Sustainability Assessment Framework for Buildings: A User Perspective

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A Thesis
In the Department
of
Building, Civil and Environmental Engineering

Presented in Partial Fulfilment of the Requirements
For the Degree of
Doctor of Philosophy (Building Engineering) at
Concordia University
Montreal, Quebec, Canada

June 2018

CONCORDIA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

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Entitled: Sustainability Assessment Framework for Buildings: A User Perspective

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ABSTRACT

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According to the Intergovernmental Panel on Climate Change, the building sector accounts for 32% of global energy consumption, 19% of energy-related CO_2 emissions and 51% of global electricity consumption. Moreover, numerous studies have highlighted that the operational phase is considered to be the most crucial stage in a building's lifecycle, accounting for 70-90% of a building's overall impact on the environment. However, over the past few decades, practitioners and researchers have worked together to develop frameworks that enhance and evaluate the sustainability of buildings using different measures and technologies. The majority of these frameworks address sustainability from economic and organizational perspectives. However, considerably less work has focused on assessing and enhancing the sustainability of buildings from the user's perspective.

The present research aims to develop a new and comprehensive framework that assists users in assessing and updating sustainability from a user's perspective. The developed methodology consists of four levels: 1) Identify and study the factors that contribute to building sustainability from users'/occupants' perspectives; 2) Develop a user-based framework to assess and enhance the sustainability of existing buildings; 3) Develop a framework to upgrade conventional buildings into sustainable ones, based on the user's perspective; and 4) Develop a User-based Sustainability Assessment and Upgrading Tool (USAUT) to assess and enhance the user's perspective in existing buildings. The research utilized two modeling techniques: Fuzzy Expert Systems and a fuzzy ANP model to determine the overall user perspective scale (OSS) and the weight of each factor and sub-factor. In addition, the Pugh Matrix is utilized and integrated with Genetic Algorithm GA optimization to determine several optimal or near optimal alternatives.

The user's perspective assessment model was implemented with an actual education building case study in Montreal, Canada (the E.V. building at Concordia University). Collecting data such as the dissatisfaction level based on the users' perspective, the weight of each factor, sub-factor and on user's opinions was a crucial step. This was accomplished by utilizing questionnaires and interviews with (100 facility managers (FM) and building experts and 40 users) at Concordia University and its users, while observing the guidelines of Concordia University's ethics protocols.

Based on the information in the FM's and building expert's questionnaires, the OSS differs based on a 5-point Likert scale as trapezoidal fuzzy numbers (TFN) according to each type of building (Industrial, Commercial, Education, and Residential). Within the Education buildings that are represented with the E.V. building as a case study, the research revealed the difference between the user's perspective weights for the main user's perspective factors (Thermal comfort and air quality, Aesthetics, Design and flexibility, and Lighting and acoustics). For example, the highest weights among the main four factors were Thermal comfort with 40% and Aesthetics with 22%. In addition, the E.V. building's users' s opinions revealed that the E.V. building rates a score of 5.7 as a building sustainability BS, which means that the E.V. building was located in the U zone when the researchers compared it with the OSS, and thus required an immediate user's perspective upgrade. The factors that do not meet the user's perspective based on OSS are thermal comfort and lightening and acoustics. To propose options to upgrade these aspects, the users' perspective upgrade model used three different scenarios (Optimistic, Pessimistic and Average). The model illustrated that the optimal scenario is the optimistic scenario with $180000 and 15000 Hr and which improved the BS from 5.7 to 7 out of 10.

The main contribution of the present research can be presented in two main points: 1) it determines the current users' perspective of four types of buildings and highlights the weak areas that require more attention from the users' perspective, and 2) it proposes various rehabilitation alternatives that upgrade the users' perspective in sustainable buildings as a step towards establishing a comprehensive global sustainability assessment framework for buildings from the user's perspective.

Acknowledgement

First of all, I am extremely thankful to ALLAH for all His guidance and blessings that enabled me to accomplish this work. I ask ALLAH to accept this work from me, and to make it sincere and solely for His sake.

I am really thankful to Professor Tarek Zayed as a Co-Supervisor for his help, valuable advises and support throughout my studies in Concordia University. I have learned a lot from him and it was a great honor to work with him.

I am also so grateful to my beloved parents, Mr. Alfalah and Mrs. Alali, for all their unlimited love, support and cooperation throughout my life. Thanks for being the type of parents that they are, I could never achieve this goal without their endless encouragement, advises and help. I ask ALLAH to be as good as them.

TO MY PARENTS:

MR. ALFALAH

AND

MRS. ALALI

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LIST OF NOMENCLATURES AND ABBREVIATIONS

IEQ	Internal Environmental Quality
FM	Facility Management
LEED	Leadership in Energy and Environmental Design
LT	Location and Transportation
SS	Sustainable Site
WE	Water Efficiency
EA	Energy and Atmosphere
MR	Materials and Resources
ID	Innovation in Design
RP	Regional Priority
ANSI	American National Standards Institute
GBP	The Green Building Program
BREEAM	The Building Research Establishment Environmental Assessment Method
DGNB	German Sustainable Building Council
GBCA	Green Building Council system of Australia
UPC	Abu Dhabi Urban Planning Council
L and Q	Represent the Built Environment Load And the Built Environmental Quality, Respectively
BEE	Built Environment Efficiency

M&R	Maintenance and Repair
BMDSS	Building Maintenance Decision Support System
BUS	Building Use Studies
UN	United Nations
SUN	Sustainable United Nations
EIA	The Energy Information Administration
CHP	Combined Heat and Power
PV	Solar Photo-Voltaic
ICAB	Integrated Condition Assessment Model for Buildings
BIM	Building Information Modeling
MCDA	Multi-Criteria Decision Analysis
MAUT	Multi-Attribute Utility Theory
AHP	The Analytic Hierarchy Process
ANP	The Analytic Network Process
FT	Fuzzy Theory
CBR	Case-Based Reasoning
DEA	Data Envelopment Analysis
TOPSIS	The Technique for Order of Preference by Similarity to Ideal Solution
SMART	The Simple Multi-Attribute Rating Technique
GP	Goal Programming
GRA	Grey Relational Analysis
SAW	Simple Additive Weighting
ELECTRE	Elimination and Choice Translating Reality

PROMETHEE	Preference Ranking Organization Method for Enrichment of Evaluations
FST	The Fuzzy Set Theory
FES	The Fuzzy Expert System
FANP	Fuzzy Analytic Network Process
c	Criterion
SC	Sub-Criterion
C'	Represents the Vector of Importance Factor (IF) Of Criteria (C)
SCi	Represents the Vector of Sub-Criteria Weights in Respect to Criteria "I"
N	Represents the Number of Criteria
ni	Represents the Number of Sub-Criteria in Respect to Criteria "I"
fsc	Represents the Fuzzy Membership Function of Sub-Criteria (Sc)
(fsc)i	Represents the Fuzzy Membership Function of Sub-Criteria (Sc) Evaluated by Users "I"
Nusers	Represents the Number of Users Participated in The Evaluation Process
fsc	Represents the Fuzzy Memberships of User Perspective in Respect to Sub-Criterion "Sc"
Wsc	Represents the Weight of Sub-Criterion "Sc" In Respect to Criteria "C"
fc	Represents the Fuzzy Memberships of User Perspective in Respect to Criterion "C"
Nsc	Represents the Number of Sub-Criteria (Sc) That Affect the Criterion "C"
fc	Fc, Represents the Fuzzy Memberships of User Perspective in Respect to Criterion "C"

IFc	Represents the Importance Factor of Criterion “C” In Respect to Building Sustainability
Nc	Represents the Number of Criteria (C) That Affect the Building Sustainability
BS	Represents the Fuzzy Memberships of User Perspective in Respect to Building Sustainability
AI	Represents the Agreement Index with Two Fuzzy Membership Functions
BS	Represents the Fuzzy Membership of Building Score
OSSm	Represents the State M in The Overall Perspective Scale
SLK	Represents the Perspective of Users in Respect to Sustainability at Level “K”
LPSk	Represents the Ultimate List of Possible Solutions for Dissatisfying Criterion “K”
LPSkj	Represents the List of Possible Solutions for Dissatisfying Criterion “K” Generated by Expert “J”
N	Represents the Number of Experts
A (1) and A (2)	Represent Respectively the Alternatives That Was Ranked First and Second in Respect to Q Values
LI	Less Important
EI	Equally Important
MI	More Important
NI	Not Important
EI	Extremely Important
OSS	Overall User Perspective Scale
VU	Very Unsatisfied

