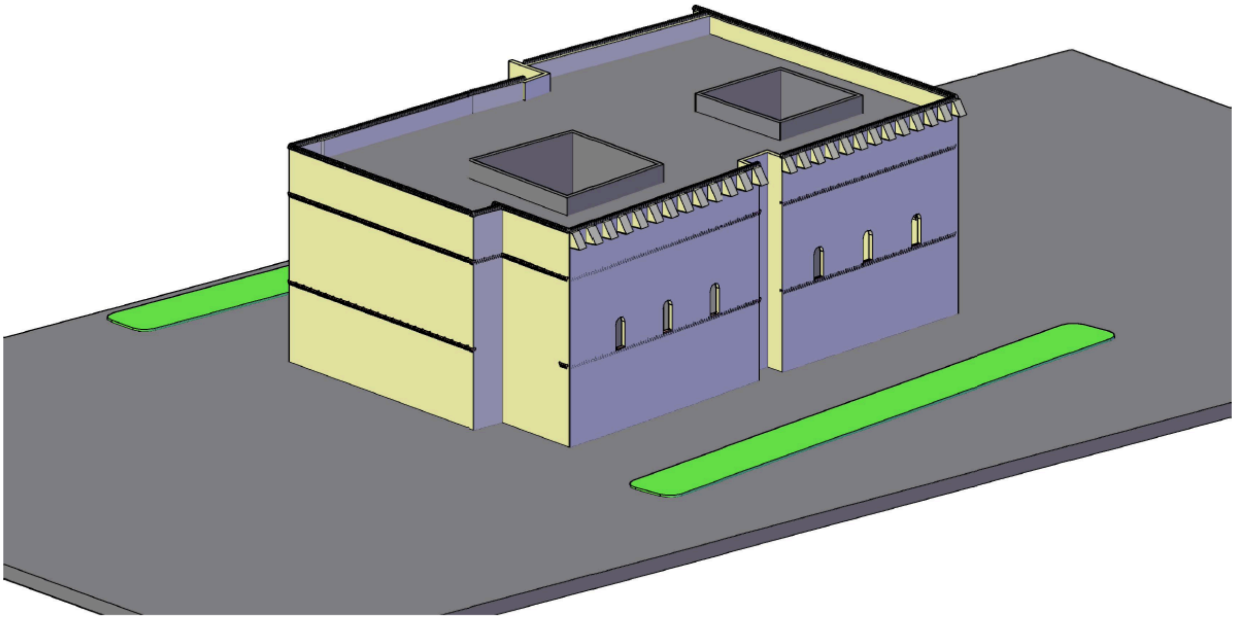


Figure 5-26: BIM model of Murabba Palace, KSA using ArchiCAD®

Table 5-18: Energy Consumption for Riyadh and Montreal

Total energy consumption for Riyadh and Montreal cities in MWh				
Total	Riyadh	Montreal	0.878	R
	8639.33	23656.78	1.559	M
Carbon emissions in Riyadh and Montreal cities in KgCO$_2$				
Total	Riyadh	Montreal	176.51	R
	4061332	6467297	412.54	M
Cost per year in Riyadh and Montreal cities in CAD				
Total	Riyadh	Montreal	2.180	R
	21,459.72	$13,827.40	$ 0.9112	M

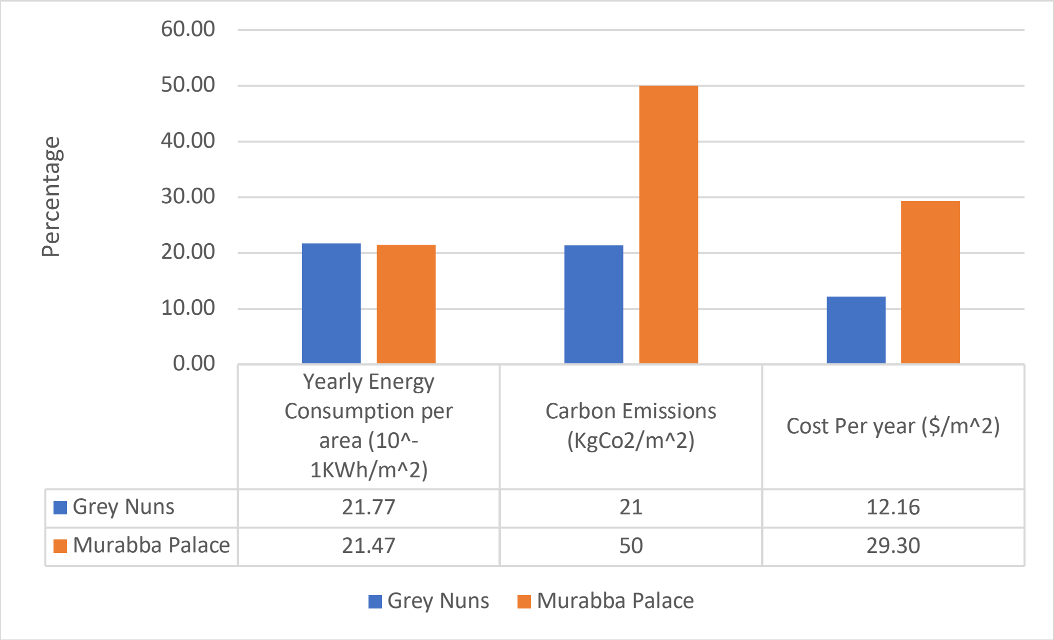


Figure 5-27: Energy, carbon consumption and cost per m^2

In Figure 5.27, the yearly energy consumption per unit area of the two buildings are quite similar. However, Murabba Palace has more carbon emission and energy cost per unit area is higher than Grey Nuns building (per unit area).

Table 5-19: Energy, carbon consumption and cost per m^2 for GN & MP

Activity	Grey Nuns	Murabba Palace
Energy Consumption per year (MWh)	3303	2114
Carbon Emissions ($KgCO_2$)	314924.8	492070
Cost Per year ($)	288,422.09	184,590.14

Activity	Grey Nuns	Murabba Palace
Yearly Energy Consumption per area (10^-1KWh/m^2)	21.77	21.47
Carbon Emissions ($KgCO_2/m^2$)	21	50
Cost Per year ($/$m^2$)	12.16	29.30

5.10 Building Energy Analysis of HBs

In this section, the project life cycle phases for heritage buildings are revisited. Particularly, the proposed phases are analyzed to evaluate the significance of each phase and the associated building energy and gas consumption and cost. So, building energy analysis of heritage buildings may help to do efficient maintenance properly.

After ensuring the reliability and consistency of the data obtained from the answers to the questionnaire, questionnaire responses were analyzed and presented in Figures 5.28, 5.29 and 5.30 to illustrate the electricity consumption, gas consumption, and cost, respectively, for both of the case studies. In Figure 5.30, the operation phase had the highest energy and gas consumption for both buildings, with energy consumption of almost 150,000 kWh per area and 20,000 kWh per area for the Grey Nuns Building (GN) and Murabba Palace (MP), respectively. Similarly, the cost of the operation phase was also the highest among all the different phases, with values of 222,085 CAD/m^2 and 142134 CAD/m^2 for GN and MP, respectively. The planning phase, however, had the lowest energy, gas consumption and cost in both GN and MP, with costs of 5,768 CAD/m^2 and 3,692 CAD/m^2, respectively. The energy-savings generated from using mud envelope material rather than the current stone envelope material was calculated as 1,052,598 kWh per year in GN.

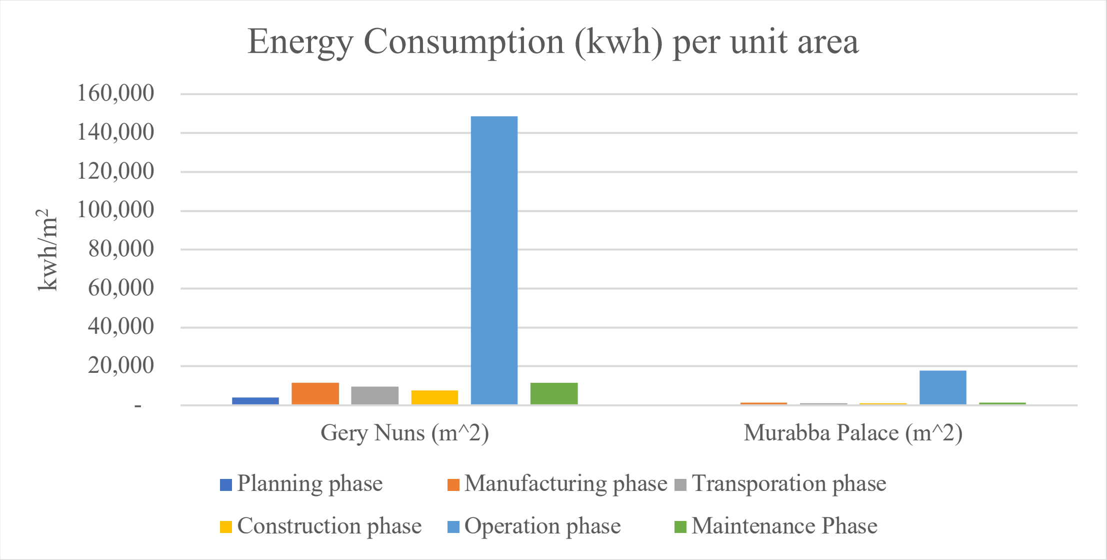


Figure 5-28: Electricity consumption in the life cycle phases of both case studies

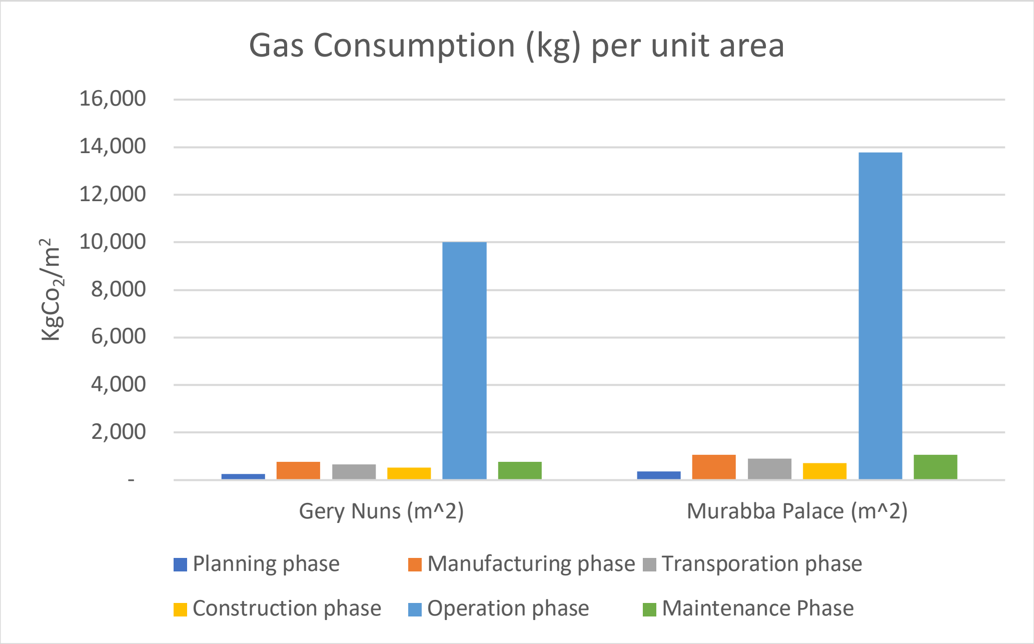
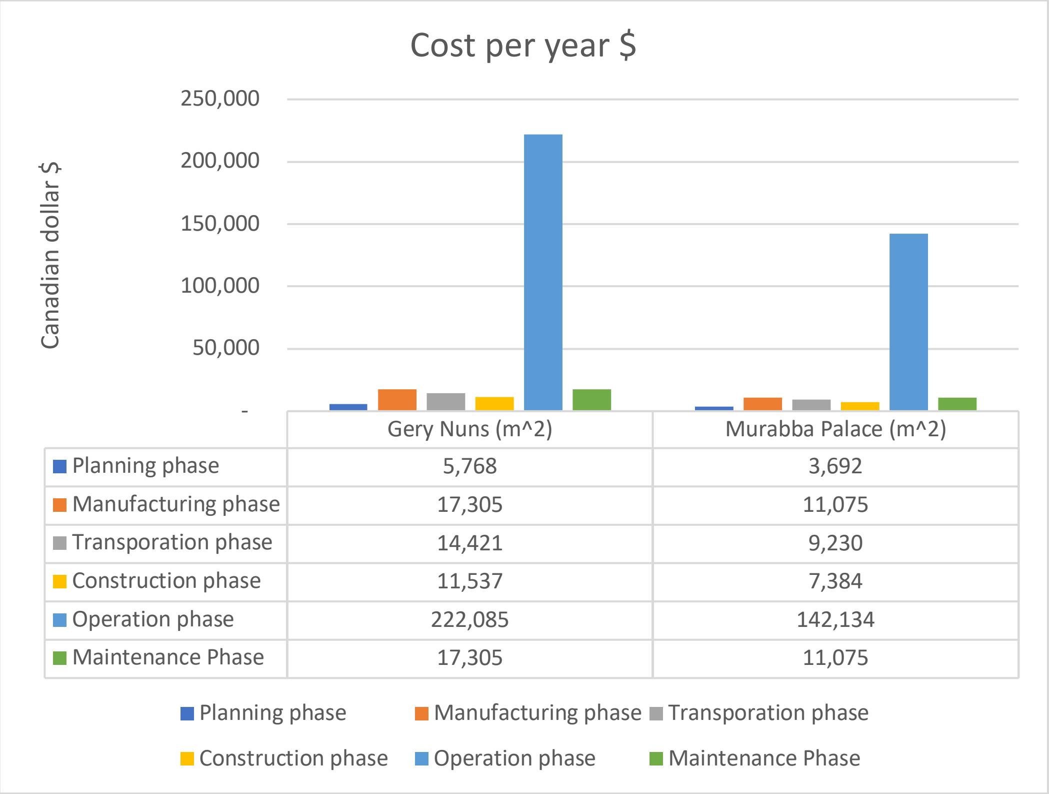


Figure 5-29: Gas consumption in the life cycle phases of both case studies



	Gery Nuns (m^2)	Murabba Palace (m^2)
Planning phase	5,768	3,692
Manufacturing phase	17,305	11,075
Transporation phase	14,421	9,230
Construction phase	11,537	7,384
Operation phase	222,085	142,134
Maintenance Phase	17,305	11,075

Figure 5-30: Cost in the life cycle phases of both case studies

Sensitivity Analysis

For both case studies, sensitivity analysis was performed with respect to LCC of energy for HBs (Tables 5.20, 5.21 and Figure 5.31). Figure 5.31 shows the impact of weight changes on the overall LCC of energy by highlighting the percent difference of LCC of energy on the y axis. It is evident that LCC of energy is not greatly affected by significant weight changes. The least percent difference in LCC of energy is seen in the first and fourth cases while similar percent differences can be observed in the second, third and sixth cases (reduction from 0.77 to 0.76). However, for the fifth case, a significantly greater percent difference for the LCC of energy can be observed. Therefore, for both case studies, compared to the other life cycle phases, the operation phase greatly impacts energy and gas consumption and cost.

The six cases are described as:

Case 1 - the weight of the planning phase was increased by +15%

Case 2 - the weight of the manufacturing phase was increased by +15%

Case 3 - the weight of the transportation phase was increased by +15%

Case 4 - the weight of the construction phase was increased by +15%

Case 5 - the weight of the operation phase was increased by +15%

Case 6 - the weight of the maintenance phase was increased by +15%

Table 5-20: LCP Sensitivity analysis for Grey Nuns

Gery Nuns						
Phases#	Energy Consumption		Gas Consumption		Cost per year $	
	value	*weight*	*value*	*weight*	*value*	*weight*
Planning phase	3,861	0.02	260	0.02	5,768	0.02
Manufacturing phase	11,584	0.06	781	0.06	17,305	0.06
Transportation phase	9,653	0.05	651	0.05	14,421	0.05
Construction phase	7,723	0.04	520	0.04	11,537	0.04
Operation phase	148,661	0.77	10,018	0.77	222,085	0.77
Maintenance Phase	11,584	0.06	781	0.06	17,305	0.06

Table 5-21: LCP Sensitivity analysis for Murabba Palace

Murabba Palace						
Phases#	Energy Consumption		Gas Consumption		Cost per year $	
	value	*weight*	*value*	*weight*	*value*	*weight*
Planning phase	460	0.02	358	0.02	3,692	0.02
Manufacturing phase	1,381	0.06	1,075	0.06	11,075	0.06
Transportation phase	1,150	0.05	895	0.05	9,230	0.05
Construction phase	920	0.04	716	0.04	7,384	0.04
Operation phase	17,717	0.77	13,790	0.77	142,134	0.77
Maintenance Phase	1,381	0.06	1,075	0.06	11,075	0.06

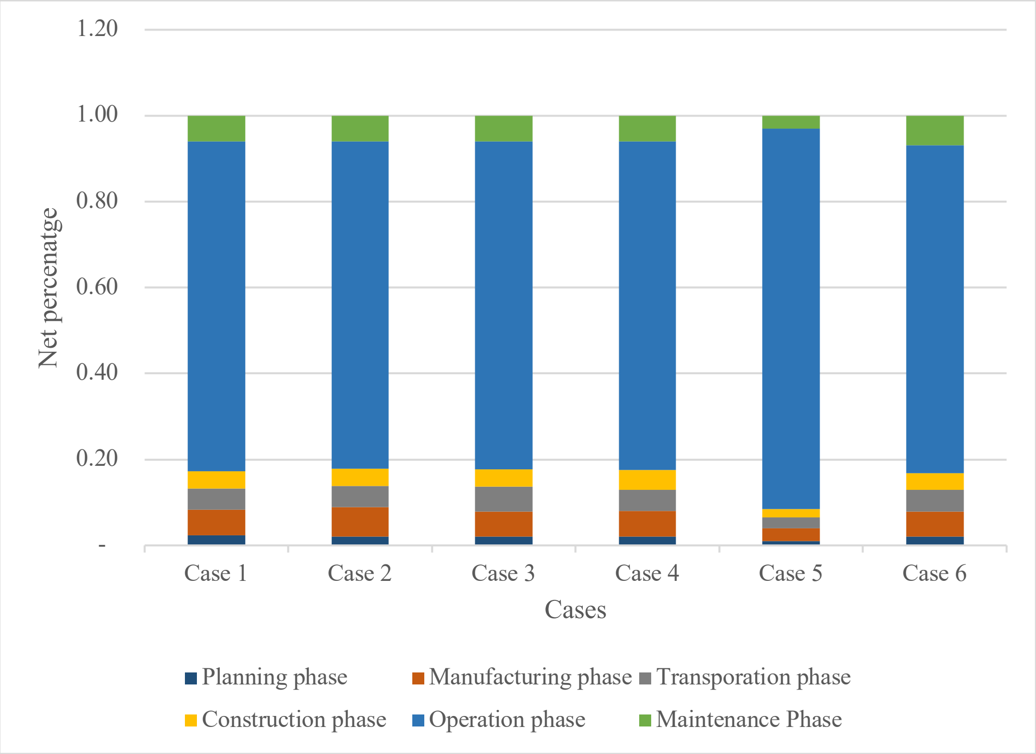


Figure 5-31: Sensitivity analysis of LCC for HBs

5.11 Sustainability Assessment (SA)

The score of each factor/indicator is calculated by leveraging the collected data of each case study and results from BIM, assessment model and energy simulations, according to the previous Equations 4.8 to 4.12. The process and scoring system are illustrated in detail in Tables 5.22 and 5.23. Particularly, the tables contain ten sections: a description of the attributes associated with sustainability (criteria, factors and indicators), calculation of the local and global weights, scoring system for each indicator of the building, the sustainability index of each indicator, the *HBI* of the case study, and the *SAHB* of the study. The scoring system and the sustainability index of each indicator can be classified under attained and maximum subsections to represent the actually obtained scores and the maximum allowable scores per indicator.

There are three main criteria that affect sustainability assessment, which are environmental, physical and sustainable criteria. Each has factors and indicators. For instance, the environmental criterion has three factors: (a) *site and ecology factor* has *local weight (WL)* 0.507 and *global weight (WG)* 0.232. This factor has four indicators which are: site selection, site management, and reduced heat island effect and site emission. For case studies, MP achieved a score of 10; GN had 9 out of 18 points; and the maximum indicator index (MII) was 0.921, (b) *material waste reduction factor* has *local weight (WL)* 0.191 and *global weight (WG)* 0.087. This factor has three indicators: sustainability purchasing policy, efficient use of materials, and solid waste management practice. For case studies, MP achieved a score of 3; GN had 11 out of 25 points; and the maximum indicator index (MII) was 0.667, c) *transportation factor* has *local weight (WL)* 0.302 and *global weight (WG)* 0.138. This factor has three indicators: public transport accessibility, car parking, and fuel-efficient vehicle. For case studies, MP achieved a score of 2; GN had 7 out of 12 points; and the maximum indicator index (MII) was 0.653.

For the physical criterion, four factors exist: (a) *energy factor* has the highest weights in both *local weight (WL)* 0.325 and *global weight (WG)* 0.122. This factor has four indicators: energy performance, provision of energy management and energy-efficient systems and equipment. For case studies, MP achieved a score of 51; GN had 60 out of 78 points; and the maximum indicator index (MII) was 2.447, (b) *water use factor* has *local weight (WL)* 0.044 and *global weight (WG)* 0.016. This factor has two indicators: water conservation and water management. For case studies, MP achieved a score of 16; GN had 6 out of 31 points; and the maximum indicator index (MII) was 0.263.

For the sustainable criterion, two factors exist: (a) *IEQ factor* has *local weight (WL)* 0.666 and *global weight (WG)* 0.113. This factor has six indicators: visual comfort, hygiene, indoor air quality, thermal comfort, acoustic performance and building amenities. For case studies, MP achieved a score of 13; GN had 36 out of 48 points; and the maximum indicator index (MII) was 0.964, (b) *building management factor* has *local weight (WL)* 0.334 and *global weight (WG)* 0.056. This factor has five indicators: maintenance management, innovation, security measures, green lease, and risk management. For case studies, MP achieved a score of 10; GN had 20 out of 36 points; and the maximum indicator index (MII) was 0.446.

Finally, the heritage building indices for MP and GN were determined as 3.447 and 4.549 over 7.238, respectively, based on the proposed method. For the total sustainability assessment for heritage buildings, MP had 47.63%, which corresponds to *Unsatisfied* while GN had 62.84%, which corresponds to *Satisfied,* based on the SAHB scale.

Table 5-22: Determination of the Sustainability Index for Murabba palace & Grey Nuns Building (Factors & Indicators)

		Sustainability Index Determination											
Criterion	Criteria Weight	**Factor Name**	**Factor WL**	**Factor WG**	**Indicator**	**Weight Local (W)**	**Weight global (WG)**	**Murabba palace**		**Grey Nuns**		**Maximum Score (SC)**	**Maximum Indicator Index (MII)**
								Achieved Score (SC)	**Indicator Index (II)**	**Achieved Score (SC)**	**Indicator Index (II)**		
Enviromental	0.457	Site and Ecology Factor	0.507	0.232	Site Selection	0.391	0.091	2	0.181	2	0.181	2	0.181
					Site Management	0.329	0.076	4	0.305	2	0.152	6	0.457
					Reduce Heat Island	0.110	0.025	2	0.051	4	0.102	8	0.204
					Site Emissions	0.170	0.039	2	0.079	1	0.039	2	0.079
					Total		**0.232**	**10**	**0.616**	**9**	**0.475**	**18**	**0.921**
		Material Waste Reduction Factor	0.191	0.087	Sustainable Purchasing Policy	0.468	0.041	0	0.000	0	0.000	5	0.204
					Efficient Use of Materials	0.270	0.024	0	0.000	5	0.118	7	0.165
					Solid waste Management practice	0.262	0.023	3	0.069	6	0.137	13	0.297
					Total		**0.087**	**3**	**0.069**	**11**	**0.255**	**25**	**0.667**
		Transportation Factor	0.302	0.138	Public Transport Accessibility	0.415	0.057	0	0.000	5	0.286	10	0.573
					Car Parking Capacity	0.366	0.051	1	0.051	1	0.051	1	0.051
					Fuel Efficient Vehicle	0.219	0.030	1	0.030	1	0.030	1	0.030
					Total		**0.138**	**2**	**0.081**	**7**	**0.367**	**12**	**0.653**
Physical	0.374	Energy Factor	0.325	0.122	Energy Performance	0.320	0.039	20	0.778	20	0.778	28	1.089
					Provision of Energy Management	0.274	0.033	10	0.333	15	0.500	15	0.500
					Energy Efficient Systems	0.199	0.024	17	0.411	17	0.411	24	0.581
					Energy Efficient Equipment	0.208	0.025	4	0.101	8	0.202	11	0.278
					Total		**0.122**	**51**	**1.623**	**60**	**1.891**	**78**	**2.447**
		Water Use Factor	0.044	0.016	Water Conservation	0.342	0.006	10	0.056	2	0.011	14	0.079
					Water Management	0.658	0.011	6	0.065	4	0.043	17	0.184
					Total		**0.016**	**16**	**0.121**	**6**	**0.055**	**31**	**0.263**
		Heritage Value Factor	0.298	0.111	Building Age	0.371	0.041	2	0.083	4	0.165	4	0.165
					Building Function	0.362	0.040	4	0.161	2	0.081	4	0.161
					Building Revenues	0.267	0.030	2	0.060	2	0.060	4	0.119
					Total		**0.111**	**8**	**0.304**	**8**	**0.306**	**12**	**0.446**
		Structural Condition Factor	0.333	0.125	Building Material	0.498	0.062	4	0.248	3	0.186	4	0.248
					Maintenance Plan	0.324	0.040	0	0.000	1	0.040	4	0.161
					Safety	0.178	0.022	0	0.000	1	0.022	1	0.022
					Total		**0.125**	**4**	**0.248**	**5**	**0.249**	**9**	**0.432**
Sustainable	0.169	IEQ factor	0.666	0.113	Visual Comfort	0.175	0.020	4	0.079	11	0.217	11	0.217
					Hygiene	0.169	0.019	2	0.038	6	0.114	7	0.133
					Indoor Air Quality	0.190	0.021	2	0.043	11	0.235	19	0.406
					Thermal Comfort	0.224	0.025	3	0.076	3	0.076	5	0.126
					Acoustic Performance	0.107	0.012	1	0.012	3	0.036	3	0.036
					Building Amenities	0.135	0.015	1	0.015	2	0.030	3	0.046
					Total		**0.113**	**13**	**0.262**	**36**	**0.708**	**48**	**0.964**
		Building Management Factor	0.334	0.056	Maintenance Management	0.252	0.014	5	0.071	10	0.142	17	0.242
					Innovations	0.198	0.011	2	0.022	2	0.022	10	0.112
					Security Measures	0.149	0.008	2	0.017	4	0.034	4	0.034
					Green Lease	0.168	0.009	0	0.000	2	0.019	2	0.019
					Risk Management	0.233	0.013	1	0.013	2	0.026	3	0.039
					Total		**0.056**	**10**	**0.123**	**20**	**0.244**	**36**	**0.446**
Heritage Building Index (HBI)								3.447		4.549		7.238	
Total of Sustainability Assessment for Heritage Building (TSAHB)								47.63		62.84			

Table 5-23: Determination of the Sustainability Index for Murabba palace & Grey Nuns Building (Sub-indicators)

Factor	Factor Weight	Indicator	Indicator Weight	Sub-Indicator	Weight local (WL)	Weight Global (WG)	Murabba palace		Grey Nuns		Maximum Score (SC)	Maximum sub Indicator Index (SMII)
							Achieved Score (SC)	Sub-Indicator Index (SII)	Achieved Score (SC)	Sub-Indicator Index (SII)		
Energy factor	0.122	Energy Performance	0.039	Minimum Energy Performance	0.368	0.0143	Fulfilled	Fulfilled	Fulfilled	Fulfilled	Prerequiste	Prerequiste
				Optimizing Energy Efficiency Performance & Reduction of CO2 emissions	0.337	0.0131	18	0.236	18	0.236	18	0.236
				Evaluation of Thermal Performance Reduction of Building Envelope	0.295	0.0115	0	0.000	10	0.115	10	0.115
				Total		**0.0389**	**18**	**0.236**	**28.000**	**0.351**	**28**	**0.351**
		Provision of Energy Management	0.033	Energy Operating Plan	0.252	0.0084	1	0.008	1	0.008	1	0.008
				Energy Monitoring and Metering	0.149	0.0050	2	0.010	3	0.015	4	0.020
				Commissioning and Testing Energy Systems	0.168	0.0056	3	0.017	3	0.017	5	0.028
				Building Automation System, or Energy Management System (EMS)	0.233	0.0078	1	0.008	1	0.008	1	0.008
				Sustainable Maintenance	0.198	0.0066	7	0.043	7	0.046	11	0.064
				Total		**0.0333**	**14**	**0.086**	**15**	**0.094**	**22**	**0.733**
		Energy Efficient Systems	0.024	Interior Lighting Efficiency and Zoning Control.	0.351	0.0084	11	0.093	14	0.118	16	0.135
				Renewable Energy Systems	0.394	0.0095	4	0.038	4	0.038	6	0.057
				Energy Efficient Circulation Systems (Lifts and escalators)	0.255	0.0061	1	0.006	2	0.012	2	0.012
				Total		**0.0240**	**16**	**0.137**	**20**	**0.168**	**24**	**0.204**
		Energy Efficient Equipment	0.025	Energy Efficient Appliances and Cloth Drying Facilities	0.411	0.0103	2	0.021	2	0.021	2	0.021
				Energy Efficient AC Equipment	0.334	0.0084	6	0.050	6	0.050	8	0.067
				High Efficiency Boilers	0.255	0.0064	1	0.006	1	0.006	1	0.006
				Total		**0.0250**	**9**	**0.077**	**9**	**0.077**	**11**	**0.094**
IEQ	0.133	Visual Comfort	0.2	Natural Lighting and External Views	0.320	0.0640	1	0.064	1	0.064	1	0.064
				Glare Control	0.274	0.0548	2	0.110	4	0.219	4	0.219
				Interior Lighting Distribution in Normally and Non-normally Occupied Areas	0.199	0.0398	2	0.080	2	0.080	2	0.080
				High Frequency Ballasts	0.208	0.0416	4	0.166	4	0.166	4	0.166
				Total		**0.2002**	**9**	**0.420**	**11**	**0.529**	**11**	**0.5292**
		Indoor Air Quality	0.21	Minimum IAQ Performance	0.175	0.0368	Fulfilled	Fulfilled	Fulfilled	Fulfilled	Prerequiste	Prerequiste
				Environmental tobacco Smoke Control	0.190	0.0399	Fulfilled	Fulfilled	Fulfilled	Fulfilled	Prerequiste	Prerequiste
				Increased Ventilation Performance, Localized Ventilation& Ventilation in Common Areas	0.224	0.0470	2	0.094	2	0.094	2	0.094
				Indoor Air Quality Performance & management (audit, Construction management, Management Plan and Monitoring of CO2, CO & NO2)	0.106	0.0223	6	0.134	4	0.089	6	0.134
				Indoor Air Quality Pollutant monitoring (chemical, physical and biological)	0.169	0.0355	3	0.106	3	0.106	3	0.106
				Green Cleaning Policy	0.136	0.0286	4	0.114	4	0.114	8	0.228
				Total		**0.2100**	**15**	**0.448**	**13**	**0.404**	**19**	**0.563**
		Thermal Comfort	0.025	Design and Verification	0.417	0.0104	1	0.010	1	0.010	1	0.010
				Controllability of Temperature	0.352	0.0088	1	0.009	1	0.009	1	0.009
				Thermal Comfort in Air Conditioned Premises and in Naturally Ventilated premises	0.231	0.0058	1	0.006	1	0.006	3	0.017
				Total		**0.0250**	**3**	**0.025**	**3**	**0.025**	**5**	**0.037**
		Acoustic Performance	0.012	Room Acoustic	0.387	0.0046	1	0.005	1	0.005	1	0.005
				Noise isolation	0.356	0.0043	1	0.004	1	0.004	1	0.004
				Background Noise	0.257	0.0031	1	0.003	1	0.003	1	0.003
				Total		**0.0120**	**3**	**0.012**	**3**	**0.012**	**3**	**0.012**
		Hygiene	0.019	Plumbing and Drainage	0.233	0.0044	2	0.009	2	0.009	2	0.009
				Chemical storage	0.130	0.0025	1	0.002	1	0.002	1	0.002
				Biological contamination Reduction	0.195	0.0037	0	0.000	1	0.004	2	0.007
				Waste disposal facilities de-odorizing system	0.227	0.0043	0	0.000	1	0.004	1	0.004
				Occupancy Comfort Survey	0.215	0.0041	1	0.004	1	0.004	1	0.004
				Total		**0.0190**	**4**	**0.015**	**6**	**0.023**	**7**	**0.027**
		Building Amenities	0.015	Access for Persons with Disability	0.498	0.0075	1	0.007	1	0.007	1	0.007
				Amenity features	0.502	0.0075	1	0.008	1	0.008	2	0.015
				Total		**0.0150**	**2**	**0.015**	**2**	0.030	**3**	**0.023**
Heritage Building Index (HBI)							1.471		1.713		2.571	

5.12 Summary

This chapter focused on the study of 12 selected global rating systems. It was demonstrated that the 12 rating systems are different in terms of the considered indicators. These systems did not completely overlap in their list of considered criteria. Compared to rating systems which considered insufficient type and number of factors or indicators, it is determined that rating systems with a greater number of considered factors and indicators will be more extensive in their sustainability assessment. Nevertheless, not all the criteria are applicable when evaluating the sustainability of heritage buildings. It is necessary to include heritage building-specific criteria to the rating tools. Among the 12 examined rating tools, there is a difference in the protocol employed to calculate the weights, units, scale and lower limits. No single rating system could be identified as the most ideal for assessing sustainability in heritage buildings. It is therefore necessary to an appropriate rating system that is pertinent to the sustainability assessment of heritage buildings.

This chapter focused on sustainability model implementations. The first part of this section is about data reliability to testify the data which collected by using the questionnaire. The second part discussed weighted normalized decision matrix calculation. Also, this chapter introduced BIM model for the case studies MP and GN.

Finally, in this chapter also discussed results of the emission and building energy analysis. The last part of the chapter described the compilation of all elements in order to implement the sustainability assessment model.

CHAPTER 6 : AN AUTOMATED TOOL (SAHB)

6.1 Chapter Overview

In this chapter, the new rating system, *Sustainability Assessment Heritage Buildings* (SAHB), for heritage buildings is presented. The new system relies on the previously demonstrated sustainability rating system and the sustainability-based rehabilitation model. The model enables the 1) evaluation of a building's sustainability; 2) generation of statistical results that are based on the building's sustainability; and 3) provision of alternative upgrade options that minimize LCC and include an explanation of the parameters involved. This involves: 1) technical components of the model, 2) graphical user interface, 3) process of sustainability rating, and 4) output in the display.

This section will discuss three results: 1) the values of the determined weight based on the Riyadh and Montreal context; 2) the SAHB of the case study according to the three selected regional contexts, and 3) the model validation. Furthermore, Appendix F depicts the conversion of the experts' answers to the questionnaire into scores for the factors, indicators and sub-indicators.

6.2 Sustainability Assessment for Heritage Buildings (*SAHB)*

The actual implementation and workflow of the web application are demonstrated in Figures 6.1, 6.2 and 6.3. The user would click on the URL of the application and choose *Start Assessment* to start the actual assessment process. Once started, the user is prompted to enter the scores of each factor, indicator and sub-indicator for the three different criteria - environmental, physical, and sustainable. Once completed, the weight values are sent to the backend and input to the corresponding equations. Then, four different values are computed - the Total Sustainability Assessment for Heritage Buildings as a percentage, the score for each of the criteria, the Heritage Building Index, and the overall sustainability scale level. These values are reported to the user.

Sustainability Assessment for Heritage Buildings Tool

Since the appearance of the first environmental assessment method (BREEAM), the result of building assessment process is converted into a single ranking expression. Follow on environmental assessment methods (e.g. LEED, BREEAM CASBEE, and ITECCA) have adopted the same strategy, with some variations. For example, in BREEAM and LEED the score is calculated out of 100 percent and then converted into a single expression

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Step 1: Click
start assessment

Factor: Site & Ecology (Total Max Points 18)

Indicator: Site selection (Total Max Points 2)

Sub Indicator: Previously certified design & construction (Total Max Points 1)

Alternative:
One point for a building that has been previously certified under New Construction or Major Innovations scheme.

Points (max = 1 min = 0) 0

Sub Indicator: Respect for sites of historic or cultural interest (Total Max Points 1)

Alternative:
An attention to local character and Revitalization of cultural heritage buildings.

Points (max = 1 min = 0) 0

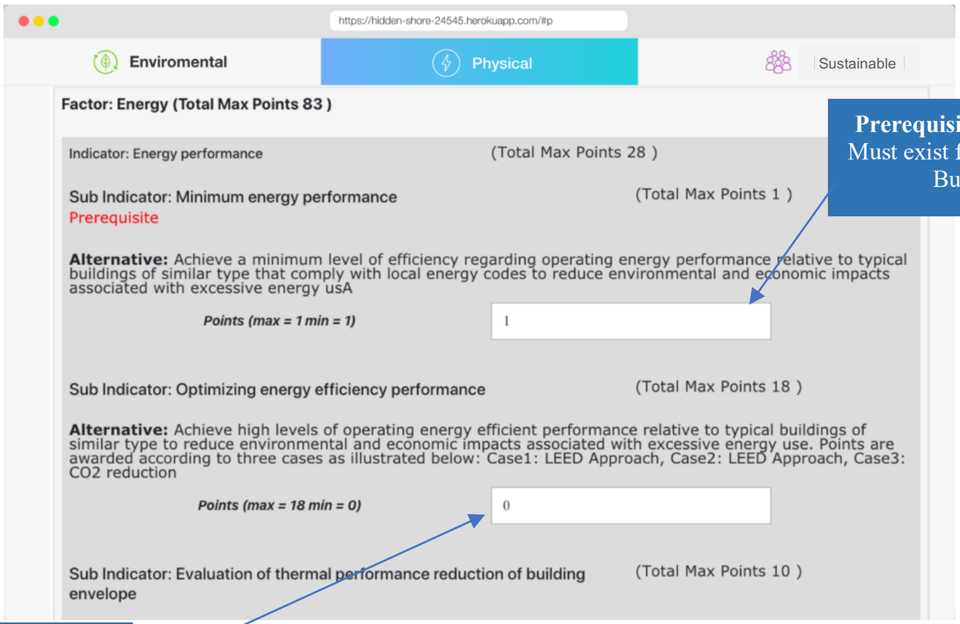
Total max points site and ecology could have (sum of all max points for sub-indicators)

Ex. 1 points (max) for a building that is previously certified or 0 (min) if not

Provide points for each alternative below all sub-indicators

Step 2: Enter
environmental criteria data

Figure 6-1: Steps 1 and 2 of the proposed rating tool scale (SAHB)



Factor: Energy (Total Max Points 83)

Indicator: Energy performance (Total Max Points 28)

Sub Indicator: Minimum energy performance (Total Max Points 1)

Prerequisite

Alternative: Achieve a minimum level of efficiency regarding operating energy performance relative to typical buildings of similar type that comply with local energy codes to reduce environmental and economic impacts associated with excessive energy usA

Points (max = 1 min = 1) 1

Sub Indicator: Optimizing energy efficiency performance (Total Max Points 18)

Alternative: Achieve high levels of operating energy efficient performance relative to typical buildings of similar type to reduce environmental and economic impacts associated with excessive energy use. Points are awarded according to three cases as illustrated below: Case1: LEED Approach, Case2: LEED Approach, Case3: CO2 reduction

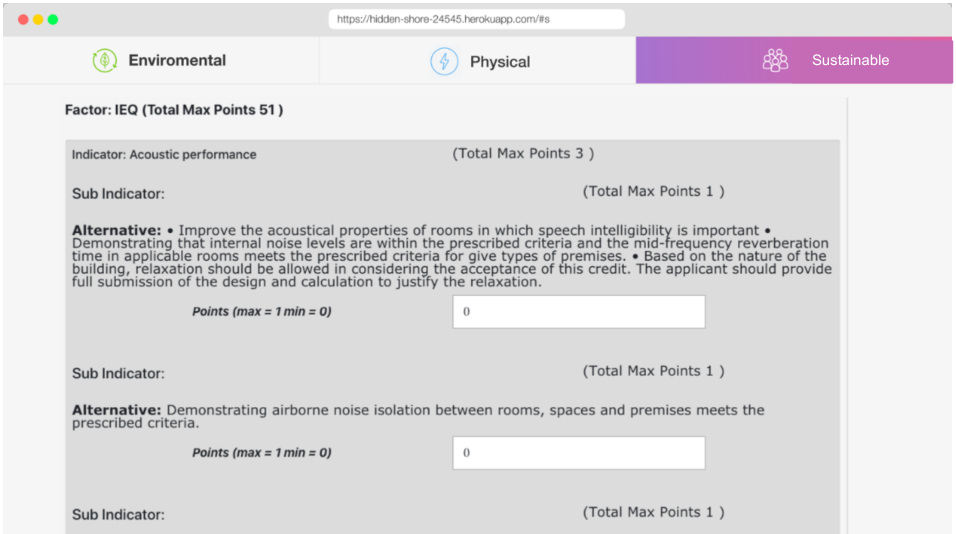
Points (max = 18 min = 0) 0

Sub Indicator: Evaluation of thermal performance reduction of building envelope (Total Max Points 10)

Prerequisite alternative: Must exist for any Heritage Buildings

Step 4: Enter physical criteria data

Step 3: Once physical criteria done, **Click** Sustainable



Factor: IEQ (Total Max Points 51)

Indicator: Acoustic performance (Total Max Points 3)

Sub Indicator: (Total Max Points 1)

Alternative: • Improve the acoustical properties of rooms in which speech intelligibility is important • Demonstrating that internal noise levels are within the prescribed criteria and the mid-frequency reverberation time in applicable rooms meets the prescribed criteria for give types of premises. • Based on the nature of the building, relaxation should be allowed in considering the acceptance of this credit. The applicant should provide full submission of the design and calculation to justify the relaxation.

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 1)

Alternative: Demonstrating airborne noise isolation between rooms, spaces and premises meets the prescribed criteria.