U	Unsatisfied
M	Medium
S	Satisfied
VS	Very Satisfied
BS	Building Sustainability
LDC	List of Dissatisfying Criteria
DC	Dissatisfying Criteria
LPS	List of Possible Solutions
LPSjk	That Combines All the Lists of Possible Solutions
j	Expert
k	Dissatisfying Criterion
VOCs	Volatile Organic Compounds

CHAPTER I: INTRODUCTION

I.1. BUILDING SECTOR AND RELATED SUSTAINABLE FACILITY MANAGEMENT

Sustainable facility management (SFM) is a unique process that gives a facility manager the authority to makes structural, architectural and operational changes that will reduce the negative impact of a building on the environment and on its occupants. SFM encompasses several principles, including energy and water efficiency, waste management, ecological design, sustainable materials, users' perspectives, indoor air quality assurance, appropriate landscaping, enhanced quality of life, financial aspects and strategic maintenance. The SFM expands the FM role and how it encompasses and impacts multiple aspects, such as energy and water efficiency, waste avoidance and minimization, ecological conservation, conservation of building materials, users' perspectives, indoor air quality enhancement, appropriate landscaping, enhancement of community life, human resources, security, financial aspects, contracting, strategic maintenance and public relations and media (Fennimore 2014).

SFM aims to minimize the negative environmental impact of the building sector. In 2007, the building sector consumed 40% of global energy and produced 33% of global greenhouse gas emissions (UNEP 2009). In terms of amounts, the building sector emitted 8.6 GTCO2-eq., 0.4 GTCO2- eq. CH4, 0.1 GTCO2- eq. N2O, 1.5 GTCO2- eq. Halocarbons (CFC and HCFC) (IPCC 2007). Moreover, the IPCC (2007) indicated that in 2030, the estimated carbon dioxide emissions will be 15.6 GTCO2- eq., taking into consideration expected economic growth. In addition, the IPCC (2007) indicated the building sector consumes 32% of the global energy produced, including 51% of global electricity production, and emits 19% of the global energy-related CO2 emissions of greenhouse gasses (IPCC 2014). GHG emissions can be classified into carbon-related gasses (e.g. TBE) and non-carbon related gasses (e.g. halocarbons). Carbon-related emissions are a consequence of buildings' energy consumption, whichdepends on fossil fuels for its production. Halocarbons (i.e. CFCs & HCFCs), on the other hand, are emitted from the use of various construction materials, such as paints, adhesives, refrigerants, insulation materials, etc. (UNEP 2009).

UNEP-SKANSKA (2013) gives an example of how energy consumption is used in commercial buildings, showing how space and water heating, ventilation, cooling, and lighting in a commercial building consume the largest amounts of energy, thereby illustrating how focusing on these areas can result in the greatest energy savings. According to UNEP-SKANSA, the largest energy consuming aspects of commercial buildings are space heating with its 32%, cooling at 23% and air ventilation at 15%, indicating where architects and engineers should look for ways to reduce the energy needs of these buildings.

I.1.1 Background of the Facility Management Role in Sustainable Buildings

In the 21st century, FM manage a changing business environment that may be impacted by legislative and market changes (Thornhill et al. 2000). FM is also responsible for developing a workforce that follows a set of practical procedures and policies and that can achieve measurable operational targets (Jensen and Andersen 2010). The IFMA defines FM as a process that encompasses multiple disciplines and integrates people, places, processes and technologies to ensure the functionality of the built environment (IFMA 2007). Other authors have focused more on the organization of FM and its environmental goals.

For example, Barrett (1995) defines FM as an integrated approach to how to maintain, improve and adapt the environment of their facilities. Despite these differences, there is general agreement that the role of FM involves work at the core and support levels of an organization (Noor and Pitt 2009; Kincaid 2004). Moreover, the crucial role of FM involves the planning and implementation of organizational changes. McLennan (2000) consider that the intellectual capital of FM is uniquely useful as a source of strategic and operational value for the development of organizational changes.

Kincaid (2004) demonstrates the usefulness of this range of knowledge and provides an effective overview of the various disciplines involved in FM, from 'unglamorous' tasks (such as cleaning management) to high-value and high-impact tasks (such as planning and budgeting). Figure I.1 shows the FM role across four categories: (1) Management Roles' Strategic Alignment, which includes strategy analysis, strategy briefing, proposing, deciding, approving, planning and budgeting, space and facilities standards, control and measurement, environmental programs, energy programs and departmental management; (2) Management Knowledge, which includes organization theory, resource management theory, change management, risk management, quality management concepts, statistical quality analysis, corporate strategy implementation, decision aide, decision progresses, planning and allocation resources, financial management, and personal skills: communication, self-assurance, and negotiation; (3) Operation Activity, which includes new build, acquisition and disposal, rearrange and refurbish, space configuration, operations, maintenance and repair, cleaning, security and reception, catering, reprographic mail, porterage and landscape; and (4) Facility Knowledge, which include performance measures, space measures and auditee and occupancy coating.

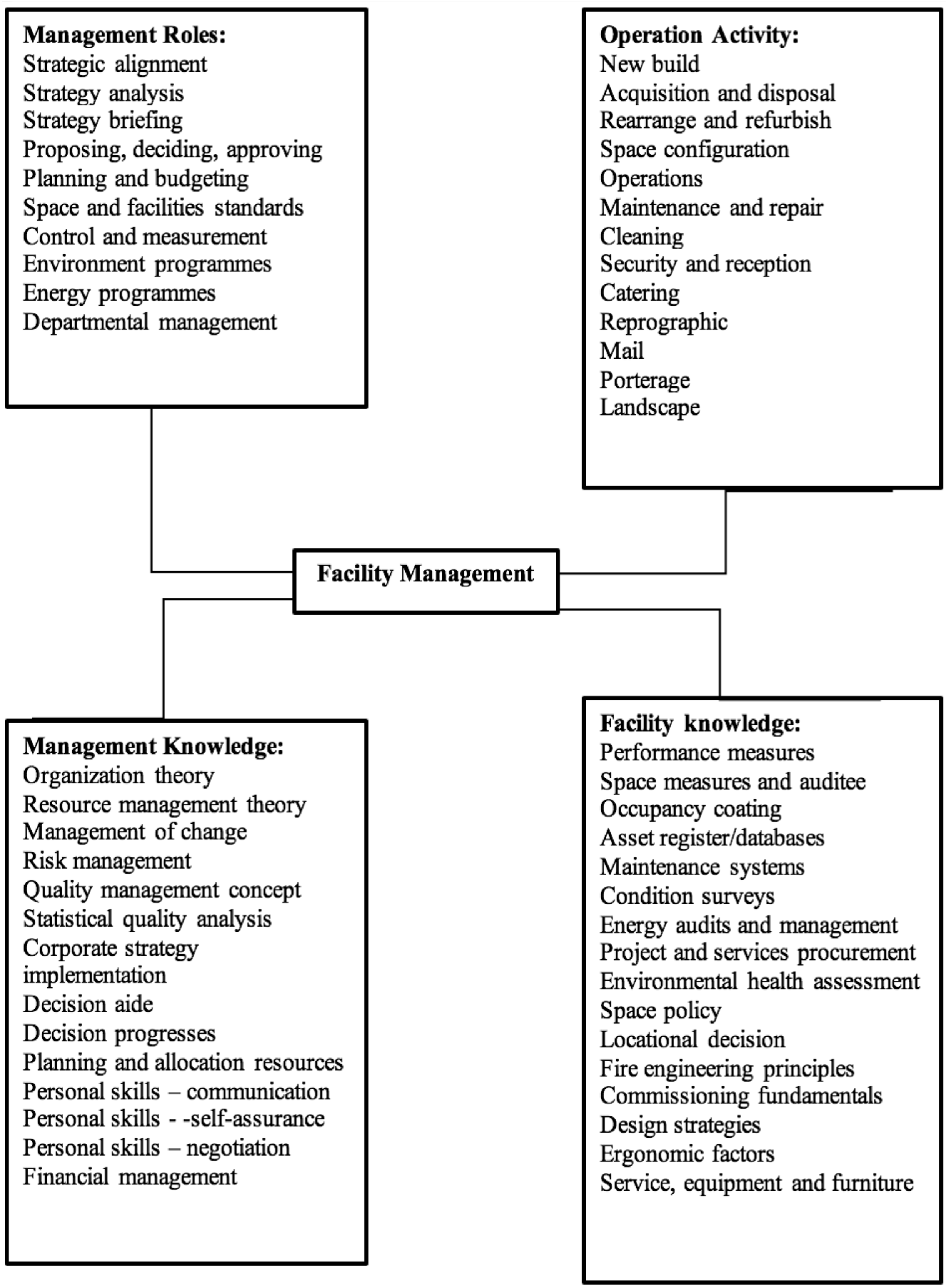


Figure I.1 Knowledge and activities effectively for facility manage. (Kincaid 2004)

I.2. PROBLEM STATEMENT AND RESEARCH MOTIVATION

As stated in the overview, the building sector has a considerable impact on the environment and consequently on human health and human productivity. However, it possesses a high mitigation potential when compared to other sectors. The operational or occupational stages of buildings have the greatest impacts on the environment and on their occupants compared to the other stages. Mitigating the impacts of buildings on the environment and on occupants has led practitioners and researchers to develop frameworks, methodologies and best practices for updating building sustainability.

The majority of research has focused on the evaluation of building sustainability by providing a comprehensive set of criteria and strategies to minimize the cost of energy and reduce GHG emissions (Che-Ani et al. 2010; Waly and Helal 2010; Jensen et al. 2009). These efforts have limitations that hinder their effectiveness and usefulness, including but not limited to: the lack of an optimum selection of users' satisfaction indicators, non-identification of users' needs, non-consideration of the variations of users' needs, ineffective modelling of the complexity associated with users' satisfaction, and unaddressed difficulties associated with the development of weighting schemes and measurement scales.

Assessing and reducing the true impacts of buildings are the primary concern of the sustainable building movement. Over the past few decades, practitioners and researchers have worked together to develop frameworks that enhance and evaluate the sustainability of buildings using different measures and technologies (Edward 2006; Noor and Piee 2009; Vanier 2000). Life cycle assessment is one method used to evaluate buildings' sustainability. The majority of these frameworks address sustainability from the economic and organizational perspectives. However, considerably less work has focused on enhancing the sustainability of buildings from the user's perspective.

Furthermore, the factors that affect the user's perspective in respect to building sustainability are yet to be identified, evaluated, and incorporated into the framework of upgrading conventional buildings into sustainable ones. A significant number of studies have focused on assessing the role of FM in sustainable buildings from different perspectives, including energy efficiency (Wisner et al. 2006; Dixit et al. 2016; Chotipanich and Lertariyanun 2011), GHG emissions (Patrick et al. 2014; Wilkinson and Reed. 2006) and economic performance (Grussing and Marrano 2007; Grussing 2013). Considerably less work has focused on FM in sustainable buildings from users' perspective, and none of these works have considered the building types and their effects on the user satisfaction assessment procedure. Users' needs depend on the type of building being assessed, which means that the FM must evaluate the perspective of users in various aspects, such as Indoor Environmental Quality (IEQ). IEQ includes the environmental aspects that provide occupants with good air quality, at least a minimum amount of daylight and views, pleasant acoustic conditions, and control over lighting and thermal comfort. It also includes the functional aspects of space in terms of accessibility and ratio (i.e. the amount of space in relation to the number of occupants). In a way, these aspects are correlated, but their importance to users vary from one building type (and/or culture) to another.

Therefore, the assessment procedure for understanding the users' perspective in respect to building sustainability should alter dynamically from one building type to another while preserving the key assessment criteria and attributes to maintain consistency.

This research aims to develop a sustainability assessment model for buildings from a user's perspective that: 1) Identifies and studies the factors that contribute to building sustainability from users'/occupants' perspectives; 2) Develops a user-based model to assess and enhance the sustainability of existing buildings; 3) Develops a model to upgrade conventional buildings into sustainable ones, based on the users' perspective, and 4) Develops a User-based Sustainability Assessment and Upgrading Tool (USAUT) to assess and enhance the user's perspective in existing buildings. The developed model identifies and evaluates the factors that affect the perspective of users/occupants in sustainable buildings. Considering these factors, the developed model evaluates the user perspective in various types of sustainable education buildings. It also evaluates the FM of sustainable education buildings from the users' perspective. The problem consists of two sub-problems:1) identification and assessment of the different factors that affect the user's perspective in order to establish a scale for assessing the user perspective in sustainable buildings; and 2) development of a sustainability assessment model for buildings from the users' perspective to update or upgrade the sustainability of existing buildings to maximize the users' appreciation.

I.3. RESEARCH AIM AND OBJECTIVES

The academic objective of this research is to develop a sustainability assessment framework for buildings from the users' perspective. This framework will provide decision-makers with a comprehensive evaluation incorporating the user's perspective in sustainable buildings. In addition, this framework will provide facility managers a guideline for updating the sustainability of buildings and for upgrading a conventional building into a sustainable one, and to do both from the users' perspective. To achieve the primary objectives, the following sub-objectives were developed:

1. Identify and study the factors that contribute to building sustainability from users'/occupants' perspectives;
2. Develop a user-based model to assess and enhance the sustainability of existing buildings;
3. Develop a model to upgrade conventional buildings into sustainable ones, based on the users' perspective.

4. Develop a User-based Sustainability Assessment and Upgrading Tool (USAUT) to assess and enhance the user's perspective in existing buildings.

I.4. RESEARCH METHODOLOGY

This research evaluates the user perspective in four types of sustainable buildings: industrial, commercial, educational, and residential. It also evaluates FM in different types of sustainable buildings from the users' perspective. These evaluations allow the identification and study of the factors that contribute to the satisfaction of the users/occupants of sustainable buildings, help to develop a sustainability assessment model for existing buildings from a user's perspective, and make it possible to update conventional buildings to sustainable ones in a manner that maximizes the users' perspective in respect to FM.

I.4.1. Literature Review

1. An extensive literature review was conducted to examine the existing rating systems used to evaluate building sustainability. In addition, a comparison was performed to identify the various factors that affect users' assessment of sustainable buildings.

2. Some of the more appropriate multi-attribute decision making methods were reviewed, especially Fuzzy ANP and the Pugh Matrix (criteria-based) method. This last method will be utilized to identify the weight of each criterion and factor used in the sustainability assessment process.

3. Various software for physical model development were investigated, e.g. Revit software, as well as other software utilized such as Excel software, and Evolver to evaluate the user's perspective in buildings based on various inputs such as orientation, occupancy schedules, HVAC systems, lighting systems, etc.

4. A number of evolutionary multi-objective optimization algorithms were explored. A Genetic algorithm optimization was implemented as part of the decision-making process for upgrading the users' perspective in sustainable buildings.

I.4.2. Model Development

Three models were integrated together to develop the sustainability assessment model for buildings from the user's perspective. The first is the overall user perspective scale (OSS) that evaluates the overall users' perspective in four types of sustainable buildings (Education, Commercial, Industrial and Residential). The second model is an assessment model of education buildings based on predefined factors and sub-factors, according to their interchanging weights. The third model is an integrated decision-support model optimization that identifies, evaluates and ranks a set of alternatives to update/upgrade the sustainability of education buildings. The decision-support model will assist decision makers in selecting the most effective set of alternatives to maximize the users' perspective in sustainable education buildings under budget and schedule constraints. The step-by-step development procedure of these three models is outlined below:

1.Model development: This phase evaluates the importance level of each criterion and sub-criterion in respect to the user's perspective. Pairwise comparisons for criteria and sub-criteria are generated and used to calculate the weights of each criteria and sub-criteria using the analytic network process (ANP).

2. Assessment of the user's perspective before upgrading the sustainability: This phase evaluates the user perspective level in a sustainable building using the user responses collected on a 5-point Likert scale: very dissatisfied, dissatisfied, medium, satisfied and very satisfied. The collected responses are aggregated using fuzzy set theory and multiplied by the weights and importance levels of the sub-criteria and criteria to calculate the overall perspective of users in the sustainable building being considered. It should be noted that if the overall perspective of users is equal to satisfied or higher, no action is required. Otherwise, phase 3 is initiated to upgrade the sustainability of the building being considered to elevate the overall user perspective level.

3. Upgrading sustainability: The criteria that cause user dissatisfaction are identified; each criterion or sub-criterion that has a perspective level lower than medium will be considered for upgrade. Once these criteria are identified, a set of possible solutions will be identified and the Pugh Matrix (criteria-based) technique employed to evaluate and rank those solutions and select the highest-ranked options. These selected solutions are then implemented to elevate the user perspective in respect to that criterion and its related sub-criteria.