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 1)

Step 5: Enter sustainable criteria data

Figure 6-2: Steps 2,3 and 5 of the proposed rating tool scale (SAHB)

Sub Indicator: (Total Max Points 2)

Alternative: Provide details of the instructions and guidance materials issued to tenants/users of the building. Credit shall be awarded where it is demonstrated that the guidance given encourages and promotes environmentally friendly building use and activities by users ==> 1 point Building User Information : A notice board or display area present within the asset to provide staff and visitors with information related to the environmental policies and/or performance of the asset ==> 1

Points (max = 2 min = 0) 0

Sub Indicator: (Total Max Points 4)

Alternative: BY Type of maintenance policy: Reactive policy only. Policy reviewed more than 1 year ago ==> 1 | Reactive policy only. Policy reviewed within the last year ==> 2 | Proactive maintenance policy. Policy reviewed more than 1 year ago ==>3 | Proactive maintenance policy. Policy reviewed within the last year ==> 4

Points (max = 4 min = 0) 0

Step 6: Once all done click **Submit** at the end

Result According to Sustainability Assessment for Heritage Buildings Tool (SAHBT)

Murabba Palace

Total of Sustainability Assessment for Heritage Building (TSAHB): ٪47.63

15/55

79/130

23/90

Heritage Building Index (HBI): 3.477

Sustainability Scale Level Is

Unsatisfied

Total number of point the Heritage Buildings gains

Step 7: Results will be displayed

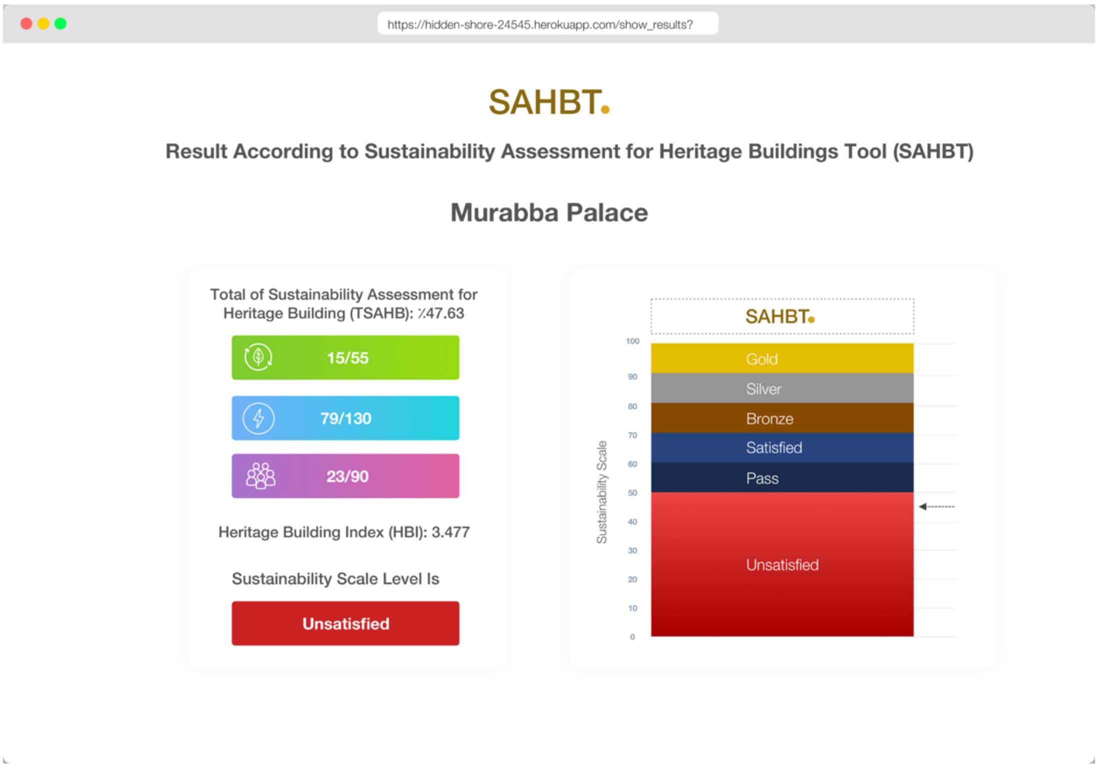
The score level for the heritage relative to 100%

In each criterion, how many points the Heritage Buildings gains

Figure 6-3: Step 6 and the output of proposed rating tool scale (SAHB)

The workflow of the web application is demonstrated in Figures 6.1, 6.2 and 6.3. The user would access the URL of the application and choose *Start Assessment* to start the assessment process. Once started, the user is prompted to enter the scores of each factor, indicator and sub-indicator in three different criteria - environmental, physical, and sustainable. The application would then output four different values - the Total Sustainability Assessment for Heritage Buildings as a percentage, the score for each of the criteria, the Heritage Buildings Index, and the overall sustainability scale level.

After applying the related points for each factor, indicator and sub-indicator of each case study to the automated tool (SAHB), the results of the sustainability assessment are shown in Figure 6.4 for Murabba Palace, which indicates *Unsatisfied*, with a Total Sustainability Assessment for Heritage Buildings of 47.63%. On the other hand, Figure 6.5 displays the results from the automated tool for 3the Grey Nuns Building, which indicates *Satisfied* with a SAHB of 62.84%.



https://hidden-shore-24545.herokuapp.com/show_results?

SAHBT.

Result According to Sustainability Assessment for Heritage Buildings Tool (SAHBT)

Murabba Palace

Total of Sustainability Assessment for Heritage Building (TSAHB): ٪47.63

15/55

79/130

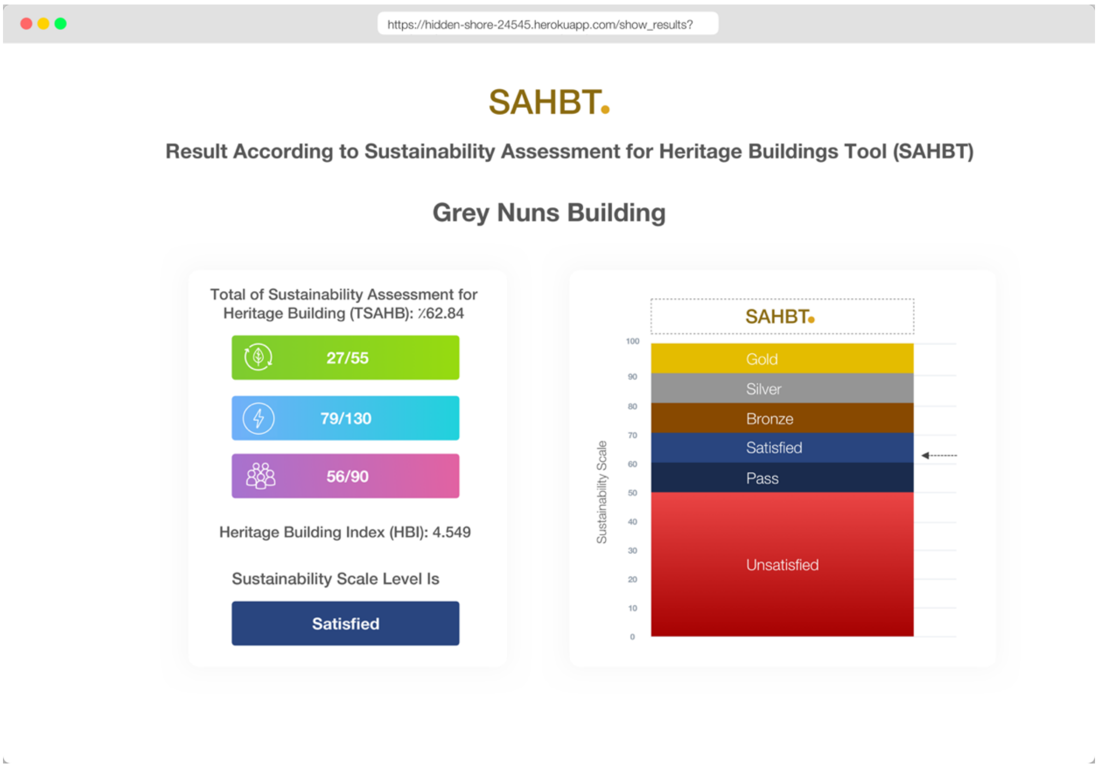
23/90

Heritage Building Index (HBI): 3.477

Sustainability Scale Level Is

Unsatisfied

Figure 6-4: The output of Murabba Palace using SAHB


https://hidden-shore-24545.herokuapp.com/show_results?

SAHBT.

Result According to Sustainability Assessment for Heritage Buildings Tool (SAHBT)

Grey Nuns Building

Total of Sustainability Assessment for Heritage Building (TSAHB): ٪62.84

27/55

79/130

56/90

Heritage Building Index (HBI): 4.549

Sustainability Scale Level Is

Satisfied

Figure 6-5: The output of the Grey Nuns Building using SAHB

6.3 Weight values

Based on the answers obtained from the questionnaires and the Fuzzy TOPSIS technique, the weight values were calculated and represented in Table 6.1. Due to the small sample size, there was significant variation in the local weight; thus, differential weighting was used. Thus, this model is flexible modify, project manager cannot add or ignore some the aspects directly, but can be done by changing some of the factors weights.

From Table 6.1, it is evident that the water management indicator has the highest weight of 0.685. This is followed by sustainable purchasing practice, public transport accessibility, and building material with weights of 0.468, 0.415 and 0.498, respectively. Similarly, for the Site and Ecology factor, the site selection indicator had the highest weight of 0.391, and the reduced heat island effect had the lowest weight of 0.110. Moreover, the solid waste management practice indicator within the Material Waste Reduction factor had the lowest weight of 0.262 while the sustainable purchasing practice indicator had the highest weight of

0.468. As for the Transportation factor, the fuel-efficient vehicle indicator had the lowest weight of 0.218 while the public transport accessibility indicator had the highest weight of 0.415. Regarding the Energy factor, the energy performance indicator had the highest weight of 0.32 while the lowest weight was attributed to the energy efficiency systems with a value of 0.199. In addition, the Water Use factor had the highest weight for water management (0.658) and the lowest weight for water conservation (0.342). The building age indicator within the Heritage factor had the highest weight of 0.371 while the lowest weight was for the building revenue indicator. Furthermore, the Structural Condition factor had the highest weight attributed to the building material indicator (0.498) and the lowest weight to safety (0.178). Concerning the IEQ factor, the highest weight was that of the indoor air quality (0.190) and the lowest weight was that of the building amenities (0.135). Finally, the highest indicator in the Building Management factor was the security measure and the lowest was the risk management indicator.

Table 6-1: Comparison of Weights of Factors and Indicators

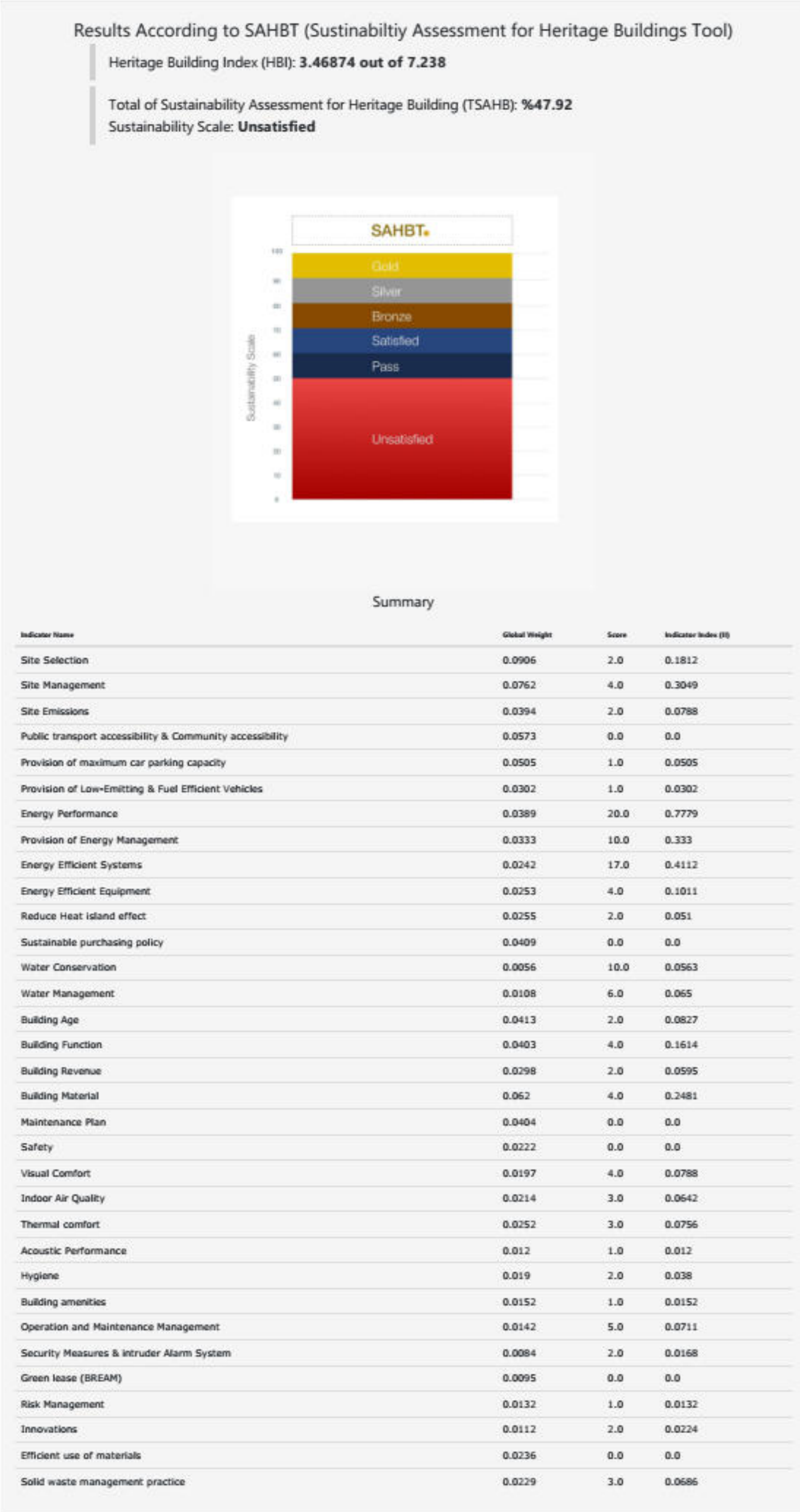
	Site and Ecology Factor	**Material Waste Reduction Factor**	**Transportation Factor**	**Energy Factor**	**Water Use Factor**	**Heritage Value Factor**	**Structural Condition Factor**	**IEQ Factor**	**Building Management Factor**
Murabba									
GNR	0.391		0.329	0.110	0.170				
Indicators of 1st factor	Site Selection		Site Management	Reduce Heat Island	Site Emissions				
Murabba									
GNR	0.468		0.262	0.270					
Indicators of 2nd factor	Sustainable Purchasing Practice		Solid Waste Management Practice	Efficient Use of Materials					
Murabba									
GNR	0.415	0.366		0.218					
Indicators of 3rd factor	Public Transport Accessibility	Car Parking Capacity		Fuel-Efficient Vehicle					
Murabba									
GNR	0.320		0.274		0.199	0.208			
Indicators for 4th factor	Energy Performance		Provision of Energy Management		Energy-Efficient Systems	Energy Efficient Equipment			
Murabba									
GNR	0.342		0.658						
Indicators of 5th factor	Water Conservation		Water Management						
Murabba									
GNR	0.371	0.362	0.267						
Indicators of 6th factor	Building Age	Building Function	Building Revenues						
Murabba									
GNR	0.498	0.324	0.178						
Indicators of 7th factor	Building Material	Maintenance Plan	Safety						
Murabba									
GNR	0.175	0.169	0.190	0.224	0.106			0.135	
Indicators of 8th factor	Visual Comfort	Hygiene	Indoor Air Quality	Thermal Comfort	Acoustic Performance			Building Amenities	
Murabba									
GNR	0.175	0.169	0.190	0.224	0.106				
Indicators of 9th factor	Maintenance Management	Innovations	Security Measures	Green Lease	Risk Management				

6.4 Sustainability assessment results

The results of the sustainability assessment are shown in Tables 6.2 and 6.3. The results are divided into three parts. The first part is the Factor Score (FS), which is illustrated in Table 6.2. The FS depicts the achieved score of each factor based on its qualitative and quantitative indicators and is summarized in the above subsection. The second part is the sustainability index (SI), heritage buildings index (HBI), and total sustainability assessment for heritage buildings (SAHB)of each factor and indicator. The results are depicted in Table 6.2. The last part is the sustainability index results for each sub-indicator shown in Table 6.3.

From Table 6.2, the Site and Ecology factor in the environmental criterion had the highest factor index in both case studies with a value of 0.616 for the Murabba Palace (MP) and 0.475 for the Grey Nuns Building (GN). Moreover, the lowest-ranked factor was the Material Waste Reduction factor with an index of 0.069 and 0.255 for the Murabba Palace (MP) and Grey Nuns Building (GN), respectively. Under the physical criteria, the Energy factor was ranked the highest with a sum of indicator indices of 1.623 Murabba Palace (MP) and 1.891 Grey Nuns Building (GN). The Water Use factor was the lowest-ranked factor with a total indicator index of 0.121 Murabba Palace (MP) and 0.055 Grey Nuns Building (GN). Interestingly, the sum of the indicator indices for both the Heritage Value and Structural Condition factors was very close for both buildings, with almost a 0.5% difference in values. Lastly, the IEQ factor under the sustainable criteria had the highest indicator indices, with a total of 0.262 for the Murabba Palace (MP) and 0.708 for the Grey Nuns Building (GN). From Tables 6.2 and 6.3, the total Heritage Buildings Index for Murabba Palace (MP) was 3.447 while that of the Grey Nuns building (GN) was 4.549. Moreover, the Total of Sustainability Assessment for Heritage Buildings (SAHB) was 47.63% for the Murabba Palace (MP) and 62.84% for Grey Nuns Building (GN). A comparison of the factors of the weights is illustrated in Figure 6.9.

Table 6-2: Sustainability results for Murabba palace- KSA



Results According to SAHBT (Sustinabiltiy Assessment for Heritage Buildings Tool)

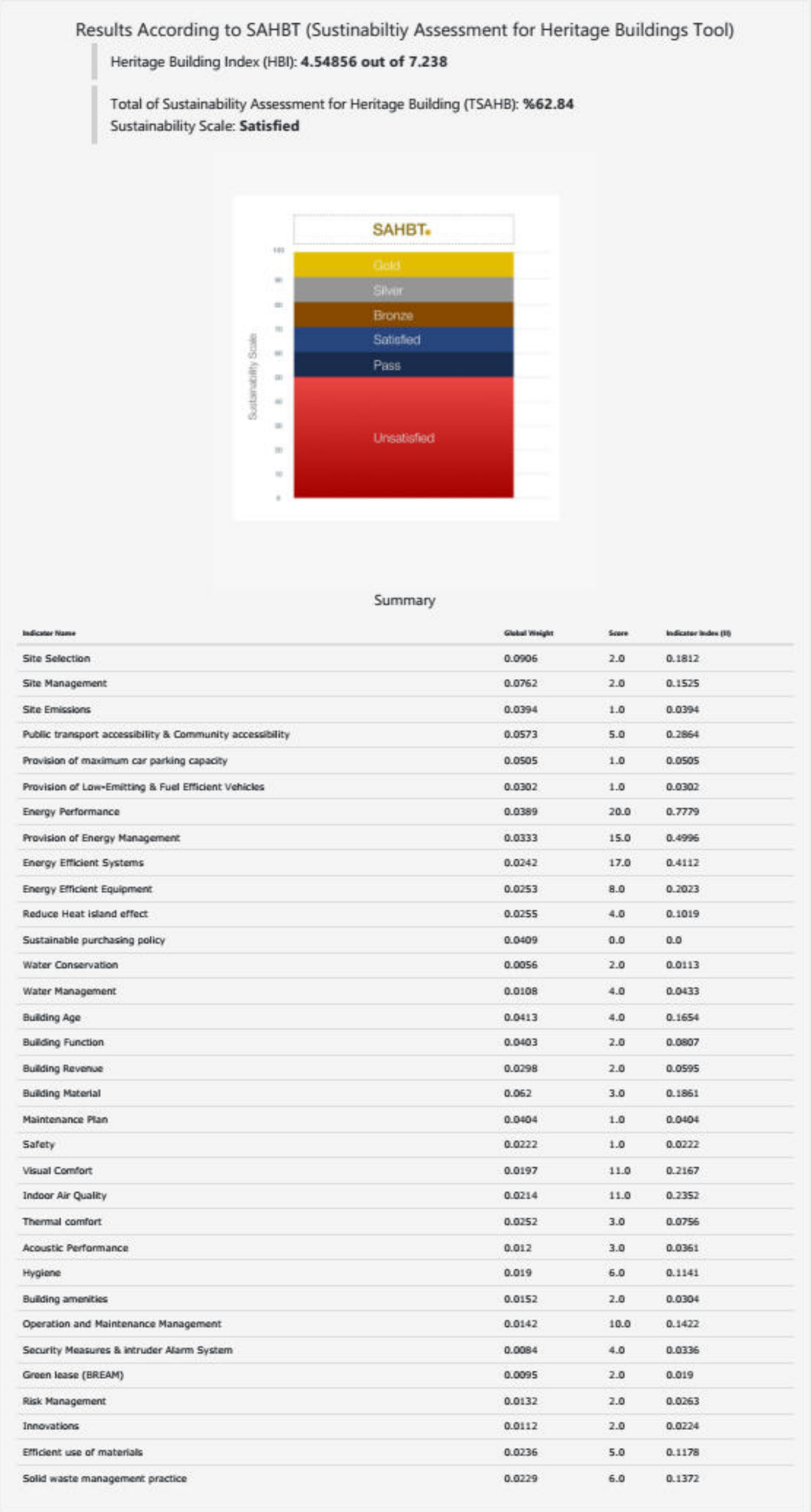
Heritage Building Index (HBI): **3.46874 out of 7.238**

Total of Sustainability Assessment for Heritage Building (TSAHB): **%47.92**
Sustainability Scale: **Unsatisfied**

Summary

Indicator Name	Global Weight	Score	Indicator Index (II)
Site Selection	0.0906	2.0	0.1812
Site Management	0.0762	4.0	0.3049
Site Emissions	0.0394	2.0	0.0788
Public transport accessibility & Community accessibility	0.0573	0.0	0.0
Provision of maximum car parking capacity	0.0505	1.0	0.0505
Provision of Low-Emitting & Fuel Efficient Vehicles	0.0302	1.0	0.0302
Energy Performance	0.0389	20.0	0.7779
Provision of Energy Management	0.0333	10.0	0.333
Energy Efficient Systems	0.0242	17.0	0.4112
Energy Efficient Equipment	0.0253	4.0	0.1011
Reduce Heat island effect	0.0255	2.0	0.051
Sustainable purchasing policy	0.0409	0.0	0.0
Water Conservation	0.0056	10.0	0.0563
Water Management	0.0108	6.0	0.065
Building Age	0.0413	2.0	0.0827
Building Function	0.0403	4.0	0.1614
Building Revenue	0.0298	2.0	0.0595
Building Material	0.062	4.0	0.2481
Maintenance Plan	0.0404	0.0	0.0
Safety	0.0222	0.0	0.0
Visual Comfort	0.0197	4.0	0.0788
Indoor Air Quality	0.0214	3.0	0.0642
Thermal comfort	0.0252	3.0	0.0756
Acoustic Performance	0.012	1.0	0.012
Hygiene	0.019	2.0	0.038
Building amenities	0.0152	1.0	0.0152
Operation and Maintenance Management	0.0142	5.0	0.0711
Security Measures & intruder Alarm System	0.0084	2.0	0.0168
Green lease (BREAM)	0.0095	0.0	0.0
Risk Management	0.0132	1.0	0.0132
Innovations	0.0112	2.0	0.0224
Efficient use of materials	0.0236	0.0	0.0
Solid waste management practice	0.0229	3.0	0.0686

Table 6.3: Sustainability results for Grey Nuns Building- Canada



Results According to SAHBT (Sustinabiltiy Assessment for Heritage Buildings Tool)

Heritage Building Index (HBI): **4.54856 out of 7.238**

Total of Sustainability Assessment for Heritage Building (TSAHB): **%62.84**
Sustainability Scale: **Satisfied**

Summary

Indicator Name	Global Weight	Score	Indicator Index (II)
Site Selection	0.0906	2.0	0.1812
Site Management	0.0762	2.0	0.1525
Site Emissions	0.0394	1.0	0.0394
Public transport accessibility & Community accessibility	0.0573	5.0	0.2864
Provision of maximum car parking capacity	0.0505	1.0	0.0505
Provision of Low-Emitting & Fuel Efficient Vehicles	0.0302	1.0	0.0302
Energy Performance	0.0389	20.0	0.7779
Provision of Energy Management	0.0333	15.0	0.4996
Energy Efficient Systems	0.0242	17.0	0.4112
Energy Efficient Equipment	0.0253	8.0	0.2023
Reduce Heat island effect	0.0255	4.0	0.1019
Sustainable purchasing policy	0.0409	0.0	0.0
Water Conservation	0.0056	2.0	0.0113
Water Management	0.0108	4.0	0.0433
Building Age	0.0413	4.0	0.1654
Building Function	0.0403	2.0	0.0807
Building Revenue	0.0298	2.0	0.0595
Building Material	0.062	3.0	0.1861
Maintenance Plan	0.0404	1.0	0.0404
Safety	0.0222	1.0	0.0222
Visual Comfort	0.0197	11.0	0.2167
Indoor Air Quality	0.0214	11.0	0.2352
Thermal comfort	0.0252	3.0	0.0756
Acoustic Performance	0.012	3.0	0.0361
Hygiene	0.019	6.0	0.1141
Building amenities	0.0152	2.0	0.0304
Operation and Maintenance Management	0.0142	10.0	0.1422
Security Measures & intruder Alarm System	0.0084	4.0	0.0336
Green lease (BREAM)	0.0095	2.0	0.019
Risk Management	0.0132	2.0	0.0263
Innovations	0.0112	2.0	0.0224
Efficient use of materials	0.0236	5.0	0.1178
Solid waste management practice	0.0229	6.0	0.1372

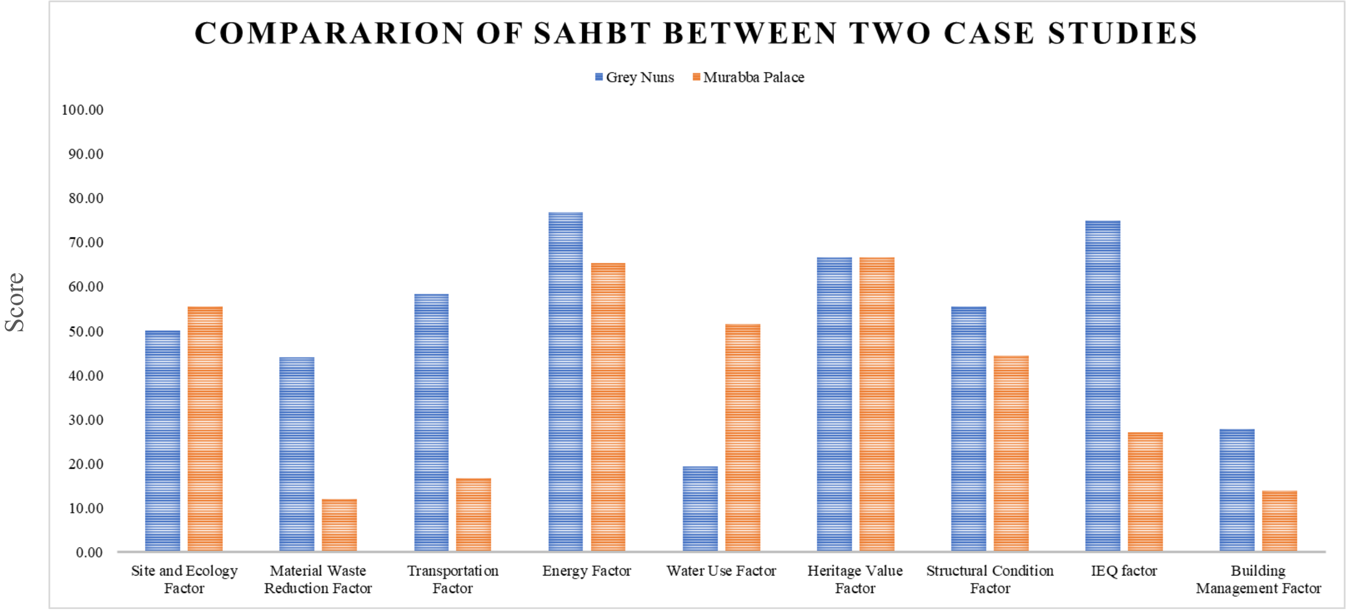


Figure 6-6: Comparison of SAHB between Case Studies

In light of the above discussion, the results of two of the highest factors are highlighted by analyzing the index of their sub-indicators. The two highest weights from Table 6.2 were the Energy factor and the IEQ under the physical and sustainable criteria, respectively. Table 6.3 details the sustainability index of each of the sub-indicators of these factors for both buildings. From the table, the highest-ranked indicator for the Energy factor was the energy performance with a value of 0.236 for the Murabba Palace (MP) and 0.351 for the Grey Nuns Building (GN). In contrast, the lowest-ranked indicator was the provision of energy management with a value of 0.086 for the Murabba Palace (MP) and 0.094 for the Grey Nuns Building (GN). As for the IEQ factor, the lowest-ranked indicator was the acoustic performance, with a value of 0.012 for both buildings. More interestingly, the highest-ranked indicator was the indoor air quality for the Murabba Palace (MP), with a value of 0.448. However, the highest-ranked indicator in the case of the Grey Nuns Building (GN) was as the visual comfort with a value of 0.529.

6.5 Model Validation

The results from all the decision-making techniques are shown in Tables 6.4 and 6.5 for the Murabba Palace and Grey Nuns Building, respectively. From the table, the Fuzzy TOPISS (FT) and Simple Additive Weight (SAW) produced a very similar sustainability index for the Murabba Palace with an overall evaluation of *Unsatisfied*. Similarly, the OCRA technique resulted in an *Unsatisfied* rating with a very low index of 24.09%. The Weighted Sum Model (WSM) technique resulted in a *Pass* rating while the Weighted Product Model (WPM) was the only technique that resulted in a *Satisfied* rating. For the Grey Nuns Building, the FT technique resulted in a *Satisfied* rating with an index of 62.84%. Further, both the SAW and WPM techniques resulted in similar scores of 83.02% and 83.35%, respectively, with an overall rating of *Silver*. In addition, the WSM resulted in a *Pass* rating while the OCRA reported an *Unsatisfied* rating with an index of 40.35%.

Table 6-5: Ranking of SI obtained from five decision-making techniques MP

Murabba Palace		
Techniques	**Sustainability Index %**	**SA Category**
FT	47.63	Unsatisfied
SAW	49.57	Unsatisfied
WSM	52.24	Pass
WPM	69.57	Satisfied
OCRA	24.09	Unsatisfied

Table 6-6: : Ranking of SI obtained from five decision-making techniques GN

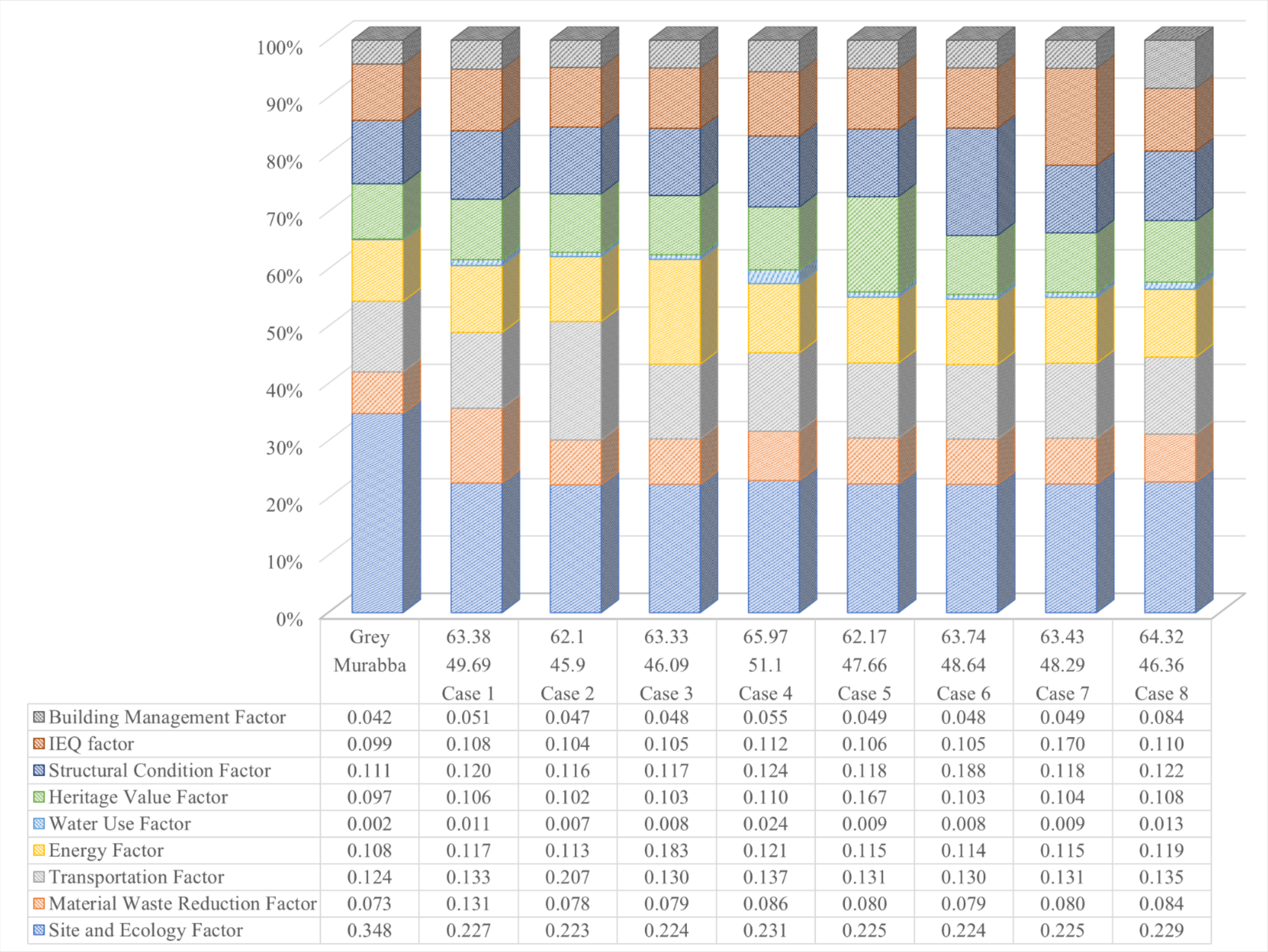
Grey Nuns Building		
Techniques	**Sustainability Index %**	**SA Category**
FT	62.84	Satisfied
SAW	83.02	Silver
WSM	54.25	Pass
WPM	83.34	Silver
OCRA	40.35	Unsatisfied

6.6 Sensitivity analysis

Sensitivity analysis is a measure of how stable the system. In particular, the input parameters are adjusted by a specific value and the overall condition of the system is observed. For both case studies, Table 6.6 illustrates the results of the sensitivity analysis. Figure 6.10 depicts the difference in the percentage of the overall condition as a function of the change in weight. Both show the change in the overall sustainability index with respect to the change of the factors' weights. As shown, the overall condition is not affected by significant changes. For instance, the biggest change appears in the first case for the Site and Ecology factor with a value of 0.348. On the other hand, the lowest change was also in the first case for the Water Use factor with a value of 0.002. This implies that the stability of the system does not move drastically to a different level for all the scenarios.

Table 6-7: Sensitivity analysis

	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**	**Case 9**
Murabba Palace	49.69	45.9	46.09	51.1	47.66	48.64	48.29	46.36	47.09
Grey Nuns Building	63.38	62.1	63.33	65.97	62.17	63.74	63.43	64.32	62.93
Site and Ecology Factor	0.348	0.227	0.223	0.224	0.231	0.225	0.224	0.225	0.229
Material Waste Reduction Factor	0.073	0.131	0.078	0.079	0.086	0.080	0.079	0.080	0.084
Transportation Factor	0.124	0.133	0.207	0.130	0.137	0.131	0.130	0.131	0.135
Energy Factor	0.108	0.117	0.113	0.183	0.121	0.115	0.114	0.115	0.119
Water Use Factor	0.002	0.011	0.007	0.008	0.024	0.009	0.008	0.009	0.013
Heritage Value Factor	0.097	0.106	0.102	0.103	0.110	0.167	0.103	0.104	0.108
Structural Condition Factor	0.111	0.120	0.116	0.117	0.124	0.118	0.188	0.118	0.122
IEQ Factor	0.099	0.108	0.104	0.105	0.112	0.106	0.105	0.170	0.110
Building Management Factor	0.042	0.051	0.047	0.048	0.055	0.049	0.048	0.049	0.084



	Grey Murabba	63.38 49.69 Case 1	62.1 45.9 Case 2	63.33 46.09 Case 3	65.97 51.1 Case 4	62.17 47.66 Case 5	63.74 48.64 Case 6	63.43 48.29 Case 7	64.32 46.36 Case 8
▨ Building Management Factor	0.042	0.051	0.047	0.048	0.055	0.049	0.048	0.049	0.084
▨ IEQ factor	0.099	0.108	0.104	0.105	0.112	0.106	0.105	0.170	0.110
▨ Structural Condition Factor	0.111	0.120	0.116	0.117	0.124	0.118	0.188	0.118	0.122
▨ Heritage Value Factor	0.097	0.106	0.102	0.103	0.110	0.167	0.103	0.104	0.108
▨ Water Use Factor	0.002	0.011	0.007	0.008	0.024	0.009	0.008	0.009	0.013
▨ Energy Factor	0.108	0.117	0.113	0.183	0.121	0.115	0.114	0.115	0.119
▨ Transportation Factor	0.124	0.133	0.207	0.130	0.137	0.131	0.130	0.131	0.135
▨ Material Waste Reduction Factor	0.073	0.131	0.078	0.079	0.086	0.080	0.079	0.080	0.084
▨ Site and Ecology Factor	0.348	0.227	0.223	0.224	0.231	0.225	0.224	0.225	0.229

Figure 6-7: Weight variation sensitivity analysis for each factor

6.7 Summary

This chapter focused on the automated tool SAHB. The first part of this chapter discussed sustainability assessment for heritage buildings attributes which was collected by using a questionnaire. The second part was about weight values calculation. Also, this chapter discussed the sustainability assessment results.

In addition, the model validation part was used to justify the sustainability assessment index for both case studies MP and GN by using four different multi decision making techniques. The last part of this chapter discussed sensitivity analysis to check the changes and the differences between all nine factors weights.

CHAPTER 7 : CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

This study aimed to develop a sustainability assessment for heritage buildings. What was developed is a two-level rating tool that will enable decision-making and sustain existing buildings. The first level comprises of the sustainability rating model, which enable decision-makers to obtain a general and extensive picture regarding the sustainability of their buildings. This will also serve to point out the strong and weak points regarding their buildings, and the suggested upgrade alternatives. The second level enables the heritage buildings specialists, engineers, architects and project managers to make informed decisions from the list of upgrade alternatives in order to improve the sustainability of their respective buildings, based on the LCC approach. In particular, the proposed method defines three main criteria of sustainability: environmental, physical, and sustainable. To identify these criteria, an extensive survey was conducted on existing tools and research studies as well as interviews and questionnaires with subject-matter experts. These three criteria and their corresponding factors, indicators and sub-indicators were then integrated into the model framework. With the hierarchy of model attributes identified, a method of quantifying the significance of each attribute by leveraging a scoring system was proposed. By aggregating the scores of these attributes, the final sustainability score of the building was determined. In addition, a scale was proposed that ranks the sustainability of heritage buildings into one of five categories based on the obtained sustainability scores. Once the scores were determined, a life-cycle phase analysis was performed to assess the possible upgrade alternatives for the heritage buildings. The proposed methodology was applied on two heritage buildings in two very different countries - Murabba Palace, Saudi Arabia, and Grey Nuns Building, Canada. Based on the scores obtained, Murabba Palace was ranked as *Unsatisfied* with an overall *SAHB* of 47.63%, while the Grey Nuns

Building was ranked as *Satisfied* with an overall *SAHB* of 62.84%. Energy analysis was performed to identify the different upgrade alternatives. Upgrading the Grey Nuns building with concrete would result in a yearly energy consumption of 4,957,290 kWh. In addition, for a fair comparison between the two buildings, the calculations were obtained on a per-meter-square basis, as the areas of both buildings were not the same. The last part of this research was to develop an automated tool to perform the proposed methodology. This would help decision-makers to seamlessly evaluate the sustainability rating of heritage buildings without the need for manual labor.

7.2 Research Contributions

The main contribution of this research is the development of a comprehensive tool that is targeted towards the assessment of the sustainability of heritage buildings. Although different tools exist that are employed to measure the sustainability of different buildings, the value of this work lies in its comprehensiveness and novelty. Particularly, this work can be categorized into three main modules:

- **Comparative Study:**

The main goal of this module was to identify the gaps and areas of improvements in the different existing sustainability rating tools. For that, the following activities were performed:

- Compiled twelve of the most popular sustainability rating tools and compared, in detail, their methodologies in terms of the employed attributes, scales, thresholds and numerical equations.
- Conducted structured and unstructured interviews with subject-matter experts to obtain a detailed view on the essential attributes and factors that must be present in an assessment tool designed specifically for heritage buildings.

The comparative study provides a detailed overview on existing technologies as well as the opinions of experts in the field of sustainability assessment for heritage buildings. Thus, in a sense, it serves as a benchmark for different researchers looking to design their own assessment tool.

- **Novel Assessment tool:**

The purpose of this module is to compile results from the comparative study and design, evaluate and test an assessment tool that takes into consideration the limitations of the existing tools and opinions of experts. For that, e following activities were performed:

- Proposed novel attributes including Heritage Value and Structural Condition that were not considered in any of the existing tools.
- Developed a scoring system to quantify the importance and added value of each of the identified attributes to the sustainability of heritage buildings.
- Developed a more informative sustainability scale that is representative of the actual sustainability rating of the building.
- Performed life-cycle phase analysis to properly evaluate the upgrade alternatives in terms of energy and gas consumption and cost.
- Designed a hybrid framework that is based on multiple criteria and enables decision-making. The goal was to examine different sustainability alternatives for heritage buildings.
- Studied the robustness of the proposed methodology by leveraging sensitivity analysis.

The results of this module are the establishment of a novel assessment tool that provides decision-makers with a more refined assessment of their heritage buildings by considering a much more comprehensive list of attributes and criteria as well as a more informative assessment scale.

- **Automation:**

The purpose of this module is to provide a seamless experience for the end-users by eliminating the manual work in calculating the weights and overall score. For that, the following activities were performed:

- Built a fully functional web application where a user would just input the weights of the factors and the application would display the different scores and the overall sustainability assessment for heritage buildings in a user-friendly format.

7.3 Research Limitations

Despite the research contributions described above, there were some limitations in this work.

- Due to limited time, only the *energy* factor was investigated in detail from the list of factors. Other factors were not investigated in as much detail.
- The list of factors presented in this work is not exhaustive. Sustainability is an evolving concept and more factors continue to be added to the list.
- Only one case study from Canada and one from KSA were analyzed. It is necessary to evaluate more case studies from other Canadian provinces and elsewhere in the world to see the effect of social, cultural, and climatic differences in different areas.
- Insufficient or manually stored data increased the labor-intensiveness of the work in this research. Water use and revenue data were not available for both case studies. Manual drawings were retrieved for Murabba Palace and AutoCAD® versions needed to be created prior to further analysis. Also, BIM models had to be created from the scratch for both case studies.

7.4 Recommendations for Future Research

7.4.1 Recommendations

- One area of potential research is to focus on the weight determination process. Particularly, the weights used in our research were focused on Canada and Saudi Arabia. Thus, as an extension, including weights from more countries could be studied in terms of its impact on the overall sustainability rating. This will also improve the model flexibility.
- Saudi Arabia has four weather zones and the developed rating model examined a heritage building in one of the four zones. The rating model can also be examined for other types of heritage buildings present in the other three zones in Saudi Arabia.
- Since a majority of the building assessment systems are re-evaluated yearly or every two years, **SAHB** should follow the same re-evaluation frequency in order to keep the system up to date.
- Course certification on sustainability development is essential for the person assessing the building in order for him or her to be able to perform an authentic assessment.
- Since **SAHB** works well for residential buildings, a similar model can be developed for commercial buildings like schools and hospitals.
- It is necessary that building professionals decide on the prerequisite criteria for **SAHB**. This cannot be done now, based on the suggestions of experts, until the model has been extensively applied for heritage buildings.
- BIM can be integrated into the newly developed rating model. This will allow for a rapid assessment and a better automated data transfer process. BIM can manage the large data required for sustainability assessments. Hence, future research can focus on the incorporation of the developed model into BIM packages, specifically, Revit® and

ArchiCAD®. Exploring the integration of heritage building information modeling (HBIM) with the **SAHB** would valuable.

7.4.2 Future Research

- Established international and local building standards such as ISO, CIBSE and ASHRIA exist and their criteria should be compared with the criteria involved in **SAHB**. This will enable the establishment of a standard for evaluating the sustainability of heritage buildings.
- The developed model should be applied to other types of heritage buildings that have other functions such as governmental or residential. This might point to the relevance of other factors and the prevalence of other problems.
- The developed rating model can be applied for other regions in Saudi Arabia and Canada. The varying climatic conditions in different parts of both countries might emphasize some factors more than others. This will also demonstrate the flexibility of the developed model.
- Building a prediction module to forecast the building's deterioration rate would be a novel extension of the tool that would aid the establishment of a more comprehensive set of upgrade alternatives.
- A maintenance and rehabilitation protocol based on **SAHB** can be established for heritage buildings in Saudi Arabia and Canada. This will also promote the sustainability of heritage buildings and be beneficial to decision makers in their efforts to maintain the condition of their heritage buildings.
- The addition of new factors, indicators and sub-indicators will lead to a more robust version of the proposed model. This will also enable the applicability of the model to different regions and climatic conditions.

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APPENDIX A: SAMPLE OF QUESTIONNAIRE

Sustainability Rating Tool and Rehabilitation Model for Heritage Building

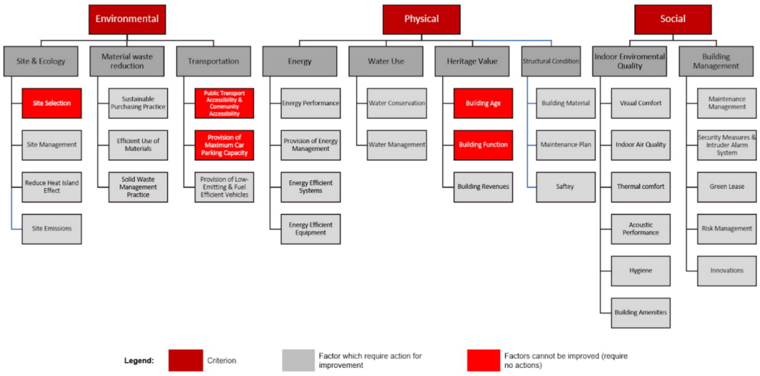
Dear Sir/Madam

I would like to present my appreciation and thanks to you for taking some of your time to complete this questionnaire. This questionnaire aims to identifying the degree of importance of the factors that affect the sustainability assessment of heritage buildings. In addition, it aims to identifying the required rehabilitation actions to increase the sustainability score of heritage buildings. This questionnaire is a part of the requirements of an academic research, which is conducted under the supervision of Concordia University, that opts to establishing an integrated rating system for heritage buildings, as well as, a sustainable-based rehabilitation model to increase the sustainability score of heritage buildings. The information in the questionnaire will be solely used for academic research with complete commitment for absolute confidentiality to all the provided information. Based on the literature review and interviews with experts, the main factors that were found to have an effect on sustainability of heritage buildings can be summarized in Figure 1.

Cordially,
Abobakr Al-Sakkaf, Arch.Eng, M.Sc.
Ph.D. Student- Building Engineering
BCEE, Concordia University
Montreal, Quebec, Canada

* Required

Figure 1: Criteria, factors and sub-factors affecting the assessment of sustainability of Heritage Buildings) https://drive.google.com/file/d/1Ez4wEcRLAlPCmAFzCepchhB6EQ_G0bUt/view?usp=sharing



1. **How do you describe your occupation?** *

Mark only one oval.

○ Architect
○ Civil Engineer
○ Mechanical/Electrical Engineer
○ Other: ______________________

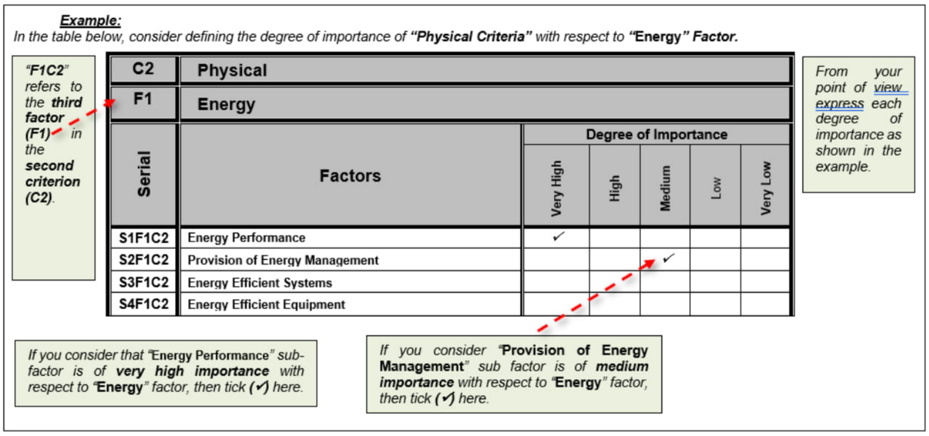
2. **Which best describes your working experience?** *

Mark only one oval.

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

Degree of Importance of Criteria & Factors

Figure 2: Degree of importance of Criteria and factors with respect to main Goal (Total Assessment of Sustainability of Heritage Buildings)



Example:

*In the table below, consider defining the degree of importance of **"Physical Criteria"** with respect to **"Energy" Factor.***

*"**F1C2**" refers to the **third factor (F1)** in the **second criterion (C2)**.*

C2	Physical					
F1	Energy					
Serial	Factors	Degree of Importance				
		Very High	High	Medium	Low	Very Low
S1F1C2	Energy Performance	✓				
S2F1C2	Provision of Energy Management			✓		
S3F1C2	Energy Efficient Systems					
S4F1C2	Energy Efficient Equipment					

From your point of view express each degree of importance as shown in the example.

*If you consider that "**Energy Performance**" sub-factor is of **very high importance** with respect to "**Energy**" factor, then tick (✓) here.*

*If you consider "**Provision of Energy Management**" sub factor is of **medium importance** with respect to "**Energy**" factor, then tick (✓) here.*

Related Definitions

Site and Ecology Factor=> deals with the site and all its related aspects

Material and Waste Reduction Factor=> evaluates the efficient use of materials and assesses the practices utilized to manage the solid waste efficiently, safely and environment-friendly

Transportation Factor=> It encourages utilizing of efficient means of transportation, and urge using public means of transportation rather than private ones in commuting

Energy Factor=> It is one of the primary targets of sustainability assessment aims for the reduction in energy consumption and the unwanted life cycle buildings' impact

Water Use Factor=> it assesses the practices used to conserve water and decrease water consumption by employing efficient and innovative practices

Historic Value=> An aspect of the worth or importance attached by people to qualities of places, categorized as aesthetic, communal or historical value.

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

3. **With respect to "Total Assessment of Sustainability of Heritage Buildings" How important do you think are the following criteria** *

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Environmental Criteria	○	○	○	○	○
Physical Criteria	○	○	○	○	○
Social Criteria	○	○	○	○	○

4. **With respect to "Total Assessment of Sustainability of Heritage Buildings" How important do you think are the following factors**

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Site & Ecology	○	○	○	○	○
Material Waste Reduction	○	○	○	○	○
Transportation	○	○	○	○	○
Energy	○	○	○	○	○
Water Use	○	○	○	○	○
Structural Condition	○	○	○	○	○
Indoor Environmental Quality	○	○	○	○	○
Heritage Value	○	○	○	○	○
Building Management	○	○	○	○	○

Degree of importance of sub-factors with respect to factors:

5. **With respect to "Site & Ecology" factor how important do you think is each of the following ?**

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Site Selection	○	○	○	○	○
Site Management	○	○	○	○	○
Reduce Heat Island Effect	○	○	○	○	○
Site Emissions	○	○	○	○	○

6. **With respect to "Material waste reduction" factor how important do you think is each of the following ?** *

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Sustainable Purchasing Practice	○	○	○	○	○
Efficient Use of Materials	○	○	○	○	○
Solid Waste Management Practice	○	○	○	○	○

7. **With respect to "Transportation" factor how important do you think is each of the following ?** *

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Public Transport Accessibility & Community Accessibility	○	○	○	○	○
Provision of Low-Emitting & Fuel Efficient Vehicles	○	○	○	○	○
Provision of Low-Emitting & Fuel Efficient Vehicles	○	○	○	○	○

8. **With respect to "Energy " factor how important do you think is each of the following ?** *

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Energy Performance	○	○	○	○	○
Provision of Energy Management	○	○	○	○	○
Energy Efficient Systems	○	○	○	○	○
Energy Efficient Equipment	○	○	○	○	○

9. **With respect to "Water Use" how important do you think is each the following?** *

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Water Conservation	○	○	○	○	○
Water Management	○	○	○	○	○

10. **With respect to "Structural Condition" how important do you think is each the following?** *

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Building Material	○	○	○	○	○
Maintenance Plan	○	○	○	○	○
Saftey	○	○	○	○	○

11. **With respect to “Indoor Environmental Quality” factor how important do you think is each of the following ?** *

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Visual Comfort	○	○	○	○	○
Indoor Air Quality	○	○	○	○	○
Thermal Comfort	○	○	○	○	○
Acoustic Performance	○	○	○	○	○
Hygiene	○	○	○	○	○
Building Amenities	○	○	○	○	○

12. **With respect to “Building Management” factor how important do you think is each of the following?** *

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Maintenance Management	○	○	○	○	○
Security Measures & Intruder Alarm System	○	○	○	○	○
Green Lease	○	○	○	○	○
Risk Management	○	○	○	○	○
Innovations	○	○	○	○	○

Skip to question 18.

PART (3):Numerical Representation for Each Degree of Importance

Please insert two values from 0-10 to represent maximum and minimum values for each linguistic degree of importance

13. **1) How do you represent (maximum and minimum) numerical range for "Very Low" linguistic degree of importance ?** *

14. **2) How do you represent (maximum and minimum) numerical range for " Low" linguistic degree of importance ?** *

15. **3) How do you represent (maximum and minimum) numerical range for " Moderate" linguistic degree of importance ?** *

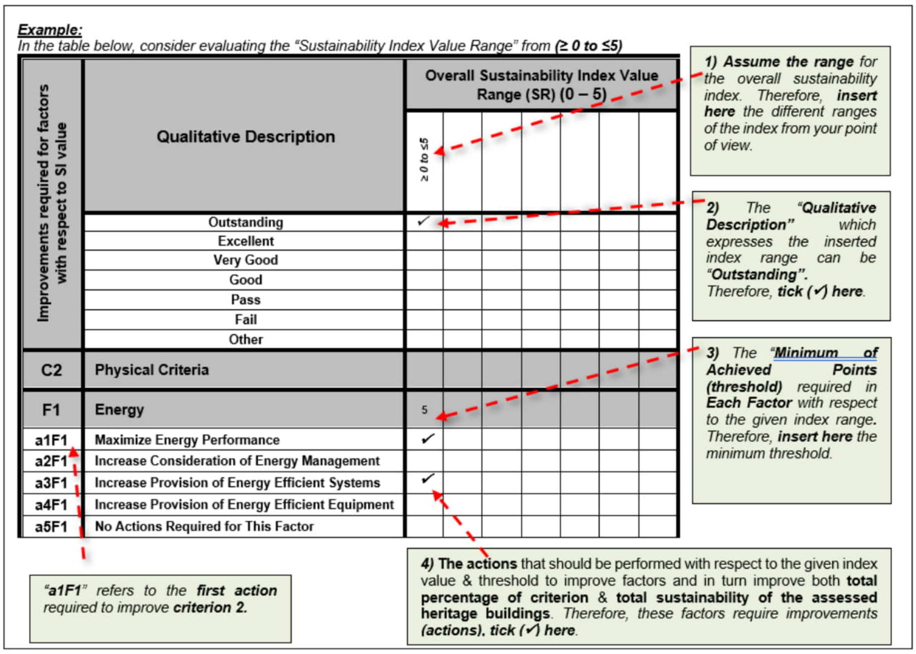
16. **4) How do you represent (maximum and minimum) numerical range for " High" linguistic degree of importance ?** *

17. **5) How do you represent (maximum and minimum) numerical range for " Very High" linguistic degree of importance ?** *

PART (4):Numerical Representation for the Final Sustainability of Heritage Buildings Ranking (SR)

Please insert two values from 0-100 to represent maximum and minimum values for each linguistic degree of importance

Figure 3: Degree of Importance for the actions and their impact on Building Overall Sustainability Ranking (SR)



Example:
In the table below, consider evaluating the "Sustainability Index Value Range" from ***(≥ 0 to ≤5)***

Improvements required for factors with respect to SI value	Qualitative Description	Overall Sustainability Index Value Range (SR) (0 – 5)						
		≥ 0 to ≤5						
	Outstanding	✓						
	Excellent							
	Very Good							
	Good							
	Pass							
	Fail							
	Other							
C2	Physical Criteria							
F1	Energy	5						
a1F1	Maximize Energy Performance	✓						
a2F1	Increase Consideration of Energy Management							
a3F1	Increase Provision of Energy Efficient Systems	✓						
a4F1	Increase Provision of Energy Efficient Equipment							
a5F1	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 of Achieved Points (threshold)** required in **Each Factor** with respect to the given index range. Therefore, **insert here** the minimum threshold.*

***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 heritage buildings**. Therefore, these factors require improvements (actions), **tick (✓) here**.*

*"**a1F1**" refers to the **first action** required to improve **criterion 2.***

18. **1) How do you represent (maximum and minimum) numerical range for "Fail" linguistic degree of importance ?** *

19. **2) How do you represent (maximum and minimum) numerical range for "Pass" linguistic degree of importance ?** *

20. **3) How do you represent (maximum and minimum) numerical range for "Good" linguistic degree of importance ?** *

21. **4) How do you represent (maximum and minimum) numerical range for "Very Good" linguistic degree of importance ?** *

22. **5) How do you represent (maximum and minimum) numerical range for "Excellent" linguistic degree of importance ?** *

23. **6) How do you represent (maximum and minimum) numerical range for "Outstanding" linguistic degree of importance ?** *

24. **7) How do you represent the minimum threshold required for the following factors with regard to Sustainability Heritage Buildings Ranking ?** *

Mark only one oval per row.

	Fail	Pass	Good	Very Good	Excellent	Outstanding
Site & Ecology	○	○	○	○	○	○
Material Waste Reduction	○	○	○	○	○	○
Transportation	○	○	○	○	○	○
Energy	○	○	○	○	○	○
Water Use	○	○	○	○	○	○
Indoor Environmental Quality	○	○	○	○	○	○
Building Management	○	○	○	○	○	○

Heritage Value & Structural Condition

A) Heritage Value

25. **With respect to “Heritage Value” how important do you think is each the following?**

Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Building Age	○	○	○	○	○
Building Fucntion	○	○	○	○	○
Building Material	○	○	○	○	○
Building Revenue	○	○	○	○	○

26. **With respect to “Building Age” how important do you think is each the following?** *
Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
100-200 yrs	○	○	○	○	○
200-300 yrs	○	○	○	○	○
300 - 400 yrs	○	○	○	○	○
400 yrs and above	○	○	○	○	○

27. **With respect to “Building Function” how important do you think is each the following?** *
Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Residential	○	○	○	○	○
Commercial	○	○	○	○	○
Governmental	○	○	○	○	○
Tourism	○	○	○	○	○

28. **With respect to “Building Material” how important do you think is each the following?** *
Mark only one oval per row.

	Very High	High	Moderate	Low	Very Low
Mud	○	○	○	○	○
Stone	○	○	○	○	○
Concrete	○	○	○	○	○
Cast Iron	○	○	○	○	○

29. **Approximately, how much per year is the revenue for a heritage building you are familiar with?** *
Mark only one oval.

○ less than $ 100,000
○ $100,000 - 200,000
○ $200,000 - 300,000
○ $300,000 and above
○ Other: ____________________

B) Structural Condition

Interventions depend on the type of primary treatment used ; Preservation, Rehabilitation or Restoration.
Preservation (minor): requires protecting existing material without extensive repair or replacement
Rehabilitation (major): more than just minor repair is needed. It may include replacement of missing elements or introduction of new features.
Restoration (major): may include the removal of features and/or the reconstruction of missing features

30. **What do you think the following should be ?**
Mark only one oval per row.

	1 yr	2 yrs	3 yrs	4 yrs
The maintenance frequency?	○	○	○	○
The inspection frequency	○	○	○	○
The Intervention Minor in the last 5 years	○	○	○	○

31. **Did you do any major intervention in the last 5 years?**
Mark only one oval.

○ Yes
○ No

32. **Did you do any major intervention in the last 2 years?**
Mark only one oval.

○ Yes
○ No

33. **Did you do any minor intervention in the last 5 years?**
Mark only one oval.

○ Yes
○ No

34. **Did you do any minor intervention in the last 2 years?**
Mark only one oval.

○ Yes
○ No

Table A. 2-1: Comparison between 12 rating systems of Building Sustainability, Environmental criteria

	Criteria, factors, indicators and sub-indicators of the proposed system	Oveall Score	LEED US	Green Globe	GBI Malaysia	GBI German	GSI Indonesia	BOMA BESt	GSBC	BCA GM	CASBEE Japan	BREEAM UK	HK BEAM	ITACA Italy
	Environmental Criteria													
Site & Ecology Factor	Site Selection Indicator	2	1	0	1	0	1	0	0	0	1	0	1	0
	Previously Certified Design & Construction	1	1	0	1								1	
	Respect for Sites of Historic or Cultural Interest	1		0	0		1				1			
	Site Management Indicator	4	2	0	2	0	2	1	0	2	1	0	3	0
	Environmentally Purchasing Plan	1		0						1			1	
	Environmentally Purchasing Practices & Green Cleaning	1		0						1			1	
	Building Exterior and Hardscape Management Plan	1	1	0	1		1				1		1	
	Integrated Pest Management Erosion Control and Landscape Management	1	1	0	1		1	1						
	Reduction of Heat Island Effect Indicator	5	2	0	2	0	0	0	0	3	5	1	0	0
	Heat Island Reduction in Not Roofed Areas	1	1	0	1						1			
	Heat Island Reduction in Roof Areas	1	1	0	1					1	1			
	Exterior Walls Finishing Materials & Planting	1		0						1	1			
	Consideration of Wind Movement and Building Exterior Design	1		0							1			
	Greenery Provision & Ecological Features	1		0						1	1	1		
	Site Emission Indicator	4	1	0	0	0	0	1	0	0	1	0	2	0
	Noise from Building Equipment	1		0									1	
	Light Pollution Reduction	1	1	0							1		1	
	Boiler Emission	1		0				1						
	Asbestos Management Plan	1		0										
	Total	15	6	0	5	0	3	2	0	5	8	1	6	0
	Coverage percentag		40.0%	0.0%	33.3%	0.0%	20.0%	13.3%	0.0%	33.3%	53.3%	6.7%	40.0%	0.0%
Material & Waste Reduction Factor	Sustainable Purchasing Practice Indicator	5	5	2	3	2	4	0	2	3	4	1	2	2
	Sustainable Purchasing Policy	1	1		1		1							
	Ongoing Consumables	1	1							1	1			
	Durable Goods & Sustainable Forest Products	1	1	1	1	1	1		1	1	1	1	1	1
	Facility Alternations and Additions & Reuse	1	1	1	1	1	1		1	1	1		1	1
	Reduced Mercury in Lamps	1	1				1				1			
	Efficient Use & Selection of Materials Indicator	5	1	1	1	1	2	1	1	1	0	4	3	1
	Modular and Standardized Design	1											1	
	Adaptability and Deconstruction	1										1	1	
	Designing for robustness for Asset & Landscape	1										1		
	Using Non-Ozone Depleting Substances (Non-CFC, non-HCFC)	1	1	1	1	1	1	1	1	1		1	1	1
	Monitoring, Testing, and Controlling Leak of Refrigerants	1					1					1		
	Solid Waste Management Practice Indicator	8	5	1	1	1	3	5	1	1	3	1	3	1
	Solid Waste Management Policy	1	1				1	1					1	
	Hazardous Waste Management	1					1	1						
	Waste Stream Audit	1	1				1	1			1		1	
	Ongoing Consumables	1	1											
	Durable Goods	1	1											
	Facility Alternations and Additions	1	1											
	Storage, Collection and Disposal of Recyclables among tenants	1		1	1	1		1	1	1	1	1	1	1
	Installation of Equipment for Water Reduction, Compaction or Composting	1						1			1			
	Total	18	11	4	5	4	9	6	4	5	7	6	8	4
	Coverage percentag		61.1%	22.2%	27.8%	22.2%	50.0%	33.3%	22.2%	27.8%	38.9%	33.3%	44.4%	22.2%
Transportation Factor	Provision of Max. Car Parking Capacity Indicator	1			1									
	Cyclist Facilities & Alternative Methods of Transport Indicator	3	1	0	0	0	2	0	0	1	0	1	0	0
	Cyclist Facilities	1					1			1		1		
	Carpooling & Vanpooling	1					1							
	Reduction in Conventional Commuting Trips	1	1											
	Public & Community Accessibility Indicator	2	0	0	0	0	1	0	0	1	0	2	0	0
	Public Transport Accessibility	1								1		1		
	Proximity to Amenities	1					1					1		
	Provision of Low Emitting & Fuel Efficient Vehicles	1			1					1				
	Total	7	1	0	2	0	3	0	0	3	0	3	0	0
	Coverage percentag		14.3%	0.0%	28.6%	0.0%	42.9%	0.0%	0.0%	42.9%	0.0%	42.9%	0.0%	0.0%

Table A. 2-2: Comparison between 12 rating systems of Building Sustainability, Physical criteria

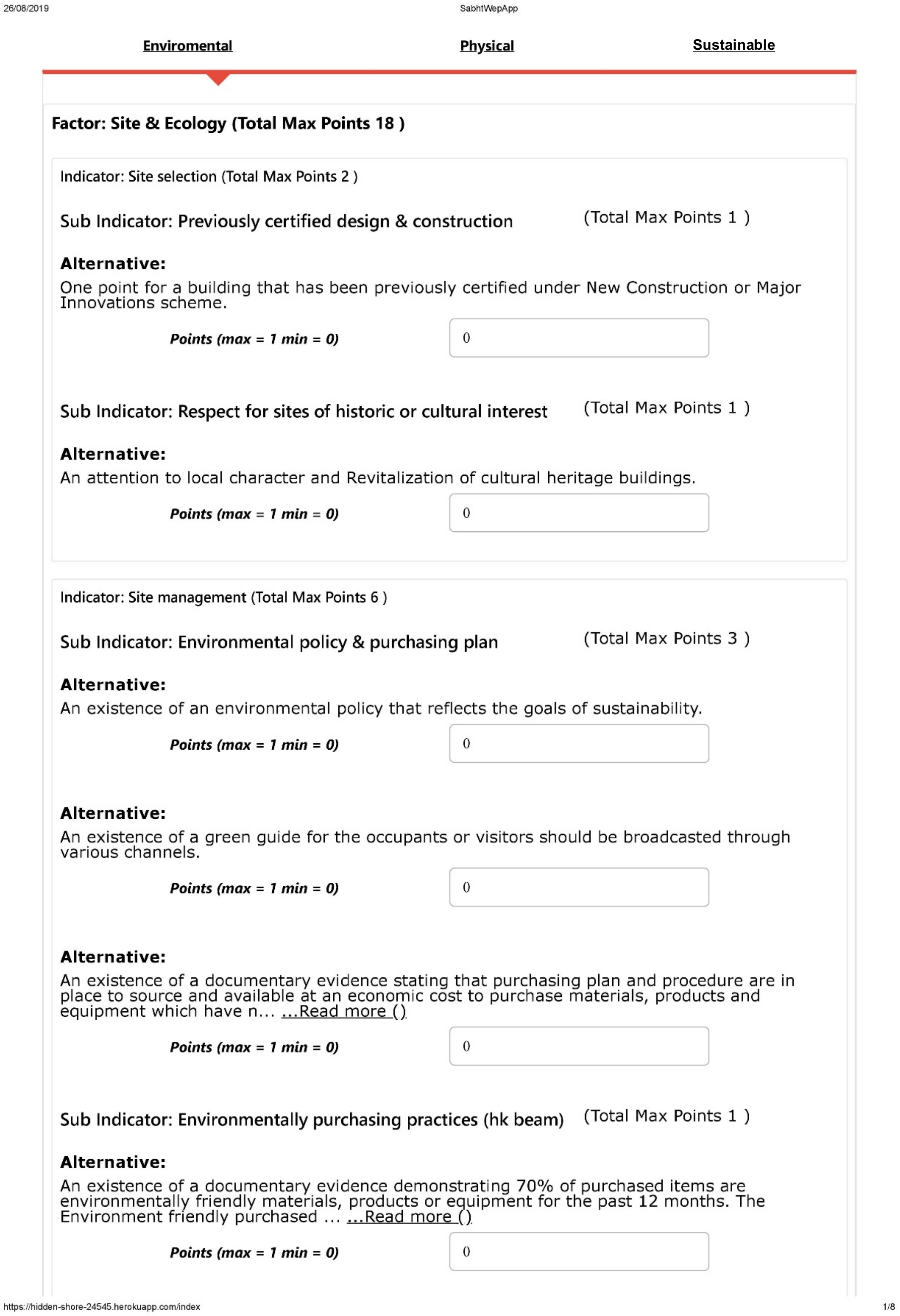
								Physical Criteria						
	Coverage percentag													
Energy Factor	Energy Performance Indicator	3	2	1	2	1	2	1	1	0	0	1	2	1
	Minimum Energy Performance	1	1		1		1						1	
	Optimizing Energy Efficiency Performance & Reduction of CO2	1	1	1	1	1	1	1	1			1	1	1
	Evaluation of Thermal Performance Reduction of Building	1						1		1				
	Provision of Energy Management Indicator	6	5	0	4	0	5	2	0	1	1	1	3	0
	Energy Operating Plan	1	1				1	1		1			1	
	Energy Monitoring and Metering	1	1		1		1				1		1	
	Commissioning and Testing Energy Systems	1	1		1		1	1				1	1	
	Building Automation System, or Energy Management System	1	1		1									
	Emission Reduction Reporting	1	1				1							
	Sustainable Maintenance	1			1		1							
	Energy Efficient Systems Indicator	4	2	2	2	2	2	1	2	4	1	2	3	2
	Interior Lighting Efficiency and Zoning Control	1	1	1	1	1	1		1	1		1	1	1
	Renewable Energy Systems	1	1	1	1	1	1	1	1	1	1	1	1	1
	Energy Efficient Circulation Systems (Lifts and Escalators)	1								1				
	Efficient Ventilation System in Car Parks and Common Areas	1								1			1	
	Energy Efficient Equipment Indicator	3	0	1	0	1	1	1	1	1	1	2	2	1
	Energy Efficient Appliances and Cloth Drying Facilities	1											1	
	Energy Efficient AC Equipment	1		1		1	1		1	1	1	1	1	1
	High Efficiency Boilers	1						1				1		
	Total	16	9	4	8	4	10	5	4	6	3	6	10	4
	Coverage percentag		56.3%	25.0%	50.0%	25.0%	62.5%	31.3%	25.0%	37.5%	18.8%	37.5%	62.5%	25.0%
Water Use	Water Conservation Indicator	5	3	3	3	3	4	4	3	0	2	3	4	3
	Minimum Indoor Plumbing Fixtures and Fittings Efficiency	1	1	1		1	1	1	1			1	1	1
	Additional Indoor Plumbing Fixtures and Fitting Efficiency	1	1	1	1	1	1	1	1		1	1	1	1
	Water Recycling & Rain Water Harvesting	1		1	1	1	1	1	1		1	1	1	1
	Water Efficient Landscaping and Irrigation	1	1		1			1					1	
	Water Tap Efficiency in Public Areas	1					1							
	Water Management Indicator	5	3	1	1	1	4	5	1	0	0	3	2	1
	Water Conservation Plan	1					1	1					1	
	Regular Procedures for Checking and fixing Leaks	1					1	1				1		
	Water Performance monitoring	1	1	1	1	1	1	1	1			1	1	1
	Cooling Tower Water Management	1	1					1						
	Storm Water Quantity Control & Surface Water run off	1	1				1	1				1		
	Total	10	6	4	4	4	8	9	4	0	2	6	6	4
	Coverage percentag		60.0%	40.0%	40.0%	40.0%	80.0%	90.0%	40.0%	0.0%	20.0%	60.0%	60.0%	40.0%
Heritage Value Factor	Building Age Indicator	4	0	0	0	0	0	0	0	0	0	0	0	0
	100-200 yrs.	1												
	200-300 yrs.	1												
	300-400 yrs.	1												
	400 yrs. & above	1												
	Building Function Indicator	4	0	0	0	0	0	0	0	0	0	0	0	0
	Residential	1												
	Commercial	1												
	Governmental	1												
	Tourism	1												
	Building Revenue Indicator	4	0	0	0	0	0	0	0	0	0	0	0	0
	Less than $100 K	1												
	$100,000-200,000	1												
	$200,000-300,000	1												
	$300,000 & above	1												
	Total	12	0	0	0	0	0	0	0	0	0	0	0	0
	Coverage percentag		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Structural Condition Factor	Building Material Indicator	4	0	0	0	0	0	0	0	0	0	0	0	0
	Mud	1												
	Stone	1												
	Concrete	1												
	Cast Iron	1												
	Maintenance Plan Indicator	4	0	0	0	0	0	0	0	0	0	0	0	0
	Maintenance Frequency	1												
	Inspection Frequency	1												
	Intervention Minor	1												
	Intervention Major	1												
	Safety Indicator	1	0	0	0	0	0	0	0	0	0	0	0	0
	Total	9	0	0	0	0	0	0	0	0	0	0	0	0
	Coverage percentag		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table A. 2-3: Comparison between 12 rating systems of Building Sustainability, Social criteria

		Social Criteria												
Indoor Environment Quality Factor	Visual Comfort Indicator	4	2	2	3	2	0	0	2	2	3	4	2	2
	Natural Lighting and External Views	1	1		1						1	1	1	
	Glare Control	1			1							1		
	Interior Lighting Distribution in Normally and Non-Normally Occupied	1		1	1	1			1	1	1	1	1	1
	Controllability of Lighting System	1	1	1		1			1	1	1	1		1
	Hight Frequency Ballasts	1			1		1					1		
	Indoor Air Quality Indicator	7	6	3	4	3	4	1	3	3	4	4	5	3
	Minimum IAQ Performance	1	1		1									
	Environmental Tobacco Smoke Control	1	1				1				1		1	
	Increased Ventilation Performance, Localized Ventilation & Ventilation	1	1								1	1	1	
	Indoor Air Quality Performance & Management	1	1	1	1	1	1	1	1	1	1	1	1	1
	Indoor Air Quality Pollutant Monitoring	1	1	1	1	1	1		1	1	1	1	1	1
	Green Cleaning Policy	1	1	1		1	1		1	1		1	1	1
	IAQ Verification Before/ During Occupancy	1			1									
	Thermal Comfort Indicator	3	1	0	2	0	0	0	0	2	2	1	1	0
	Design, Verification	1	1		1						1			
	Controllability of Temperature	1			1					1		1		
	Thermal Comfort in Air-Conditioned Premises and in Naturally	1								1	1		1	
	Acoustic Performance Indicator	3	2	1	2	1	3	0	1	1	2	0	3	1
	Room Acoustic	1	1		1		1						1	
	Noise Isolation	1					1				1		1	
	Background Noise	1	1	1	1	1	1		1	1	1		1	1
	Hygiene Indicator	5	1	0	1	0	0	0	0	0	0	2	3	0
	Plumbing and Drainage	1											1	
	Chemical Storage	1										1		
	Biological Contamination Reduction	1										1	1	
	Waste Disposal facilities de-odorizing System	1											1	
	Occupancy Comfort Survey	1	1		1									
	Building Amenities Indicator	2	0	0	0	0	0	0	0	0	0	1	2	0
	Access for Persons with Disability	1										1	1	
	Amenity Features	1											1	
	Total	24	12	6	12	6	7	1	6	8	11	12	16	6
	Coverage percentag		50.0%	25.0%	50.0%	25.0%	29.2%	4.2%	25.0%	33.3%	45.8%	50.0%	66.7%	25.0%
Building Management Factor	Operation and Maintenance Management Indicator	5	0	0	1	0	2	0	0	2	0	4	2	0
	Condition Survey	1										1		
	Staffing Quality and Resources	1								1			1	
	Building User Manual and Information	1			1					1		1	1	
	Operation & Maintenance Policy	1					1					1		
	Operation & maintenance Procedures and Manuals	1					1					1		
	Security Measures & Intruder Alarm System Indicator	1					1			1		1		
	Green Lease Indicator	1					1			1		1		
	Risk Management Indicator	2	2	0	0	0	0	0	0	0	0	0	0	0
	Fire Risk Assessment, Fire Risk Manager	1	1											
	Natural Hazards	1	1											
	Innovations Indicator	2	0	0	0	0	2	0	0	0	0	2	2	0
	Innovations in Techniques	1					1					1	1	
	Performance Enhancement	1					1					1	1	
	Total	11	2	0	1	0	6	0	0	4	0	8	4	0
	Coverage percentag		18.2%	0.0%	9.1%	0.0%	54.5%	0.0%	0.0%	36.4%	0.0%	72.7%	36.4%	0.0%

APPENDIX B: AUTOMATED TOOL (SAHB)

Appendix B-1: Calculation sheets for environmental criteria



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Factor: Site & Ecology (Total Max Points 18)

Indicator: Site selection (Total Max Points 2)

Sub Indicator: Previously certified design & construction (Total Max Points 1)

Alternative:
One point for a building that has been previously certified under New Construction or Major Innovations scheme.

Points (max = 1 min = 0) 0

Sub Indicator: Respect for sites of historic or cultural interest (Total Max Points 1)

Alternative:
An attention to local character and Revitalization of cultural heritage buildings.

Points (max = 1 min = 0) 0

Indicator: Site management (Total Max Points 6)

Sub Indicator: Environmental policy & purchasing plan (Total Max Points 3)

Alternative:
An existence of an environmental policy that reflects the goals of sustainability.

Points (max = 1 min = 0) 0

Alternative:
An existence of a green guide for the occupants or visitors should be broadcasted through various channels.

Points (max = 1 min = 0) 0

Alternative:
An existence of a documentary evidence stating that purchasing plan and procedure are in place to source and available at an economic cost to purchase materials, products and equipment which have n... ...Read more ()

Points (max = 1 min = 0) 0

Sub Indicator: Environmentally purchasing practices (hk beam) (Total Max Points 1)

Alternative:
An existence of a documentary evidence demonstrating 70% of purchased items are environmentally friendly materials, products or equipment for the past 12 months. The Environment friendly purchased ... ...Read more ()

Points (max = 1 min = 0) 0

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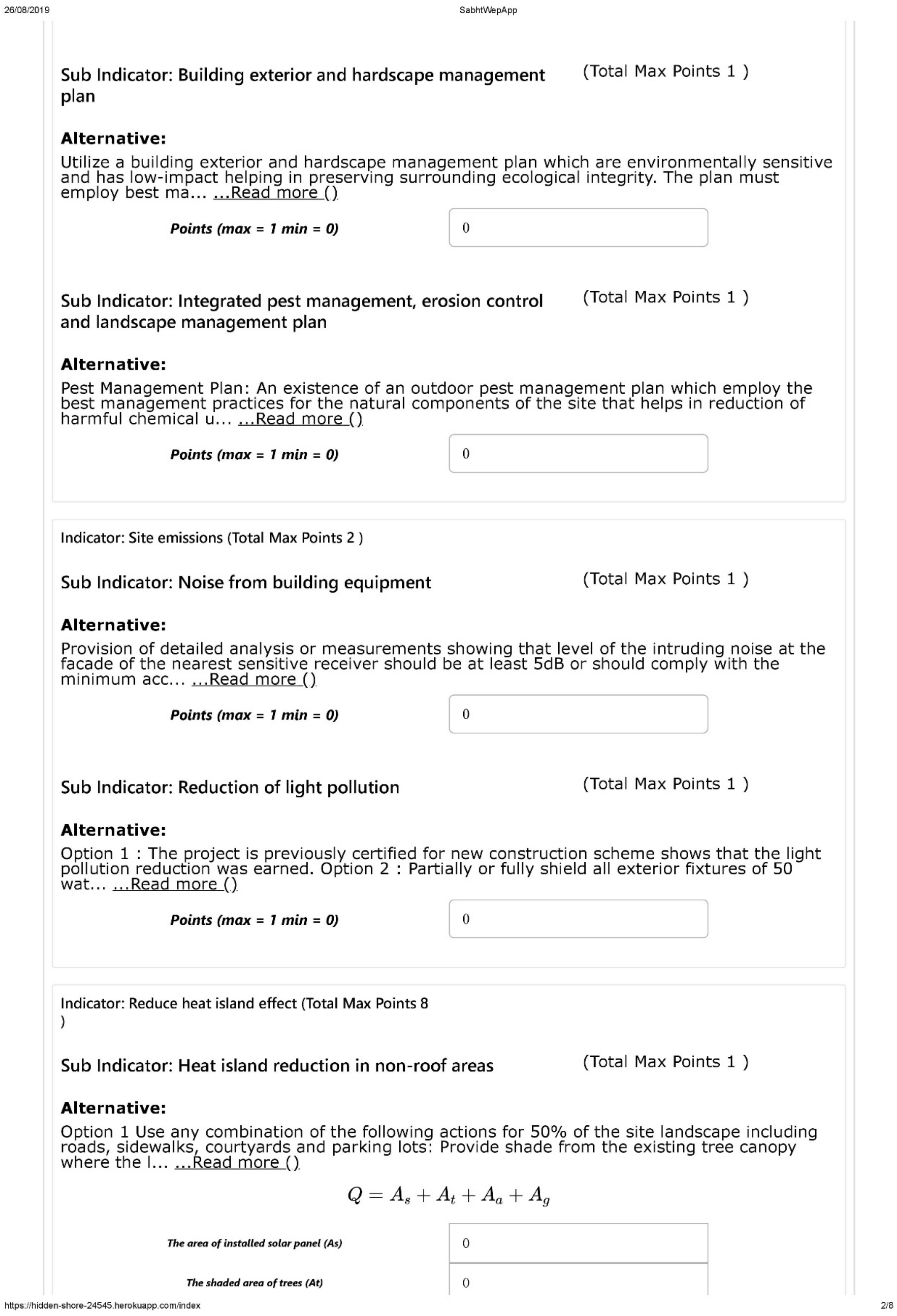

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Sub Indicator: Building exterior and hardscape management plan (Total Max Points 1)

Alternative:

Utilize a building exterior and hardscape management plan which are environmentally sensitive and has low-impact helping in preserving surrounding ecological integrity. The plan must employ best ma... ...Read more ()

Points (max = 1 min = 0) 0

Sub Indicator: Integrated pest management, erosion control and landscape management plan (Total Max Points 1)

Alternative:

Pest Management Plan: An existence of an outdoor pest management plan which employ the best management practices for the natural components of the site that helps in reduction of harmful chemical u... ...Read more ()

Points (max = 1 min = 0) 0

Indicator: Site emissions (Total Max Points 2)

Sub Indicator: Noise from building equipment (Total Max Points 1)

Alternative:

Provision of detailed analysis or measurements showing that level of the intruding noise at the facade of the nearest sensitive receiver should be at least 5dB or should comply with the minimum acc... ...Read more ()

Points (max = 1 min = 0) 0

Sub Indicator: Reduction of light pollution (Total Max Points 1)

Alternative:

Option 1 : The project is previously certified for new construction scheme shows that the light pollution reduction was earned. Option 2 : Partially or fully shield all exterior fixtures of 50 wat... ...Read more ()

Points (max = 1 min = 0) 0

Indicator: Reduce heat island effect (Total Max Points 8)

Sub Indicator: Heat island reduction in non-roof areas (Total Max Points 1)

Alternative:

Option 1 Use any combination of the following actions for 50% of the site landscape including roads, sidewalks, courtyards and parking lots: Provide shade from the existing tree canopy where the l... ...Read more ()

$$Q = A_s + A_t + A_a + A_g$$

The area of installed solar panel (As) 0

The shaded area of trees (At) 0

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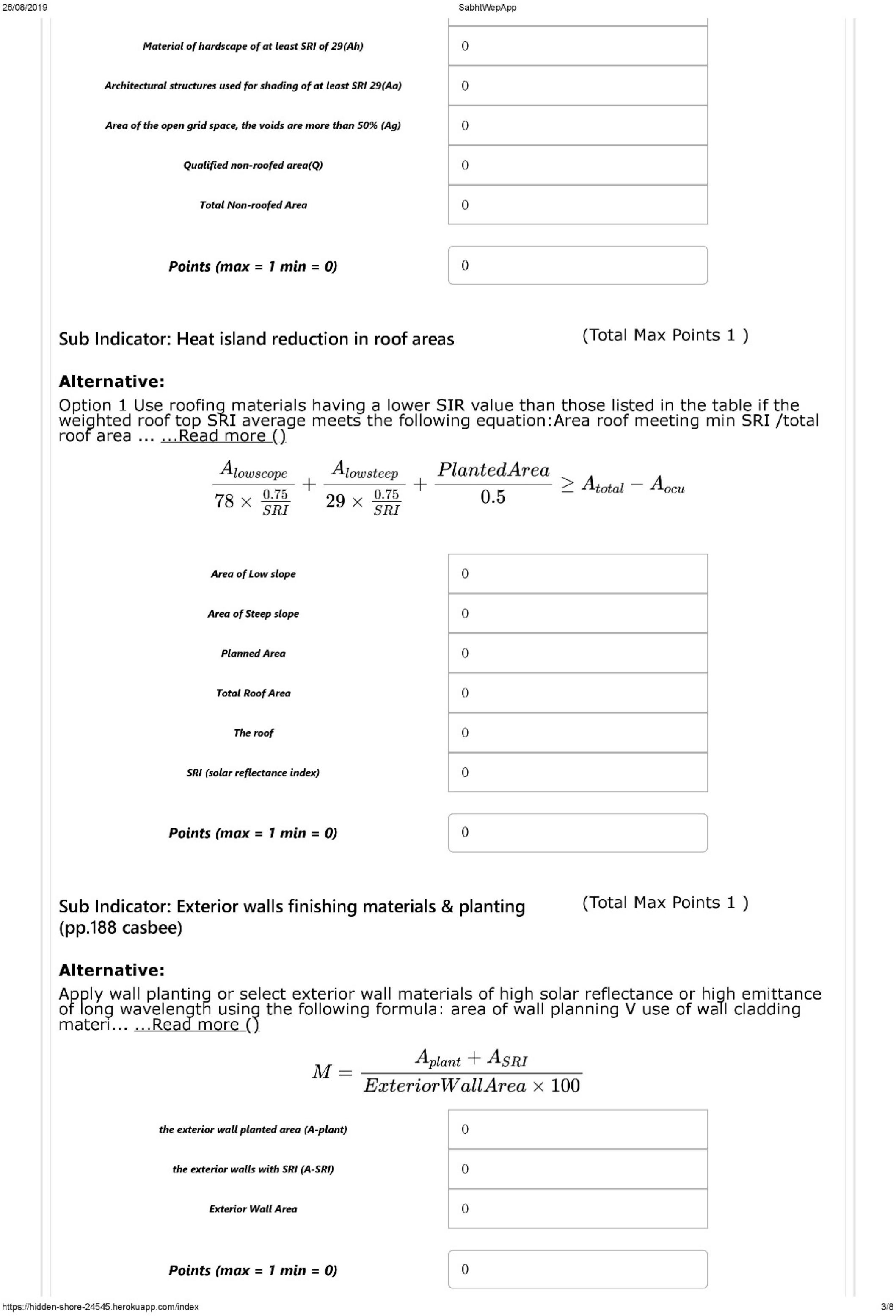

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Material of hardscape of at least SRI of 29(Ah)	0
Architectural structures used for shading of at least SRI 29(Aa)	0
Area of the open grid space, the voids are more than 50% (Ag)	0
Qualified non-roofed area(Q)	0
Total Non-roofed Area	0

Points (max = 1 min = 0) 0

Sub Indicator: Heat island reduction in roof areas (Total Max Points 1)

Alternative:

Option 1 Use roofing materials having a lower SIR value than those listed in the table if the weighted roof top SRI average meets the following equation:Area roof meeting min SRI /total roof area ... ...Read more ()

$$\frac{A_{lowscope}}{78 \times \frac{0.75}{SRI}} + \frac{A_{lowsteep}}{29 \times \frac{0.75}{SRI}} + \frac{PlantedArea}{0.5} \geq A_{total} - A_{ocu}$$

Area of Low slope	0
Area of Steep slope	0
Planned Area	0
Total Roof Area	0
The roof	0
SRI (solar reflectance index)	0

Points (max = 1 min = 0) 0

Sub Indicator: Exterior walls finishing materials & planting (pp.188 casbee) (Total Max Points 1)

Alternative:

Apply wall planting or select exterior wall materials of high solar reflectance or high emittance of long wavelength using the following formula: area of wall planning V use of wall cladding materi... ...Read more ()

$$M = \frac{A_{plant} + A_{SRI}}{ExteriorWallArea \times 100}$$

the exterior wall planted area (A-plant)	0
the exterior walls with SRI (A-SRI)	0
Exterior Wall Area	0