. I.5. THESIS ORGANIZATION

The report contains seven chapters. Chapter I includes the introduction and the related sustainable building FM, problem statement and research motivation, research objectives, research methodology, and report organization. Chapter II contains a comprehensive literature review presented in five main sections as follows: (1) a study of the existing rating systems used for SFM; (2) an assessment of the user's perspective before upgrading sustainability; (3) various research efforts concerning the users' perspective in FM; (4) an overview of multi-attribute decision making to obtain the weights of criteria and factors, and an overview of the Pugh Matrix and the Fuzzy ANP decision-making methods; and (5) a review of some evolutionary optimization algorithms, especially artificial immune system optimization.

Chapter III describes the methodology for the development of a model for the assessment of User Perspective of FM in Sustainable Buildings. It is divided into four main sections as follows: (1) Model Development for each type of sustainable building; (2) Assessment of User perspective before Upgrading sustainability; (3) the Upgrading Sustainability Phase; and (4) the Assessment of User perspective after the Upgrading Sustainability Phase. In addition, it illustrates the Model Development for Genetic Algorithm (GA) optimization method

Chapter IV addresses the procedures followed to select the assessment attributes based on a literature review. Every criterion and its related sub-factor is illustrated, as well as its objective. This chapter also provides a detailed description of the questionnaire employed to gather information related to the importance of each attribute, and in turn, explains how this information is used to estimate their weight. An illustration of the strategies applied to establish a users' perspective assessment scale to measure the degree of the users' perspective performance in sustainable buildings completes this chapter. Chapter V introduces the OSS determination based on a fuzzy expert system. The weight determination procedures are introduced by applying the fuzzy ANP technique. Additionally, this chapter shows the assessment scale and threshold development procedures. The upgrade models are applied on a case study by utilizing Pugh Matrix modelling and Genetic algorithm optimization.

Chapter VI demonstrates the developed automated tool under title the Integrated Users Perspective Assessment and Upgrade Tool (USAUT). It illustrates the basic features of the tool, the graphical user interface and how to navigate through its different windows and buttons related to user's perspective assessment and optimization. Finally, the last chapter, chapter VII, presents the research conclusions, contributions to the body of knowledge and recommendations for future work.

CHAPTER II: LITERATURE REVIEW

II.1 CHAPTER OVERVIEW

The main aim of this chapter is to provide a comprehensive literature review on the importance of user perspective in the design and construction of sustainable buildings. It provides an overview of the most important rating systems worldwide, highlighting the main drawbacks of certain rating systems and how they affect users' perspectives on building sustainability. This chapter also investigates the leading attributes that influence users' perspectives of sustainable buildings. Another important element included is an illustration of one of the decision-making support techniques, the fuzzy ANP technique, with a thorough discussion of the Pugh Matrix technique, an evolutionary, multi-objective optimization technique. The primary sources of the information included in this chapter are journal papers, technical reports, rating-system manuals and guides, textbooks, and relevant websites.

II.2 FACILITY MANAGEMENT AND THE USER PERSPECTIVE IN SUSTAINABLE BUILDINGS

Energy efficiency in buildings has become mandatory and is one of the requirements in many building codes worldwide (e.g., Australia). Such building-code requirements are designed to increase energy efficiency, a standard that is expected to be increased in the future in order to reduce building-related greenhouse gas emissions. Increasing the energy efficiency of buildings in the form of insulation, light fittings, building-management systems (BMS), and micro-generation (e.g., solar panels and wind turbines) leads to measurable and thus quantifiable reductions in operating costs. However, many owners have not yet realized the benefits of sustainability, and thus the adoption of sustainable building practices remains restricted to relatively few industry leaders (Clements-Croome 2006).

Figure II.1 demonstrates how users can gain benefits from sustainable buildings based on research showing that employees working in commercial buildings receive salaries and on-costs that equate to approximately 85% of a typical commercial building. Quantifying the levels of employee productivity, absenteeism, and churn in sustainable buildings could then be used to identify the potentially significant financial benefits businesses can realize. The reduced operating costs during the life cycles of sustainable buildings have been established, although intangible effects, such as whether sustainable buildings meet users' needs and realize users' satisfaction and if so, to what degree, are uncertain. This and other intangible aspects have not been accurately quantified and thus are not (yet) part of the measurement of sustainability of buildings. In addition, there are several uncertainties in quantifying the direct and indirect benefits that arise from enhancing sustainability to satisfy building occupants (Brown and Cole 2009).

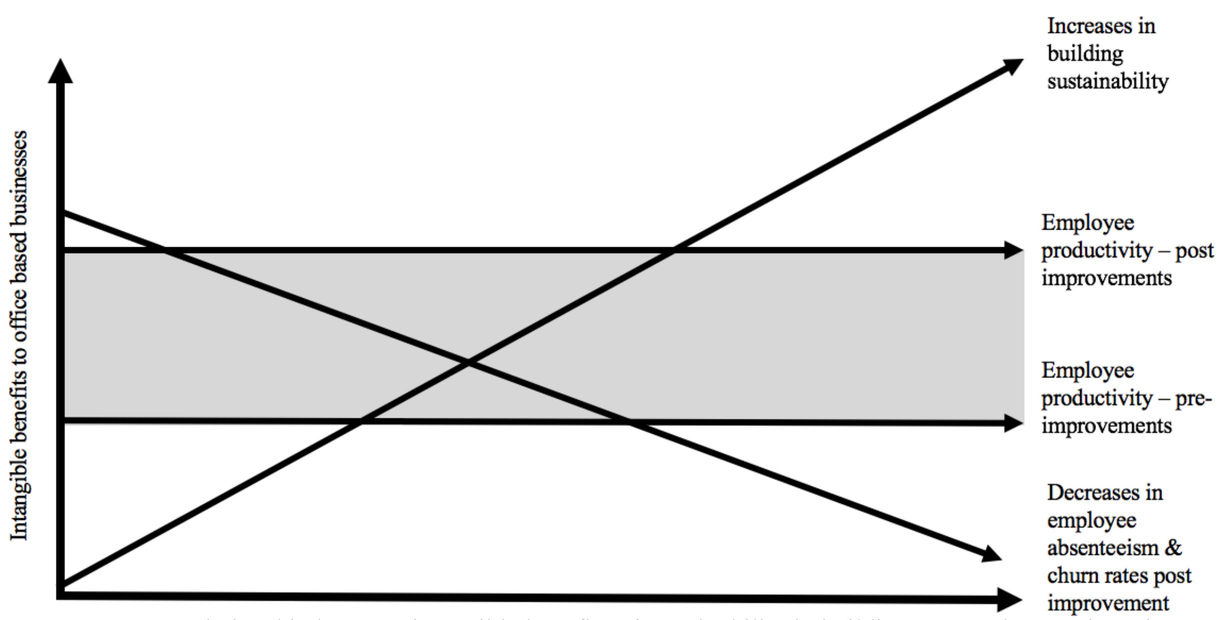


Figure II.1 Relationship between intangible benefits of sustainability in buildings pre-and post-adaptation. (Wilkinson et al. 2011)

II.2.1 User Issues in Sustainable Buildings

Longer building life cycles with healthier environments for occupants are two of the positive attributes that represent financial benefits to be gained from a sustainable building (Ang et al. 2008). A modern design that incorporates state-of-the-art services and new technologies allows buildings to meet recognized sustainability criteria; however, the user perspective in regard to design remains the most important factor for a successful sustainable-building design (Abbaszadeh et al. 2006)

Previous studies have distinguished between occupants' well-being and their health, which represent two factors of the user perspective and are considered as measures of building performance (Roulet et al. 2006). In other words, the occupants of sustainable buildings either feel well, healthy, and comfortable, or they do not (Edwards 2006; Roulet et al. 2006). Meir et al. (2009) stated that the satisfaction or dissatisfaction of users is related to the level of sustainability in a building. Sustainable-building design considers three main categories of sustainability benefits: economic, environmental, and social. However, it is extremely important to strike a balance between design creativity and utility in a sustainable building (Meir et al. 2009).

Abbaszadeh et al. (2006) and Edwards (2006) developed methods to evaluate users' perspectives in regard to various sustainable aspects, such as internal environmental quality (IEQ). These methods focused on office layout, office furnishings, thermal comfort, air quality, lighting, acoustic qualities, and cleaning and maintenance of the workplace. Indeed, the relationship between the users' perspectives and IEQ are positively correlated with high performance in sustainable buildings.