Points (max = 1 min = 0) 0

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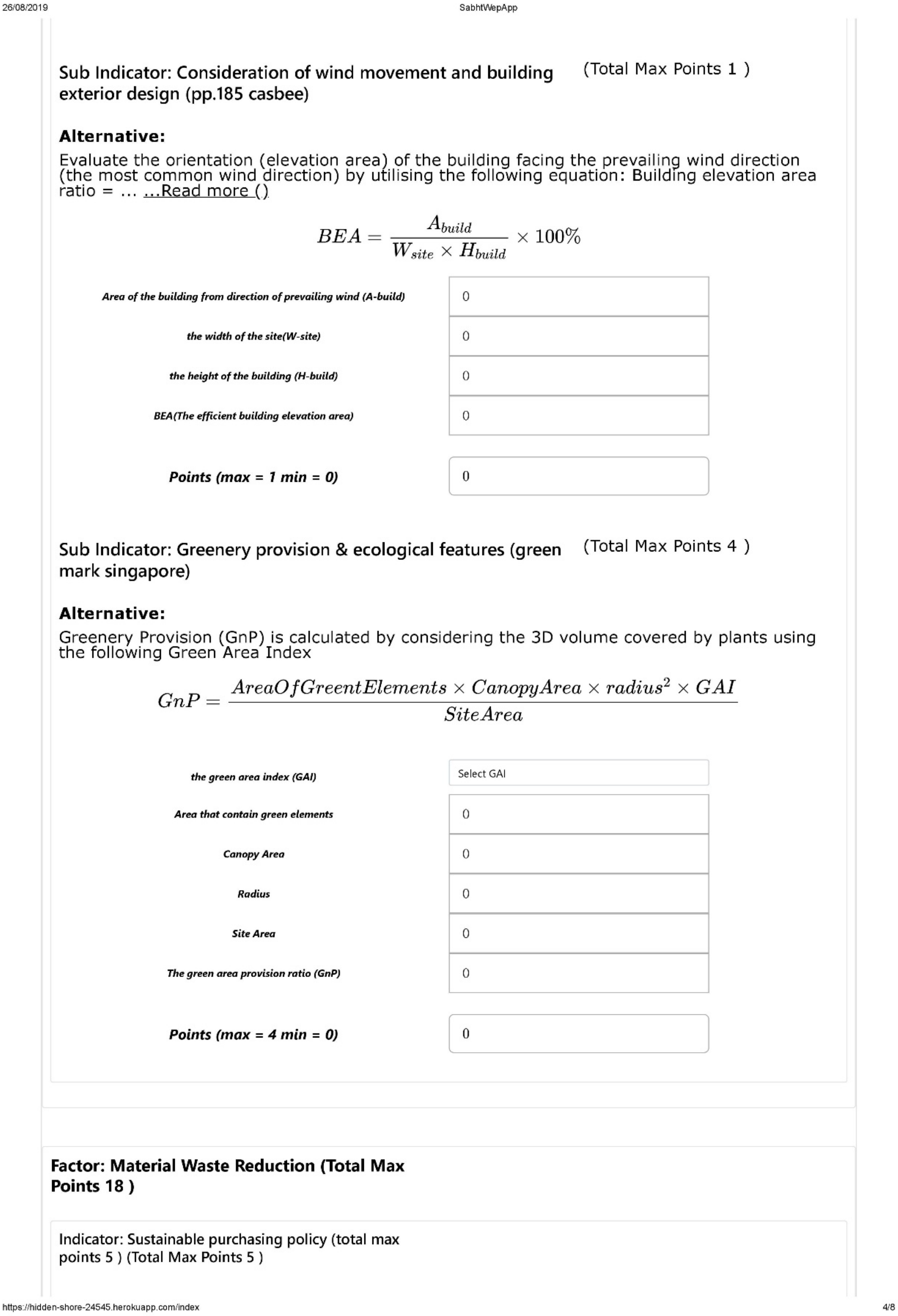

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Sub Indicator: Consideration of wind movement and building exterior design (pp.185 casbee) (Total Max Points 1)

Alternative:

Evaluate the orientation (elevation area) of the building facing the prevailing wind direction (the most common wind direction) by utilising the following equation: Building elevation area ratio = ...Read more ()

$$BEA = \frac{A_{build}}{W_{site} \times H_{build}} \times 100\%$$

Area of the building from direction of prevailing wind (A-build)	0
the width of the site(W-site)	0
the height of the building (H-build)	0
BEA(The efficient building elevation area)	0
Points (max = 1 min = 0)	0

Sub Indicator: Greenery provision & ecological features (green mark singapore) (Total Max Points 4)

Alternative:

Greenery Provision (GnP) is calculated by considering the 3D volume covered by plants using the following Green Area Index

$$GnP = \frac{AreaOfGreentElements \times CanopyArea \times radius^2 \times GAI}{SiteArea}$$

the green area index (GAI)	Select GAI
Area that contain green elements	0
Canopy Area	0
Radius	0
Site Area	0
The green area provision ratio (GnP)	0
Points (max = 4 min = 0)	0

Factor: Material Waste Reduction (Total Max Points 18)

Indicator: Sustainable purchasing policy (total max points 5) (Total Max Points 5)

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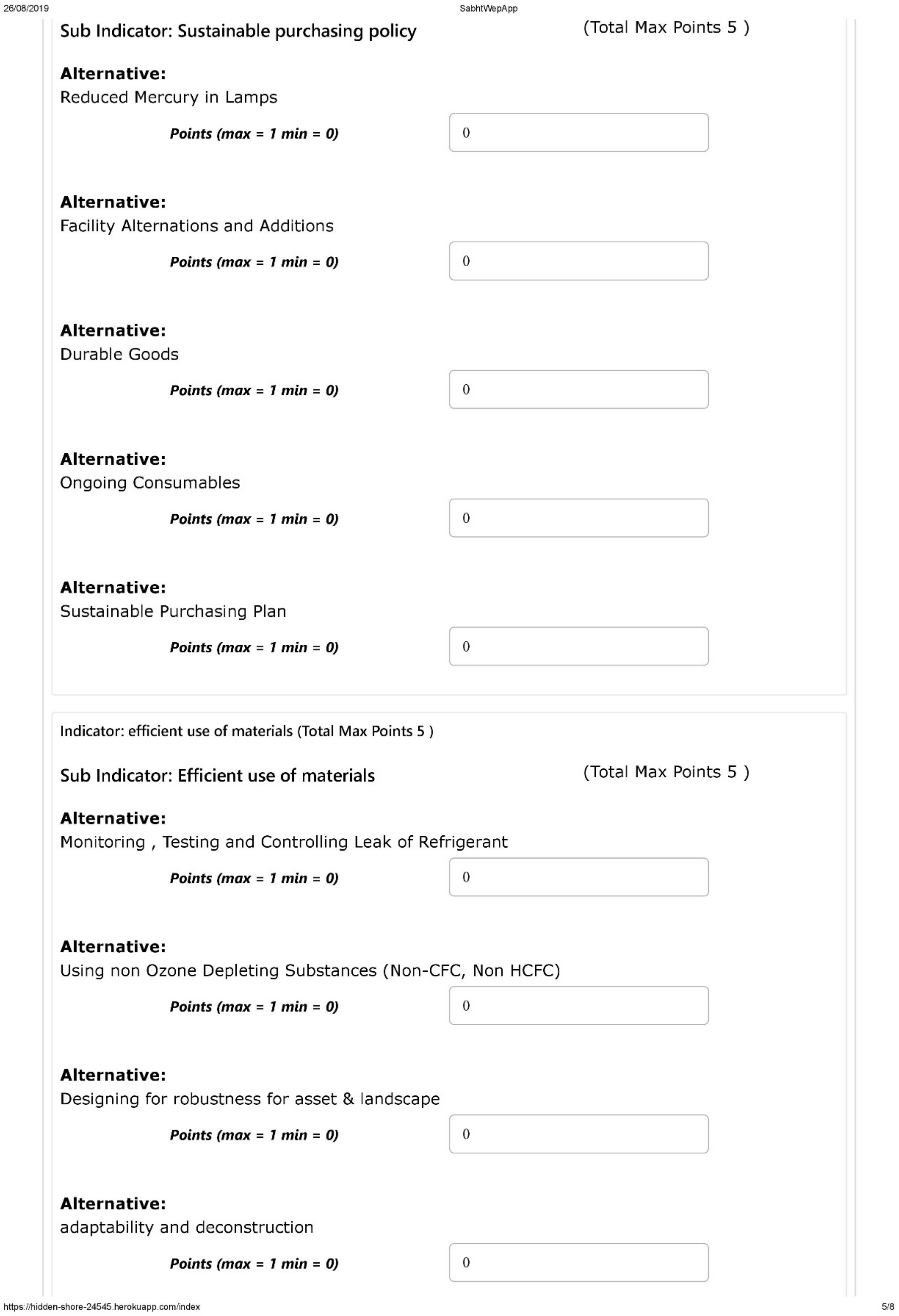


Sub Indicator: Sustainable purchasing policy (Total Max Points 5)

Alternative:
Reduced Mercury in Lamps

Points (max = 1 min = 0) 0

Alternative:
Facility Alternations and Additions

Points (max = 1 min = 0) 0

Alternative:
Durable Goods

Points (max = 1 min = 0) 0

Alternative:
Ongoing Consumables

Points (max = 1 min = 0) 0

Alternative:
Sustainable Purchasing Plan

Points (max = 1 min = 0) 0

Indicator: efficient use of materials (Total Max Points 5)

Sub Indicator: Efficient use of materials (Total Max Points 5)

Alternative:
Monitoring , Testing and Controlling Leak of Refrigerant

Points (max = 1 min = 0) 0

Alternative:
Using non Ozone Depleting Substances (Non-CFC, Non HCFC)

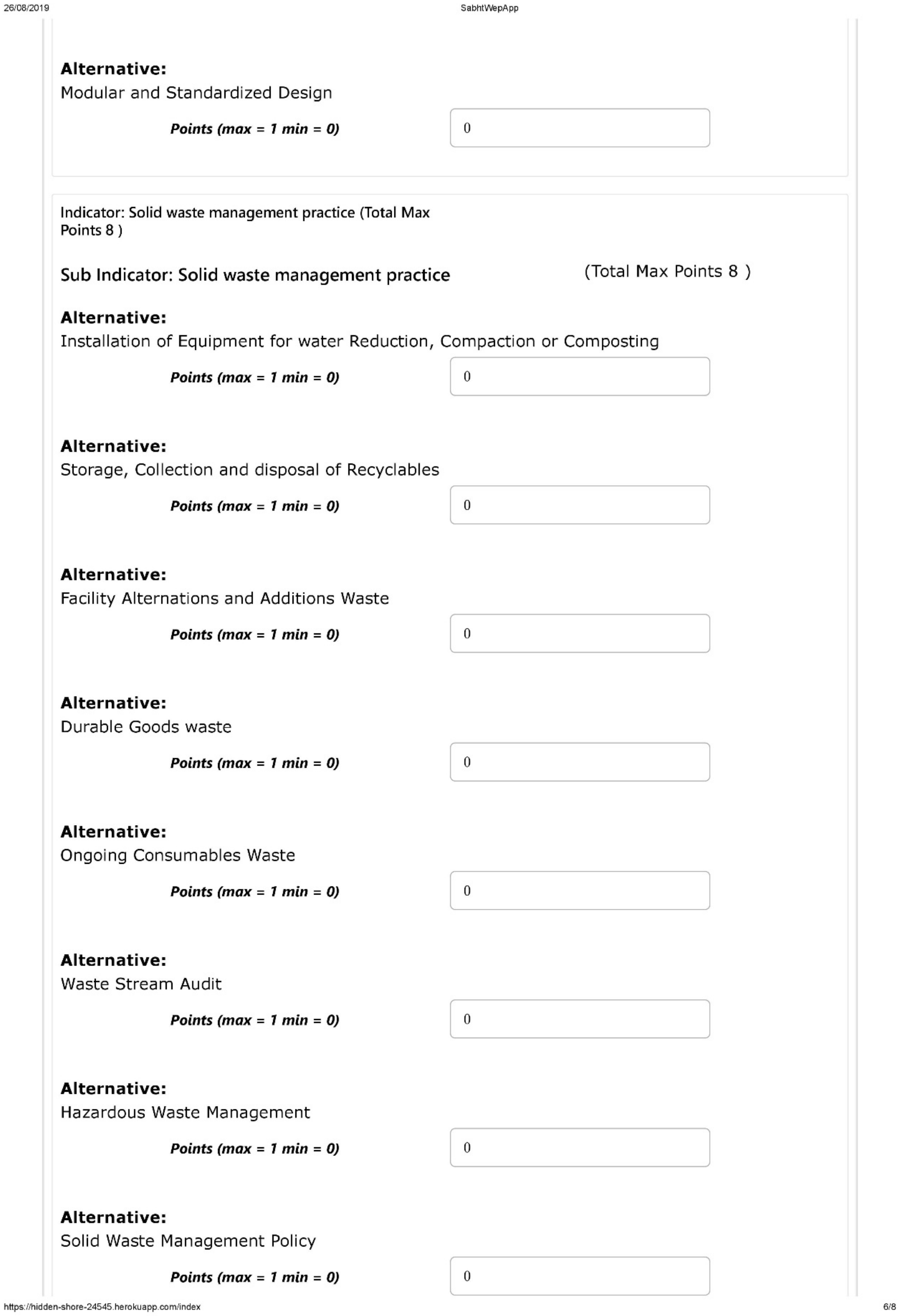
Points (max = 1 min = 0) 0

Alternative:
Designing for robustness for asset & landscape

Points (max = 1 min = 0) 0

Alternative:
adaptability and deconstruction

Points (max = 1 min = 0) 0



Alternative:
Modular and Standardized Design

Points (max = 1 min = 0) 0

Indicator: Solid waste management practice (Total Max Points 8)

Sub Indicator: Solid waste management practice (Total Max Points 8)

Alternative:
Installation of Equipment for water Reduction, Compaction or Composting

Points (max = 1 min = 0) 0

Alternative:
Storage, Collection and disposal of Recyclables

Points (max = 1 min = 0) 0

Alternative:
Facility Alternations and Additions Waste

Points (max = 1 min = 0) 0

Alternative:
Durable Goods waste

Points (max = 1 min = 0) 0

Alternative:
Ongoing Consumables Waste

Points (max = 1 min = 0) 0

Alternative:
Waste Stream Audit

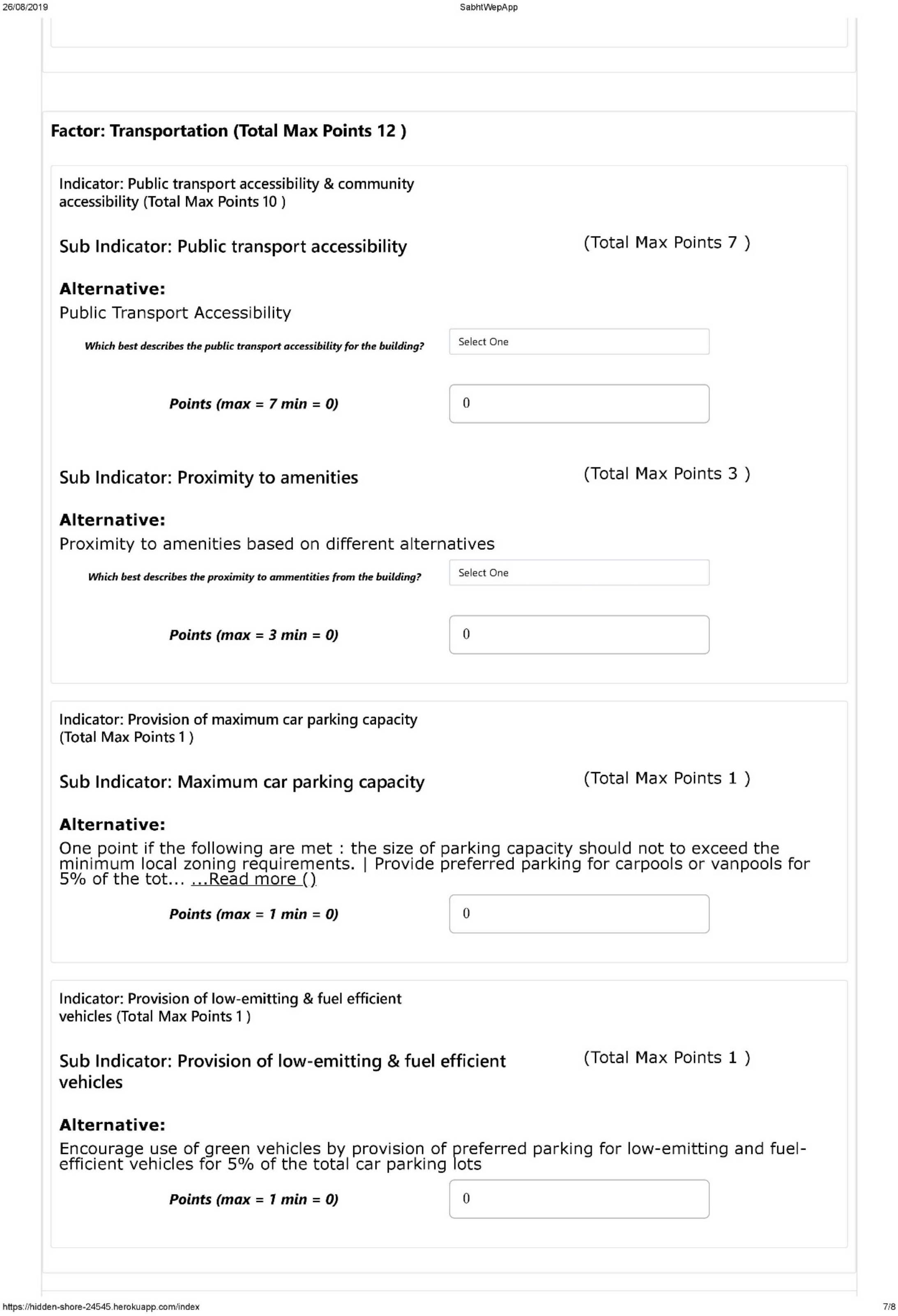
Points (max = 1 min = 0) 0

Alternative:
Hazardous Waste Management

Points (max = 1 min = 0) 0

Alternative:
Solid Waste Management Policy

Points (max = 1 min = 0) 0



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Factor: Transportation (Total Max Points 12)

Indicator: Public transport accessibility & community accessibility (Total Max Points 10)

Sub Indicator: Public transport accessibility (Total Max Points 7)

Alternative:
Public Transport Accessibility

Which best describes the public transport accessibility for the building? Select One

Points (max = 7 min = 0) 0

Sub Indicator: Proximity to amenities (Total Max Points 3)

Alternative:
Proximity to amenities based on different alternatives

Which best describes the proximity to ammentities from the building? Select One

Points (max = 3 min = 0) 0

Indicator: Provision of maximum car parking capacity (Total Max Points 1)

Sub Indicator: Maximum car parking capacity (Total Max Points 1)

Alternative:
One point if the following are met : the size of parking capacity should not to exceed the minimum local zoning requirements. | Provide preferred parking for carpools or vanpools for 5% of the tot... ...Read more ()

Points (max = 1 min = 0) 0

Indicator: Provision of low-emitting & fuel efficient vehicles (Total Max Points 1)

Sub Indicator: Provision of low-emitting & fuel efficient vehicles (Total Max Points 1)

Alternative:
Encourage use of green vehicles by provision of preferred parking for low-emitting and fuel-efficient vehicles for 5% of the total car parking lots

Points (max = 1 min = 0) 0

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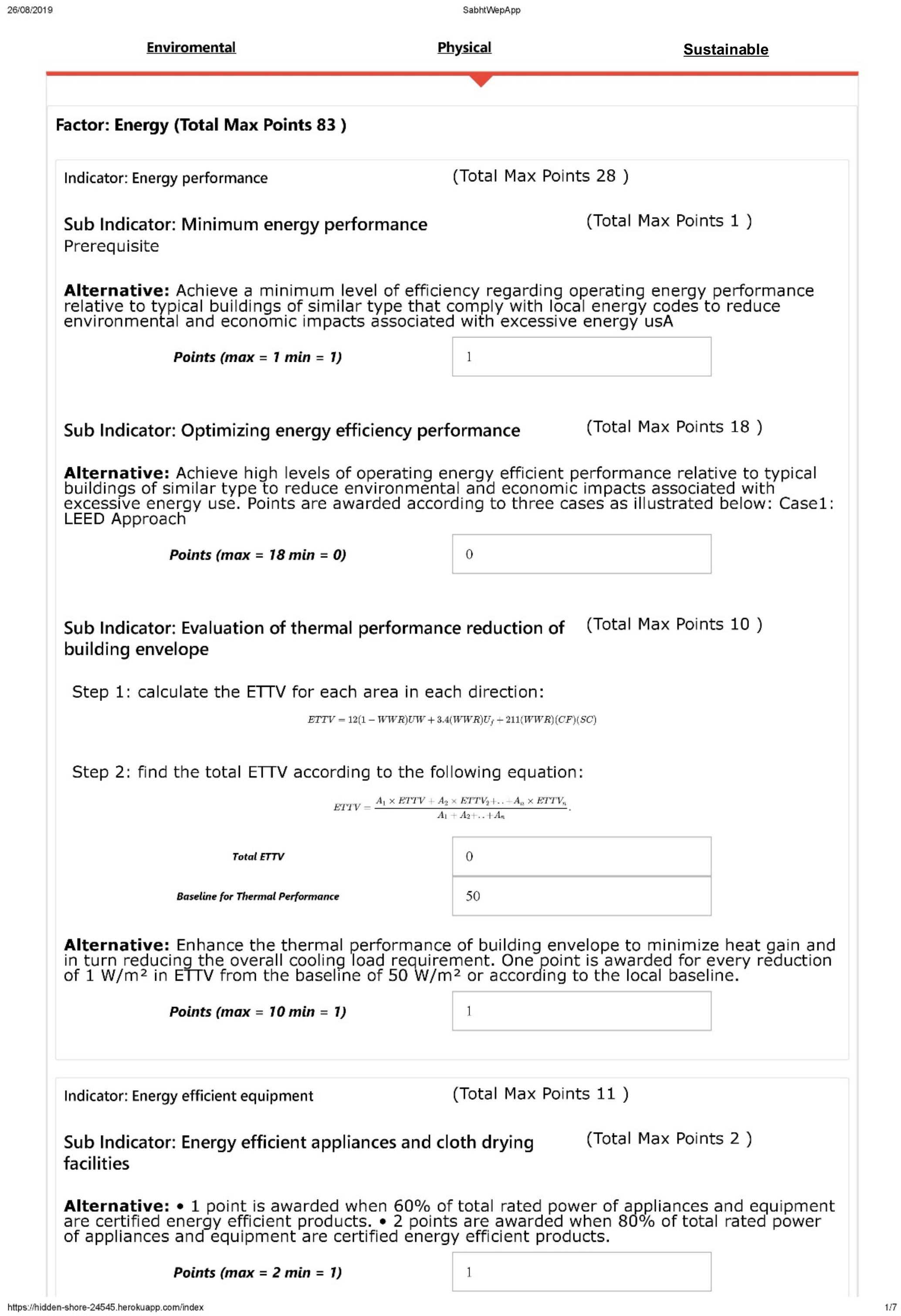
Appendix B-2: Calculation sheets for physical criteria



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Factor: Energy (Total Max Points 83)

Indicator: Energy performance (Total Max Points 28)

Sub Indicator: Minimum energy performance (Total Max Points 1)
Prerequisite

Alternative: Achieve a minimum level of efficiency regarding operating energy performance relative to typical buildings of similar type that comply with local energy codes to reduce environmental and economic impacts associated with excessive energy usA

Points (max = 1 min = 1) 1

Sub Indicator: Optimizing energy efficiency performance (Total Max Points 18)

Alternative: Achieve high levels of operating energy efficient performance relative to typical buildings of similar type to reduce environmental and economic impacts associated with excessive energy use. Points are awarded according to three cases as illustrated below: Case1: LEED Approach

Points (max = 18 min = 0) 0

Sub Indicator: Evaluation of thermal performance reduction of building envelope (Total Max Points 10)

Step 1: calculate the ETTV for each area in each direction:

$$ETTV = 12(1 - WWR)UW + 3.4(WWR)U_f + 211(WWR)(CF)(SC)$$

Step 2: find the total ETTV according to the following equation:

$$ETTV = \frac{A_1 \times ETTV + A_2 \times ETTV_2 + .. + A_n \times ETTV_n}{A_1 + A_2 + .. + A_n}.$$

Total ETTV 0

Baseline for Thermal Performance 50

Alternative: Enhance the thermal performance of building envelope to minimize heat gain and in turn reducing the overall cooling load requirement. One point is awarded for every reduction of 1 W/m² in ETTV from the baseline of 50 W/m² or according to the local baseline.

Points (max = 10 min = 1) 1

Indicator: Energy efficient equipment (Total Max Points 11)

Sub Indicator: Energy efficient appliances and cloth drying facilities (Total Max Points 2)

Alternative: • 1 point is awarded when 60% of total rated power of appliances and equipment are certified energy efficient products. • 2 points are awarded when 80% of total rated power of appliances and equipment are certified energy efficient products.

Points (max = 2 min = 1) 1

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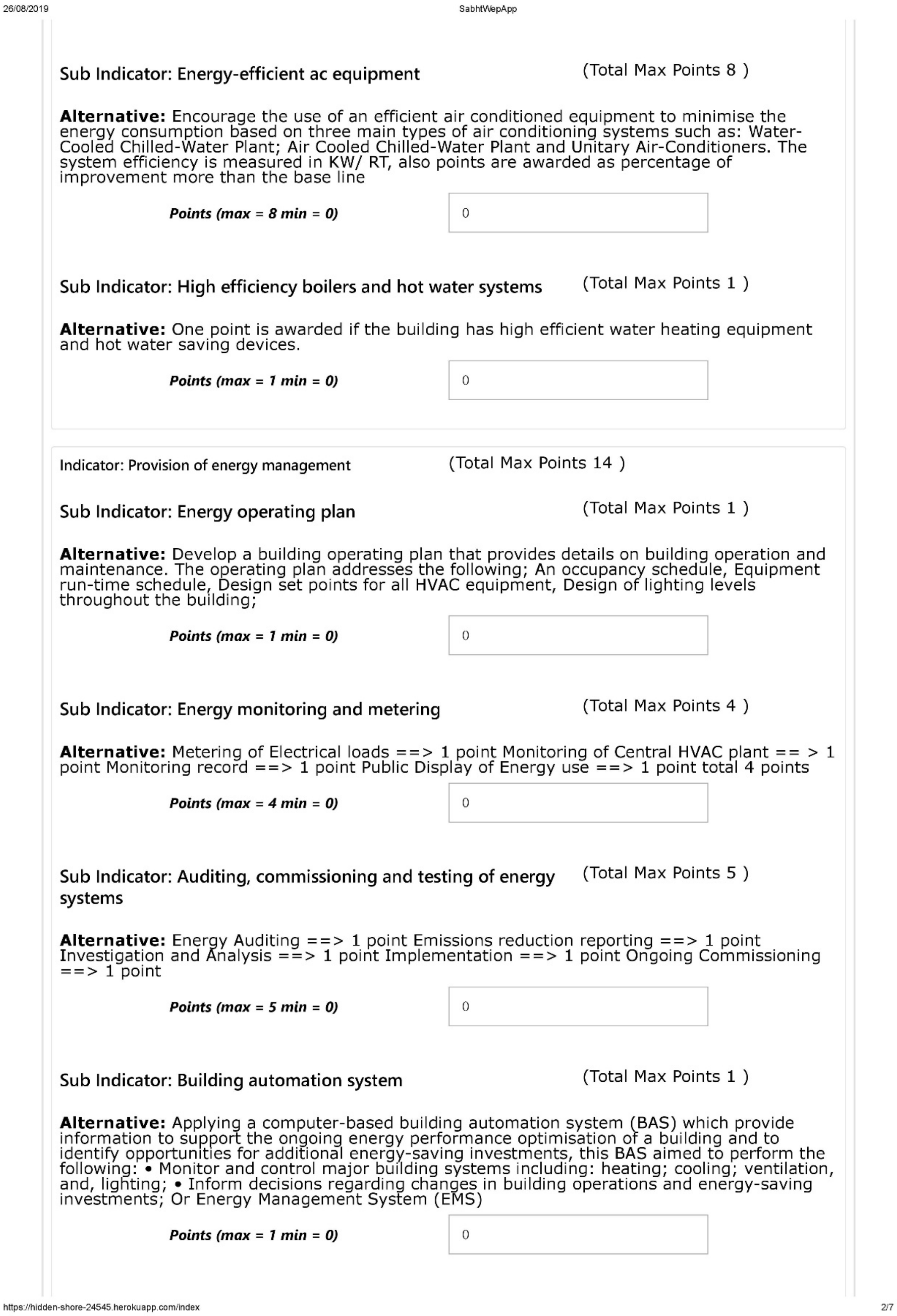


Sub Indicator: Energy-efficient ac equipment (Total Max Points 8)

Alternative: Encourage the use of an efficient air conditioned equipment to minimise the energy consumption based on three main types of air conditioning systems such as: Water-Cooled Chilled-Water Plant; Air Cooled Chilled-Water Plant and Unitary Air-Conditioners. The system efficiency is measured in KW/ RT, also points are awarded as percentage of improvement more than the base line

Points (max = 8 min = 0) 0

Sub Indicator: High efficiency boilers and hot water systems (Total Max Points 1)

Alternative: One point is awarded if the building has high efficient water heating equipment and hot water saving devices.

Points (max = 1 min = 0) 0

Indicator: Provision of energy management (Total Max Points 14)

Sub Indicator: Energy operating plan (Total Max Points 1)

Alternative: Develop a building operating plan that provides details on building operation and maintenance. The operating plan addresses the following; An occupancy schedule, Equipment run-time schedule, Design set points for all HVAC equipment, Design of lighting levels throughout the building;

Points (max = 1 min = 0) 0

Sub Indicator: Energy monitoring and metering (Total Max Points 4)

Alternative: Metering of Electrical loads ==> 1 point Monitoring of Central HVAC plant == > 1 point Monitoring record ==> 1 point Public Display of Energy use ==> 1 point total 4 points

Points (max = 4 min = 0) 0

Sub Indicator: Auditing, commissioning and testing of energy systems (Total Max Points 5)

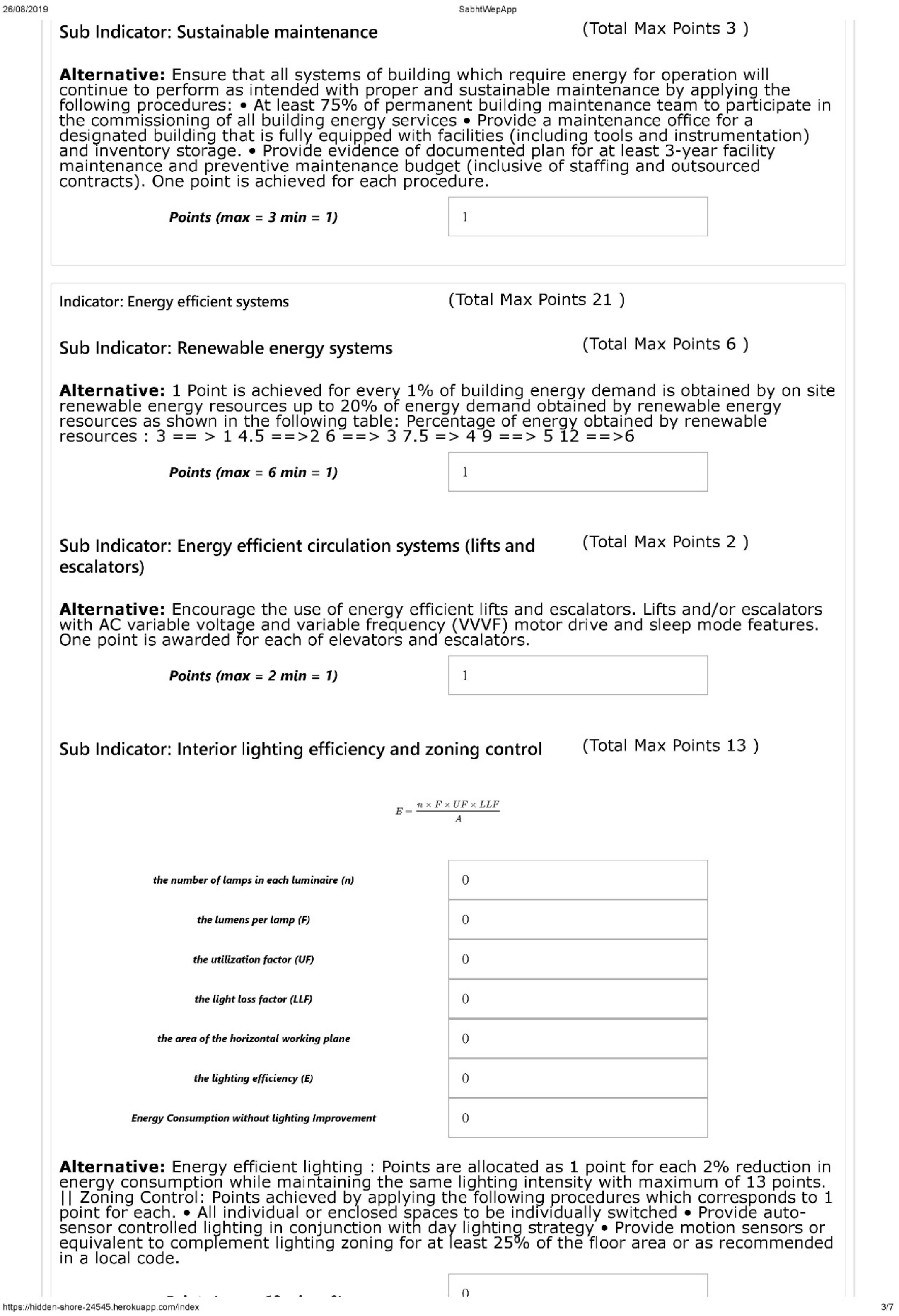
Alternative: Energy Auditing ==> 1 point Emissions reduction reporting ==> 1 point Investigation and Analysis ==> 1 point Implementation ==> 1 point Ongoing Commissioning ==> 1 point

Points (max = 5 min = 0) 0

Sub Indicator: Building automation system (Total Max Points 1)

Alternative: Applying a computer-based building automation system (BAS) which provide information to support the ongoing energy performance optimisation of a building and to identify opportunities for additional energy-saving investments, this BAS aimed to perform the following: • Monitor and control major building systems including: heating; cooling; ventilation, and, lighting; • Inform decisions regarding changes in building operations and energy-saving investments; Or Energy Management System (EMS)

Points (max = 1 min = 0) 0



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Sub Indicator: Sustainable maintenance (Total Max Points 3)

Alternative: Ensure that all systems of building which require energy for operation will continue to perform as intended with proper and sustainable maintenance by applying the following procedures: • At least 75% of permanent building maintenance team to participate in the commissioning of all building energy services • Provide a maintenance office for a designated building that is fully equipped with facilities (including tools and instrumentation) and inventory storage. • Provide evidence of documented plan for at least 3-year facility maintenance and preventive maintenance budget (inclusive of staffing and outsourced contracts). One point is achieved for each procedure.

Points (max = 3 min = 1) 1

Indicator: Energy efficient systems (Total Max Points 21)

Sub Indicator: Renewable energy systems (Total Max Points 6)

Alternative: 1 Point is achieved for every 1% of building energy demand is obtained by on site renewable energy resources up to 20% of energy demand obtained by renewable energy resources as shown in the following table: Percentage of energy obtained by renewable resources : 3 == > 1 4.5 ==>2 6 ==> 3 7.5 => 4 9 ==> 5 12 ==>6

Points (max = 6 min = 1) 1

Sub Indicator: Energy efficient circulation systems (lifts and escalators) (Total Max Points 2)

Alternative: Encourage the use of energy efficient lifts and escalators. Lifts and/or escalators with AC variable voltage and variable frequency (VVVF) motor drive and sleep mode features. One point is awarded for each of elevators and escalators.

Points (max = 2 min = 1) 1

Sub Indicator: Interior lighting efficiency and zoning control (Total Max Points 13)

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

the number of lamps in each luminaire (n)	0
the lumens per lamp (F)	0
the utilization factor (UF)	0
the light loss factor (LLF)	0
the area of the horizontal working plane	0
the lighting efficiency (E)	0
Energy Consumption without lighting Improvement	0

Alternative: Energy efficient lighting : Points are allocated as 1 point for each 2% reduction in energy consumption while maintaining the same lighting intensity with maximum of 13 points. || Zoning Control: Points achieved by applying the following procedures which corresponds to 1 point for each. • All individual or enclosed spaces to be individually switched • Provide auto-sensor controlled lighting in conjunction with day lighting strategy • Provide motion sensors or equivalent to complement lighting zoning for at least 25% of the floor area or as recommended in a local code.

0

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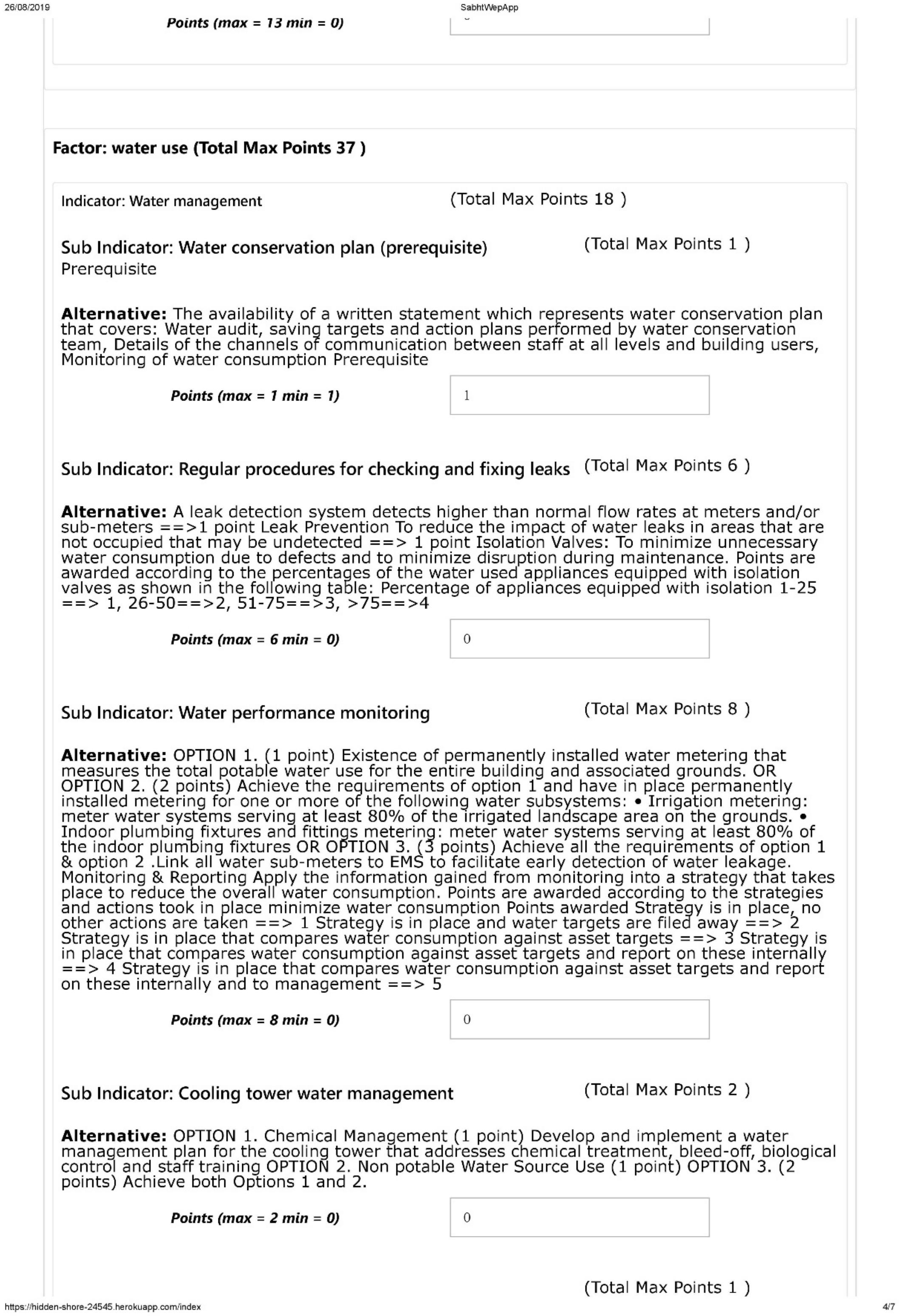


Points (max = 13 min = 0)

Factor: water use (Total Max Points 37)

Indicator: Water management (Total Max Points 18)

Sub Indicator: Water conservation plan (prerequisite) (Total Max Points 1)
Prerequisite

Alternative: The availability of a written statement which represents water conservation plan that covers: Water audit, saving targets and action plans performed by water conservation team, Details of the channels of communication between staff at all levels and building users, Monitoring of water consumption Prerequisite

Points (max = 1 min = 1) 1

Sub Indicator: Regular procedures for checking and fixing leaks (Total Max Points 6)

Alternative: A leak detection system detects higher than normal flow rates at meters and/or sub-meters ==>1 point Leak Prevention To reduce the impact of water leaks in areas that are not occupied that may be undetected ==> 1 point Isolation Valves: To minimize unnecessary water consumption due to defects and to minimize disruption during maintenance. Points are awarded according to the percentages of the water used appliances equipped with isolation valves as shown in the following table: Percentage of appliances equipped with isolation 1-25 ==> 1, 26-50==>2, 51-75==>3, >75==>4

Points (max = 6 min = 0) 0

Sub Indicator: Water performance monitoring (Total Max Points 8)

Alternative: OPTION 1. (1 point) Existence of permanently installed water metering that measures the total potable water use for the entire building and associated grounds. OR OPTION 2. (2 points) Achieve the requirements of option 1 and have in place permanently installed metering for one or more of the following water subsystems: • Irrigation metering: meter water systems serving at least 80% of the irrigated landscape area on the grounds. • Indoor plumbing fixtures and fittings metering: meter water systems serving at least 80% of the indoor plumbing fixtures OR OPTION 3. (3 points) Achieve all the requirements of option 1 & option 2 .Link all water sub-meters to EMS to facilitate early detection of water leakage. Monitoring & Reporting Apply the information gained from monitoring into a strategy that takes place to reduce the overall water consumption. Points are awarded according to the strategies and actions took in place minimize water consumption Points awarded Strategy is in place, no other actions are taken ==> 1 Strategy is in place and water targets are filed away ==> 2 Strategy is in place that compares water consumption against asset targets ==> 3 Strategy is in place that compares water consumption against asset targets and report on these internally ==> 4 Strategy is in place that compares water consumption against asset targets and report on these internally and to management ==> 5

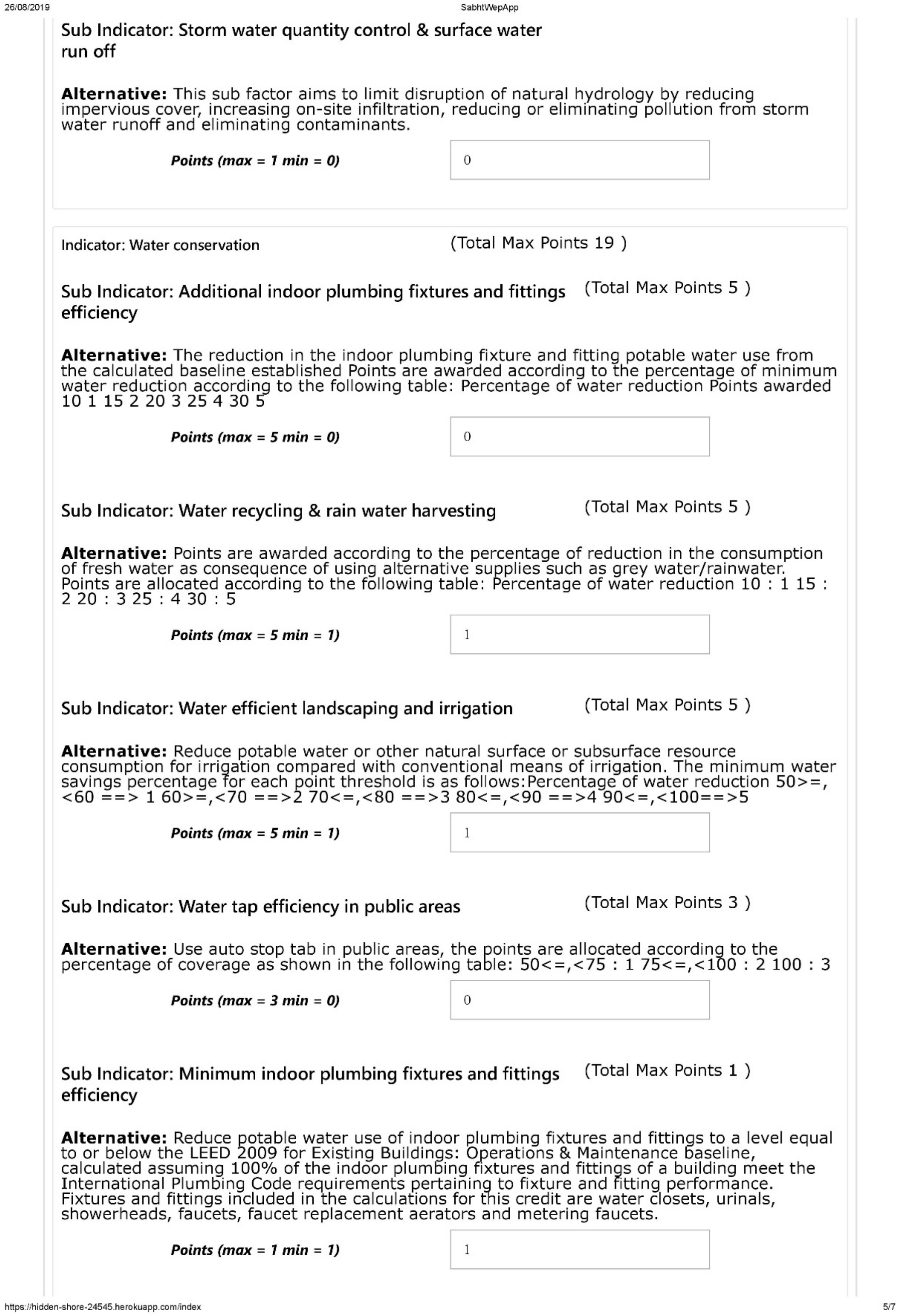
Points (max = 8 min = 0) 0

Sub Indicator: Cooling tower water management (Total Max Points 2)

Alternative: OPTION 1. Chemical Management (1 point) Develop and implement a water management plan for the cooling tower that addresses chemical treatment, bleed-off, biological control and staff training OPTION 2. Non potable Water Source Use (1 point) OPTION 3. (2 points) Achieve both Options 1 and 2.

Points (max = 2 min = 0) 0

(Total Max Points 1)



Sub Indicator: Storm water quantity control & surface water run off

Alternative: This sub factor aims to limit disruption of natural hydrology by reducing impervious cover, increasing on-site infiltration, reducing or eliminating pollution from storm water runoff and eliminating contaminants.

Points (max = 1 min = 0) 0

Indicator: Water conservation (Total Max Points 19)

Sub Indicator: Additional indoor plumbing fixtures and fittings efficiency (Total Max Points 5)

Alternative: The reduction in the indoor plumbing fixture and fitting potable water use from the calculated baseline established Points are awarded according to the percentage of minimum water reduction according to the following table: Percentage of water reduction Points awarded 10 1 15 2 20 3 25 4 30 5

Points (max = 5 min = 0) 0

Sub Indicator: Water recycling & rain water harvesting (Total Max Points 5)

Alternative: Points are awarded according to the percentage of reduction in the consumption of fresh water as consequence of using alternative supplies such as grey water/rainwater. Points are allocated according to the following table: Percentage of water reduction 10 : 1 15 : 2 20 : 3 25 : 4 30 : 5

Points (max = 5 min = 1) 1

Sub Indicator: Water efficient landscaping and irrigation (Total Max Points 5)

Alternative: Reduce potable water or other natural surface or subsurface resource consumption for irrigation compared with conventional means of irrigation. The minimum water savings percentage for each point threshold is as follows:Percentage of water reduction 50>=, <60 ==> 1 60>=,<70 ==>2 70<=,<80 ==>3 80<=,<90 ==>4 90<=,<100==>5

Points (max = 5 min = 1) 1

Sub Indicator: Water tap efficiency in public areas (Total Max Points 3)

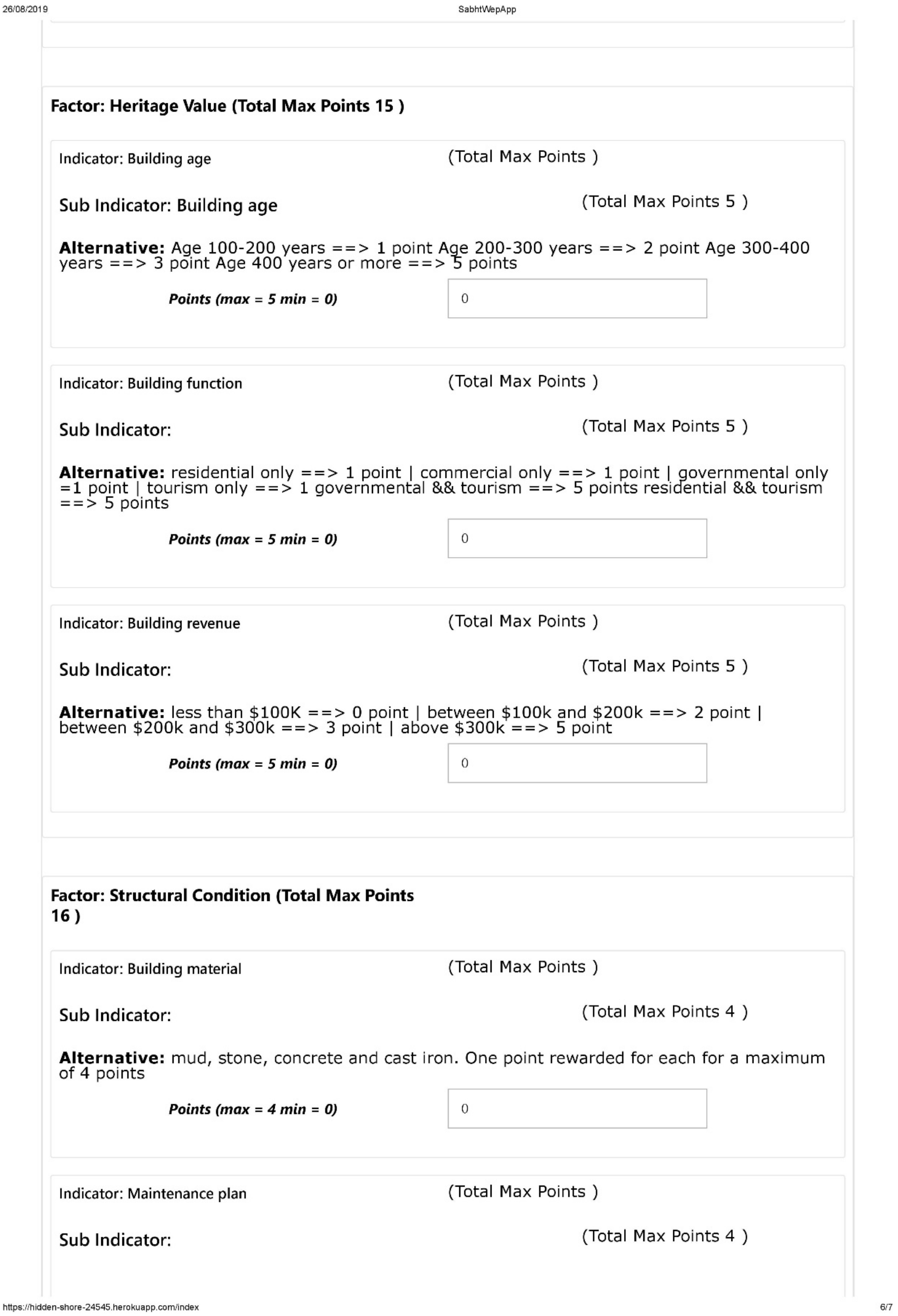
Alternative: Use auto stop tab in public areas, the points are allocated according to the percentage of coverage as shown in the following table: 50<=,<75 : 1 75<=,<100 : 2 100 : 3

Points (max = 3 min = 0) 0

Sub Indicator: Minimum indoor plumbing fixtures and fittings efficiency (Total Max Points 1)

Alternative: Reduce potable water use of indoor plumbing fixtures and fittings to a level equal to or below the LEED 2009 for Existing Buildings: Operations & Maintenance baseline, calculated assuming 100% of the indoor plumbing fixtures and fittings of a building meet the International Plumbing Code requirements pertaining to fixture and fitting performance. Fixtures and fittings included in the calculations for this credit are water closets, urinals, showerheads, faucets, faucet replacement aerators and metering faucets.

Points (max = 1 min = 1) 1



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Factor: Heritage Value (Total Max Points 15)

Indicator: Building age (Total Max Points)

Sub Indicator: Building age (Total Max Points 5)

Alternative: Age 100-200 years ==> 1 point Age 200-300 years ==> 2 point Age 300-400 years ==> 3 point Age 400 years or more ==> 5 points

Points (max = 5 min = 0) 0

Indicator: Building function (Total Max Points)

Sub Indicator: (Total Max Points 5)

Alternative: residential only ==> 1 point | commercial only ==> 1 point | governmental only =1 point | tourism only ==> 1 governmental && tourism ==> 5 points residential && tourism ==> 5 points

Points (max = 5 min = 0) 0

Indicator: Building revenue (Total Max Points)

Sub Indicator: (Total Max Points 5)

Alternative: less than $100K ==> 0 point | between $100k and $200k ==> 2 point | between $200k and $300k ==> 3 point | above $300k ==> 5 point

Points (max = 5 min = 0) 0

Factor: Structural Condition (Total Max Points 16)

Indicator: Building material (Total Max Points)

Sub Indicator: (Total Max Points 4)

Alternative: mud, stone, concrete and cast iron. One point rewarded for each for a maximum of 4 points

Points (max = 4 min = 0) 0

Indicator: Maintenance plan (Total Max Points)

Sub Indicator: (Total Max Points 4)

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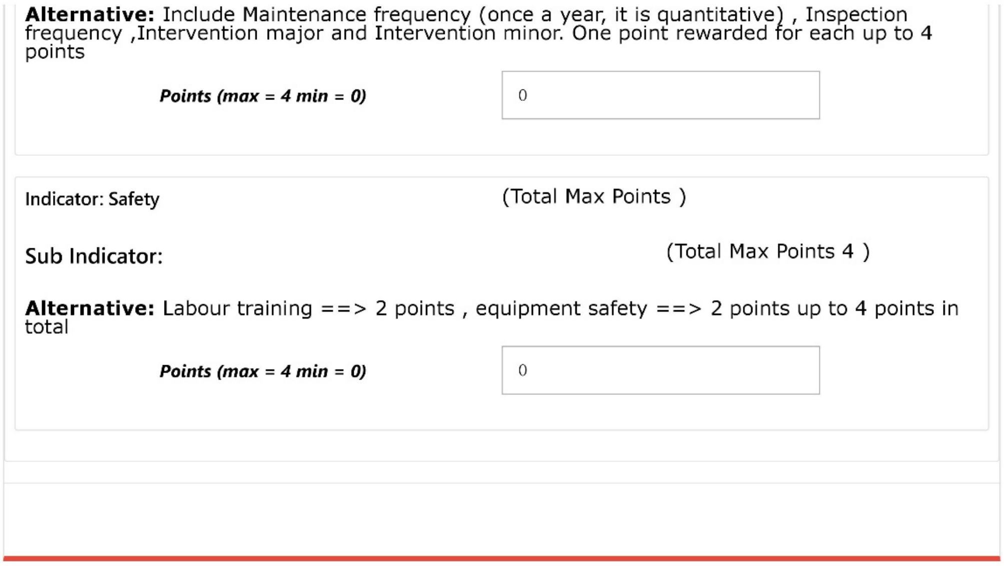


Alternative: Include Maintenance frequency (once a year, it is quantitative) , Inspection frequency ,Intervention major and Intervention minor. One point rewarded for each up to 4 points

Points (max = 4 min = 0) 0

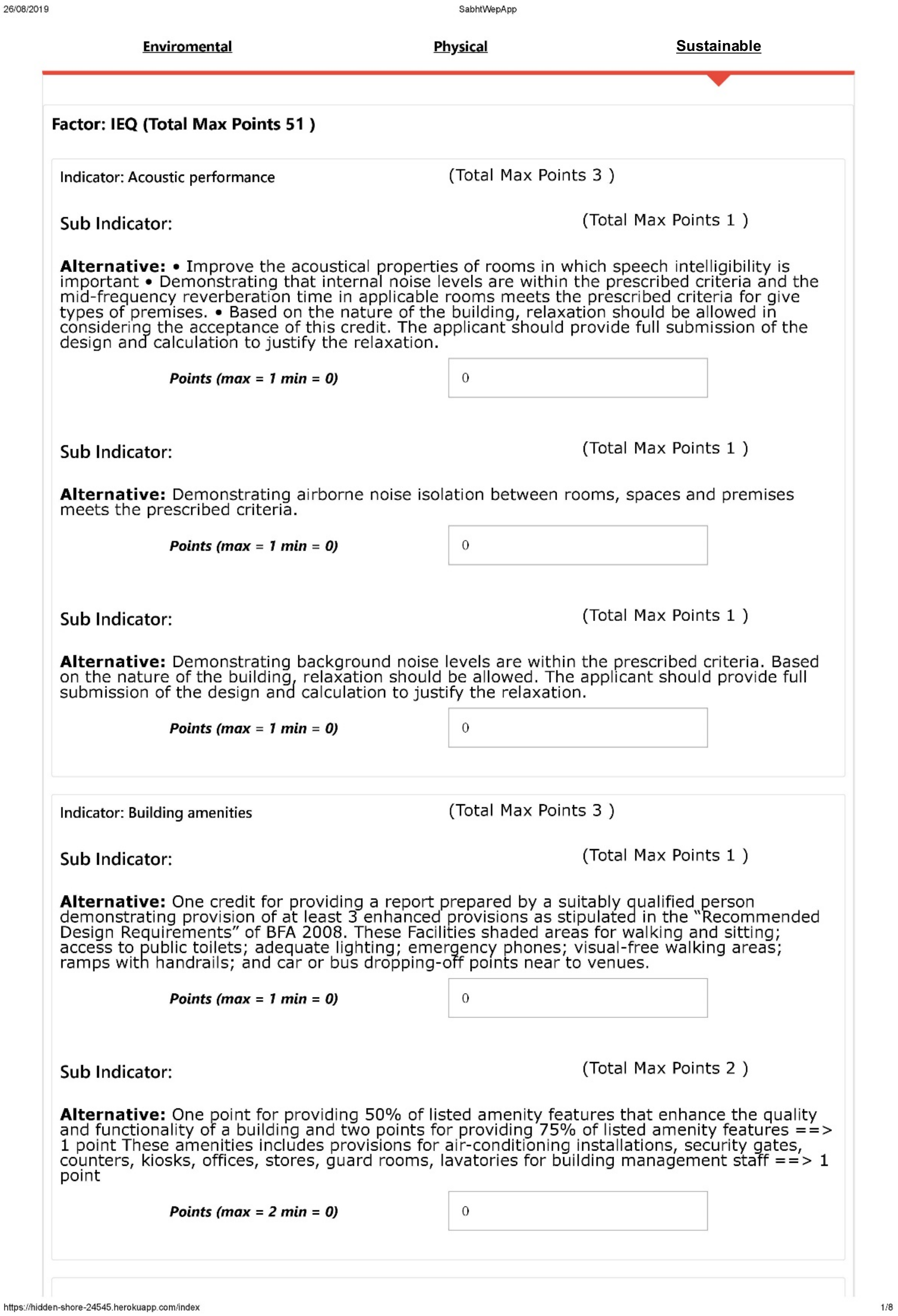
Indicator: Safety (Total Max Points)

Sub Indicator: (Total Max Points 4)

Alternative: Labour training ==> 2 points , equipment safety ==> 2 points up to 4 points in total

Points (max = 4 min = 0) 0

Appendix B-3: Calculation sheets for sustainable criteria



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Factor: IEQ (Total Max Points 51)

Indicator: Acoustic performance (Total Max Points 3)

Sub Indicator: (Total Max Points 1)

Alternative: • Improve the acoustical properties of rooms in which speech intelligibility is important • Demonstrating that internal noise levels are within the prescribed criteria and the mid-frequency reverberation time in applicable rooms meets the prescribed criteria for give types of premises. • Based on the nature of the building, relaxation should be allowed in considering the acceptance of this credit. The applicant should provide full submission of the design and calculation to justify the relaxation.

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 1)

Alternative: Demonstrating airborne noise isolation between rooms, spaces and premises meets the prescribed criteria.

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 1)

Alternative: Demonstrating background noise levels are within the prescribed criteria. Based on the nature of the building, relaxation should be allowed. The applicant should provide full submission of the design and calculation to justify the relaxation.

Points (max = 1 min = 0) 0

Indicator: Building amenities (Total Max Points 3)

Sub Indicator: (Total Max Points 1)

Alternative: One credit for providing a report prepared by a suitably qualified person demonstrating provision of at least 3 enhanced provisions as stipulated in the "Recommended Design Requirements" of BFA 2008. These Facilities shaded areas for walking and sitting; access to public toilets; adequate lighting; emergency phones; visual-free walking areas; ramps with handrails; and car or bus dropping-off points near to venues.

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 2)

Alternative: One point for providing 50% of listed amenity features that enhance the quality and functionality of a building and two points for providing 75% of listed amenity features ==> 1 point These amenities includes provisions for air-conditioning installations, security gates, counters, kiosks, offices, stores, guard rooms, lavatories for building management staff ==> 1 point

Points (max = 2 min = 0) 0

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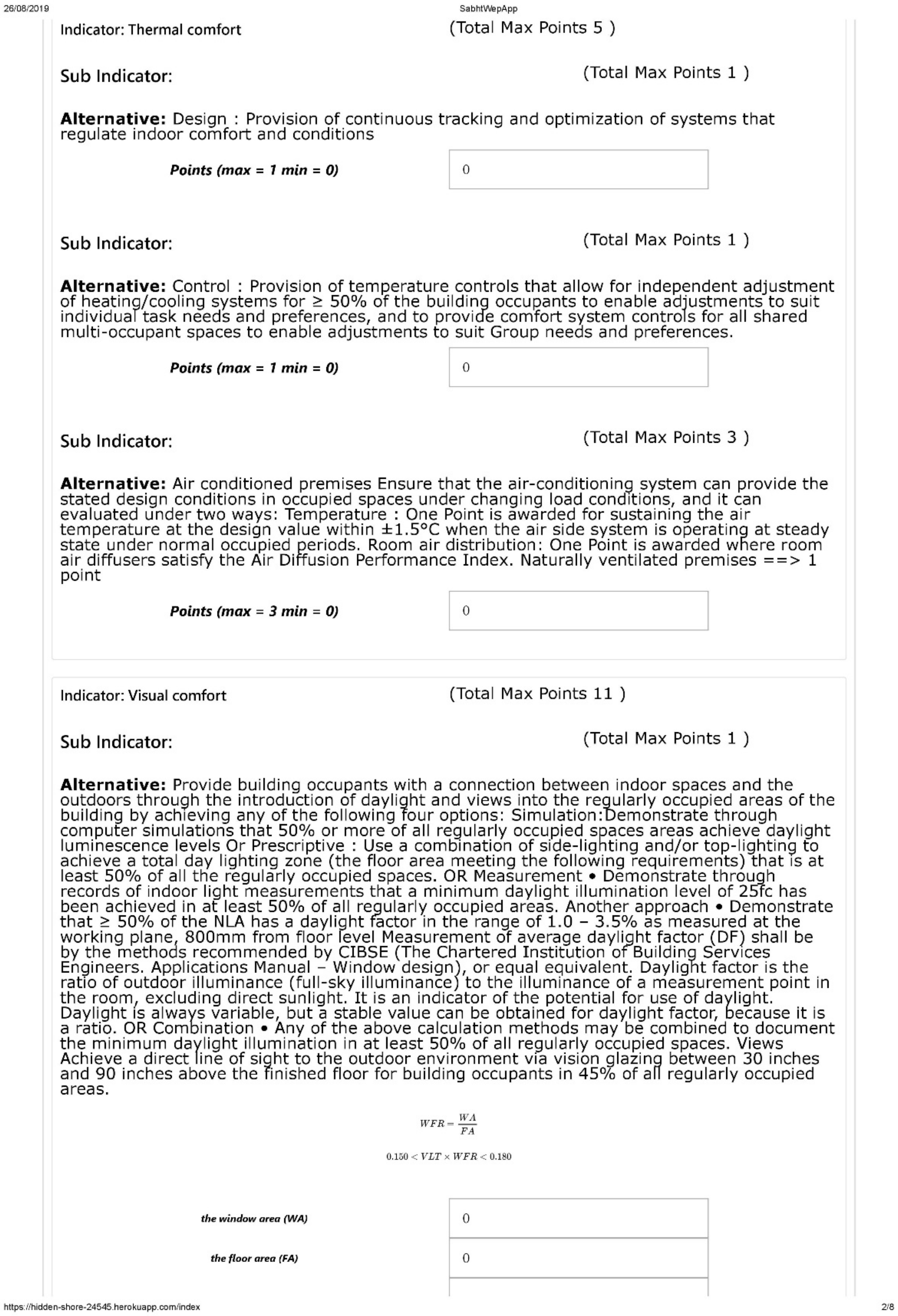


Indicator: Thermal comfort (Total Max Points 5)

Sub Indicator: (Total Max Points 1)

Alternative: Design : Provision of continuous tracking and optimization of systems that regulate indoor comfort and conditions

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 1)

Alternative: Control : Provision of temperature controls that allow for independent adjustment of heating/cooling systems for ≥ 50% of the building occupants to enable adjustments to suit individual task needs and preferences, and to provide comfort system controls for all shared multi-occupant spaces to enable adjustments to suit Group needs and preferences.

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 3)

Alternative: Air conditioned premises Ensure that the air-conditioning system can provide the stated design conditions in occupied spaces under changing load conditions, and it can evaluated under two ways: Temperature : One Point is awarded for sustaining the air temperature at the design value within ±1.5°C when the air side system is operating at steady state under normal occupied periods. Room air distribution: One Point is awarded where room air diffusers satisfy the Air Diffusion Performance Index. Naturally ventilated premises ==> 1 point

Points (max = 3 min = 0) 0

Indicator: Visual comfort (Total Max Points 11)

Sub Indicator: (Total Max Points 1)

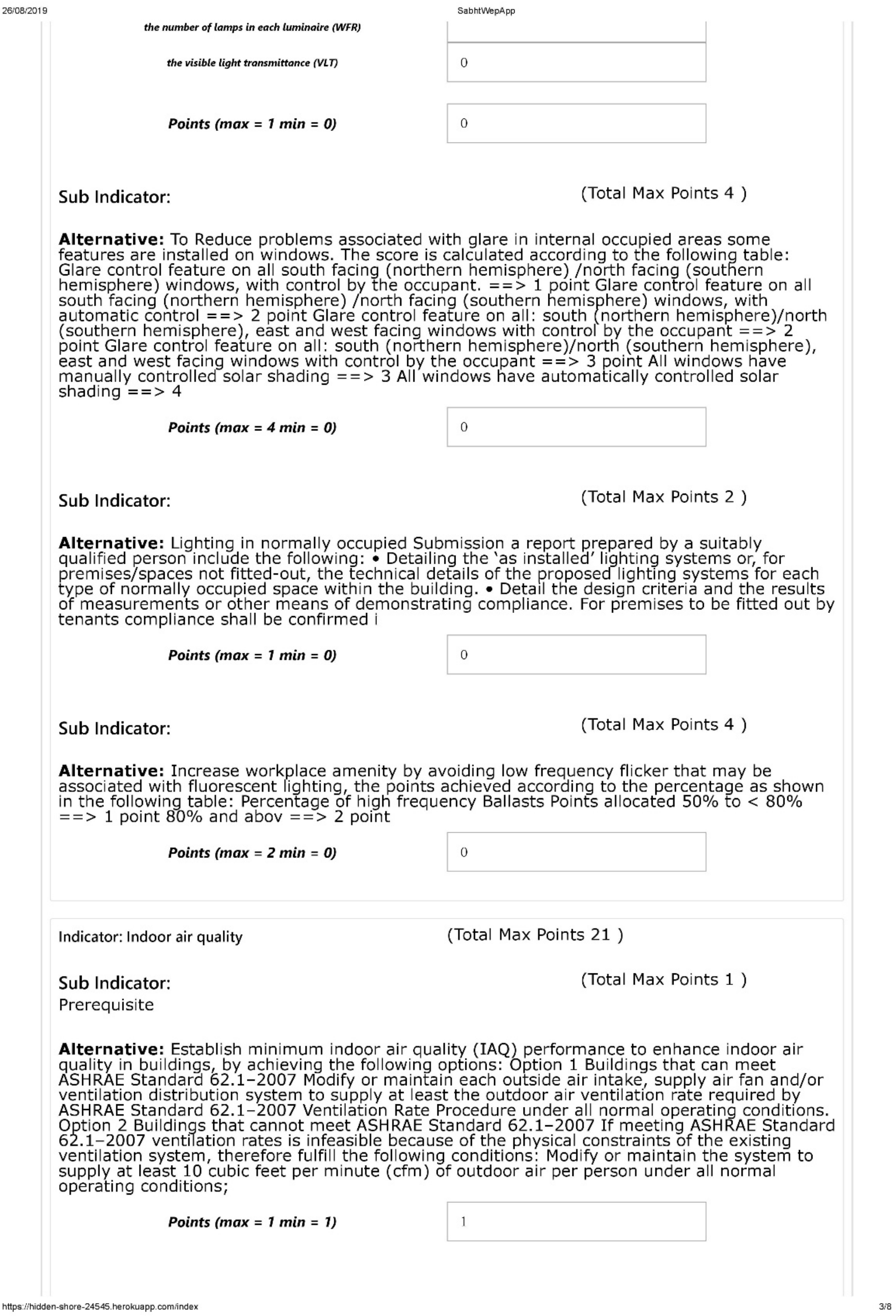
Alternative: Provide building occupants with a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building by achieving any of the following four options: Simulation:Demonstrate through computer simulations that 50% or more of all regularly occupied spaces areas achieve daylight luminescence levels Or Prescriptive : Use a combination of side-lighting and/or top-lighting to achieve a total day lighting zone (the floor area meeting the following requirements) that is at least 50% of all the regularly occupied spaces. OR Measurement • Demonstrate through records of indoor light measurements that a minimum daylight illumination level of 25fc has been achieved in at least 50% of all regularly occupied areas. Another approach • Demonstrate that ≥ 50% of the NLA has a daylight factor in the range of 1.0 – 3.5% as measured at the working plane, 800mm from floor level Measurement of average daylight factor (DF) shall be by the methods recommended by CIBSE (The Chartered Institution of Building Services Engineers. Applications Manual – Window design), or equal equivalent. Daylight factor is the ratio of outdoor illuminance (full-sky illuminance) to the illuminance of a measurement point in the room, excluding direct sunlight. It is an indicator of the potential for use of daylight. Daylight is always variable, but a stable value can be obtained for daylight factor, because it is a ratio. OR Combination • Any of the above calculation methods may be combined to document the minimum daylight illumination in at least 50% of all regularly occupied spaces. Views Achieve a direct line of sight to the outdoor environment via vision glazing between 30 inches and 90 inches above the finished floor for building occupants in 45% of all regularly occupied areas.

$$WFR = \frac{WA}{FA}$$

$$0.150 < VLT \times WFR < 0.180$$

the window area (WA) 0

the floor area (FA) 0



the number of lamps in each luminaire (WFR)

the visible light transmittance (VLT) 0

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 4)

Alternative: To Reduce problems associated with glare in internal occupied areas some features are installed on windows. The score is calculated according to the following table: Glare control feature on all south facing (northern hemisphere) /north facing (southern hemisphere) windows, with control by the occupant. ==> 1 point Glare control feature on all south facing (northern hemisphere) /north facing (southern hemisphere) windows, with automatic control ==> 2 point Glare control feature on all: south (northern hemisphere)/north (southern hemisphere), east and west facing windows with control by the occupant ==> 2 point Glare control feature on all: south (northern hemisphere)/north (southern hemisphere), east and west facing windows with control by the occupant ==> 3 point All windows have manually controlled solar shading ==> 3 All windows have automatically controlled solar shading ==> 4

Points (max = 4 min = 0) 0

Sub Indicator: (Total Max Points 2)

Alternative: Lighting in normally occupied Submission a report prepared by a suitably qualified person include the following: • Detailing the 'as installed' lighting systems or, for premises/spaces not fitted-out, the technical details of the proposed lighting systems for each type of normally occupied space within the building. • Detail the design criteria and the results of measurements or other means of demonstrating compliance. For premises to be fitted out by tenants compliance shall be confirmed i

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 4)

Alternative: Increase workplace amenity by avoiding low frequency flicker that may be associated with fluorescent lighting, the points achieved according to the percentage as shown in the following table: Percentage of high frequency Ballasts Points allocated 50% to < 80% ==> 1 point 80% and abov ==> 2 point

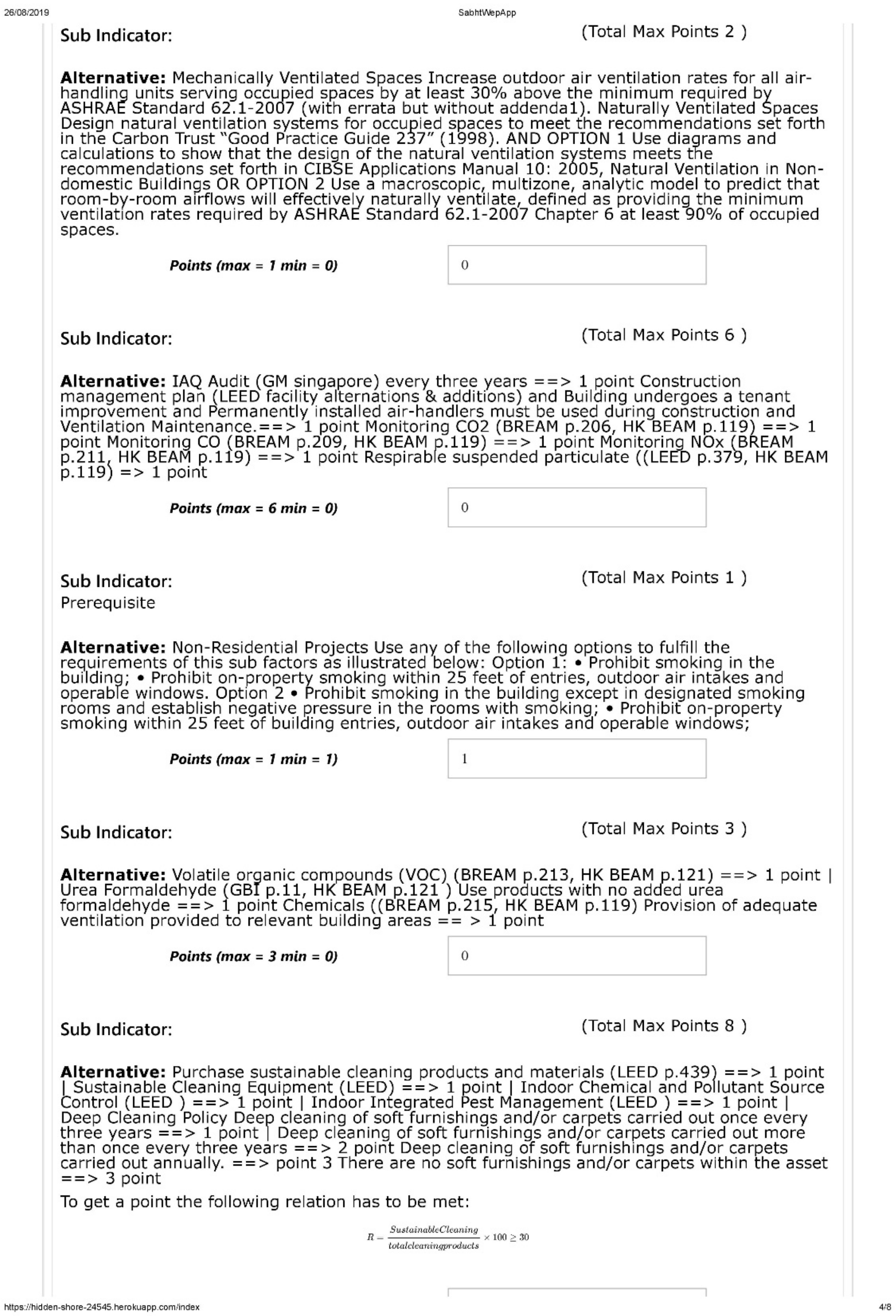
Points (max = 2 min = 0) 0

Indicator: Indoor air quality (Total Max Points 21)

Sub Indicator: (Total Max Points 1)
Prerequisite

Alternative: Establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, by achieving the following options: Option 1 Buildings that can meet ASHRAE Standard 62.1–2007 Modify or maintain each outside air intake, supply air fan and/or ventilation distribution system to supply at least the outdoor air ventilation rate required by ASHRAE Standard 62.1–2007 Ventilation Rate Procedure under all normal operating conditions. Option 2 Buildings that cannot meet ASHRAE Standard 62.1–2007 If meeting ASHRAE Standard 62.1–2007 ventilation rates is infeasible because of the physical constraints of the existing ventilation system, therefore fulfill the following conditions: Modify or maintain the system to supply at least 10 cubic feet per minute (cfm) of outdoor air per person under all normal operating conditions;

Points (max = 1 min = 1) 1



Sub Indicator: (Total Max Points 2)

Alternative: Mechanically Ventilated Spaces Increase outdoor air ventilation rates for all air-handling units serving occupied spaces by at least 30% above the minimum required by ASHRAE Standard 62.1-2007 (with errata but without addenda1). Naturally Ventilated Spaces Design natural ventilation systems for occupied spaces to meet the recommendations set forth in the Carbon Trust "Good Practice Guide 237" (1998). AND OPTION 1 Use diagrams and calculations to show that the design of the natural ventilation systems meets the recommendations set forth in CIBSE Applications Manual 10: 2005, Natural Ventilation in Non-domestic Buildings OR OPTION 2 Use a macroscopic, multizone, analytic model to predict that room-by-room airflows will effectively naturally ventilate, defined as providing the minimum ventilation rates required by ASHRAE Standard 62.1-2007 Chapter 6 at least 90% of occupied spaces.

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 6)

Alternative: IAQ Audit (GM singapore) every three years ==> 1 point Construction management plan (LEED facility alternations & additions) and Building undergoes a tenant improvement and Permanently installed air-handlers must be used during construction and Ventilation Maintenance.==> 1 point Monitoring CO2 (BREAM p.206, HK BEAM p.119) ==> 1 point Monitoring CO (BREAM p.209, HK BEAM p.119) ==> 1 point Monitoring NOx (BREAM p.211, HK BEAM p.119) ==> 1 point Respirable suspended particulate ((LEED p.379, HK BEAM p.119) => 1 point

Points (max = 6 min = 0) 0

Sub Indicator: (Total Max Points 1)

Prerequisite

Alternative: Non-Residential Projects Use any of the following options to fulfill the requirements of this sub factors as illustrated below: Option 1: • Prohibit smoking in the building; • Prohibit on-property smoking within 25 feet of entries, outdoor air intakes and operable windows. Option 2 • Prohibit smoking in the building except in designated smoking rooms and establish negative pressure in the rooms with smoking; • Prohibit on-property smoking within 25 feet of building entries, outdoor air intakes and operable windows;

Points (max = 1 min = 1) 1

Sub Indicator: (Total Max Points 3)

Alternative: Volatile organic compounds (VOC) (BREAM p.213, HK BEAM p.121) ==> 1 point | Urea Formaldehyde (GBI p.11, HK BEAM p.121) Use products with no added urea formaldehyde ==> 1 point Chemicals ((BREAM p.215, HK BEAM p.119) Provision of adequate ventilation provided to relevant building areas == > 1 point

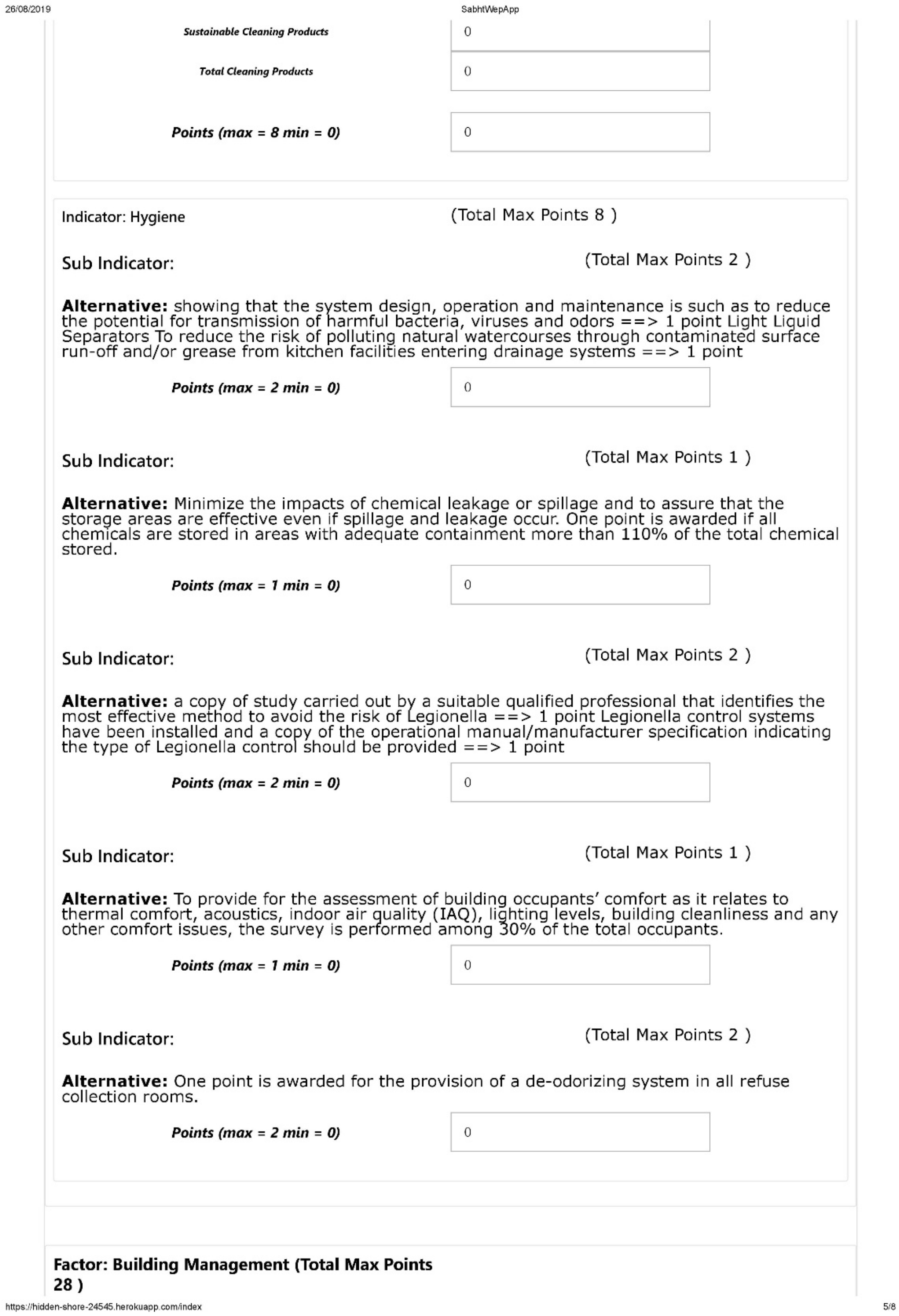
Points (max = 3 min = 0) 0

Sub Indicator: (Total Max Points 8)

Alternative: Purchase sustainable cleaning products and materials (LEED p.439) ==> 1 point | Sustainable Cleaning Equipment (LEED) ==> 1 point | Indoor Chemical and Pollutant Source Control (LEED) ==> 1 point | Indoor Integrated Pest Management (LEED) ==> 1 point | Deep Cleaning Policy Deep cleaning of soft furnishings and/or carpets carried out once every three years ==> 1 point | Deep cleaning of soft furnishings and/or carpets carried out more than once every three years ==> 2 point Deep cleaning of soft furnishings and/or carpets carried out annually. ==> point 3 There are no soft furnishings and/or carpets within the asset ==> 3 point

To get a point the following relation has to be met:

$$R = \frac{SustainableCleaning}{totalcleaningproducts} \times 100 \geq 30$$



Sustainable Cleaning Products 0

Total Cleaning Products 0

Points (max = 8 min = 0) 0

Indicator: Hygiene (Total Max Points 8)

Sub Indicator: (Total Max Points 2)

Alternative: showing that the system design, operation and maintenance is such as to reduce the potential for transmission of harmful bacteria, viruses and odors ==> 1 point Light Liquid Separators To reduce the risk of polluting natural watercourses through contaminated surface run-off and/or grease from kitchen facilities entering drainage systems ==> 1 point

Points (max = 2 min = 0) 0

Sub Indicator: (Total Max Points 1)

Alternative: Minimize the impacts of chemical leakage or spillage and to assure that the storage areas are effective even if spillage and leakage occur. One point is awarded if all chemicals are stored in areas with adequate containment more than 110% of the total chemical stored.

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 2)

Alternative: a copy of study carried out by a suitable qualified professional that identifies the most effective method to avoid the risk of Legionella ==> 1 point Legionella control systems have been installed and a copy of the operational manual/manufacturer specification indicating the type of Legionella control should be provided ==> 1 point

Points (max = 2 min = 0) 0

Sub Indicator: (Total Max Points 1)

Alternative: To provide for the assessment of building occupants' comfort as it relates to thermal comfort, acoustics, indoor air quality (IAQ), lighting levels, building cleanliness and any other comfort issues, the survey is performed among 30% of the total occupants.

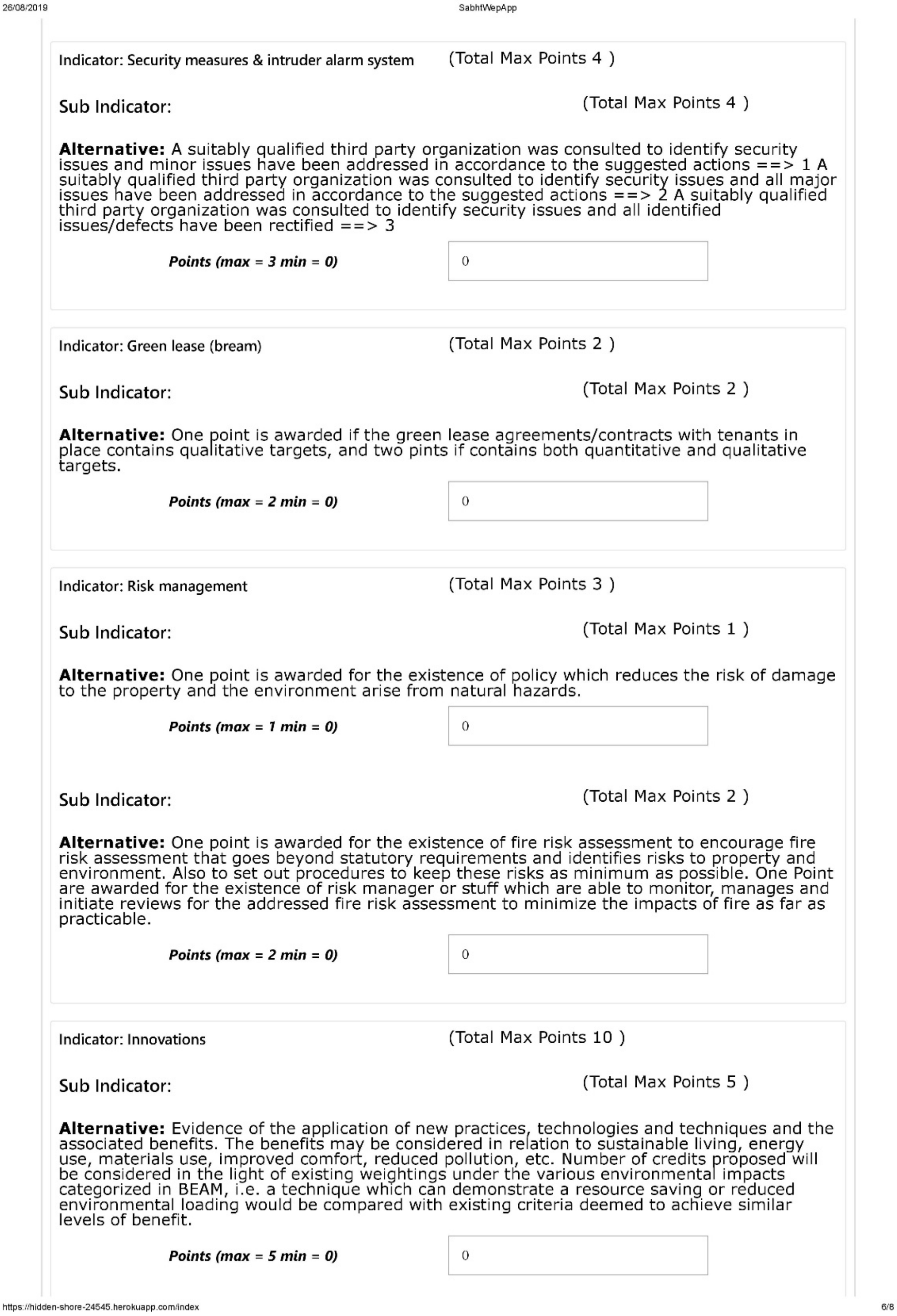
Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 2)

Alternative: One point is awarded for the provision of a de-odorizing system in all refuse collection rooms.