II.2.2 A Framework of Strategies to Evaluate and Upgrade Buildings to Sustainable Buildings

A facility manager works with the owner(s) of sustainable buildings to incorporate renewable energy. The cost of updating a building's sustainability and the anticipated payback period are critical factors for building owners. Therefore, integrating renewable energy should be discussed during a building's lease negotiations, especially if a refurbishment or upgrade of one or more building services is anticipated.

Table II.1 shows the top 10 actions taken to reduce energy use in a building, including their relative costs. Three of these involve no outlay costs at all: ensure that the building is on the most appropriate (i.e., hours of usage) tariff for gas, electricity, and other fuels used and that bills are checked regularly, including verifying unit rates and power factors; conduct an energy audit if waste is suspected; and incorporate energy awareness into maintenance activities.

Following an energy audit, low-cost measures would be to ensure that buildings are as airtight as possible to exclude drafts from ill-fitting windows and doors; fitting electric immersion water heaters and hot-water circulating pumps with time switches and, if boiler systems are used, ensuring that hot-water tanks and pipework are well insulated; ensuring that AC/ventilation systems are operating in the most energy-efficient manner; improving the efficiency of lighting systems; and installing or increasing loft- or roof-space insulation and cavity-wall insulation where possible.

If there are no cavities in a building's external walls, one option to consider is installing thermal lining paper. Another low-cost measure for saving heating/cooling costs is ensuring that heating and cooling systems are operating at maximum efficiency and at hours that correspond to occupancy by installing timers and temperature controls and ensuring that all staff know how they operate. A higher-cost investment to reduce energy use would be to invest in double- or triple-glazed windows (an especially rewarding option in Scandinavia).

Table II.1 Top Ten measures for Cost-effective Energy Use (UNEP-Skanska 2013)

Top 10 Actions	
Establishment of current energy usage by checking bills and costs (no-cost)	Incorporation of energy efficiency into maintenance activities (no-cost)
Exclusion of draughts (low cost)	Increasing the energy efficiency of water heating systems (low cost)
Improvement of the efficiency of air conditioning /ventilation systems (low cost/no-cost)	Improvement of the efficiency of lighting systems (low cost)
Installing or updating loft /roof space insulation (low cost)	Improvement of the efficiency of lighting systems (low cost)
Increasing the efficiency of space heating systems (low cost)	Use of double or triple glazed windows (medium cost)

Table II.2 suggests different technologies for upgrading buildings to be sustainable, as well as the factors that facilities management (FM) should take into consideration when selecting and applying them. These advanced techniques include on-site solar- and wind-power generation, the use of biomass, and the use of heat pumps. Photovoltaic (PV) solar panels and micro turbines (< 10 kW) can be installed on roofs to supply electricity directly to a building or to the grid. Biomass can be used as a fuel to provide electricity to the grid or to a combined heat and power plant (CHP) providing space, water, and processing for heating and electricity. Using a heating coil, ground, air, and water-source heat pumps take latent heat from the soil, standing water, or air and compress and concentrate it to provide useable heat. Heat-pump systems use a small amount of electricity and a device similar to the compressor of a refrigerator.

FMs must consider several factors in order to evaluate which technology would be most appropriate. For solar- and wind-power generation, these include roof-space availability and over-shading, wind speeds and patterns, and weather factors. The ability to generate electricity from wind is related to wind-yield availability, and urban sites often have poor availability, as buildings create air turbulence. In addition, if a building is in close proximity to other buildings, planning and good-neighbor factors can be problematic. Most building codes are reducing their barriers to PV panels. Lead times are typically under 12 months depending on planning issues and grid-connection details.

There are significant challenges related to biomass technology outside of continental Europe and Scandinavia, including technology risks and immature fuel-supply chains. While the biomass technology can be adapted to work with conventional heating systems, most are best suited to below-floor heating. Biomass systems are similar in size to air-conditioning plants. Ground-source heat pumps, if using a horizontally laid collector pipe, require substantial outdoor space around a building. The alternative is to drill a bore hole and lay the collector vertically, but this option is more expensive. Air-source systems are the most economical to install but are unsuitable in regions that experience extended periods of extreme heat or cold.

Table II.2 Framework to evaluate and upgrade sustainable strategies (UNEP-Skanska 2013).

Technology	Issues to Consider	Costs	Benefits
Solar PV (photovoltaics) can be installed on roofs to supply electricity directly to a building or to the grid, during daylight.	Generation depends on roof space availability and over shading issues. Lead times are decreasing and are typically <12 months. Most planning systems now are reducing their barriers to PV panels.	Operating costs are very low, with only periodic maintenance / cleaning required. The cost of generation varies considerably due to the setting. For a high performance system with a load factor of 10%, costs of US$650-US$875 per MWh can be assumed. Installation costs vary and economies of scale are very pronounced typical costs are US$4,375 - US$7,300 per kWh installed. Smaller systems can cost up to US$14,500 per kWh.	Can be maximised, where possible by integrating systems into the design of new buildings. Offers energy security and vastly reduced electricity bills for the summer months in high latitude regions, and all year round in sunnier climes. Also a high visible demonstration of 'green credentials'
On-site wind power. Micro turbines (< 10 kW) can be mounted to the building directly to provide electricity to the building or into the grid.	Ability to generate electricity is related to wind yield availability and urban sites often have poor availability and buildings create air turbulence. If in close proximity to other buildings, planning issues can be problematic. Lead times are typically under 12 months dependant on planning issues and grid connection.	Installation costs range from US$3,600 - US$7,200 per kWh installed. Operating costs are low, typically in the range of US$21 to US$30 per kW installed to cover periodic maintenance. Assuming a typical urban load factor of 20% generation costs will be in the region of US$150 – US$300 per MWh.	Offers energy security and vastly reduced electricity bills. Also a highly visible demonstration of 'green credentials'.
Biomass can be used as a fuel to provide electricity to the grid or combined heat and power plant (CHP) providing space, water and process heating and electricity.	Large units are often problematic because of the storage space required for fuel, and the need to constantly transport fuel into urban areas. There are significant issues with biomass technology outside of continental Europe and Scandinavia, including technology risks and immature fuel supply chains.	Cost estimates are highly case specific and usually undisclosed. However, major existing biomass developments indicate generation costs of US$100 per MWh. Operating costs are higher than for other renewables reflecting the need for regular inspection and intervention for fuel loading.	These systems do not eliminate fuel supply costs but are likely to be a cheaper fuel option in the medium term as fossil fuel prices rise. They offer energy security, and can generate both heat and power.
Ground, air and water source heat pumps take the latent heat using a heating coil, from the soil, standing water or the air and compress and concentrate it to provide useable heat. Systems use a small amount of electricity and a device similar to the compressor on a refrigerator.	They can be adapted to fit with conventional heating systems but are most suited to under floor heating. Systems are of a similar size to air conditioning plant. Ground source heat pumps, if using a horizontally laid collector pipe require substantial outdoor space around the building, the alternative is to drill a bore hole and lay the collector vertically but this option is more expensive. Air source systems are the cheapest to install but are unsuitable in regions of the world which experience significant periods of extreme heat or cold.	Cost estimates are highly case specific. The initial cost of installing a ground, air or water source heat pump is usually quite high and can range from US$3,600 to US$8,750 for a 2,000 sq. ft. office. However the average cost of most systems is around US$14,500 including groundworks if needed. The cost of installation is impacted by the geology of the area, size and location of the property. The system can save the reducing the average heating/cooling costs by 35-70% depending on the system installed.	For every unit of electricity into the system, typically you get 3 or 4 of heat out. There are no visibility benefits but this could be an advantage in areas with strict planning guidelines.

II.3 EXISTING RATING SYSTEMS FOR SUSTAINABLE FACILITY MANAGEMENT

II.3.1 Leadership in Energy and Environmental Design (LEED)

LEED is a rating system that provides guidelines regarding the factors that affect the sustainability of a building during its life span. Table II.3 identifies that this rating and certification system has four levels: certified 40 to 49, silver 50 to 59, gold 60 to 79, and platinum 80+. To achieve LEED accreditation, eight elements should be considered in the evaluation of new construction and major renovations: location and transportation (LT), sustainable site (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor environment quality (IEQ), innovation in design (ID), and regional priority (RP).