Points (max = 2 min = 0) 0

Factor: Building Management (Total Max Points 28)



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Indicator: Security measures & intruder alarm system (Total Max Points 4)

Sub Indicator: (Total Max Points 4)

Alternative: A suitably qualified third party organization was consulted to identify security issues and minor issues have been addressed in accordance to the suggested actions ==> 1 A suitably qualified third party organization was consulted to identify security issues and all major issues have been addressed in accordance to the suggested actions ==> 2 A suitably qualified third party organization was consulted to identify security issues and all identified issues/defects have been rectified ==> 3

Points (max = 3 min = 0) 0

Indicator: Green lease (bream) (Total Max Points 2)

Sub Indicator: (Total Max Points 2)

Alternative: One point is awarded if the green lease agreements/contracts with tenants in place contains qualitative targets, and two pints if contains both quantitative and qualitative targets.

Points (max = 2 min = 0) 0

Indicator: Risk management (Total Max Points 3)

Sub Indicator: (Total Max Points 1)

Alternative: One point is awarded for the existence of policy which reduces the risk of damage to the property and the environment arise from natural hazards.

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 2)

Alternative: One point is awarded for the existence of fire risk assessment to encourage fire risk assessment that goes beyond statutory requirements and identifies risks to property and environment. Also to set out procedures to keep these risks as minimum as possible. One Point are awarded for the existence of risk manager or stuff which are able to monitor, manages and initiate reviews for the addressed fire risk assessment to minimize the impacts of fire as far as practicable.

Points (max = 2 min = 0) 0

Indicator: Innovations (Total Max Points 10)

Sub Indicator: (Total Max Points 5)

Alternative: Evidence of the application of new practices, technologies and techniques and the associated benefits. The benefits may be considered in relation to sustainable living, energy use, materials use, improved comfort, reduced pollution, etc. Number of credits proposed will be considered in the light of existing weightings under the various environmental impacts categorized in BEAM, i.e. a technique which can demonstrate a resource saving or reduced environmental loading would be compared with existing criteria deemed to achieve similar levels of benefit.

Points (max = 5 min = 0) 0

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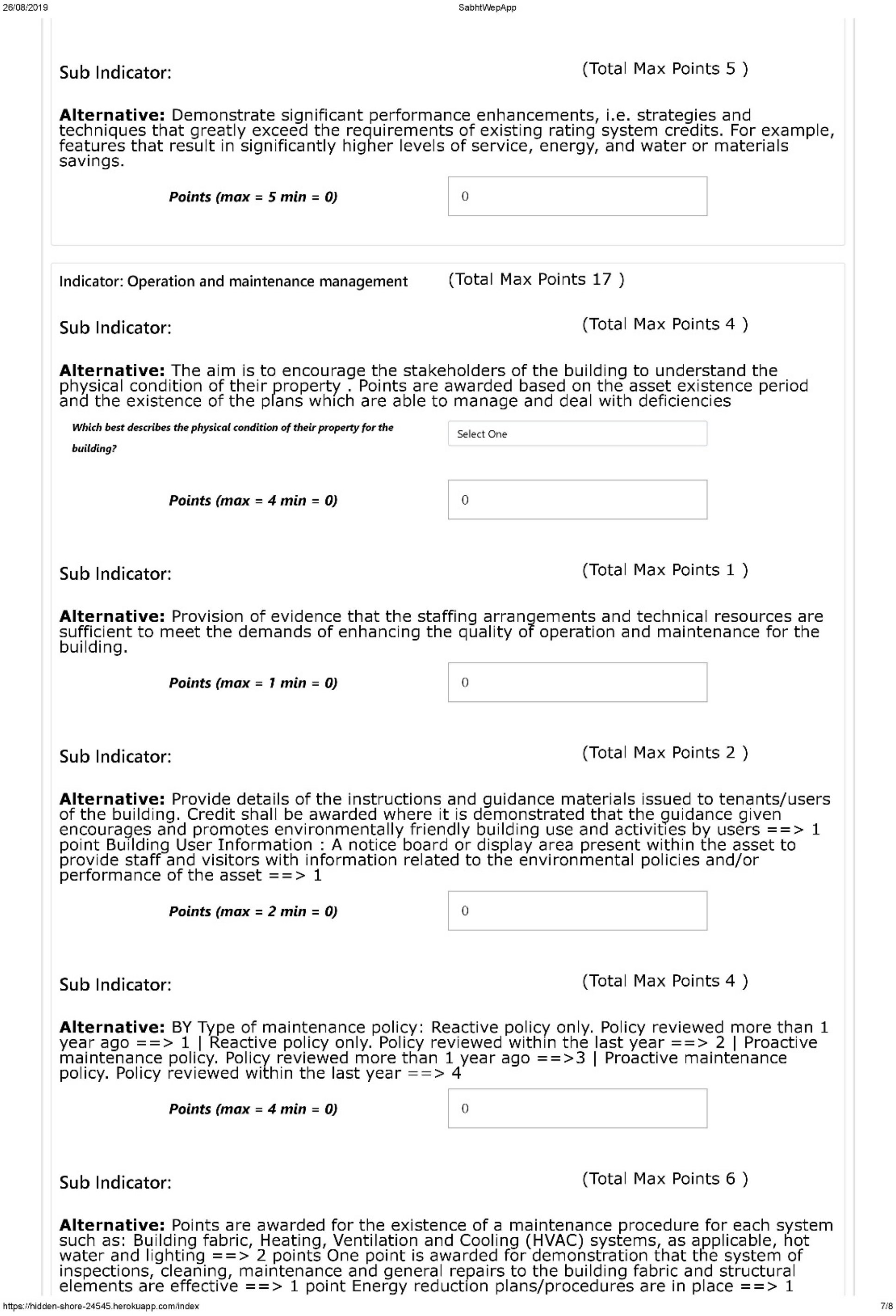


Sub Indicator: (Total Max Points 5)

Alternative: Demonstrate significant performance enhancements, i.e. strategies and techniques that greatly exceed the requirements of existing rating system credits. For example, features that result in significantly higher levels of service, energy, and water or materials savings.

Points (max = 5 min = 0) 0

Indicator: Operation and maintenance management (Total Max Points 17)

Sub Indicator: (Total Max Points 4)

Alternative: The aim is to encourage the stakeholders of the building to understand the physical condition of their property . Points are awarded based on the asset existence period and the existence of the plans which are able to manage and deal with deficiencies

Which best describes the physical condition of their property for the building? Select One

Points (max = 4 min = 0) 0

Sub Indicator: (Total Max Points 1)

Alternative: Provision of evidence that the staffing arrangements and technical resources are sufficient to meet the demands of enhancing the quality of operation and maintenance for the building.

Points (max = 1 min = 0) 0

Sub Indicator: (Total Max Points 2)

Alternative: Provide details of the instructions and guidance materials issued to tenants/users of the building. Credit shall be awarded where it is demonstrated that the guidance given encourages and promotes environmentally friendly building use and activities by users ==> 1 point Building User Information : A notice board or display area present within the asset to provide staff and visitors with information related to the environmental policies and/or performance of the asset ==> 1

Points (max = 2 min = 0) 0

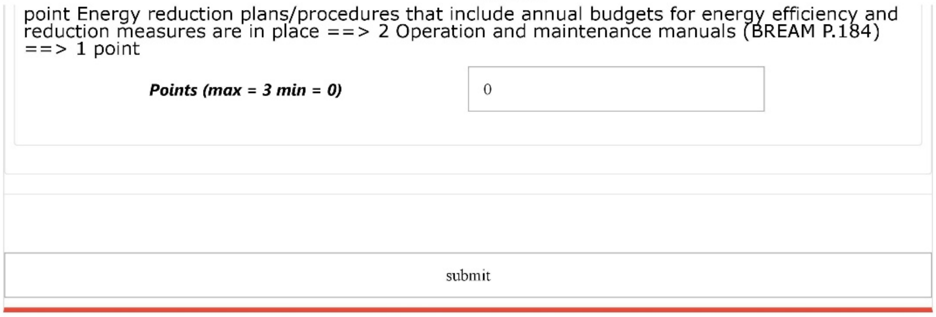
Sub Indicator: (Total Max Points 4)

Alternative: BY Type of maintenance policy: Reactive policy only. Policy reviewed more than 1 year ago ==> 1 | Reactive policy only. Policy reviewed within the last year ==> 2 | Proactive maintenance policy. Policy reviewed more than 1 year ago ==>3 | Proactive maintenance policy. Policy reviewed within the last year ==> 4

Points (max = 4 min = 0) 0

Sub Indicator: (Total Max Points 6)

Alternative: Points are awarded for the existence of a maintenance procedure for each system such as: Building fabric, Heating, Ventilation and Cooling (HVAC) systems, as applicable, hot water and lighting ==> 2 points One point is awarded for demonstration that the system of inspections, cleaning, maintenance and general repairs to the building fabric and structural elements are effective ==> 1 point Energy reduction plans/procedures are in place ==> 1



point Energy reduction plans/procedures that include annual budgets for energy efficiency and reduction measures are in place ==> 2 Operation and maintenance manuals (BREAM P.184) ==> 1 point

Points (max = 3 min = 0) 0

APPENDIX C: WEIGHT DETERMINATION MEASURES

Table C.1: Determination of the Triangular Fuzzy Numbers

No	Very Low			Low			Medium			High			Very High		
1	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
2	0	0.2	0.2	0.3	0.3	0.3	0.4	0.5	0.6	0.6	0.6	0.8	0.8	0.8	1
3	0	0	0	0.1	0.2	0.3	0.4	0.5	0.7	0.7	0.8	1	0.9	0.9	1
4	0	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.7	0.8	0.9	0.9	0.9	1	1
5	0	0.1	0.2	0.3	0.3	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1
6	0	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.9	1
7	0	0.1	0.3	0.3	0.2	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	1	1
8	0	0.2	0.4	0.3	0.3	0.5	0.6	0.6	0.7	0.75	0.8	0.9	0.9	0.95	1
9	0.1	0.1	0.1	0.2	0.4	0.5	0.6	0.6	0.65	0.8	0.85	0.9	0.95	0.95	1
10	0	0.2	0.3	0.3	0.4	0.4	0.5	0.65	0.75	0.8	0.8	1	0.85	0.95	1
11	0	0.1	0.15	0.2	0.3	0.3	0.45	0.5	0.6	0.65	0.7	0.8	0.85	0.9	1
12	0	0	0.1	0.2	0.25	0.3	0.35	0.4	0.55	0.6	0.65	0.7	0.85	0.9	1
13	0	0	0.1	0	0.2	0.3	0.4	0.4	0.6	0.7	0.8	1	0.8	0.9	1
14	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
15	0	0	0.2	0	0.2	0.5	0.5	0.5	0.7	0.6	0.6	0.8	0.8	0.9	1
16	0	0	0.3	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	0.9	0.95	1	1
17	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.6	0.7	0.8	0.85	0.9	1
18	0	0.2	0.5	0.5	0.6	0.65	0.65	0.7	0.75	0.8	0.85	0.85	0.9	0.9	1
19	0	0.1	0.2	0.2	0.3	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.9	1
20	0	0	0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
21	0	0.1	0.2	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.7	0.75	0.8	0.9	1
22	0	0.2	0.3	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
23	0	0	0.1	0	0.1	0.1	0.2	0.4	0.5	0.6	0.7	0.8	0.9	1	1
24	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
25	0	0.1	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1
	0.01	**0.10**	**0.21**	**0.21**	**0.30**	**0.40**	**0.45**	**0.52**	**0.63**	**0.66**	**0.74**	**0.84**	**0.85**	**0.93**	**1.00**

Table C.2: Frequency of Degree of import factors

Respondent	Water Use Factor				Heritage Value Factor				Structural Condition Factor				IEQ factor				Building Maanagment factor			
1	High	0.65	0.76	0.87	High	0.44	0.54	0.64	High	0.84	0.95	1	High	0.84	0.95	1	High	0.65	0.76	0.87
2	High	0.44	0.54	0.64	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87
3	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.84	0.95	1	High	0.44	0.54	0.64
4	High	0.21	0.33	0.44	High	0.44	0.54	0.64	High	0.84	0.95	1	High	0.84	0.95	1	High	0.84	0.95	1
5	High	0.84	0.95	1	High	0.84	0.95	1	High	0.84	0.95	1	High	0.44	0.54	0.64	High	0.44	0.54	0.64
6	High	0.21	0.33	0.44	High	0.21	0.33	0.44	High	0.84	0.95	1	High	0.84	0.95	1	High	0.65	0.76	0.87
7	High	0.44	0.54	0.64	High	0.44	0.54	0.64	High	0.65	0.76	0.87	High	0.84	0.95	1	High	0.84	0.95	1
8	High	0.21	0.33	0.44	High	0.21	0.33	0.44	High	0.84	0.95	1	High	0.44	0.54	0.64	High	0.21	0.33	0.44
9	High	0.21	0.33	0.44	High	0.21	0.33	0.44	High	0.65	0.76	0.87	High	0.84	0.95	1	High	0.84	0.95	1
10	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.84	0.95	1	High	0.44	0.54	0.64
11	High	0.21	0.33	0.44	High	0.21	0.33	0.44	High	0.44	0.54	0.64	High	0.44	0.54	0.64	High	0.44	0.54	0.64
12	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.44	0.54	0.64	High	0.65	0.76	0.87
13	High	0.44	0.54	0.64	High	0.44	0.54	0.64	High	0.44	0.54	0.64	High	0.65	0.76	0.87	High	0.44	0.54	0.64
14	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.84	0.95	1	High	0.44	0.54	0.64	High	0.44	0.54	0.64
15	Low	0.21	0.33	0.44	Low	0.21	0.33	0.44	High	0.44	0.54	0.64	Medium	0.65	0.76	0.87	High	0.65	0.76	0.87
16	Low	0.44	0.54	0.64	Low	0.65	0.76	0.87	High	0.65	0.76	0.87	Medium	0.84	0.95	1	Low	0.65	0.76	0.87
17	Low	0.65	0.76	0.87	Low	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.65	0.76	0.87	Medium	0.44	0.54	0.64
18	Low	0.44	0.54	0.64	Low	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.65	0.76	0.87	Medium	0.84	0.95	1
19	Low	0.65	0.76	0.87	Low	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	Medium	0.65	0.76	0.87
20	Low	0.65	0.76	0.87	Medium	0.65	0.76	0.87	Low	0.65	0.76	0.87	Medium	0.84	0.95	1	Medium	0.84	0.95	1
21	Low	0.21	0.33	0.44	Medium	0.84	0.95	1	Medium	0.21	0.33	0.44	Medium	0.84	0.95	1	Medium	0.84	0.95	1
22	Low	0.44	0.54	0.64	Medium	0.84	0.95	1	Medium	0.84	0.95	1	Medium	0.65	0.76	0.87	Medium	0.44	0.54	0.64
23	Low	0.44	0.54	0.64	Medium	0.65	0.76	0.87	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64
24	Low	0.21	0.33	0.44	Medium	0.84	0.95	1	Medium	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
25	Low	0.44	0.54	0.64	Medium	0.84	0.95	1	Medium	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Medium	0.65	0.76	0.87
26	Low	0.21	0.33	0.44	Medium	0.65	0.76	0.87	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	Medium	0.65	0.76	0.87
27	Low	0.44	0.54	0.64	Very High	0.84	0.95	1	Medium	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Medium	0.84	0.95	1
28	Medium	0.65	0.76	0.87	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Very High	0.44	0.54	0.64	Very High	0.44	0.54	0.64
29	Medium	0.21	0.33	0.44	Very High	0.84	0.95	1	Medium	0.84	0.95	1	Very High	0.65	0.76	0.87	Very High	0.84	0.95	1
30	Medium	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Very High	0.44	0.54	0.64	Very High	0.44	0.54	0.64	Very High	0.84	0.95	1
31	Medium	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Very High	0.84	0.95	1	Very High	0.65	0.76	0.87
32	Medium	0.21	0.33	0.44	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.65	0.76	0.87
33	Medium	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Very High	0.84	0.95	1	Very High	0.65	0.76	0.87
34	Medium	0.21	0.33	0.44	Very High	0.84	0.95	1	Very High	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Very High	0.65	0.76	0.87
35	Medium	0.44	0.54	0.64	Very High	0.65	0.76	0.87	Very High	0.44	0.54	0.64	Very High	0.65	0.76	0.87	Very High	0.65	0.76	0.87
36	Medium	0.65	0.76	0.87	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1
37	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	Very High	0.44	0.54	0.64	Very High	0.84	0.95	1	Very High	0.65	0.76	0.87
38	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	Very High	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Very High	0.84	0.95	1
39	Medium	0.65	0.76	0.87	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1
40	Very High	0.21	0.33	0.44	Very High	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Very High	0.65	0.76	0.87	Very High	0.84	0.95	1

Table C.3-1: Fuzzification of Factors Responses

Respondent	Site and Ecology Factor				Material Waste Reduction Factor				Transportation Factor				Energy Factor			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	High	0.65	0.76	0.9	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Very High	0.84	0.95	1
2	Medium	0.44	0.54	0.6	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87
3	High	0.65	0.76	0.9	Medium	0.44	0.54	0.64	Low	0.21	0.33	0.44	High	0.65	0.76	0.87
4	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87
5	Medium	0.44	0.54	0.6	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1
6	High	0.65	0.76	0.9	High	0.65	0.76	0.87	Low	0.21	0.33	0.44	High	0.65	0.76	0.87
7	High	0.65	0.76	0.9	Medium	0.44	0.54	0.64	Low	0.21	0.33	0.44	Very High	0.84	0.95	1
8	High	0.65	0.76	0.9	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87
9	Medium	0.44	0.54	0.6	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
10	Medium	0.44	0.54	0.6	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1
11	High	0.65	0.76	0.9	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64
12	Very High	0.84	0.95	1	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1
13	High	0.65	0.76	0.9	Very High	0.84	0.95	1	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
14	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1	High	0.65	0.76	0.87
15	Medium	0.44	0.54	0.6	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1
16	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1
17	Very High	0.84	0.95	1	Low	0.21	0.33	0.44	Very High	0.84	0.95	1	High	0.65	0.76	0.87
18	High	0.65	0.76	0.9	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
19	Very High	0.84	0.95	1	Very High	0.84	0.95	1	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
20	Very High	0.84	0.95	1	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Very High	0.84	0.95	1
21	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	Very High	0.84	0.95	1
22	High	0.65	0.76	0.9	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	High	0.65	0.76	0.87
23	High	0.65	0.76	0.9	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64
24	Very High	0.84	0.95	1	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87
25	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
26	Very High	0.84	0.95	1	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87
27	High	0.65	0.76	0.9	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64
28	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	High	0.65	0.76	0.87
29	Medium	0.44	0.54	0.6	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64
30	High	0.65	0.76	0.9	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
31	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	High	0.65	0.76	0.87
32	High	0.65	0.76	0.9	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
33	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1	High	0.65	0.76	0.87
34	High	0.65	0.76	0.9	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1
35	High	0.65	0.76	0.9	Very High	0.84	0.95	1	Very High	0.84	0.95	1	High	0.65	0.76	0.87
36	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	High	0.65	0.76	0.87
37	High	0.65	0.76	0.9	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64
38	Medium	0.44	0.54	0.6	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87
39	Very High	0.84	0.95	1	High	0.65	0.76	0.87	Very High	0.84	0.95	1	High	0.65	0.76	0.87
40	High	0.65	0.76	0.9	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64

Table C.3-2: Fuzzification of Factors Responses

Respondent	Water Use Factor				Heritage Value Factor				Structural Condition Factor				IEQ factor				Building Maanagment factor			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	Very High	0.84	0.95	1	High	0.65	0.76	0.87
2	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87
3	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64
4	Low	0.21	0.33	0.44	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1
5	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64
6	Low	0.21	0.33	0.44	Low	0.21	0.33	0.44	Very High	0.84	0.95	1	Very High	0.84	0.95	1	High	0.65	0.76	0.87
7	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Very High	0.84	0.95	1
8	Low	0.21	0.33	0.44	Low	0.21	0.33	0.44	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Low	0.21	0.33	0.44
9	Low	0.21	0.33	0.44	Low	0.21	0.33	0.44	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Very High	0.84	0.95	1
10	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64
11	Low	0.21	0.33	0.44	Low	0.21	0.33	0.44	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64
12	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87
13	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
14	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64
15	Low	0.21	0.33	0.44	Low	0.21	0.33	0.44	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	High	0.65	0.76	0.87
16	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1	High	0.65	0.76	0.87
17	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
18	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1
19	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87
20	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Very High	0.84	0.95	1
21	Low	0.21	0.33	0.44	Very High	0.84	0.95	1	Low	0.21	0.33	0.44	Very High	0.84	0.95	1	Very High	0.84	0.95	1
22	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	Very High	0.84	0.95	1	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
23	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64
24	Low	0.21	0.33	0.44	Very High	0.84	0.95	1	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64
25	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87
26	Low	0.21	0.33	0.44	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	High	0.65	0.76	0.87
27	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1
28	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64
29	Low	0.21	0.33	0.44	Very High	0.84	0.95	1	Very High	0.84	0.95	1	High	0.65	0.76	0.87	Very High	0.84	0.95	1
30	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1
31	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1	High	0.65	0.76	0.87
32	Low	0.21	0.33	0.44	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1	High	0.65	0.76	0.87
33	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1	High	0.65	0.76	0.87
34	Low	0.21	0.33	0.44	Very High	0.84	0.95	1	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87
35	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	Medium	0.44	0.54	0.64	High	0.65	0.76	0.87	High	0.65	0.76	0.87
36	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1
37	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	High	0.65	0.76	0.87
38	Medium	0.44	0.54	0.64	Very High	0.84	0.95	1	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1
39	High	0.65	0.76	0.87	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1	Very High	0.84	0.95	1
40	Low	0.21	0.33	0.44	High	0.65	0.76	0.87	High	0.65	0.76	0.87	High	0.65	0.76	0.87	Very High	0.84	0.95	1

Table C. 4: Fuzzification of Energy Factor Responses

	Energy Factor															
	Energy Performance				Provision of Energy Management				Energy Efficient Systems				Energy Efficient Equipment			
Respondent	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Very High	0.840	0.950	1.000	Medium	0.650	0.760	0.870	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
2	High	0.650	0.760	0.870	Medium	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
3	Very High	0.840	0.950	1.000	Medium	0.650	0.760	0.870	Low	0.210	0.330	0.440	High	0.650	0.760	0.870
4	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
5	Very High	0.840	0.950	1.000	Medium	0.210	0.330	0.440	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
6	High	0.650	0.760	0.870	High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
7	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
8	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
9	High	0.650	0.760	0.870	Medium	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
10	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
11	Very High	0.840	0.950	1.000	Medium	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
12	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
13	High	0.650	0.760	0.870	Very High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
14	Medium	0.440	0.540	0.640	Very High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
15	Medium	0.440	0.540	0.640	High	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
16	High	0.650	0.760	0.870	Very High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
17	Medium	0.440	0.540	0.640	Low	0.440	0.540	0.640	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
18	Medium	0.440	0.540	0.640	Medium	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
19	High	0.650	0.760	0.870	Very High	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
20	Medium	0.440	0.540	0.640	High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
21	Very High	0.840	0.950	1.000	Medium	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
22	High	0.650	0.760	0.870	Medium	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
23	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
24	High	0.650	0.760	0.870	High	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870
25	Medium	0.440	0.540	0.640	Medium	0.650	0.760	0.870	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000
26	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
27	High	0.650	0.760	0.870	High	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
28	Medium	0.440	0.540	0.640	Medium	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
29	Very High	0.840	0.950	1.000	Medium	0.650	0.760	0.870	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640
30	High	0.650	0.760	0.870	Medium	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
31	Very High	0.840	0.950	1.000	Medium	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
32	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
33	Medium	0.440	0.540	0.640	Very High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640
34	Medium	0.440	0.540	0.640	High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
35	Very High	0.840	0.950	1.000	Very High	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
36	High	0.650	0.760	0.870	Medium	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
37	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
38	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000
39	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
40	High	0.650	0.760	0.870	Medium	0.650	0.760	0.870	Low	0.210	0.330	0.440	Low	0.210	0.330	0.440

Table C. 5: Fuzzification of Energy Performance Indicator Responses

Respondent	Energy Performance											
	Minimum Energy Performance				Optimizing Energy Efficiency Performance & Reduction of CO2 emissions				Evaluation of Thermal Performance Reduction of Building Envelope			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
2	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
3	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
4	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
5	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
6	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
7	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
8	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
9	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
10	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
11	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
12	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000
13	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
14	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
15	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
16	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
17	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
18	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
19	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
20	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
21	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
22	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
23	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
24	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
25	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
26	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
27	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
28	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
29	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
30	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
31	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
32	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
33	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
34	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
35	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
36	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
37	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
38	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440
39	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440	High	0.650	0.760	0.870
40	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640

Table C. 6: Fuzzification of provision of Energy Management Indicator Responses

Provision of Energy Management

Respondent	Energy Operating Plan				Energy Monitoring and Metering				Building Automation System, or Energy Management System (EMS)				Sustainable Maintenance			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870
2	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870
3	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
4	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
5	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
6	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
7	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
8	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
9	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
10	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
11	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
12	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
13	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
14	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
15	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
16	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
17	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
18	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
19	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
20	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
21	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
22	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
23	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
24	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
25	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
26	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
27	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
28	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
29	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
30	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
31	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
32	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
33	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
34	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
35	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
36	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
37	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
38	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
39	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
40	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640

Table C. 7: Fuzzification of Energy Efficient Systems Indicator Responses

	Energy Efficient Systems											
Respondent	Interior Lighting Efficiency and Zoning Control.				Renewable Energy Systems				Energy Efficient Circulation Systems (Lifts and escalators)			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
2	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
3	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
4	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
5	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
6	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
7	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
8	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
9	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
10	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
11	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
12	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
13	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
14	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
15	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
16	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
17	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
18	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
19	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
20	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
21	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
22	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
23	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
24	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
25	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
26	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
27	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
28	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
29	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
30	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
31	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
32	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
33	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
34	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
35	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
36	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
37	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
38	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
39	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
40	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870

Table C. 8: Fuzzification of Energy Efficient Equipment Indicator Responses

Respondent	Energy Efficient Equipment											
	Energy Efficient Appliances and Cloth Drying Facilities				Energy Efficient AC Equipment				High Efficiency Boilers			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
2	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
3	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
4	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
5	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
6	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
7	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
8	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
9	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
10	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870
11	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
12	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	Low	0.210	0.330	0.440
13	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
14	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
15	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
16	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
17	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
18	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
19	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
20	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
21	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
22	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
23	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
24	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
25	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
26	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
27	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
28	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
29	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
30	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
31	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
32	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
33	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
34	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
35	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000
36	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
37	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
38	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
39	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
40	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000

Table C. 9: Fuzzification of IEQ Factor Responses

Respondent	IEQ Factor																							
	Visual Comfort				Hygiene				Indoor Air Quality				Thermal Comfort				Acoustic Performance				Building Amenities			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
2	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
3	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
4	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
5	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440	Low	0.210	0.330	0.440
6	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
7	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
8	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very Low	0.000	0.100	0.240
9	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
10	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
11	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
12	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
13	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
14	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
15	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
16	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
17	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
18	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very Low	0.000	0.100	0.240	High	0.650	0.760	0.870
19	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000
20	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
21	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
22	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
23	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
24	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
25	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
26	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
27	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
28	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
29	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
30	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
31	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
32	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
33	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440	High	0.650	0.760	0.870
34	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
35	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
36	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
37	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
38	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
39	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
40	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870

Table C. 10: Fuzzification of Visual Comfort Indicator Responses

Respondent	Visual Comfort															
	Natural Lighting and External Views				Glare Control				Interior Lighting Distribution in Normally and Non-normally Occupied Areas				High Frequency Ballasts			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
2	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
3	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	High	0.650	0.760	0.870
4	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
5	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
6	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
7	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
8	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
9	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
10	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
11	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
12	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
13	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
14	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
15	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
16	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
17	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
18	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
19	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
20	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
21	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
22	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
23	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
24	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870
25	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000
26	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
27	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
28	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
29	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640
30	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
31	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
32	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
33	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640
34	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
35	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
36	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
37	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
38	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000
39	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
40	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Low	0.210	0.330	0.440

Table C. 11: Fuzzification of Indoor Air Quality Indicator Responses

Respondent	Indoor Air Quality																							
	Minimum IAQ Performance				Environmental tobacco Smoke Control				Increased Ventilation Performance, Localized Ventilation& Ventilation in Common Areas				Indoor Air Quality Performance & management (audit, Construction management, Management Plan and Monitoring of CO2, CO & NO2)				Indoor Air Quality Pollutant monitoring (chemical, physical and biological)				Green Cleaning Policy			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	High	0.650	0.760	0.870
2	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	Low	0.210	0.330	0.440
3	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
4	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
5	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440	Low	0.210	0.330	0.440	Low	0.210	0.330	0.440
6	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
7	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
8	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very Low	0.000	0.100	0.240
9	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	Low	0.210	0.330	0.440
10	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
11	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
12	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
13	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
14	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
15	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
16	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
17	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
18	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very Low	0.000	0.100	0.240	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
19	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
20	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
21	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
22	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
23	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
24	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
25	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
26	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
27	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
28	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
29	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
30	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
31	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
32	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
33	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870
34	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
35	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
36	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
37	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
38	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
39	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
40	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870

Table C. 12: Fuzzification of Thermal Comfort Indicator Responses

Respondent	Thermal Comfort											
	Design and Verification				Controllability of Temperature				Thermal Comfort in Air Conditioned Premises and in Naturally Ventilated premises			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
2	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
3	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
4	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
5	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
6	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
7	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
8	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
9	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
10	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
11	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
12	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
13	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
14	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
15	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
16	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
17	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
18	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
19	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
20	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
21	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
22	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
23	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
24	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
25	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
26	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
27	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
28	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
29	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
30	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
31	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
32	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
33	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
34	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
35	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
36	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
37	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
38	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
39	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
40	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870

Table C. 13: Fuzzification of Acoustic Performance Indicator Responses

	Acoustic Performance											
	Room Acoustic				Noise isolation				Background Noise			
Respondent	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
2	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
3	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
4	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
5	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
6	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
7	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
8	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
9	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
10	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870
11	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
12	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	Low	0.210	0.330	0.440
13	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
14	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
15	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
16	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
17	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
18	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
19	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
20	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
21	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
22	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
23	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
24	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
25	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
26	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
27	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
28	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
29	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
30	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
31	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
32	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
33	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
34	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
35	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000
36	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
37	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
38	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
39	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
40	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000

Table C.14: Fuzzification of Hygiene Indicator Responses

Hygiene

Respondent	Plumbing and Drainage				Chemical storage				Biological contamination Reduction				Waste disposal facilities de-odorizing system				Occupancy Comfort Survey			
	Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN			Linguistic Variable	TFN		
1	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870
2	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
3	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440
4	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
5	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
6	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
7	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
8	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
9	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
10	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
11	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
12	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870
13	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
14	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
15	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
16	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
17	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
18	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
19	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
20	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
21	High	0.650	0.760	0.870	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
22	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
23	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
24	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
25	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
26	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
27	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
28	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
29	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
30	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
31	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
32	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
33	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870
34	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
35	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
36	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
37	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	High	0.650	0.760	0.870
38	Low	0.210	0.330	0.440	Very High	0.840	0.950	1.000	Low	0.210	0.330	0.440	High	0.650	0.760	0.870	High	0.650	0.760	0.870
39	High	0.650	0.760	0.870	Low	0.210	0.330	0.440	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Low	0.210	0.330	0.440
40	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870

Table C.15: Fuzzification of Building Amenities Responses

	Building Amenities							
Respondent	Access for Persons with Disability				Amenity features			
	Linguistic Variable	TFN			Linguistic Variable	TFN		
1	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
2	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
3	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
4	High	0.650	0.760	0.870	High	0.650	0.760	0.870
5	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
6	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
7	High	0.650	0.760	0.870	High	0.650	0.760	0.870
8	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
9	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
10	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
11	Medium	0.440	0.540	0.640	Low	0.210	0.330	0.440
12	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
13	High	0.650	0.760	0.870	High	0.650	0.760	0.870
14	High	0.650	0.760	0.870	High	0.650	0.760	0.870
15	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
16	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
17	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
18	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
19	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
20	High	0.650	0.760	0.870	High	0.650	0.760	0.870
21	High	0.650	0.760	0.870	High	0.650	0.760	0.870
22	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
23	Very High	0.840	0.950	1.000	Very High	0.840	0.950	1.000
24	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
25	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
26	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
27	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
28	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
29	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
30	High	0.650	0.760	0.870	High	0.650	0.760	0.870
31	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
32	Medium	0.440	0.540	0.640	High	0.650	0.760	0.870
33	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
34	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640
35	Medium	0.440	0.540	0.640	Medium	0.440	0.540	0.640
36	High	0.650	0.760	0.870	Very High	0.840	0.950	1.000
37	High	0.650	0.760	0.870	Medium	0.440	0.540	0.640
38	Very High	0.840	0.950	1.000	High	0.650	0.760	0.870
39	Medium	0.440	0.540	0.640	Very High	0.840	0.950	1.000
40	Very High	0.840	0.950	1.000	Medium	0.440	0.540	0.640

Table C.16-1: Normalized and Weighted Matrices of Factors

Respondent	Site and Ecology Factor			Material Waste Reduction Factor			Transportation Factor			Energy Factor		
	Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix		
1	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.021	0.024	0.025
2	0.017	0.021	0.025	0.017	0.021	0.025	0.017	0.021	0.025	0.019	0.022	0.025
3	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013	0.019	0.022	0.025
4	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016	0.016	0.019	0.022
5	0.017	0.021	0.025	0.017	0.021	0.025	0.017	0.021	0.025	0.021	0.024	0.025
6	0.019	0.022	0.025	0.019	0.022	0.025	0.006	0.009	0.013	0.016	0.019	0.022
7	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013	0.021	0.024	0.025
8	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.016	0.019	0.022
9	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018
10	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.021	0.024	0.025
11	0.019	0.022	0.025	0.013	0.016	0.018	0.013	0.016	0.018	0.017	0.021	0.025
12	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025
13	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.017	0.021	0.025
14	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022
15	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025	0.021	0.024	0.025
16	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025
17	0.021	0.024	0.025	0.005	0.008	0.011	0.021	0.024	0.025	0.019	0.022	0.025
18	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018
19	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.013	0.016	0.018
20	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
21	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025
22	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022
23	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.013	0.016	0.018
24	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022
25	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016
26	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.019	0.022	0.025
27	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.011	0.014	0.016
28	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022
29	0.017	0.021	0.025	0.017	0.021	0.025	0.017	0.021	0.025	0.011	0.014	0.016
30	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018
31	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.019	0.022	0.025
32	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.011	0.014	0.016
33	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.019	0.022	0.025
34	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.021	0.024	0.025
35	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.019	0.022	0.025
36	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022
37	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016
38	0.017	0.021	0.025	0.017	0.021	0.025	0.017	0.021	0.025	0.016	0.019	0.022
39	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022
40	0.019	0.022	0.025	0.013	0.016	0.018	0.013	0.016	0.018	0.013	0.016	0.018

Table C.16-2: Normalized and Weighted Matrices of Factors

Respondent	Water Use Factor			Heritage Value Factor			Structural Condition Factor			IEQ factor			Building Management Factor		
	Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix		
1	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022
2	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025
3	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.021	0.024	0.025	0.011	0.014	0.016
4	0.005	0.008	0.011	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025
5	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.017	0.021	0.025	0.017	0.021	0.025
6	0.005	0.008	0.011	0.005	0.008	0.011	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022
7	0.011	0.014	0.016	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
8	0.005	0.008	0.011	0.005	0.008	0.011	0.021	0.024	0.025	0.017	0.021	0.025	0.008	0.013	0.017
9	0.006	0.009	0.013	0.006	0.009	0.013	0.019	0.022	0.025	0.021	0.024	0.025	0.021	0.024	0.025
10	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016
11	0.008	0.013	0.017	0.008	0.013	0.017	0.017	0.021	0.025	0.017	0.021	0.025	0.017	0.021	0.025
12	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.013	0.016	0.018	0.019	0.022	0.025
13	0.017	0.021	0.025	0.017	0.021	0.025	0.017	0.021	0.025	0.019	0.022	0.025	0.013	0.016	0.018
14	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.017	0.021	0.025	0.017	0.021	0.025
15	0.005	0.008	0.011	0.005	0.008	0.011	0.011	0.014	0.016	0.019	0.022	0.025	0.019	0.022	0.025
16	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022
17	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018
18	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025	0.016	0.019	0.022	0.021	0.024	0.025
19	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025
20	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
21	0.005	0.008	0.011	0.021	0.024	0.025	0.005	0.008	0.011	0.021	0.024	0.025	0.021	0.024	0.025
22	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025	0.019	0.022	0.025	0.013	0.016	0.018
23	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.017	0.021	0.025	0.017	0.021	0.025
24	0.005	0.008	0.011	0.021	0.024	0.025	0.016	0.019	0.022	0.019	0.022	0.025	0.013	0.016	0.018
25	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.019	0.022	0.025	0.019	0.022	0.025
26	0.006	0.009	0.013	0.019	0.022	0.025	0.013	0.016	0.018	0.021	0.024	0.025	0.016	0.019	0.022
27	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025
28	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.017	0.021	0.025	0.017	0.021	0.025
29	0.005	0.008	0.011	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025
30	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.011	0.014	0.016	0.021	0.024	0.025
31	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.021	0.024	0.025	0.016	0.019	0.022
32	0.005	0.008	0.011	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022
33	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.021	0.024	0.025	0.016	0.019	0.022
34	0.005	0.008	0.011	0.021	0.024	0.025	0.016	0.019	0.022	0.019	0.022	0.025	0.019	0.022	0.025
35	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025
36	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025
37	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022
38	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025
39	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025
40	0.006	0.009	0.013	0.019	0.022	0.025	0.019	0.022	0.025	0.016	0.019	0.022	0.021	0.024	0.025

Table C.17-1: Normalized and Weighted Matrices of Energy Indicators

Respondent	Energy Performance			Provision of Energy Management			Energy Efficient Systems			Energy Efficient Equipment		
	Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix		
1	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.006	0.009	0.013
2	0.017	0.021	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016
3	0.019	0.022	0.025	0.016	0.019	0.022	0.005	0.008	0.011	0.016	0.019	0.022
4	0.021	0.024	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025
5	0.017	0.021	0.025	0.005	0.008	0.011	0.011	0.014	0.016	0.021	0.024	0.025
6	0.019	0.022	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
7	0.019	0.022	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
8	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013
9	0.013	0.016	0.018	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016
10	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025
11	0.019	0.022	0.025	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022
12	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016
13	0.016	0.019	0.022	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025
14	0.021	0.024	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025
15	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018
16	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025
17	0.021	0.024	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.006	0.009	0.013
18	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025
19	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022
20	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016
21	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022
22	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022
23	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025
24	0.021	0.024	0.025	0.006	0.009	0.013	0.019	0.022	0.025	0.019	0.022	0.025
25	0.021	0.024	0.025	0.016	0.019	0.022	0.005	0.008	0.011	0.021	0.024	0.025
26	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016
27	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025
28	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025
29	0.017	0.021	0.025	0.016	0.019	0.022	0.005	0.008	0.011	0.011	0.014	0.016
30	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018
31	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022
32	0.019	0.022	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016
33	0.021	0.024	0.025	0.019	0.022	0.025	0.006	0.009	0.013	0.013	0.016	0.018
34	0.019	0.022	0.025	0.021	0.024	0.025	0.011	0.014	0.016	0.005	0.008	0.011
35	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016
36	0.021	0.024	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025
37	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025
38	0.017	0.021	0.025	0.011	0.014	0.016	0.005	0.008	0.011	0.021	0.024	0.025
39	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016
40	0.019	0.022	0.025	0.019	0.022	0.025	0.006	0.009	0.013	0.006	0.009	0.013

Table C.17-1: Normalized and Weighted Matrices of Energy Indicators

Respondent	Energy Performance			Provision of Energy Management			Energy Efficient Systems			Energy Efficient Equipment		
	Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix		
1	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.006	0.009	0.013
2	0.017	0.021	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016
3	0.019	0.022	0.025	0.016	0.019	0.022	0.005	0.008	0.011	0.016	0.019	0.022
4	0.021	0.024	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025
5	0.017	0.021	0.025	0.005	0.008	0.011	0.011	0.014	0.016	0.021	0.024	0.025
6	0.019	0.022	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
7	0.019	0.022	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
8	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013
9	0.013	0.016	0.018	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016
10	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025
11	0.019	0.022	0.025	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022
12	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016
13	0.016	0.019	0.022	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025
14	0.021	0.024	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025
15	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018
16	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025
17	0.021	0.024	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.006	0.009	0.013
18	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025
19	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022
20	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016
21	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022
22	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022
23	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025
24	0.021	0.024	0.025	0.006	0.009	0.013	0.019	0.022	0.025	0.019	0.022	0.025
25	0.021	0.024	0.025	0.016	0.019	0.022	0.005	0.008	0.011	0.021	0.024	0.025
26	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016
27	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025
28	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025
29	0.017	0.021	0.025	0.016	0.019	0.022	0.005	0.008	0.011	0.011	0.014	0.016
30	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018
31	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022
32	0.019	0.022	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016
33	0.021	0.024	0.025	0.019	0.022	0.025	0.006	0.009	0.013	0.013	0.016	0.018
34	0.019	0.022	0.025	0.021	0.024	0.025	0.011	0.014	0.016	0.005	0.008	0.011
35	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016
36	0.021	0.024	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025
37	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025
38	0.017	0.021	0.025	0.011	0.014	0.016	0.005	0.008	0.011	0.021	0.024	0.025
39	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016
40	0.019	0.022	0.025	0.019	0.022	0.025	0.006	0.009	0.013	0.006	0.009	0.013

Table C.17-2: Normalized and Weighted Matrices of IEQ Indicators

Respondent	Visual Comfort			Hygiene			Indoor Air Quality			Thermal Comfort			Acoustic Performance			Building Amenities		
	Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix		
1	0.013	0.016	0.018	0.006	0.009	0.013	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025
2	0.019	0.022	0.025	0.006	0.009	0.013	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013
3	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016
4	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016
5	0.016	0.019	0.022	0.005	0.008	0.011	0.016	0.019	0.022	0.021	0.024	0.025	0.005	0.008	0.011	0.005	0.008	0.011
6	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022
7	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016
8	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.000	0.003	0.006
9	0.013	0.016	0.018	0.006	0.009	0.013	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013
10	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025
11	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022
12	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016
13	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
14	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
15	0.005	0.008	0.011	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016	0.016	0.019	0.022
16	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022
17	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025
18	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025	0.000	0.003	0.007	0.019	0.022	0.025
19	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.005	0.008	0.011	0.021	0.024	0.025
20	0.011	0.014	0.016	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.005	0.008	0.011
21	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
22	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022
23	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022
24	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022
25	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022
26	0.005	0.008	0.011	0.011	0.014	0.016	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016
27	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016
28	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016
29	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022
30	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022
31	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016
32	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025
33	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.005	0.008	0.011	0.016	0.019	0.022
34	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
35	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022
36	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022
37	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025
38	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025
39	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022
40	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022

Table C.18: Normalized and Weighted Matrices of Visual Comfort sub-indicators

	Visual Comfort											
Repondents	**Natural Lighting and External Views**			**Glare Control**			**Interior Lighting Distribution in Normally and Non-normally Occupied Areas**			**High Frequency Ballasts**		
	Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix		
1	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.005	0.008	0.011
2	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016
3	0.021	0.024	0.025	0.016	0.019	0.022	0.005	0.008	0.011	0.016	0.019	0.022
4	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025
5	0.021	0.024	0.025	0.005	0.008	0.011	0.011	0.014	0.016	0.021	0.024	0.025
6	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
7	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
8	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013
9	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016
10	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025
11	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022
12	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016
13	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025
14	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025
15	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018
16	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025
17	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025	0.006	0.009	0.013
18	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025
19	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022
20	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016
21	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022
22	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022
23	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025
24	0.019	0.022	0.025	0.006	0.009	0.013	0.019	0.022	0.025	0.019	0.022	0.025
25	0.011	0.014	0.016	0.016	0.019	0.022	0.005	0.008	0.011	0.021	0.024	0.025
26	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016
27	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025
28	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025
29	0.021	0.024	0.025	0.016	0.019	0.022	0.005	0.008	0.011	0.011	0.014	0.016
30	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018
31	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022
32	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016
33	0.013	0.016	0.018	0.019	0.022	0.025	0.006	0.009	0.013	0.013	0.016	0.018
34	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016	0.005	0.008	0.011
35	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016
36	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025
37	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025
38	0.011	0.014	0.016	0.011	0.014	0.016	0.005	0.008	0.011	0.021	0.024	0.025
39	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016
40	0.019	0.022	0.012	0.019	0.022	0.025	0.006	0.009	0.013	0.006	0.009	0.013

Table C.19: Normalized and Weighted Matrices of Indoor Air Quality sub-indicators

Repondents	Indoor Air Quality																	
	Minimum IAQ Performance			**Environmental tobacco Smoke Control**			**Increased Ventilation Performance, Localized Ventilation& Ventilation in**			**Indoor Air Quality Performance & management (audit,**			**Indoor Air Quality Pollutant monitoring (chemical, physical and biological)**			**Green Cleaning Policy**		
	Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix			Weighted Matrix		
1	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013	0.006	0.009	0.013
2	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013	0.006	0.009	0.013
3	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
4	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022
5	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.005	0.008	0.011	0.005	0.008	0.011	0.005	0.008	0.011
6	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016	0.011	0.014	0.016
7	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
8	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
9	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013	0.006	0.009	0.013
10	0.011	0.014	0.016	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
11	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016
12	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016
13	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022
14	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
15	0.005	0.008	0.011	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025
16	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025
17	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
18	0.019	0.022	0.025	0.019	0.022	0.025	0.019	0.022	0.025	0.000	0.003	0.007	0.013	0.016	0.018	0.013	0.016	0.018
19	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.005	0.008	0.011	0.021	0.024	0.025	0.021	0.024	0.025
20	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016
21	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
22	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
23	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
24	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.014	0.016	0.011	0.014	0.016
25	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
26	0.005	0.008	0.011	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016
27	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
28	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
29	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016	0.011	0.014	0.016
30	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
31	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
32	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025
33	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.005	0.008	0.011	0.016	0.019	0.022	0.016	0.019	0.022
34	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
35	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
36	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022	0.016	0.019	0.022
37	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
38	0.011	0.014	0.016	0.016	0.019	0.022	0.011	0.014	0.016	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
39	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
40	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025

Table C.20: Normalized and Weighted Matrices of Thermal Comfort sub-indicators

Repondents	Thermal Comfort								
	Design and Verification			**Controllability of Temperature**			**Thermal Comfort in Air Conditioned Premises and in Naturally Ventilated premises**		
	Weighted Matrix			Weighted Matrix			Weighted Matrix		
1	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016
2	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
3	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025
4	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025
5	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025
6	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018
7	0.021	0.024	0.025	0.011	0.014	0.016	0.011	0.014	0.016
8	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025
9	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025
10	0.019	0.022	0.025	0.019	0.022	0.025	0.006	0.009	0.013
11	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016
12	0.019	0.022	0.025	0.013	0.016	0.018	0.006	0.009	0.013
13	0.019	0.022	0.025	0.013	0.016	0.018	0.013	0.016	0.018
14	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
15	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.014	0.016
16	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025
17	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016
18	0.013	0.016	0.018	0.019	0.022	0.025	0.013	0.016	0.018
19	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016
20	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016
21	0.017	0.021	0.025	0.017	0.021	0.025	0.017	0.021	0.025
22	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
23	0.013	0.016	0.018	0.019	0.022	0.025	0.006	0.009	0.013
24	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025
25	0.011	0.014	0.016	0.011	0.014	0.016	0.021	0.024	0.025
26	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025
27	0.019	0.022	0.025	0.019	0.022	0.025	0.013	0.016	0.018
28	0.021	0.024	0.025	0.011	0.014	0.016	0.021	0.024	0.025
29	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016
30	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022
31	0.019	0.022	0.025	0.013	0.016	0.018	0.019	0.022	0.025
32	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025
33	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016
34	0.011	0.014	0.016	0.021	0.024	0.025	0.011	0.014	0.016
35	0.011	0.014	0.016	0.021	0.024	0.025	0.021	0.024	0.025
36	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025
37	0.021	0.024	0.025	0.011	0.014	0.016	0.016	0.019	0.022
38	0.013	0.016	0.018	0.013	0.016	0.018	0.019	0.022	0.025
39	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.014	0.016
40	0.013	0.016	0.018	0.019	0.022	0.025	0.019	0.022	0.025

Table C.21-1: Defuzzification of Factors

Repondents	Site and Ecology Factor			Material Waste Reduction Factor			Transportation Factor			Energy Factor		
	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-
1	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.023	0.000	0.010
2	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000	0.022	0.000	0.006
3	0.022	0.000	0.012	0.016	0.006	0.006	0.009	0.012	0.000	0.022	0.000	0.000
4	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000	0.019	0.004	0.011
5	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000	0.023	0.000	0.000
6	0.022	0.000	0.012	0.022	0.000	0.012	0.009	0.012	0.000	0.019	0.004	0.011
7	0.022	0.000	0.012	0.016	0.006	0.006	0.009	0.012	0.000	0.023	0.000	0.010
8	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.019	0.004	0.011
9	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.006
10	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.023	0.000	0.004
11	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000	0.021	0.000	0.008
12	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004
13	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.021	0.000	0.000
14	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000	0.019	0.004	0.000
15	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.023	0.000	0.015
16	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010
17	0.023	0.000	0.015	0.008	0.015	0.000	0.023	0.000	0.015	0.022	0.000	0.006
18	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
19	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.016	0.006	0.000
20	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
21	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.015
22	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
23	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.016	0.006	0.000
24	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.011
25	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000
26	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.022	0.000	0.012
27	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000	0.014	0.010	0.000
28	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
29	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000	0.014	0.010	0.005
30	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
31	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.022	0.000	0.000
32	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.014	0.010	0.005
33	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000	0.022	0.000	0.000
34	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.023	0.000	0.015
35	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.022	0.000	0.006
36	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.000
37	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000
38	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000	0.019	0.004	0.006
39	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
40	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000	0.016	0.006	0.006
S^+ S^-		0.038	0.199		0.163	0.074		0.118	0.119		0.126	0.209
CC		0.840			0.312			0.502			0.624	
Weight		0.507			0.191			0.302			0.325	

Table C.22-2: Defuzzification of Factors

Repondents	Water Use Factor			Heritage Value Factor			Structural Condition Factor			IEQ factor			Building Management Factor		
	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-
1	0.016	0.006	0.000	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.004	0.019	0.004	0.000
2	0.021	0.000	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.000	0.022	0.000	0.000
3	0.016	0.006	0.006	0.022	0.000	0.000	0.022	0.000	0.000	0.023	0.000	0.010	0.014	0.010	0.000
4	0.014	0.010	0.000	0.014	0.010	0.005	0.023	0.000	0.015	0.023	0.000	0.000	0.023	0.000	0.000
5	0.021	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000
6	0.022	0.000	0.012	0.008	0.015	0.000	0.023	0.000	0.015	0.023	0.000	0.004	0.019	0.004	0.000
7	0.016	0.006	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.000	0.023	0.000	0.000
8	0.022	0.000	0.000	0.008	0.015	0.000	0.023	0.000	0.015	0.021	0.000	0.008	0.013	0.008	0.000
9	0.016	0.006	0.000	0.009	0.012	0.000	0.022	0.000	0.012	0.023	0.000	0.000	0.023	0.000	0.000
10	0.022	0.000	0.006	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.010	0.014	0.010	0.000
11	0.016	0.006	0.000	0.013	0.008	0.000	0.021	0.000	0.008	0.021	0.000	0.000	0.021	0.000	0.000
12	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.016	0.006	0.000	0.022	0.000	0.006
13	0.023	0.000	0.004	0.021	0.000	0.000	0.021	0.000	0.000	0.022	0.000	0.006	0.016	0.006	0.000
14	0.023	0.000	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.021	0.000	0.000	0.021	0.000	0.000
15	0.022	0.000	0.006	0.008	0.015	0.000	0.014	0.010	0.005	0.022	0.000	0.000	0.022	0.000	0.000
16	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.004	0.019	0.004	0.000
17	0.008	0.015	0.000	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000
18	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006	0.019	0.004	0.000	0.023	0.000	0.004
19	0.023	0.000	0.004	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
20	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.000	0.023	0.000	0.000
21	0.014	0.010	0.000	0.023	0.000	0.015	0.008	0.015	0.000	0.023	0.000	0.000	0.023	0.000	0.000
22	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.022	0.000	0.006	0.016	0.006	0.000
23	0.019	0.004	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.021	0.000	0.000	0.021	0.000	0.000
24	0.019	0.004	0.000	0.023	0.000	0.015	0.019	0.004	0.011	0.022	0.000	0.006	0.016	0.006	0.000
25	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.022	0.000	0.000	0.022	0.000	0.000
26	0.019	0.004	0.000	0.022	0.000	0.012	0.016	0.006	0.006	0.023	0.000	0.004	0.019	0.004	0.000
27	0.022	0.000	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.000	0.023	0.000	0.004
28	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.021	0.000	0.000	0.021	0.000	0.000
29	0.021	0.000	0.000	0.023	0.000	0.015	0.023	0.000	0.015	0.019	0.004	0.000	0.023	0.000	0.004
30	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.014	0.010	0.000	0.023	0.000	0.010
31	0.014	0.010	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.023	0.000	0.004	0.019	0.004	0.000
32	0.016	0.006	0.000	0.023	0.000	0.015	0.023	0.000	0.015	0.023	0.000	0.004	0.019	0.004	0.000
33	0.023	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.023	0.000	0.004	0.019	0.004	0.000
34	0.022	0.000	0.000	0.023	0.000	0.015	0.019	0.004	0.011	0.022	0.000	0.000	0.022	0.000	0.000
35	0.023	0.000	0.004	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.000	0.022	0.000	0.000
36	0.014	0.010	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.000	0.023	0.000	0.000
37	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.004	0.019	0.004	0.000
38	0.021	0.000	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.000	0.023	0.000	0.004
39	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.000	0.023	0.000	0.000
40	0.016	0.006	0.000	0.022	0.000	0.012	0.022	0.000	0.012	0.019	0.004	0.000	0.023	0.000	0.004
S^+ S^-		0.163	0.074		0.133	0.202		0.109	0.226		0.042	0.084		0.084	0.042
CC		0.312			0.603			0.675			0.667			0.333	
Weight		0.044			0.298			0.333			0.666			0.666	

Table C.23: Defuzzification of Energy Indicators

Repondents	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	0.022	0.000	0.012	0.022	0.000	0.012	0.022	0.000	0.012	0.009	0.012	0.000
2	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
3	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000	0.019	0.004	0.011
4	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
5	0.023	0.000	0.015	0.008	0.015	0.000	0.014	0.010	0.005	0.023	0.000	0.015
6	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
7	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
8	0.022	0.000	0.012	0.022	0.000	0.012	0.016	0.006	0.006	0.009	0.012	0.000
9	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000
10	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
11	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
12	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.014	0.010	0.000
13	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
14	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.006
15	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
16	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004
17	0.016	0.006	0.006	0.016	0.006	0.006	0.022	0.000	0.012	0.009	0.012	0.000
18	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
19	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
20	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000
21	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
22	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
23	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010
24	0.022	0.000	0.012	0.009	0.012	0.000	0.022	0.000	0.012	0.022	0.000	0.012
25	0.014	0.010	0.005	0.019	0.004	0.011	0.008	0.015	0.000	0.023	0.000	0.015
26	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000
27	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
28	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010
29	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000	0.014	0.010	0.005
30	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000
31	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
32	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000
33	0.016	0.006	0.006	0.022	0.000	0.012	0.009	0.012	0.000	0.016	0.006	0.006
34	0.014	0.010	0.005	0.023	0.000	0.015	0.014	0.010	0.005	0.008	0.015	0.000
35	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000
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	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
38	0.014	0.010	0.005	0.014	0.010	0.005	0.008	0.015	0.000	0.023	0.000	0.015
39	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000
40	0.022	0.000	0.012	0.022	0.000	0.012	0.009	0.012	0.000	0.009	0.012	0.000
S^+ S^-		0.091	0.184		0.153	0.215		0.211	0.157		0.206	0.162
CC		0.669			0.584			0.426			0.440	
Weight		0.316			0.276			0.201			0.208	

Table C.24: Defuzzification of IEQ Indicators

Repondents	IEQ Factor																	
	Visual Comfort			**Hygiene**			**Indoor Air Quality**			**Thermal Comfort**			**Acoustic Performance**			**Building Amenities**		
	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-
1	0.016	0.006	0.006	0.009	0.012	0.000	0.022	0.000	0.012	0.022	0.000	0.012	0.016	0.006	0.006	0.022	0.000	0.012
2	0.022	0.000	0.012	0.009	0.012	0.000	0.022	0.000	0.012	0.022	0.000	0.012	0.016	0.006	0.006	0.009	0.012	0.000
3	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
4	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	0.014	0.010	0.000
5	0.019	0.004	0.011	0.008	0.015	0.000	0.019	0.004	0.011	0.023	0.000	0.015	0.008	0.015	0.000	0.008	0.015	0.000
6	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
7	0.019	0.004	0.006	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000
8	0.019	0.004	0.016	0.023	0.000	0.020	0.023	0.000	0.020	0.019	0.004	0.016	0.019	0.004	0.016	0.003	0.020	0.000
9	0.016	0.006	0.006	0.009	0.012	0.000	0.016	0.006	0.006	0.022	0.000	0.012	0.016	0.006	0.006	0.009	0.012	0.000
10	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010
11	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006
12	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
13	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
14	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
15	0.008	0.015	0.000	0.023	0.000	0.015	0.019	0.004	0.011	0.014	0.010	0.005	0.014	0.010	0.005	0.019	0.004	0.011
16	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
17	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
18	0.022	0.000	0.019	0.016	0.006	0.012	0.022	0.000	0.019	0.022	0.000	0.019	0.003	0.019	0.000	0.022	0.000	0.019
19	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	0.023	0.000	0.015
20	0.014	0.010	0.005	0.014	0.010	0.005	0.023	0.000	0.015	0.019	0.004	0.011	0.019	0.004	0.011	0.008	0.015	0.000
21	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
22	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
23	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
24	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006	0.019	0.004	0.006	0.019	0.004	0.006
25	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
26	0.008	0.015	0.000	0.014	0.010	0.005	0.014	0.010	0.005	0.019	0.004	0.011	0.023	0.000	0.015	0.014	0.010	0.005
27	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
28	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.014	0.010	0.000
29	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
30	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
31	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.014	0.010	0.000
32	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
33	0.019	0.004	0.011	0.019	0.004	0.011	0.019	0.004	0.011	0.023	0.000	0.015	0.008	0.015	0.000	0.019	0.004	0.011
34	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	0.019	0.004	0.000
35	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
36	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
37	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010
38	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
39	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
40	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
S^+ S^-		0.142	0.185		0.187	0.238		0.159	0.267		0.110	0.315		0.276	0.149		0.236	0.190
CC		0.578			0.559			0.741			0.741			0.350			0.447	

Table C.25: Defuzzification of Energy Performance sub-indicators

	Energy Performance								
Repondents	**Minimum Energy Performance**			**Optimizing Energy Efficiency Performance & Reduction of CO2 emissions**			**Evaluation of Thermal Performance Reduction of Building Envelope**		
	mean	D^+	D+	mean	D^+	D^-	mean	D^+	D^-
1	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
2	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006
3	0.014	0.010	0.000	0.014	0.010	0.000	0.023	0.000	0.010
4	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004
5	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000
6	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
7	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
8	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006
9	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000
10	0.022	0.000	0.012	0.016	0.006	0.006	0.009	0.012	0.000
11	0.016	0.006	0.006	0.022	0.000	0.012	0.009	0.012	0.000
12	0.014	0.010	0.005	0.008	0.015	0.000	0.023	0.000	0.015
13	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000
14	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
15	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000
16	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
17	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000
18	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
19	0.022	0.000	0.012	0.022	0.000	0.012	0.009	0.012	0.000
20	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010
21	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000
22	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
23	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
24	0.014	0.010	0.000	0.014	0.010	0.000	0.023	0.000	0.010
25	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000
26	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
27	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
28	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
29	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
30	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
31	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
32	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
33	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
34	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
35	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000
36	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
37	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
38	0.014	0.010	0.005	0.023	0.000	0.015	0.008	0.015	0.000
39	0.023	0.000	0.015	0.008	0.015	0.000	0.019	0.004	0.011
40	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
S^+ S^-		0.094	0.224		0.149	0.165		0.170	0.144
CC		0.704			0.524			0.426	
Weight		0.252			0.337			0.295	

Table C.26: Defuzzification of Provision of Energy Management sub-indicators

	Provision of Energy Management														
Repondents	**Energy Operating Plan**			**Energy Monitoring and Metering**			**Commissioning and Testing Energy Systems**			**Building Automation System, or Energy Management System**			**Sustainable Maintenance**		
	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-
1	0.023	0.000	0.015	0.023	0.000	0.015	0.014	0.010	0.005	0.019	0.004	0.011	0.008	0.015	0.000
2	0.016	0.006	0.006	0.009	0.012	0.000	0.009	0.012	0.000	0.009	0.012	0.000	0.022	0.000	0.012
3	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000	0.014	0.010	0.000
4	0.023	0.000	0.015	0.014	0.010	0.005	0.008	0.015	0.000	0.014	0.010	0.005	0.019	0.004	0.011
5	0.019	0.004	0.016	0.019	0.004	0.016	0.023	0.000	0.020	0.003	0.020	0.000	0.003	0.020	0.000
6	0.019	0.004	0.011	0.008	0.015	0.000	0.014	0.010	0.005	0.019	0.004	0.011	0.023	0.000	0.015
7	0.014	0.010	0.005	0.019	0.004	0.011	0.014	0.010	0.005	0.023	0.000	0.015	0.008	0.015	0.000
8	0.019	0.004	0.011	0.023	0.000	0.015	0.014	0.010	0.005	0.023	0.000	0.015	0.008	0.015	0.000
9	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000
10	0.014	0.010	0.000	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	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	0.019	0.004	0.000
12	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004
13	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
14	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006
15	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000
16	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
17	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
18	0.022	0.000	0.012	0.009	0.012	0.000	0.016	0.006	0.006	0.022	0.000	0.012	0.022	0.000	0.012
19	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
20	0.021	0.000	0.008	0.013	0.008	0.000	0.013	0.008	0.000	0.021	0.000	0.008	0.021	0.000	0.008
21	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
22	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
23	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000
24	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004
25	0.023	0.000	0.015	0.008	0.015	0.000	0.023	0.000	0.015	0.019	0.004	0.011	0.023	0.000	0.015
26	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
27	0.022	0.000	0.019	0.009	0.012	0.006	0.016	0.006	0.012	0.022	0.000	0.019	0.003	0.019	0.000
28	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000	0.023	0.000	0.010
29	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
30	0.019	0.004	0.012	0.013	0.014	0.004	0.014	0.010	0.008	0.023	0.000	0.016	0.014	0.010	0.008
31	0.016	0.006	0.009	0.015	0.013	0.005	0.016	0.006	0.009	0.022	0.000	0.014	0.016	0.006	0.009
32	0.023	0.000	0.018	0.009	0.016	0.004	0.008	0.015	0.005	0.019	0.004	0.014	0.019	0.004	0.014
33	0.022	0.000	0.016	0.015	0.013	0.010	0.009	0.012	0.005	0.022	0.000	0.016	0.022	0.000	0.016
34	0.016	0.006	0.010	0.015	0.013	0.010	0.009	0.012	0.005	0.022	0.000	0.016	0.016	0.006	0.010
35	0.023	0.000	0.021	0.013	0.014	0.013	0.003	0.020	0.001	0.014	0.010	0.012	0.019	0.004	0.017
36	0.022	0.000	0.016	0.015	0.013	0.010	0.009	0.012	0.005	0.022	0.000	0.016	0.022	0.000	0.016
37	0.023	0.000	0.016	0.013	0.014	0.004	0.014	0.010	0.008	0.019	0.004	0.012	0.019	0.004	0.012
38	0.019	0.004	0.011	0.013	0.014	0.000	0.019	0.004	0.011	0.023	0.000	0.014	0.019	0.004	0.011
39	0.022	0.000	0.014	0.015	0.013	0.005	0.016	0.006	0.009	0.022	0.000	0.014	0.022	0.000	0.014
40	0.023	0.000	0.016	0.015	0.014	0.008	0.019	0.004	0.012	0.019	0.004	0.012	0.014	0.010	0.008
S^+ S^-		0.090	0.212		0.307	0.219		0.262	0.232		0.167	0.312		0.216	0.269
CC		0.578			0.416			0.470			0.652			0.554	
Weight		0.175			0.149			0.168			0.233			0.198	

Table C.27: Defuzzification of Energy Efficient Systems sub-indicators

	Energy Efficient Systems								
Repondents	**Interior Lighting Efficiency and Zoning Control.**			**Renewable Energy Systems**			**Energy Efficient Circulation Systems (Lifts and escalators)**		
	mean	D^+	D+	mean	D^+	D^-	mean	D^+	D^-
1	0.013	0.008	0.000	0.021	0.000	0.008	0.021	0.000	0.008
2	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
3	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006
4	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
5	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006
6	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
7	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000
8	0.009	0.012	0.000	0.016	0.006	0.006	0.022	0.000	0.012
9	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006
10	0.022	0.000	0.012	0.022	0.000	0.012	0.009	0.012	0.000
11	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
12	0.021	0.000	0.008	0.021	0.000	0.008	0.013	0.008	0.000
13	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	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	0.010	0.019	0.004	0.006	0.014	0.010	0.000
16	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
17	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000
18	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
19	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
20	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
21	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000
22	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
23	0.016	0.006	0.006	0.022	0.000	0.012	0.009	0.012	0.000
24	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010
25	0.014	0.010	0.000	0.014	0.010	0.000	0.023	0.000	0.010
26	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
27	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000
28	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010
29	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
30	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
31	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
32	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
33	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000
34	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
35	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
36	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
37	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
38	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000
39	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000
40	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
S^+ S^-		0.095	0.133		0.107	0.203		0.179	0.131
CC		0.582			0.655			0.424	
Weight		0.351			0.394			0.255	

Table C.28: Defuzzification of Energy Efficient Equipment sub-indicators

Energy Efficient Equipment									
Repondents	**Energy Efficient Appliances and Cloth Drying Facilities**			**Energy Efficient AC Equipment**			**High Efficiency Boilers**		
	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-
1	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
2	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
3	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000
4	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
5	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006
6	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
7	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
8	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
9	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
10	0.009	0.012	0.000	0.022	0.000	0.012	0.022	0.000	0.012
11	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
12	0.021	0.000	0.008	0.013	0.008	0.000	0.013	0.008	0.000
13	0.023	0.000	0.015	0.014	0.010	0.005	0.008	0.015	0.000
14	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
15	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
16	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
17	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
18	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
19	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000
20	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010
21	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000
22	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
23	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
24	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010
25	0.013	0.008	0.000	0.021	0.000	0.008	0.021	0.000	0.008
26	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
27	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
28	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
29	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000
30	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000
31	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
32	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
33	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000
34	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
35	0.019	0.004	0.011	0.008	0.015	0.000	0.023	0.000	0.015
36	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
37	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
38	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004
39	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000
40	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
S^+ S^-		0.070	0.142		0.131	0.157		0.168	0.120
CC		0.671			0.545			0.416	
Weight		0.411			0.334			0.255	

Table C.29: Defuzzification of Visual Comfort sub-indicators

	Visual Comfort											
Repondents	**Natural Lighting and External Views**			**Glare Control**			**Interior Lighting Distribution in Normally and Non-normally Occupied Areas**			**High Frequency Ballasts**		
	mean	D^{+}	D+	mean	D^{+}	D^{-}	mean	D^{+}	D^{-}	mean	D^{+}	D^{-}
1	0.023	0.000	0.015	0.019	0.004	0.011	0.019	0.004	0.011	0.008	0.015	0.000
2	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
3	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000	0.019	0.004	0.011
4	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
5	0.023	0.000	0.015	0.008	0.015	0.000	0.014	0.010	0.005	0.023	0.000	0.015
6	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
7	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
8	0.022	0.000	0.012	0.022	0.000	0.012	0.016	0.006	0.006	0.009	0.012	0.000
9	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000
10	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
11	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
12	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.014	0.010	0.000
13	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
14	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.006
15	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
16	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004
17	0.016	0.006	0.006	0.016	0.006	0.006	0.022	0.000	0.012	0.009	0.012	0.000
18	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
19	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
20	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000
21	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
22	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
23	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010
24	0.022	0.000	0.012	0.009	0.012	0.000	0.022	0.000	0.012	0.022	0.000	0.012
25	0.014	0.010	0.005	0.019	0.004	0.011	0.008	0.015	0.000	0.023	0.000	0.015
26	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000
27	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
28	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010
29	0.023	0.000	0.015	0.019	0.004	0.011	0.008	0.015	0.000	0.014	0.010	0.005
30	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000
31	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
32	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000
33	0.016	0.006	0.006	0.022	0.000	0.012	0.009	0.012	0.000	0.016	0.006	0.006
34	0.014	0.010	0.005	0.023	0.000	0.015	0.014	0.010	0.005	0.008	0.015	0.000
35	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000
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	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004
38	0.014	0.010	0.005	0.014	0.010	0.005	0.008	0.015	0.000	0.023	0.000	0.015
39	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000
40	0.022	0.000	0.012	0.022	0.000	0.012	0.009	0.012	0.000	0.009	0.012	0.000
S^{+} S^{-}		0.091	0.187		0.158	0.213		0.216	0.155		0.209	0.162
CC		0.672			0.575			0.418			0.473	
Weight		0.320			0.274			0.199			0.208	

Table C.30: Defuzzification of Indoor Air Quality sub-indicators

Repondents	Indoor Air Quality																	
	Minimum IAQ Performance			**Environmental tobacco Smoke Control**			**Increased Ventilation Performance, Localized Ventilation& Ventilation in**			**Indoor Air Quality Performance & management (audit,**			**Indoor Air Quality Pollutant monitoring (chemical, physical and biological)**			**Green Cleaning Policy**		
	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-
1	0.023	0.000	0.015	0.022	0.000	0.012	0.022	0.000	0.012	0.016	0.006	0.006	0.009	0.012	0.000	0.022	0.000	0.012
2	0.016	0.006	0.006	0.022	0.000	0.012	0.022	0.000	0.012	0.016	0.006	0.006	0.009	0.012	0.000	0.009	0.012	0.000
3	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
4	0.023	0.000	0.015	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000
5	0.019	0.004	0.016	0.019	0.004	0.011	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	0.019	0.004	0.011	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000	0.019	0.004	0.006
7	0.014	0.010	0.005	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000
8	0.019	0.004	0.011	0.023	0.000	0.020	0.019	0.004	0.016	0.019	0.004	0.016	0.023	0.000	0.020	0.003	0.020	0.000
9	0.022	0.000	0.006	0.016	0.006	0.006	0.022	0.000	0.012	0.016	0.006	0.006	0.009	0.012	0.000	0.009	0.012	0.000
10	0.014	0.010	0.000	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
11	0.019	0.004	0.000	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
12	0.023	0.000	0.004	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.014	0.010	0.000
13	0.023	0.000	0.010	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000
14	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006
15	0.019	0.004	0.006	0.019	0.004	0.011	0.014	0.010	0.005	0.014	0.010	0.005	0.023	0.000	0.015	0.019	0.004	0.011
16	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
17	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010
18	0.022	0.000	0.012	0.022	0.000	0.019	0.022	0.000	0.019	0.003	0.019	0.000	0.016	0.006	0.012	0.022	0.000	0.019
19	0.014	0.010	0.000	0.019	0.004	0.011	0.023	0.000	0.015	0.008	0.015	0.000	0.023	0.000	0.015	0.023	0.000	0.015
20	0.021	0.000	0.008	0.023	0.000	0.015	0.019	0.004	0.011	0.019	0.004	0.011	0.014	0.010	0.005	0.008	0.015	0.000
21	0.019	0.004	0.000	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006
22	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
23	0.022	0.000	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
24	0.023	0.000	0.004	0.019	0.004	0.006	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
25	0.023	0.000	0.015	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
26	0.019	0.004	0.006	0.014	0.010	0.005	0.019	0.004	0.011	0.023	0.000	0.015	0.014	0.010	0.005	0.014	0.010	0.005
27	0.022	0.000	0.019	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000
28	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000
29	0.022	0.000	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000	0.019	0.004	0.006
30	0.019	0.004	0.012	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
31	0.016	0.006	0.009	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000
32	0.023	0.000	0.018	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
33	0.022	0.000	0.016	0.019	0.004	0.011	0.023	0.000	0.015	0.008	0.015	0.000	0.019	0.004	0.011	0.019	0.004	0.011
34	0.016	0.006	0.010	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
35	0.023	0.000	0.021	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
36	0.022	0.000	0.016	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.019	0.004	0.006
37	0.023	0.000	0.016	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010
38	0.019	0.004	0.011	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010	0.023	0.000	0.010
39	0.022	0.000	0.014	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
40	0.023	0.000	0.016	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006
S^+ S^-		0.142	0.195		0.159	0.267		0.110	0.315		0.276	0.149		0.187	0.238		0.236	0.190
CC		0.578			0.627			0.741			0.350			0.559			0.447	
Weight		0.175			0.190			0.224			0.106			0.169			0.135	

Table C.31: Defuzzification of Thermal Comfort sub-indicators

Thermal Comfort									
Repondents	**Design and Verification**			**Controllability of Temperature**			**Thermal Comfort in Air Conditioned Premises and in Naturally Ventilated premises**		
	mean	D^+	D+	mean	D^+	D^-	mean	D^+	D^-
1	0.023	0.000	0.010	0.021	0.000	0.008	0.014	0.010	0.000
2	0.023	0.000	0.004	0.022	0.000	0.006	0.019	0.004	0.000
3	0.016	0.006	0.000	0.016	0.006	0.000	0.016	0.006	0.000
4	0.023	0.000	0.000	0.023	0.000	0.010	0.023	0.000	0.000
5	0.016	0.006	0.000	0.016	0.006	0.000	0.016	0.006	0.000
6	0.022	0.000	0.006	0.019	0.004	0.006	0.022	0.000	0.006
7	0.023	0.000	0.010	0.016	0.006	0.000	0.014	0.010	0.000
8	0.016	0.006	0.000	0.016	0.006	0.006	0.016	0.006	0.000
9	0.016	0.006	0.000	0.016	0.006	0.000	0.016	0.006	0.000
10	0.022	0.000	0.012	0.022	0.000	0.012	0.022	0.000	0.012
11	0.023	0.000	0.010	0.019	0.004	0.000	0.019	0.004	0.006
12	0.022	0.000	0.012	0.021	0.000	0.008	0.016	0.006	0.006
13	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000
14	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
15	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006
16	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
17	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
18	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
19	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010
20	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010
21	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000
22	0.023	0.000	0.004	0.022	0.000	0.006	0.019	0.004	0.000
23	0.016	0.006	0.006	0.022	0.000	0.012	0.022	0.000	0.012
24	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000
25	0.014	0.010	0.000	0.014	0.010	0.000	0.014	0.010	0.000
26	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
27	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.006
28	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000
29	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010
30	0.023	0.000	0.004	0.023	0.000	0.004	0.023	0.000	0.004
31	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000
32	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
33	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
34	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
35	0.014	0.010	0.000	0.023	0.000	0.010	0.023	0.000	0.010
36	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
37	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000
38	0.016	0.006	0.000	0.016	0.006	0.000	0.016	0.006	0.000
39	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010
40	0.016	0.006	0.000	0.019	0.004	0.000	0.022	0.000	0.006
S^+ S^-		0.068	0.151		0.107	0.203		0.126	0.177
CC		0.689			0.655			0.583	
Weight		0.417			0.394			0.352	

Table C.32: Defuzzification of Acoustic Performance sub-indicators

	Acoustic Performance								
Repondents	**Room Acoustic**			**Noise isolation**			**Background Noise**		
	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-
1	0.023	0.000	0.000	0.023	0.000	0.000	0.023	0.000	0.000
2	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
3	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
4	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000
5	0.009	0.012	0.000	0.016	0.006	0.006	0.022	0.000	0.012
6	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000
7	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000
8	0.009	0.012	0.000	0.016	0.006	0.006	0.022	0.000	0.012
9	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
10	0.016	0.006	0.006	0.022	0.000	0.012	0.009	0.012	0.000
11	0.023	0.000	0.004	0.019	0.004	0.000	0.019	0.004	0.000
12	0.016	0.006	0.006	0.022	0.000	0.012	0.009	0.012	0.000
13	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000
14	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
15	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
16	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006
17	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000
18	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000
19	0.014	0.010	0.005	0.023	0.000	0.015	0.008	0.015	0.000
20	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
21	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000
22	0.023	0.000	0.015	0.008	0.015	0.000	0.019	0.004	0.011
23	0.016	0.006	0.006	0.022	0.000	0.012	0.009	0.012	0.000
24	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010
25	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000
26	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
27	0.022	0.000	0.006	0.022	0.000	0.006	0.016	0.006	0.000
28	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010
29	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000
30	0.023	0.000	0.004	0.023	0.000	0.004	0.019	0.004	0.000
31	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006
32	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006
33	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000
34	0.023	0.000	0.015	0.008	0.015	0.000	0.014	0.010	0.005
35	0.019	0.004	0.000	0.023	0.000	0.004	0.023	0.000	0.004
36	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000
37	0.016	0.006	0.000	0.016	0.006	0.000	0.022	0.000	0.006
38	0.021	0.000	0.000	0.021	0.000	0.000	0.021	0.000	0.000
39	0.022	0.000	0.000	0.022	0.000	0.000	0.022	0.000	0.000
40	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
S^+ S^-		0.097	0.135		0.135	0.155		0.178	0.112
CC		0.581			0.533			0.386	
Weight		0.387			0.356			0.257	

Table C.33: Defuzzification of Hygiene sub-indicators

Repondents	Hygiene														
	Plumbing and Drainage			**Chemical storage**			**Biological contamination Reduction**			**Waste disposal facilities de-odorizing system**			**Occupancy Comfort Survey**		
	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-	mean	D^+	D^-
1	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.019	0.004	0.006
2	0.016	0.006	0.006	0.009	0.012	0.000	0.022	0.000	0.012	0.016	0.006	0.006	0.022	0.000	0.012
3	0.019	0.004	0.011	0.019	0.004	0.011	0.019	0.004	0.011	0.023	0.000	0.015	0.008	0.015	0.000
4	0.023	0.000	0.010	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
5	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
6	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
7	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.014	0.010	0.000	0.014	0.010	0.000
8	0.019	0.004	0.006	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
9	0.022	0.000	0.006	0.016	0.006	0.000	0.022	0.000	0.006	0.016	0.006	0.000	0.016	0.006	0.000
10	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
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	0.019	0.004	0.000
12	0.016	0.006	0.000	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.006	0.022	0.000	0.006
13	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006
14	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006
15	0.019	0.004	0.006	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006	0.023	0.000	0.010
16	0.023	0.000	0.010	0.014	0.010	0.000	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
17	0.023	0.000	0.010	0.023	0.000	0.010	0.023	0.000	0.010	0.014	0.010	0.000	0.023	0.000	0.010
18	0.022	0.000	0.012	0.009	0.012	0.000	0.016	0.006	0.006	0.022	0.000	0.012	0.022	0.000	0.012
19	0.014	0.010	0.000	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000
20	0.022	0.000	0.012	0.009	0.012	0.000	0.009	0.012	0.000	0.016	0.006	0.006	0.016	0.006	0.006
21	0.019	0.004	0.000	0.019	0.004	0.000	0.019	0.004	0.000	0.023	0.000	0.004	0.019	0.004	0.000
22	0.019	0.004	0.006	0.014	0.010	0.000	0.023	0.000	0.010	0.019	0.004	0.006	0.023	0.000	0.010
23	0.009	0.012	0.000	0.022	0.000	0.012	0.022	0.000	0.012	0.016	0.006	0.006	0.016	0.006	0.006
24	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
25	0.014	0.010	0.005	0.008	0.015	0.000	0.014	0.010	0.005	0.019	0.004	0.011	0.023	0.000	0.015
26	0.019	0.004	0.006	0.023	0.000	0.010	0.019	0.004	0.006	0.014	0.010	0.000	0.019	0.004	0.006
27	0.022	0.000	0.012	0.022	0.000	0.012	0.016	0.006	0.006	0.016	0.006	0.006	0.009	0.012	0.000
28	0.014	0.010	0.000	0.023	0.000	0.010	0.014	0.010	0.000	0.014	0.010	0.000	0.023	0.000	0.010
29	0.022	0.000	0.012	0.009	0.012	0.000	0.016	0.006	0.006	0.022	0.000	0.012	0.016	0.006	0.006
30	0.023	0.000	0.014	0.013	0.014	0.000	0.023	0.000	0.014	0.023	0.000	0.014	0.023	0.000	0.014
31	0.023	0.000	0.016	0.013	0.014	0.004	0.014	0.010	0.008	0.014	0.010	0.008	0.014	0.010	0.008
32	0.023	0.000	0.016	0.009	0.016	0.000	0.019	0.004	0.012	0.019	0.004	0.012	0.014	0.010	0.008
33	0.016	0.006	0.010	0.015	0.013	0.010	0.009	0.012	0.005	0.022	0.000	0.016	0.022	0.000	0.016
34	0.014	0.010	0.008	0.009	0.016	0.000	0.019	0.004	0.012	0.023	0.000	0.016	0.014	0.010	0.008
35	0.023	0.000	0.016	0.013	0.014	0.004	0.014	0.010	0.008	0.014	0.010	0.008	0.019	0.004	0.012
36	0.014	0.010	0.009	0.013	0.014	0.009	0.008	0.015	0.005	0.023	0.000	0.018	0.023	0.000	0.018
37	0.023	0.000	0.016	0.013	0.014	0.004	0.014	0.010	0.008	0.019	0.004	0.012	0.019	0.004	0.012
38	0.008	0.014	0.005	0.015	0.011	0.012	0.008	0.014	0.005	0.019	0.003	0.014	0.019	0.003	0.014
39	0.022	0.000	0.016	0.006	0.016	0.000	0.016	0.006	0.010	0.022	0.000	0.016	0.009	0.012	0.005
40	0.016	0.006	0.009	0.015	0.013	0.005	0.016	0.006	0.009	0.016	0.006	0.009	0.022	0.000	0.014
S^+ S^-		0.106	0.195		0.313	0.178		0.217	0.257		0.172	0.296		0.189	0.281
CC		0.648			0.362			0.542			0.632			0.559	
Weight		0.233			0.130			0.195			0.227			0.215	

Table C.34: Defuzzification of Building Amenities sub-indicator

Repondents	Building Amenities					
	Access for Persons with Disability			**Amenity features**		
	mean	D^+	D^-	mean	D^+	D^-
1	0.023	0.000	0.010	0.014	0.010	0.000
2	0.022	0.000	0.006	0.016	0.006	0.000
3	0.019	0.004	0.000	0.023	0.000	0.004
4	0.022	0.000	0.000	0.022	0.000	0.000
5	0.023	0.000	0.010	0.014	0.010	0.000
6	0.023	0.000	0.004	0.019	0.004	0.000
7	0.022	0.000	0.000	0.022	0.000	0.000
8	0.014	0.010	0.000	0.023	0.000	0.010
9	0.016	0.006	0.000	0.022	0.000	0.006
10	0.023	0.000	0.000	0.023	0.000	0.000
11	0.021	0.000	0.008	0.013	0.008	0.000
12	0.023	0.000	0.010	0.014	0.010	0.000
13	0.022	0.000	0.000	0.022	0.000	0.000
14	0.022	0.000	0.000	0.022	0.000	0.000
15	0.014	0.010	0.000	0.023	0.000	0.010
16	0.019	0.004	0.000	0.023	0.000	0.004
17	0.023	0.000	0.004	0.019	0.004	0.000
18	0.016	0.006	0.000	0.022	0.000	0.006
19	0.019	0.004	0.000	0.023	0.000	0.004
20	0.022	0.000	0.000	0.022	0.000	0.000
21	0.022	0.000	0.000	0.022	0.000	0.000
22	0.023	0.000	0.000	0.023	0.000	0.000
23	0.023	0.000	0.000	0.023	0.000	0.000
24	0.023	0.000	0.004	0.019	0.004	0.000
25	0.021	0.000	0.000	0.021	0.000	0.000
26	0.014	0.010	0.000	0.023	0.000	0.010
27	0.021	0.000	0.000	0.021	0.000	0.000
28	0.019	0.004	0.000	0.023	0.000	0.004
29	0.016	0.006	0.000	0.022	0.000	0.006
30	0.022	0.000	0.000	0.022	0.000	0.000
31	0.022	0.000	0.006	0.016	0.006	0.000
32	0.016	0.006	0.000	0.022	0.000	0.006
33	0.023	0.000	0.004	0.019	0.004	0.000
34	0.023	0.000	0.010	0.014	0.010	0.000
35	0.021	0.000	0.000	0.021	0.000	0.000
36	0.019	0.004	0.000	0.023	0.000	0.004
37	0.022	0.000	0.006	0.016	0.006	0.000
38	0.023	0.000	0.004	0.019	0.004	0.000
39	0.014	0.010	0.000	0.023	0.000	0.010
40	0.023	0.000	0.010	0.014	0.010	0.000
S^+ S^-		0.066	0.057		0.098	0.086
CC		0.465			0.468	
Weight		0.498			0.502	