Table II.3 the number of credits required for each LEED certification level (ITU 2012).

No.	Levels	Point
1	Certified	40 to 49
2	Silver	50 to 59
3	Gold	60 to 79
4	Platinum	80+

II.3.2 Green Globes System

The Green Globe system offers an online assessment protocol, rating system, and guidance for green building design, operation, and maintenance. This protocol represents an interactive tool that provides market recognition of a building's environmental attributes through third-party verification. In 2005, GBI became the first green-building organization to be accredited as a standards developer by the American National Standards Institute (ANSI). In 2010, an official Green Globes ANSI standard was published. The Green Globe rating system is now used by large developers and property-management companies, including the Canadian federal government, which has adopted the program for its entire real estate portfolio.

II.3.3 Green Building Program

The Green Building Program (GBP) is a voluntary program established to enhance energy efficiency by creating awareness, providing information, and establishing public recognition for companies. The most important requirements for participation include an energy audit, an action plan, and an execution plan, as well as the commitment to report energy consumption on a regular basis. It should be noted that GBP provides modules that define the technical nature of an appropriate commitment for each energy service covered by the GBP. The modules are complemented by guidelines on related issues, such as financing, energy audits, and energy management.

II.3.4 BREEAM

The building research establishment environmental assessment method (BREEAM) is a voluntary rating system for green buildings that was established in the UK. BREEAM uses a straightforward scoring system that is transparent, flexible, easy to understand, and supported by evidence-based science and research. Table II.4 displays the BREEAM levels (outstanding 85, excellent 70 to 84, very good 55 to 69, good 45 to 54, pass 30 to 44, and unclassified 29 and below). These levels and scores consider 10 topics and 50 criteria to evaluate the sustainability of a building; BREEAM claims to have a positive influence on the design, construction, and management of buildings. It is considered an effective tool for defining and maintaining robust technical standards with rigorous quality assurance and certification (ITU 2012).

Table II.4 The number of credits required for each certification level in the BREEAM (ITU 2012).

No.	Levels	Point
1	outstanding	85
2	excellent	70 to 84
3	Very Good	55 to 69
4	good	45 to 54
5	Pass	30 to 44
6	Unclassified	Less than 30

II.3.5 German Sustainable Building Council (DGNB)

The DGNB focuses heavily on the establishment and further development of its certification system, which is considered one of the leading systems worldwide. Table II.5 indicates the scoring system (gold 80 to 65, silver 65 to 50, bronze 50 to 35 and certified 34 and below). The DGNB certification system provides a comprehensive quality concept that takes equal account of economic, environmental, and sociocultural aspects. The system is based on a holistic view of a building's entire life span, which allows users to define sustainability targets at the planning phase. The DGNB assesses 6 criteria and 64 topics. The DGNB's certification system recognizes 4 levels.

Table II.5 The number of credits required for each certification level in the DBNB (ITU 2012)

No.	Levels	Point
1	Gold	80 to 65
2	Silver	65 to 50
3	Bronze	50 to 35
4	Certified	34 and below

II.3.6 Green Building Council System of Australia

The Green Building Council of Australia (GBCA) is an organization that encourages the adoption of green building practices. It also assists in the assessment of environmental impacts that may affect the site selection, design, construction, and maintenance of a project. Table II.6 shows how it ranks the sustainability of the design and construction of a building and certifies buildings with a rating of 4 (45 to 59), 5 (60 to 74), or 6 (75 to 100) based on 9 very different categories: management, indoor environment quality, energy consumption, transport, water use, materials, land use and ecology, emissions, and innovation.

Table II.6 The number of credits required for each certification level in the GBCA (ITU 2012)

No.	Levels	Point
1	4 Star	45 to 59
2	5 Star	60 to 74
3	6 Star	75 to 100

II.3.7 Estidama – United Arab Emirates

The Abu Dhabi Urban Planning Council (UPC) introduced the Estidama program as a core guideline for the urban master plan of Abu Dhabi. The ultimate goals of Estidama are to preserve, enrich, and improve the quality of life for its residents on four equal pillars of sustainability: environmental, economic, social, and cultural. Table II.7 shows the Estidama pearl rating system for ranking the sustainability of new and existing buildings. The pearl rating system addresses seven categories: integrated development process, natural systems, livable buildings, water resources, energy efficiency, material stewardship, and innovative practices.

Table II.7: number of credits required for each certification level of Estidama's Pearl Rating. (ITU 2012)

No.	Levels	Point
1	All mandatory credits + 0 points	1 Pearl
2	All mandatory credits + 60 points	2 Pearl
3	All mandatory credits + 85 points	3 Pearl
4	All mandatory credits + 115 points	4 Pearl
5	All mandatory credits + 140 points	5 Pearl

II.3.8 CASBEE – Japan

CASBEE, developed by the Japanese GreenBuild Council (JaGBC), is a tool for assessing and rating the environmental performance of buildings and the built environment. Table II.8 shows how each load and quality aspect of the built environment includes four components, 0, 1, 2, and 3, for evaluating building sustainability at the stages of predesign, new construction, existing buildings, and major renovation, respectively. CASBEE evaluates the sustainability of a building using a built environment efficiency (BEE) score, calculated as follows:

$$BEE = Q/L \tag{2-1}$$

where L and Q represent the built environment load and the built environmental quality, respectively. Table II.8 demonstrates how each load and quality aspect of the built environment includes three components:

Table II.8 The three components of the CASBEE rating system (ITU 2012)

No.	Levels	Point
1	Energy	Q-1 Indoor Environment
2	L-2 Resources and Materials	Q-2 Quality of service
3	L-3 Off-site environment	Q3- Outdoor environment on site

Figure II.2 focused on a direct comparison between all of the rating systems for sustainable building in different countries and entities around the world: the U.K., the EU, Hong Kong, Japan, Germany, Australia, France, Canada/U.S., the U.S. and Italy with the 11 rating tools based on 15 assessment criteria: energy consumption, CO_2, ecology, economics, health and well-being, indoor environment quality, innovation, land use, management, materials, pollution, renewable technologies, transport, waste production, and water use.

According to Figure II.2, a notable observation from this matrix confirms that every assessment criterion is considered by at least one rating tool, although importantly, no single rating tool addresses all 15 criteria. It can be argued that this is due to the differences between climate zones, as previously noted (Crawly and Aho 1999), although a lack of flexibility can also be argued. It is important to incorporate assessment tools at an early stage, such as in the feasibility-study stage before the design stage. The assessment, meanwhile, is always conducted when the design process has been finalized (Crawly and Aho 1999).

Therefore, there must be an early intervention of the assessment tool so that it can be useful as a design tool and to allow early collaboration between designers and the assessment team. Moreover, most of the environmental concerns are considered mainly during the design stage, while many development options and locations are decided upon at the feasibility stage. Consequently, if a project has a number of development options, selecting the one that best achieves its environmental goals and decreases its economic costs will represent a major step in fulfilling sustainability goals. Later alterations may incur excessive costs and inconvenience, increase environmental damage and natural-resource consumption, and lead to remedial costs. Unfortunately, contemporary environmental assessment tools are utilized to assess building performance later in the design stage, where it may be too late to consider the best solutions to many environmental issues (Ding 2008).

A sustainability rating is a measure of three major aspects: economic, ecological, and social. Unfortunately, rating tools such as BREEAM, HK-BEAM, LEED, and BEPAC do not include financial aspects in their assessment framework, although the primary concern for any project is that it be financially efficient, and excessive construction costs with the aim of energy efficiency are not an easy sell. Moreover, most building-rating tools are implemented on a local scale and prove to be inefficient if applied on a global scale. Many variations distinguish a local context; several of these regional differences involve climate conditions, building materials, building types, and historical considerations. Some countries have adapted existing rating tools to align with their local contexts, such as HK-BEAM of China, which adapted the BREEAM to suit its local context (Crawly and Aho 1999).