Table C.35: Cronbach alpha using ANOVA method for all factors & indicators

Statistical Analysis for all Factor and Indicators																																										
Q	F1	Ind-1	Ind-2	Ind-3	Ind-4	F2	Ind-5	Ind-6	Ind-7	F3	Ind-8	Ind-9	Ind-10	F4	Ind-11	Ind-12	Ind-13	Ind-14	F5	Ind-15	Ind-16	F6	Ind-17	Ind-18	Ind-19	F7	Ind-20	Ind-21	Ind-22	F8	Ind-23	Ind-24	Ind-25	Ind-26	Ind-27	Ind-28	F9	Ind-30	Ind-31	Ind-32	Ind-33	Ind-34
1	0.54	0.95	0.54	0.76	0.54	0.76	0.76	0.95	0.76	0.54	0.76	0.95	0.76	0.95	0.76	0.76	0.95	0.76	0.95	0.76	0.95	0.76	0.76	0.95	0.76	0.54	0.95	0.76	0.95	0.76	0.76	0.76	0.95	0.76	0.95	0.76	0.76	0.54	0.76	0.54	0.76	0.76
2	0.76	0.76	0.95	0.95	0.95	0.95	0.54	0.54	0.54	0.95	0.95	0.76	0.54	0.76	0.95	0.95	0.76	0.54	0.76	0.54	0.76	0.95	0.95	0.76	0.54	0.95	0.76	0.54	0.76	0.54	0.95	0.95	0.76	0.54	0.76	0.54	0.95	0.95	0.95	0.95	0.95	0.54
3	0.95	0.95	0.76	0.76	0.76	0.54	0.76	0.95	0.76	0.54	0.76	0.95	0.76	0.95	0.76	0.76	0.95	0.76	0.95	0.76	0.95	0.76	0.76	0.95	0.76	0.76	0.95	0.76	0.95	0.76	0.76	0.76	0.95	0.76	0.95	0.76	0.76	0.76	0.76	0.76	0.54	0.76
4	0.54	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.54	0.76	0.54	0.76	0.54	0.54	0.76	0.54	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.76	0.76	0.54	0.76
5	0.95	0.95	0.54	0.54	0.54	0.54	0.54	0.95	0.54	0.54	0.54	0.95	0.95	0.95	0.54	0.54	0.95	0.95	0.95	0.95	0.95	0.33	0.54	0.95	0.95	0.54	0.95	0.95	0.95	0.95	0.54	0.54	0.95	0.95	0.95	0.95	0.54	0.54	0.54	0.54	0.54	0.54
6	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.95	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
7	0.95	0.95	0.76	0.76	0.76	0.54	0.76	0.95	0.76	0.76	0.76	0.95	0.76	0.95	0.76	0.76	0.95	0.76	0.95	0.76	0.95	0.54	0.76	0.95	0.76	0.76	0.95	0.76	0.95	0.76	0.76	0.76	0.95	0.76	0.95	0.76	0.76	0.76	0.76	0.76	0.54	0.76
8	0.76	0.76	0.54	0.54	0.54	0.76	0.54	0.76	0.54	0.76	0.54	0.76	0.54	0.76	0.54	0.54	0.76	0.54	0.76	0.54	0.76	0.76	0.54	0.76	0.54	0.54	0.76	0.54	0.76	0.54	0.54	0.54	0.76	0.54	0.76	0.54	0.54	0.54	0.54	0.54	0.76	0.54
9	0.76	0.76	0.95	0.95	0.95	0.76	0.76	0.76	0.95	0.76	0.76	0.76	0.54	0.76	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.76	0.54	0.95	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.95	0.95	0.95	0.95	0.76	0.76
10	0.76	0.76	0.54	0.54	0.54	0.76	0.54	0.76	0.54	0.54	0.54	0.76	0.76	0.76	0.54	0.54	0.76	0.76	0.76	0.76	0.76	0.76	0.54	0.76	0.76	0.54	0.76	0.76	0.76	0.76	0.54	0.54	0.76	0.76	0.76	0.76	0.54	0.54	0.54	0.54	0.76	0.54
11	0.76	0.95	0.54	0.54	0.54	0.95	0.76	0.95	0.76	0.76	0.76	0.95	0.76	0.76	0.76	0.76	0.95	0.76	0.95	0.76	0.95	0.95	0.76	0.95	0.76	0.54	0.95	0.76	0.95	0.76	0.76	0.76	0.95	0.76	0.95	0.76	0.54	0.54	0.54	0.54	0.95	0.76
12	0.95	0.95	0.54	0.54	0.54	0.76	0.54	0.95	0.54	0.54	0.54	0.95	0.54	0.95	0.54	0.54	0.95	0.54	0.95	0.54	0.95	0.76	0.54	0.95	0.54	0.54	0.95	0.54	0.95	0.54	0.54	0.54	0.95	0.54	0.95	0.54	0.54	0.54	0.54	0.54	0.76	0.54
13	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
14	0.54	0.54	0.76	0.76	0.76	0.76	0.76	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.54	0.76	0.54	0.76	0.54	0.76	0.76	0.54	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.76	0.76	0.76	0.76
15	0.54	0.76	0.76	0.95	0.76	0.54	0.76	0.76	0.95	0.76	0.76	0.76	0.54	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.54	0.76	0.76	0.54	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.95	0.76	0.95	0.76	0.54	0.76
16	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.95	0.76	0.76	0.76	0.76	0.95	0.76	0.95	0.76	0.76	0.76	0.76	0.95	0.76	0.76	0.95	0.76	0.95	0.76	0.76	0.76	0.95	0.76	0.95	0.76	0.76	0.76	0.76	0.76	0.76
17	0.54	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.76	0.33	0.54	0.76	0.76	0.54	0.33	0.54	0.33	0.54	0.54	0.76	0.54	0.33	0.76	0.54	0.33	0.54	0.33	0.76	0.76	0.54	0.33	0.54	0.33	0.76	0.76	0.76	0.76	0.54	0.76
18	0.54	0.54	0.54	0.54	0.54	0.76	0.54	0.54	0.54	0.54	0.54	0.54	0.76	0.54	0.54	0.54	0.54	0.76	0.54	0.76	0.54	0.76	0.54	0.54	0.76	0.54	0.54	0.76	0.54	0.76	0.54	0.54	0.54	0.76	0.54	0.76	0.54	0.54	0.54	0.54	0.76	0.54
19	0.76	0.76	0.95	0.95	0.95	0.54	0.95	0.76	0.95	0.95	0.95	0.76	0.76	0.76	0.95	0.95	0.76	0.76	0.76	0.76	0.76	0.54	0.95	0.76	0.76	0.95	0.76	0.76	0.76	0.76	0.95	0.95	0.76	0.76	0.76	0.76	0.95	0.95	0.95	0.95	0.54	0.95
20	0.54	0.54	0.54	0.54	0.54	0.95	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.95	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.95	0.54
21	0.95	0.95	0.54	0.54	0.54	0.76	0.54	0.95	0.54	0.54	0.54	0.95	0.76	0.95	0.54	0.54	0.95	0.76	0.95	0.76	0.95	0.76	0.54	0.95	0.76	0.54	0.95	0.76	0.95	0.76	0.54	0.54	0.95	0.76	0.95	0.76	0.54	0.54	0.54	0.54	0.76	0.54
22	0.76	0.76	0.95	0.95	0.95	0.76	0.95	0.76	0.95	0.95	0.95	0.76	0.76	0.76	0.95	0.95	0.76	0.76	0.76	0.76	0.76	0.76	0.95	0.76	0.76	0.95	0.76	0.76	0.76	0.76	0.95	0.95	0.76	0.76	0.76	0.76	0.95	0.95	0.95	0.95	0.76	0.95
23	0.76	0.76	0.54	0.54	0.54	0.76	0.54	0.76	0.54	0.54	0.54	0.76	0.95	0.76	0.54	0.54	0.76	0.95	0.76	0.95	0.76	0.76	0.54	0.76	0.95	0.54	0.76	0.95	0.76	0.95	0.54	0.54	0.76	0.95	0.76	0.95	0.54	0.54	0.54	0.54	0.76	0.54
24	0.76	0.76	0.76	0.76	0.76	0.33	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.33	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.33	0.76
25	0.54	0.54	0.33	0.54	0.33	0.76	0.95	0.54	0.54	0.95	0.95	0.54	0.95	0.54	0.95	0.95	0.54	0.95	0.54	0.95	0.54	0.76	0.95	0.54	0.95	0.33	0.54	0.95	0.54	0.95	0.95	0.95	0.54	0.95	0.54	0.95	0.54	0.33	0.54	0.33	0.76	0.95
26	0.95	0.95	0.76	0.76	0.76	0.76	0.95	0.95	0.76	0.95	0.95	0.95	0.54	0.95	0.95	0.95	0.95	0.54	0.95	0.54	0.95	0.76	0.95	0.95	0.54	0.76	0.95	0.54	0.95	0.54	0.95	0.95	0.95	0.54	0.95	0.54	0.76	0.76	0.76	0.76	0.76	0.95
27	0.76	0.76	0.76	0.76	0.76	0.54	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.54	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.54	0.76
28	0.54	0.54	0.95	0.95	0.95	0.95	0.95	0.54	0.95	0.95	0.95	0.54	0.95	0.54	0.95	0.95	0.54	0.95	0.54	0.95	0.54	0.95	0.95	0.54	0.95	0.95	0.54	0.95	0.54	0.95	0.95	0.95	0.54	0.95	0.54	0.95	0.95	0.95	0.95	0.95	0.95	0.95
29	0.95	0.95	0.76	0.33	0.76	0.76	0.76	0.95	0.33	0.76	0.76	0.95	0.54	0.95	0.76	0.76	0.95	0.54	0.95	0.54	0.95	0.76	0.76	0.95	0.54	0.76	0.95	0.54	0.95	0.54	0.76	0.76	0.95	0.54	0.95	0.54	0.33	0.76	0.33	0.76	0.76	0.76
30	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.54	0.76	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.76	0.54	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.76	0.76	0.76
31	0.95	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.95	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
32	0.95	0.95	0.76	0.76	0.76	0.54	0.76	0.95	0.76	0.76	0.76	0.95	0.54	0.95	0.76	0.76	0.95	0.54	0.95	0.54	0.95	0.54	0.76	0.95	0.54	0.76	0.95	0.54	0.95	0.54	0.76	0.76	0.95	0.54	0.95	0.54	0.76	0.76	0.76	0.76	0.54	0.76
33	0.54	0.54	0.33	0.33	0.33	0.76	0.33	0.54	0.33	0.33	0.33	0.54	0.54	0.54	0.33	0.33	0.54	0.54	0.54	0.54	0.54	0.76	0.33	0.54	0.54	0.33	0.54	0.54	0.54	0.54	0.33	0.33	0.54	0.54	0.54	0.54	0.33	0.33	0.33	0.33	0.76	0.33
34	0.54	0.54	0.54	0.54	0.54	0.95	0.54	0.54	0.54	0.54	0.54	0.54	0.33	0.54	0.54	0.54	0.54	0.33	0.54	0.33	0.54	0.95	0.54	0.54	0.33	0.54	0.54	0.33	0.54	0.33	0.54	0.54	0.54	0.33	0.54	0.33	0.54	0.54	0.54	0.54	0.95	0.54
35	0.95	0.95	0.76	0.76	0.76	0.54	0.76	0.95	0.76	0.76	0.76	0.95	0.54	0.95	0.76	0.76	0.95	0.54	0.95	0.54	0.95	0.54	0.76	0.95	0.54	0.76	0.95	0.54	0.95	0.54	0.76	0.76	0.95	0.54	0.95	0.54	0.76	0.76	0.76	0.76	0.54	0.76
36	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
37	0.54	0.54	0.76	0.54	0.76	0.54	0.76	0.54	0.54	0.76	0.76	0.54	0.95	0.95	0.76	0.76	0.54	0.95	0.54	0.95	0.54	0.95	0.76	0.54	0.95	0.76	0.54	0.95	0.54	0.95	0.76	0.76	0.54	0.95	0.54	0.95	0.54	0.76	0.54	0.76	0.54	0.76
38	0.54	0.54	0.95	0.54	0.95	0.76	0.76	0.54	0.54	0.76	0.76	0.54	0.95	0.54	0.76	0.76	0.54	0.95	0.54	0.95	0.54	0.76	0.76	0.54	0.95	0.95	0.54	0.95	0.54	0.95	0.76	0.76	0.54	0.95	0.54	0.95	0.54	0.95	0.54	0.95	0.76	0.76
39	0.76	0.95	0.76	0.76	0.76	0.76	0.76	0.95	0.76	0.76	0.76	0.95	0.54	0.95	0.76	0.76	0.95	0.54	0.95	0.54	0.95	0.76	0.76	0.95	0.54	0.76	0.95	0.54	0.95	0.54	0.76	0.76	0.95	0.54	0.95	0.54	0.76	0.76	0.76	0.76	0.76	0.76
40	0.54	0.76	0.76	0.76	0.76	0.95	0.76	0.76	0.76	0.76	0.76	0.76	0.54	0.76	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.54	0.76	0.76	0.54	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.54	0.76	0.54	0.76	0.76	0.76	0.76	0.95	0.76

Table C.36: Cronbach alpha using ANOVA method

Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
Row 1	31	24.8	0.8	0.01522
Row 2	31	23.86	0.769677	0.028863
Row 3	31	25.24	0.814194	0.010612
Row 4	31	20.92	0.674839	0.011866
Row 5	31	23.91	0.77129	0.047052
Row 6	31	23.75	0.766129	0.001165
Row 7	31	25.02	0.807097	0.012968
Row 8	31	19.38	0.625161	0.011866
Row 9	31	22.75	0.733871	0.018218
Row 10	31	21.14	0.681935	0.011449
Row 11	31	24.55	0.791935	0.020249
Row 12	31	21.28	0.686452	0.037097
Row 13	31	23.56	0.76	2.04E-31
Row 14	31	21.36	0.689032	0.010929
Row 15	31	21.52	0.694194	0.015678
Row 16	31	25.08	0.809032	0.007142
Row 17	31	17.7	0.570968	0.030129
Row 18	31	18.94	0.610968	0.010929
Row 19	31	25.21	0.813226	0.013536
Row 20	31	17.56	0.566452	0.010484
Row 21	31	23.04	0.743226	0.029489
Row 22	31	25.65	0.827419	0.00854
Row 23	31	22.66	0.730968	0.026502
Row 24	31	22.7	0.732258	0.011531
Row 25	31	22.29	0.719032	0.052962
Row 26	31	24.84	0.80129	0.030398
Row 27	31	23.12	0.745806	0.003018
Row 28	31	25.35	0.817742	0.037958
Row 29	31	22.84	0.736774	0.036709
Row 30	31	21.8	0.703226	0.009576
Row 31	31	23.75	0.766129	0.001165
Row 32	31	23.26	0.750323	0.02807
Row 33	31	14.87	0.479677	0.015637
Row 34	31	15.88	0.512258	0.022171
Row 35	31	23.26	0.750323	0.02807
Row 36	31	23.56	0.76	2.04E-31
Row 37	31	22.82	0.736129	0.030805
Row 38	31	23.01	0.742258	0.032271
Row 39	31	23.7	0.764516	0.024919
Row 40	31	21.77	0.702258	0.012278
Column 1	40	30.48	0.762	0.023514
Column 2	40	27.79	0.69475	0.028969
Column 3	40	30.45	0.76125	0.025683
Column 4	40	29.13	0.72825	0.02043
Column 5	40	29.13	0.72825	0.02043
Column 6	40	30.26	0.7565	0.024746
Column 7	40	27.79	0.69475	0.028969
Column 8	40	30.26	0.7565	0.024746
Column 9	40	27.79	0.69475	0.028969
Column 10	40	30.26	0.7565	0.024746
Column 11	40	28.89	0.72225	0.025669
Column 12	40	29.13	0.72825	0.02043
Column 13	40	30.26	0.7565	0.024746
Column 14	40	27.79	0.69475	0.028969
Column 15	40	28.26	0.7065	0.025752
Column 16	40	30.26	0.7565	0.024746
Column 17	40	27.79	0.69475	0.028969
Column 18	40	30.26	0.7565	0.024746
Column 19	40	27.79	0.69475	0.028969
Column 20	40	29.13	0.72825	0.02043
Column 21	40	29.13	0.72825	0.02043
Column 22	40	30.26	0.7565	0.024746
Column 23	40	27.79	0.69475	0.028969
Column 24	40	30.26	0.7565	0.024746
Column 25	40	27.79	0.69475	0.028969
Column 26	40	27.82	0.6955	0.026902
Column 27	40	28.26	0.7065	0.025752
Column 28	40	27.82	0.6955	0.026902
Column 29	40	28.26	0.7065	0.025752
Column 30	40	28.69	0.71725	0.022072
Column 31	40	28.72	0.718	0.01997

ANOVA

Source of Varia	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	8.221966	39	0.21082	11.11482	2.18E-56	1.409772
Columns	0.833767	30	0.027792	1.46526	0.051123	1.468925
Error	22.1919	1170	0.018967			
Total	31.24764	1239				

Alpha= **0.910**

Table C.37: Cronbach alpha using ANOVA method for Electricity consumption

Electercity consumption						
Q	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
1	1.0	2.0	2.0	3.0	2.0	3.0
2	2.0	3.0	2.0	3.0	3.0	2.0
3	3.0	2.0	3.0	2.0	3.0	3.0
4	1.0	4.0	3.0	5.0	6.0	2.0
5	2.0	3.0	3.0	2.0	3.0	2.0
6	1.0	3.0	2.0	3.0	1.0	1.0
7	2.0	3.0	3.0	4.0	2.0	3.0
8	1.0	2.0	3.0	2.0	2.0	2.0
9	1.0	3.0	2.0	3.0	4.0	3.0
10	1.0	2.0	2.0	3.0	3.0	1.0
11	1.0	2.0	1.0	2.0	3.0	2.0
12	2.0	3.0	3.0	2.0	3.0	2.0
13	2.0	2.0	3.0	3.0	3.0	3.0
14	2.0	3.0	2.0	3.0	3.0	2.0
15	2.0	2.0	3.0	3.0	3.0	3.0
16	1.0	2.0	2.0	3.0	3.0	2.0
17	2.0	2.0	3.0	3.0	4.0	2.0
18	1.0	1.0	3.0	3.0	4.0	2.0
19	2.0	2.0	3.0	3.0	4.0	2.0
20	2.0	3.0	4.0	4.0	5.0	3.0
21	2.0	2.0	3.0	3.0	4.0	3.0
22	1.0	2.0	2.0	3.0	4.0	2.0
23	1.0	3.0	2.0	1.0	3.0	1.0
24	1.0	2.0	1.0	1.0	1.0	2.0
25	1.0	2.0	1.0	1.0	1.0	1.0
26	2.0	8.0	7.0	4.0	8.0	3.0
27	1.0	2.0	1.0	1.0	4.0	1.0
28	1.0	2.0	1.0	1.0	1.0	1.0

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Row 1	6	13	2.16666667	0.56666667		
Row 2	6	15	2.5	0.3		
Row 3	6	16	2.66666667	0.26666667		
Row 4	6	21	3.5	3.5		
Row 5	6	15	2.5	0.3		
Row 6	6	11	1.83333333	0.96666667		
Row 7	6	17	2.83333333	0.56666667		
Row 8	6	12	2	0.4		
Row 9	6	16	2.66666667	1.06666667		
Row 10	6	12	2	0.8		
Row 11	6	11	1.83333333	0.56666667		
Row 12	6	15	2.5	0.3		
Row 13	6	16	2.66666667	0.26666667		
Row 14	6	15	2.5	0.3		
Row 15	6	16	2.66666667	0.26666667		
Row 16	6	13	2.16666667	0.56666667		
Row 17	6	16	2.66666667	0.66666667		
Row 18	6	14	2.33333333	1.46666667		
Row 19	6	16	2.66666667	0.66666667		
Row 20	6	21	3.5	1.1		
Row 21	6	17	2.83333333	0.56666667		
Row 22	6	14	2.33333333	1.06666667		
Row 23	6	11	1.83333333	0.96666667		
Row 24	6	8	1.33333333	0.26666667		
Row 25	6	7	1.16666667	0.16666667		
Row 26	6	32	5.33333333	7.06666667		
Row 27	6	10	1.66666667	1.46666667		
Row 28	6	7	1.16666667	0.16666667		
Column 1	28	42	1.5	0.33333333		
Column 2	28	72	2.57142857	1.51322751		
Column 3	28	70	2.5	1.44444444		
Column 4	28	74	2.64285714	1.05291005		
Column 5	28	90	3.21428571	2.32275132		
Column 6	28	59	2.10714286	0.54365079		
ANOVA						
rce of Variat	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	107.827381	27	3.9936067	6.20759372	2.2035E-13	1.56857721
Columns	46.3154762	5	9.26309524	14.3983963	2.7079E-11	2.28130468
Error	86.8511905	135	0.64334215			
Total	240.994048	167				
		Alpha=	**0.83890698**			

Table C.38: Cronbach alpha using ANOVA method for Carbon emission

Carbon emission						
Q	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
1	1.0	2.0	2.0	3.0	1.0	2.0
2	1.0	2.0	3.0	3.0	2.0	2.0
3	1.0	3.0	4.0	3.0	3.0	3.0
4	1.0	3.0	4.0	4.0	2.0	2.0
5	1.0	2.0	2.0	3.0	1.0	2.0
6	2.0	2.0	3.0	3.0	2.0	2.0
7	2.0	3.0	3.0	3.0	2.0	4.0
8	1.0	3.0	3.0	2.0	1.0	2.0
9	1.0	3.0	2.0	3.0	4.0	2.0
10	1.0	2.0	2.0	2.0	3.0	2.0
11	1.0	2.0	1.0	3.0	3.0	2.0
12	1.0	3.0	4.0	3.0	1.0	2.0
13	1.0	2.0	4.0	3.0	4.0	3.0
14	1.0	2.0	3.0	2.0	3.0	2.0
15	1.0	2.0	3.0	3.0	4.0	3.0
16	2.0	3.0	4.0	3.0	2.0	2.0
17	2.0	3.0	4.0	4.0	5.0	3.0
18	1.0	2.0	3.0	4.0	4.0	2.0
19	2.0	3.0	3.0	3.0	4.0	2.0
20	2.0	2.0	3.0	3.0	2.0	2.0
21	1.0	3.0	2.0	3.0	4.0	2.0
22	1.0	3.0	3.0	2.0	3.0	1.0
23	1.0	2.0	3.0	2.0	3.0	1.0
24	1.0	2.0	1.0	1.0	1.0	1.0
25	1.0	2.0	1.0	1.0	1.0	1.0
26	1.0	7.0	3.0	2.0	1.0	3.0
27	1.0	3.0	2.0	1.0	4.0	2.0
28	1.0	2.0	1.0	1.0	3.0	1.0

Anova: Two-Factor Without Replication						
SUMMARY	*Count*	*Sum*	*Average*	*Variance*		
Row 1	6	11	1.83333333	0.56666667		
Row 2	6	13	2.16666667	0.56666667		
Row 3	6	17	2.83333333	0.96666667		
Row 4	6	16	2.66666667	1.46666667		
Row 5	6	11	1.83333333	0.56666667		
Row 6	6	14	2.33333333	0.26666667		
Row 7	6	17	2.83333333	0.56666667		
Row 8	6	12	2	0.8		
Row 9	6	15	2.5	1.1		
Row 10	6	12	2	0.4		
Row 11	6	12	2	0.8		
Row 12	6	14	2.33333333	1.46666667		
Row 13	6	17	2.83333333	1.36666667		
Row 14	6	13	2.16666667	0.56666667		
Row 15	6	16	2.66666667	1.06666667		
Row 16	6	16	2.66666667	0.66666667		
Row 17	6	21	3.5	1.1		
Row 18	6	16	2.66666667	1.46666667		
Row 19	6	17	2.83333333	0.56666667		
Row 20	6	14	2.33333333	0.26666667		
Row 21	6	15	2.5	1.1		
Row 22	6	13	2.16666667	0.96666667		
Row 23	6	12	2	0.8		
Row 24	6	7	1.16666667	0.16666667		
Row 25	6	7	1.16666667	0.16666667		
Row 26	6	17	2.83333333	4.96666667		
Row 27	6	13	2.16666667	1.36666667		
Row 28	6	9	1.5	0.7		
Column 1	28	34	1.21428571	0.17460317		
Column 2	28	73	2.60714286	0.98809524		
Column 3	28	76	2.71428571	0.95238095		
Column 4	28	73	2.60714286	0.76587302		
Column 5	28	73	2.60714286	1.50661376		
Column 6	28	58	2.07142857	0.51322751		
ANOVA						
rce of Variati	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	45.3511905	27	1.67967372	2.60728218	0.00016055	1.56857721
Columns	47.1964286	5	9.43928571	14.6521799	1.8221E-11	2.28130468
Error	86.9702381	135	0.64422399			
Total	179.517857	167				
		Alpha=	**0.61645885**			

Table C.39: Weight variation sensitivity analysis

Factors	**WGj**										**Achieved Score (SC)**
F1	0.23	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	9.00
F2	0.09	0.088	0.092	0.09	0.09	0.09	0.09	0.09	0.09	0.09	11.00
F3	0.14	0.14	0.14	0.15	0.14	0.14	0.14	0.14	0.14	0.14	7.00
F4	0.12	0.12	0.12	0.12	0.13	0.12	0.12	0.12	0.12	0.12	60.00
F5	0.02	0.02	0.02	0.02	0.020	0.021	0.02	0.02	0.02	0.02	6.00
F6	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.11	0.11	8.00
F7	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.12	0.12	7.00
F8	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.030	0.032	0.03	21.00
F9	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.040	0.042	10.00

Table C.40: Weight variation with respect to achieved score:

Weight Variation	**Achieved Score (SC)**	**SC * weight**
0.243	9.00	2.19
0.092	11.00	1.02
0.147	7.00	1.03
0.126	60.00	7.56
0.021	6.00	0.13
0.116	8.00	0.92
0.126	7.00	0.88
0.032	21.00	0.66
0.042	10.00	0.42

APPENDIX D: ENERGY CONSUMPTION FOR GN & MP

Table D-1: Energy Consumption for GN (2009-2019)

Month	**Electrical Consommation (kWh) (GN)**	**Consumption per are(BTU/f2)**	**Gas Consumption (m^3)**	**Cost GN**
May-09	193066.8	4032.9	13010.6	$ 18,921.43
June-09	158703.0	3315.1	4364.7	$ 15,352.11
July-09	159746.2	3336.9	0.0	$ 15,363.91
August-09	154640.4	3230.2	0.0	$ 15,181.08
September-09	175954.6	3675.4	9101.3	$ 16,259.26
October-09	199576.5	4168.9	25235.1	$ 18,456.57
November-09	208662.1	4358.6	34158.1	$ 19,021.00
December-09	244812.9	5113.8	50792.2	$ 21,068.35
January-10	253325.0	5291.6	60762.0	$ 21,825.36
February-10	219466.7	4584.3	47629.0	$ 18,708.76
March-10	208613.3	4357.6	39672.9	$ 20,051.51
April-10	172899.3	3611.6	28877.9	$ 15,278.59
May-10	156124.1	3261.2	12251.1	$ 15,181.68
June-10	154246.6	3222.0	2392.2	$ 15,298.73
July-10	155888.7	3256.3	882.9	$ 14,320.31
August-10	155730.5	3253.0	1155.6	$ 14,516.40
September-10	163677.8	3419.0	10092.0	$ 15,994.29
October-10	183352.9	3830.0	31360.7	$ 16,366.48
November-10	205489.7	4292.4	48838.1	$ 18,202.52
December-10	240396.1	5021.5	68692.5	$ 19,956.05
January-11	271800.0	5677.5	77596.3	$ 21,339.79
February-11	231857.1	4843.1	68127.1	$ 18,316.41
March-11	237346.0	4957.8	61189.5	$ 19,281.02
April-11	189111.1	3950.2	39694.1	$ 16,838.28
May-11	162025.0	3384.5	21224.2	$ 14,970.06
June-11	156135.0	3261.4	6035.3	$ 15,030.01
July-11	158681.4	3314.6	928.7	$ 14,811.98
August-11	158358.6	3307.9	1674.6	$ 14,918.85
September-11	170181.8	3554.8	7999.0	$ 15,701.68
October-11	202868.2	4237.6	24380.8	$ 18,460.64
November-11	203350.0	4247.7	39948.3	$ 17,614.12
December-11	227163.6	4745.1	63161.0	$ 19,335.41
January-12	246365.8	5146.2	74165.8	$ 19,625.91
February-12	223527.7	4669.2	65009.0	$ 17,889.32
March-12	210857.1	4404.5	53248.1	$ 17,677.58
April-12	182369.6	3809.4	35504.0	$ 16,681.21
May-12	158816.1	3317.4	18307.7	$ 15,607.17
June-12	155658.6	3251.5	2237.9	$ 14,975.31
July-12	158441.4	3309.6	769.0	$ 14,803.05
August-12	162171.4	3387.5	1015.6	$ 14,581.48
September-12	164365.7	3433.4	10365.4	$ 14,762.44
October-12	176379.0	3684.3	28642.7	$ 15,278.24
November-12	200408.0	4186.2	43339.0	$ 17,015.08
December-12	229621.3	4796.4	61369.4	$ 19,617.24

January-13	253709.1	5299.6	72603.4	$ 21,385.29
February-13	231127.3	4827.9	63933.5	$ 18,532.64
March-13	231468.2	4835.0	55304.0	$ 19,159.88
April-13	174169.4	3638.1	33251.0	$ 14,906.72
May-13	152980.6	3195.5	8018.4	$ 13,793.36
June-13	133600.0	2790.7	840.8	$ 12,602.67
July-13	137942.9	2881.4	809.9	$ 13,017.06
August-13	142872.5	2984.4	1085.2	$ 13,271.54
September-13	143584.6	2999.3	1546.0	$ 13,118.11
October-13	148800.0	3108.2	16533.7	$ 13,577.54
November-13	169411.8	3538.8	40826.4	$ 14,451.40
December-13	180661.0	3773.7	68973.3	$ 15,222.33
January-14	193698.7	4046.1	86902.8	$ 15,465.70
February-14	178076.2	3719.7	63279.3	$ 13,705.09
March-14	197219.0	4119.6	39729.4	$ 15,132.65
April-14	170160.9	3554.4	36893.5	$ 13,465.16
May-14	146565.5	3061.5	17635.8	$ 11,632.35
June-14	148355.5	3098.9	1627.7	$ 11,640.65
July-14	166897.6	3486.2	1734.3	$ 13,617.29
August-14	210967.6	4406.8	2952.9	$ 17,837.94
September-14	259986.2	5430.7	5072.0	$ 20,694.04
October-14	296400.0	6191.4	29062.5	$ 23,599.81
November-14	324000.0	6767.9	51262.5	$ 24,505.28
December-14	313305.9	6544.5	67124.4	$ 24,801.93
January-15	346156.2	7230.7	83220.2	$ 26,124.18
February-15	297931.0	6223.3	82822.0	$ 22,889.09
March-15	309030.4	6455.2	75037.5	$ 24,136.86
April-15	269276.5	5624.8	40800.4	$ 21,994.95
May-15	195042.9	4074.2	9206.7	$ 17,199.62
June-15	168786.6	3525.7	2860.7	$ 15,346.74
July-15	183670.6	3836.6	2898.4	$ 16,376.68
August-15	189251.6	3953.2	3170.0	$ 16,720.77
September-15	225477.0	4709.9	7837.2	$ 18,894.93
October-15	257185.7	5372.2	31026.9	$ 21,033.25
November-15	250405.7	5230.6	51386.5	$ 21,077.82
December-15	267840.0	5594.8	62862.8	$ 22,365.85

January-16	296125.7	6185.6	71635.2	$ 23,808.08
February-16	284831.5	5949.7	70413.4	$ 22,972.70
March-16	295737.9	6177.5	66354.4	$ 23,924.40
April-16	259944.8	5429.9	45659.3	$ 21,703.81
May-16	183818.2	3839.7	18832.8	$ 16,461.36
June-16	162857.7	3401.9	4399.7	$ 14,850.03
July-16	175024.1	3656.0	2771.8	$ 15,726.94
August-16	193500.0	4041.9	3443.8	$ 17,357.54
September-16	212400.0	4436.7	13380.2	$ 18,423.78
October-16	263223.5	5498.3	35525.3	$ 21,990.91
November-16	273176.5	5706.2	57168.8	$ 22,652.97
December-16	269257.1	5624.4	73135.7	$ 23,050.85
January-17	293361.0	6127.9	77160.3	$ 24,114.42
February-17	271039.0	5661.6	64220.0	$ 21,940.50
March-17	297428.6	6212.8	67220.9	$ 24,423.75
April-17	241714.3	5049.0	51646.1	$ 21,430.16
May-17	223200.0	4662.3	20154.7	$ 19,545.66
June-17	188576.5	3939.1	4854.3	$ 16,699.08
July-17	192746.6	4026.2	3567.6	$ 17,129.32
August-17	201594.6	4211.0	4327.3	$ 18,183.19
September-17	204625.2	4274.3	5780.9	$ 18,721.19
October-17	248777.1	5196.6	21498.7	$ 21,678.56
November-17	295538.8	6173.4	48123.5	$ 25,464.08
December-17	332577.5	6947.0	73947.6	$ 29,394.19
January-18	385463.6	8051.8	82634.8	$ 32,356.64
February-18	383100.0	8002.4	67282.9	$ 30,243.09
March-18	400800.0	8372.1	64050.0	$ 31,941.78
April-18	314120.0	6561.5	44860.8	$ 27,316.60
May-18	220845.2	4613.1	18333.7	$ 22,085.22
June-18	184896.3	3862.2	9502.0	$ 18,334.89
July-18	199065.7	4158.2	3569.7	$ 19,253.38
August-18	210072.7	4388.1	3656.7	$ 19,884.88
September-18	215200.0	4495.2	13428.5	$ 19,801.79
October-18	250776.5	5238.3	46405.5	$ 21,760.26
November-18	266779.1	5572.6	69452.4	$ 22,268.82
December-18	271979.9	5681.3	68892.9	$ 23,174.74
January-19	278129.0	5809.7	76696.9	$ 23,617.32
February-19	271592.6	5673.2	73927.8	$ 22,261.59
March-19	292639.6	6112.8	68133.5	$ 24,587.65
April-19	257463.2	5378.0	47254.8	$ 22,335.26
May-19	212820.6	4445.5	25080.8	$ 18,824.03
June-19	96619.4	2018.2	7570.9	$ 8,528.03

Table D-2: Energy Consumption for MP (2009-2019)

Month	Electrical Consommation (kWh)	Consumption per area (BTU/ft2)	Gas Consumption (m^3)	Cost $
May-09	123562.8	6216.8	8326.8	$ 12,109.72
June-09	101569.9	5110.3	2793.4	$ 9,825.35
July-09	102237.6	5143.8	0.0	$ 9,832.90
August-09	98969.9	4979.4	0.0	$ 9,715.89
September-09	112610.9	5665.8	5824.8	$ 10,405.93
October-09	127728.9	6426.4	16150.5	$ 11,812.20
November-09	133543.7	6718.9	21861.2	$ 12,173.44
December-09	156680.3	7883.0	32507.0	$ 13,483.74
January-10	162128.0	8157.1	38887.7	$ 13,968.23
February-10	140458.7	7066.9	30482.6	$ 11,973.61
March-10	133512.5	6717.4	25390.6	$ 12,832.97
April-10	110655.6	5567.4	18481.8	$ 9,778.30
May-10	99919.4	5027.2	7840.7	$ 9,716.28
June-10	98717.8	4966.8	1531.0	$ 9,791.19
July-10	99768.8	5019.6	565.1	$ 9,165.00
August-10	99667.5	5014.5	739.6	$ 9,290.50
September-10	104753.8	5270.4	6458.8	$ 10,236.35
October-10	117345.9	5904.0	20070.9	$ 10,474.55
November-10	131513.4	6616.8	31256.4	$ 11,649.61
December-10	153853.5	7740.8	43963.2	$ 12,771.87
January-11	173952.0	8752.0	49661.7	$ 13,657.47
February-11	148388.6	7465.8	43601.3	$ 11,722.50
March-11	151901.5	7642.6	39161.3	$ 12,339.85
April-11	121031.1	6089.4	25404.2	$ 10,776.50
May-11	103696.0	5217.2	13583.5	$ 9,580.84
June-11	99926.4	5027.6	3862.6	$ 9,619.21
July-11	101556.1	5109.6	594.4	$ 9,479.67
August-11	101349.5	5099.2	1071.7	$ 9,548.06
September-11	108916.4	5479.9	5119.4	$ 10,049.08
October-11	129835.6	6532.4	15603.7	$ 11,814.81
November-11	130144.0	6547.9	25566.9	$ 11,273.04
December-11	145384.7	7314.7	40423.1	$ 12,374.66
January-12	157674.1	7933.0	47466.1	$ 12,560.58
February-12	143057.7	7197.6	41605.7	$ 11,449.16
March-12	134948.6	6789.6	34078.8	$ 11,313.65
April-12	116716.5	5872.3	22722.5	$ 10,675.97
May-12	101642.3	5113.9	11716.9	$ 9,988.59
June-12	99621.5	5012.2	1432.3	$ 9,584.20
July-12	101402.5	5101.8	492.2	$ 9,473.95
August-12	103789.7	5221.9	650.0	$ 9,332.15
September-12	105194.1	5292.6	6633.9	$ 9,447.96
October-12	112882.6	5679.4	18331.3	$ 9,778.07
November-12	128261.1	6453.2	27737.0	$ 10,889.65
December-12	146957.6	7393.8	39276.4	$ 12,555.03

January-13	162373.8	8169.5	46466.2	$ 13,686.59
February-13	147921.5	7442.3	40917.4	$ 11,860.89
March-13	148139.6	7453.3	35394.5	$ 12,262.32
April-13	111468.4	5608.3	21280.7	$ 9,540.30
May-13	97907.6	4926.0	5131.7	$ 8,827.75
June-13	85504.0	4301.9	538.1	$ 8,065.71
July-13	88283.4	4441.8	518.3	$ 8,330.92
August-13	91438.4	4600.5	694.5	$ 8,493.79
September-13	91894.2	4623.4	989.4	$ 8,395.59
October-13	95232.0	4791.4	10581.5	$ 8,689.63
November-13	108423.5	5455.1	26128.9	$ 9,248.90
December-13	115623.0	5817.3	44142.9	$ 9,742.29
January-14	123967.2	6237.1	55617.8	$ 9,898.05
February-14	113968.8	5734.1	40498.8	$ 8,771.26
March-14	126220.2	6350.5	25426.8	$ 9,684.90
April-14	108903.0	5479.2	23611.9	$ 8,617.70
May-14	93801.9	4719.4	11286.9	$ 7,444.70
June-14	94947.5	4777.1	1041.8	$ 7,450.02
July-14	106814.5	5374.1	1110.0	$ 8,715.07
August-14	135019.3	6793.2	1889.8	$ 11,416.28
September-14	166391.2	8371.6	3246.1	$ 13,244.19
October-14	189696.0	9544.1	18600.0	$ 15,103.88
November-14	207360.0	10432.8	32808.0	$ 15,683.38
December-14	200515.8	10088.5	42959.6	$ 15,873.24
January-15	221540.0	11146.3	53260.9	$ 16,719.48
February-15	190675.9	9593.4	53006.1	$ 14,649.02
March-15	197779.5	9950.8	48024.0	$ 15,447.59
April-15	172336.9	8670.7	26112.3	$ 14,076.77
May-15	124827.4	6280.4	5892.3	$ 11,007.76
June-15	108023.4	5434.9	1830.8	$ 9,821.91
July-15	117549.2	5914.2	1855.0	$ 10,481.08
August-15	121121.0	6093.9	2028.8	$ 10,701.29
September-15	144305.3	7260.4	5015.8	$ 12,092.76
October-15	164598.9	8281.4	19857.2	$ 13,461.28
November-15	160259.7	8063.1	32887.4	$ 13,489.80
December-15	171417.6	8624.5	40232.2	$ 14,314.14

January-16	189520.5	9535.3	45846.5	$ 15,237.17
February-16	182292.2	9171.6	45064.6	$ 14,702.53
March-16	189272.3	9522.8	42466.8	$ 15,311.62
April-16	166364.7	8370.3	29221.9	$ 13,890.44
May-16	117643.6	5919.0	12053.0	$ 10,535.27
June-16	104228.9	5244.0	2815.8	$ 9,504.02
July-16	112015.4	5635.8	1773.9	$ 10,065.24
August-16	123840.0	6230.7	2204.0	$ 11,108.83
September-16	135936.0	6839.3	8563.4	$ 11,791.22
October-16	168463.1	8475.8	22736.2	$ 14,074.18
November-16	174832.9	8796.3	36588.1	$ 14,497.90
December-16	172324.6	8670.1	46806.8	$ 14,752.54
January-17	187751.1	9446.3	49382.6	$ 15,433.23
February-17	173464.9	8727.5	41100.8	$ 14,041.92
March-17	190354.3	9577.2	43021.4	$ 15,631.20
April-17	154697.1	7783.2	33053.5	$ 13,715.30
May-17	142848.0	7187.1	12899.0	$ 12,509.22
June-17	120688.9	6072.2	3106.8	$ 10,687.41
July-17	123357.8	6206.5	2283.2	$ 10,962.76
August-17	129020.5	6491.4	2769.5	$ 11,637.24
September-17	130960.1	6589.0	3699.8	$ 11,981.56
October-17	159217.4	8010.7	13759.1	$ 13,874.28
November-17	189144.8	9516.4	30799.1	$ 16,297.01
December-17	212849.6	10709.0	47326.5	$ 18,812.28
January-18	246696.7	12412.0	52886.3	$ 20,708.25
February-18	245184.0	12335.9	43061.0	$ 19,355.58
March-18	256512.0	12905.8	40992.0	$ 20,442.74
April-18	201036.8	10114.7	28710.9	$ 17,482.62
May-18	141340.9	7111.2	11733.5	$ 14,134.54
June-18	118333.6	5953.7	6081.3	$ 11,734.33
July-18	127402.1	6409.9	2284.6	$ 12,322.16
August-18	134446.5	6764.4	2340.3	$ 12,726.32
September-18	137728.0	6929.5	8594.3	$ 12,673.15
October-18	160496.9	8075.0	29699.5	$ 13,926.57
November-18	170738.6	8590.3	44449.6	$ 14,252.04
December-18	174067.2	8757.8	44091.5	$ 14,831.83
January-19	178002.6	8955.8	49086.0	$ 15,115.08
February-19	173819.3	8745.3	47313.8	$ 14,247.42
March-19	187289.4	9423.0	43605.4	$ 15,736.10
April-19	164776.5	8290.3	30243.1	$ 14,294.57
May-19	136205.2	6852.9	16051.7	$ 12,047.38
June-19	61836.4	3111.2	4845.4	$ 5,457.94

APPENDIX E: PUBLICATIONS

Journals:

1- Al-Sakkaf, A.; Zayed, T. and Bagchi, A. (2019) ,*"A Sustainability Based Framework for Evaluating Heritage Buildings",* International Journal of Optimization and Engineering (IJEOE), Volume 9, Issue 2, Article 5.

2- Al-Sakkaf, A.; Zayed, T.; Bagchi, A. and Mahmoud, S. (2020) "*Development of a sustainability rating tool for heritage buildings: future implications"* Smart and Sustainable Built Environment 2020. (in press)

3- Al-Sakkaf, A.; Zayed, T. and Bagchi, A. (2020) "*Sustainability Assessment Model for Heritage Buildings"* Journal of Building Performance Simulation. (under review)

4- Al-Sakkaf, A.; Zayed, T. and Bagchi, A. (2020) "*Life Cycle Cost of Energy for Heritage Buildings"* Journal of Construction Innovation: Information, Process, Management. (under review)

Conferences:

5- Al-Sakkaf, A.; Zayed, T. and Bagchi, A. and Abdelkader, E. *"Sustainability Rating Tool and Rehabilitation Model for Heritage Buildings"*, CSCE Annual Conference, Laval, Canada, 2019.

6- Al-Sakkaf, A.; Zayed, T. and Bagchi, A. *"A Comprehensive Assessment of Heritage Buildings Areas-Detailed Case Studies"*, the 6th Urban Heritage Forum Conference, Riyadh, Kingdom of Saudi Arabia, April 2019.

7- Al-Sakkaf, A.; Zayed, T. and Bagchi, A. *"A Review of Definition and Classification of Heritage Buildings and Framework for their Evaluation"* The 2nd International Conference on New Horizons in Green Civil Engineering (NHICE-02), Victoria, British Columbia, Canada, April 2020.

8- Al-Sakkaf, A.; Zayed, T. and Bagchi, A. *"Towards a comprehensive sustainable assessment for Heritage Buildings"* ICCSTE'20 - 5th International Conference on Civil, Structural and Transportation Engineering, Niagara Falls, Canada, June 2020.

9- Al-Sakkaf, A.; Zayed, T. and Bagchi, A. *"Synthesis Evaluation for Heritage Buildings",* International Conference On Structural Civil and Architectural Engineering, Montreal, Canada, July 2020.