	U.K.	U.K.	U.K./EU	U.K./EU	Hong Kong	Japan	Germany	Australia	France	Canada/U.S.	U.S.	Italy
Assessment Criteria	BREEAM	CFSH[a]	EPCs	DECs	BEAM	CASBEE	DGNB-Seal	Green Star	HQE	Green Globes	LEED	Protocol ITACA
Energy	X	X	X	X	X	X	X	X	X	X	X	X
CO_2	X	X	X	X			X		X	X		X
Ecology	X	X			X	X	X	X	X	X	X	X
Economy							X		?	X		?
Health and Wellbeing	X	X			X	X	X	X	X	X		?
Indoor Environmental Quality	X	X			X	X	X	X	X	X	X	?
Innovation	X				X		?	X	?		X	?
Land Use	X	X			X		?	X	X	X	X	?
Management	X	X		X	X	X	?	X	?			?
Materials	X	X			X	X	X	X	?	X		X
Pollution	X	X			X	X	X	X	X	X	X	?
Renewable Technologies	X	X	X				?	X	?	X	X	X
Transport	X	X			X		X	X	?	X	X	?
Waste	X	X			X		?		X	X		X
Water	X	X			X	X	X	X	X	X	X	X

Notes: The source is King Sturge (2009).
? Data for DGNB-Seal, HQE, and Protocol ITACA is not exhaustive and additional criteria may be included in the assessment.
[a] Code for sustainable homes.

Figure II.2 A complete comparison between all the rating systems for sustainable buildings.

(Crawly and Aho 1999).

II.4. PREVIOUS RESEARCH ON THE USERS' PERSPECTIVE IN FACILITY MANAGEMENT

A structured research methodology is used to conduct a literature review for the facilities management (FM) research field. The developed methodology is divided into two phases, as shown in Figure II.3; the first phase includes the collection and selection of related papers that will be included in the literature, while the second phase is used to classify the selected papers based on methodology, techniques, and journal articles. In the first phase, a set of criteria is developed in order to select the publications that need to be included in the review. The type of paper publication (e.g., in specific journals, bibliography databases, or conference proceedings) and year of publication are considered in the search process. The search keywords should be selected carefully, and the appearance of keywords in a paper should be identified, whether in the title, abstract, or keyword list of the paper. In the second phase, an analysis framework was developed to analyze and classify the selected publications. Two types of analysis are considered in this review; the first is to make head counts, and the second is to classify the papers.

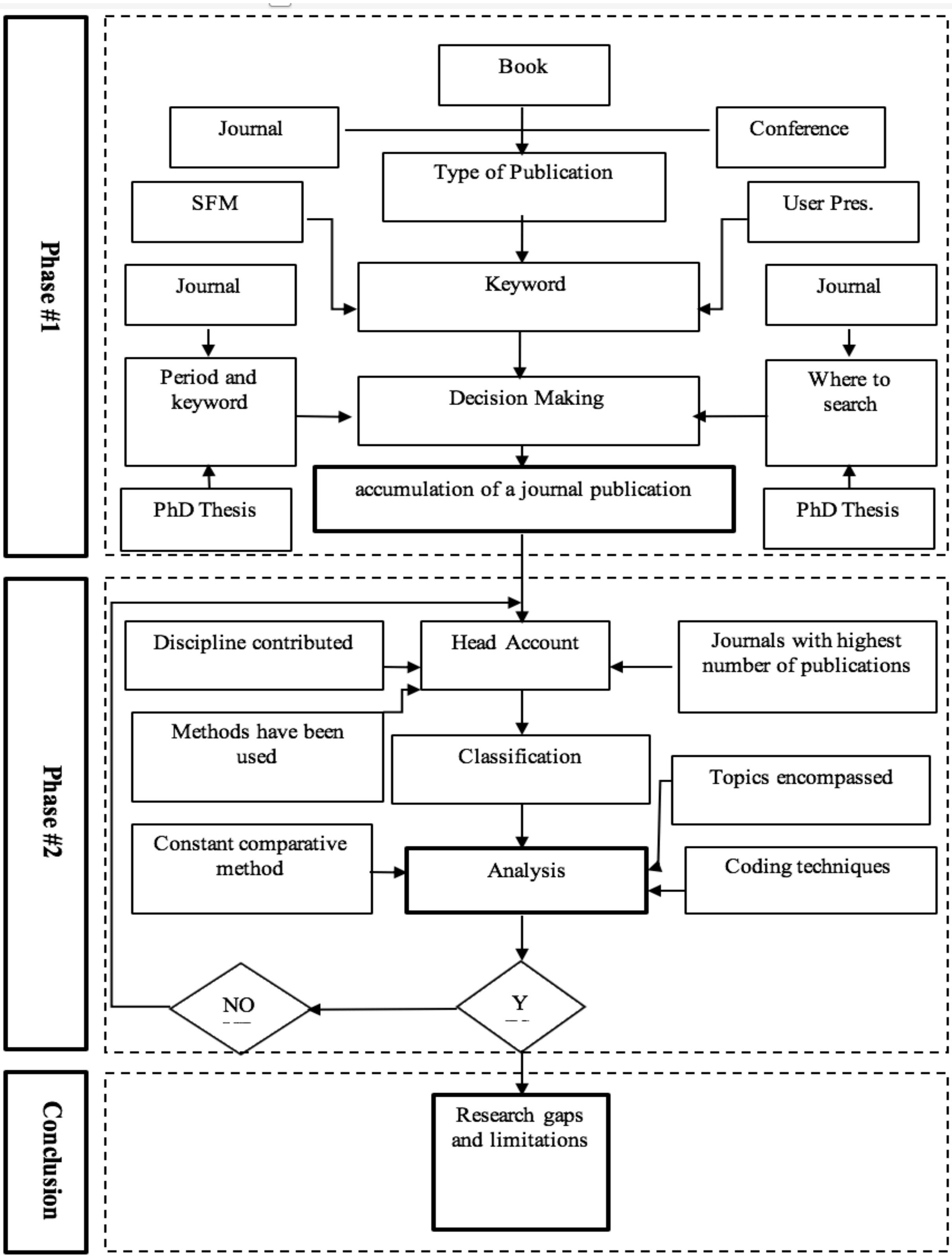


Figure II.3: Frame work of literature review method

A classification analysis requires the identification of a taxonomy that will be used to classify the selected papers. Once the taxonomy has been selected, the classification process begins, using different analysis approaches, such as quest analysis for regularity and the topics discussed by a paper (Bogdan and Biklen 1982) and content analysis using a constant comparative method or other coding technique (Cavana et al. 2001). Coding techniques include but are not limited to open coding, axial coding, and selective coding (Glaser and Strauss 1967; Strauss and Corbin 1994; Webster and Watson 2002). This literature review was conducted using a framework (shown in Figure 1) consisting of two phases as follows: phase 1, selecting and adding papers to a publication pool; and phase 2, classifying the selected publications based on three criteria: a) research discipline, b) topic studied, and c) methods used.

The selection of a time frame was one of the major review challenges since academic research in SFM started in the 1990s (Price and Akhalghi 1999) and remains under investigation (Nutt 1999). Therefore, papers published before 2007 that discuss SFM are very limited in number and can be considered as emergent. The field has matured, and thus papers published in 2007 and onwards cover more aspects of SFM. This review considers papers published from 2007 to 2017 and includes two types of publications: PhD theses and journal papers in peer-reviewed international journals. There are two main reasons for this limitation. The first is that journal papers include data that is much more current than data found in books (Dale et al. 2001), and the second is that conference papers may be difficult to access (Schlichter and Kraemmergaard 2010). PhD theses and journal papers published in academic journals are accessible through library web-search facilities. Five different bibliography databases were used as sources of published papers and PhD theses, as presented in Table II.9.

The papers were collected in three sections, the first in 2015, the second in 2016, and the third in December 2017. The keywords used in searching for papers were “SFM” and “user perspective.” A paper or thesis is included in the review only if these keywords are present in its title, abstract, or keyword list. The length of a selected paper had to be a minimum of four pages, which helped to exclude editorial comments and book reviews. The initial search generated a pool of 934 journal and thesis publications.

Table II.10 shows the four main exclusion criteria considered. First, a study was excluded if it was not a double-blind clinical trial or the intervening factors had been ignored, there was no control group, or the sample size and selection criteria were not suitable (Majd et al. 2015). Second, if a publication’s focus was on the SFM applications on different types of projects (e.g., infrastructure) rather than on buildings, the main focus of this review, the study was excluded. Third, duplicate papers were excluded if the different parts of a single study were presented in two or more papers. Fourth, papers were also excluded for other reasons, such as a loss of quantitative data or if the outcome evaluation methods were unusual. The application of exclusion criteria for the four reasons noted above reduced the pool of papers by 702 papers, as shown in Table II.10 and Figure II.4. The number of papers excluded due to exclusion criteria 1 through 4 was 345, 167, 136, and 54, respectively. The total number of publications that remained in the review pool was 232 papers, for an inclusion rate of 24.84%.

Table II.9: Bibliographical databases utilized

Database	Definition
Emerald	Publishes a range of management titles and library and information services titles by any publisher worldwide.
ScienceDirect (Elsevier)	An electronic collection of science, technology and medicine full text and bibliographic information
Wiley Inter Science	Provides access to publications from John Wiley & Sons and features over 1,000 journals
ProQuest	An online information service that provides access to thousands of current periodicals and newspapers
Concordia University Library	Provides students, faculty, and staff with the information resources fundamental to learning and the pursuit of knowledge
ACM Digital Library	A library containing 54,000 online articles from 30 journals and 900 proceedings from the Association for Computing Machinery
AIS Library	A service from the Association of Information Systems providing full-text access to journals and conferences sponsored by AIS
Digital Article Database Service (DADS)	Provides access to data from several providers, including databases, publishers and organizations

Table II.10: The main reasons for excluding articles from the literature review

Reason for exclusion	# of Publication
Total Number of Publications	*934*
The study was not a double-blind clinical trial	345
Sustainable Facility Management not present in the buildings	167
Different parts of a single study were presented other papers	136
Other reasons	54
Total number of inclusions	232
Percentage of inclusions	24.84

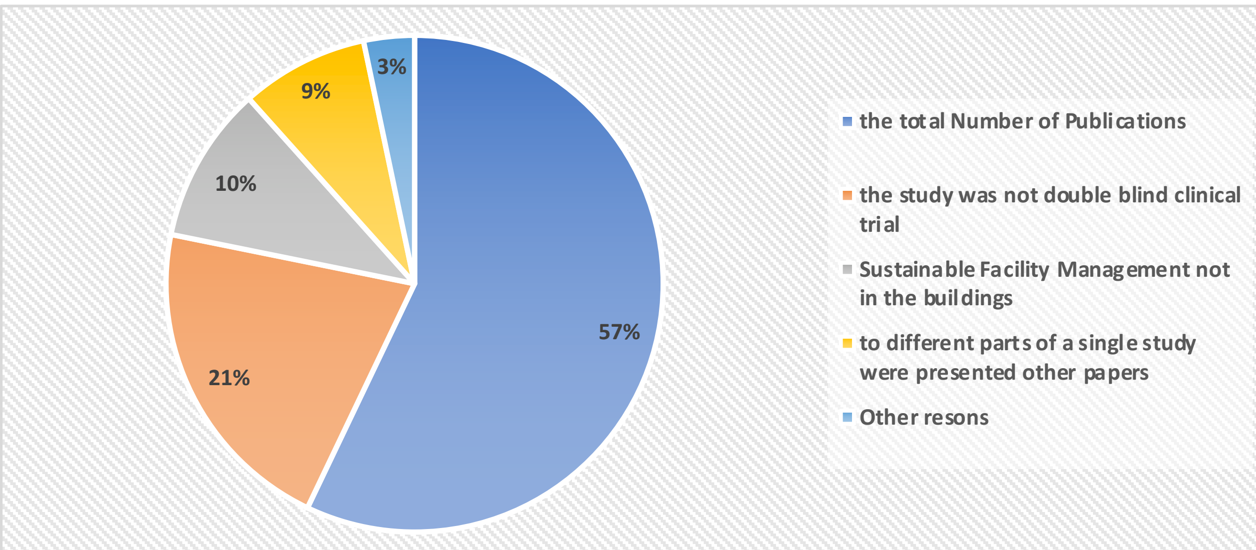


Figure II.4: Percentage of articles excluded from the literature review

II.4.1 Classification of Previous Research Work

In this phase, a head count is applied to papers in the review pool. The head count discloses the evolution of SFM papers published during the period from 2007 through 2016. The head count is applied using the following three main steps: (1) count the number of papers published per year, (2) generate a list of journals that published sustainable FM articles, and (3) identify the journals that publish the largest number of FM articles.

II4.1.1 *Building Performance*

Huat and Akasah (2011) concentrated on the requisition for vitality proficiency in the configuration of an office building, distinguishing the issue of developing a BEI (Building Energy Index) of a contemplated office building that did not attain zero BEI. They also recommended methodologies that might enhance the vitality proficiency of those office buildings. One of these is meeting sessions with the office-building administration team, engineer, and vitality specialist. Their conclusion demonstrates that a vitality-productive configuration is possible and desirable. Renewable-energy innovations implemented in an office building would allow for latent design, dynamic systems, and building-coordinated circuit photovoltaic frameworks (BIPV). Abu Jawdeh (2013) investigated the relationship between facilities management (FM) and design in construction projects in the Middle East. He identified various benefits of achieving successful integration and highlighted different means for improving the integration process and avoiding negative consequences that may affect the occupants of a facility in the future. Shortly thereafter, Azizi et al. (2014) affirmed that major pertinent arranging and overseeing of the economical instruments for "green buildings" on the operational level are required. Building green structures does not guarantee a vitality productive execution. In fact, the outcomes indicate that those green advances were wasteful. Throughout those operational stages, it was discovered that measures to encourage occupants to participate in vitality-preservation objectives differed regarding viability. Höfler et al. (2015) investigated the high performance of a thermal envelope with prefabricated façade modules and concluded that facility management should adopt a harmonized approach in order to introduce this building-performance enhancement, including reducing energy demand/consumption as well as installing on-site energy generation. In this case, it was necessary to realize a plus-energy building after the renovation.

II.4.1.2 *Sustainable Tools and Standards*

Yunqing (2011) investigated how SFMs need to perform and figure out a workable approach to move forward in those circumstances. He concluded that with sustainable tools and standards, FMs and government organizations should follow. Lee and Kang (2013) analyzed the advancement aspects of sustainable tools and standards that align with SFM objectives. They found that FMs with both a financial goal and a human comfort aspect needs to add helpful predictors to the plan by claiming SFM reception. Observability may be an important addition to the plan of SFM selection. Complexity, however, is not a critical predictor for the plan for claiming an SFM selection. Wong and Fan (2013) analyzed building information modeling (BIM) with sustainable tools and standards. They discovered that BIM is considered to be ideally suited to the conveyance of claiming required data to be moved forward to outlining and fabricating a building's execution. Two of the major advantages of BIM to sustainable building (SB) configuration are the incorporation of one-task conveyance (IPD) and plan streamlining. However, there are other obstructions to adopting BIM for a Sustainable Building (SU) outline. Kumara et al. (2016) investigated the contribution of a building management system (BMS) to the adoption of sustainable tools and standards. The results showed that user requirements, identifying BMS features, designing a BMS, installation and commissioning, and operation and maintenance play the most important roles in a BMS. Manewa et al. (2016) investigated the capacity of sustainable tools and standards to invest in "adaptable buildings" that could react to future potential building and environmental changes in a sustainable way. They discovered that the positive contributions of adaptable buildings for achieving sustainable tools and standards in terms of economic, social, and environmental considerations were very important in order to achieve sustainability.

II.4.1.3 *Users' Perception, Satisfaction and Productivity*

Leaman and Bordass (2001) investigated the consequences of strategic thinking on how best to manage buildings in order to maximize users' satisfaction. They found that the lowest user satisfaction occurs when a building and its systems have become very difficult for the users and the FM, and that the most positive influences on users are simplicity, intelligibility, managed feedback, respect for people's comments, and rapid responses to complaints. Okoroh et al. (2003) examined the benefits of FM in public buildings and how the application of FM can be performed in order to achieve a high level of user satisfaction and productivity. They conclude that it is critical to incorporate life-cycle planning, including capacity, use, and proactive maintenance policies, as well as assuring that all the resources needed to cope with changing demands are in place. Criteria such as life-cycle costs, productivity, performance values, and legislated rulings have a significant influence on FM and on the steps that FMs must follow to achieve user satisfaction and productivity.

Choi (2011) modeled the relationships among indoor environmental quality, occupants' satisfaction, and work performance. The results identified significant relationships between occupants' satisfaction in regard to furnishings, acoustics, and privacy conditions and overall work performance. Significant relationships were also identified between occupants' satisfaction in respect to overall FM, overall work performance, and sustainability (SUS) ethics. The findings of this study highlighted the connection between occupants' satisfaction, SUS ethics, and work performance. Abdul-Rahman et al. (2014) examined users' perceptions, satisfaction, and productivity in relation to an academic building and found that academic-building users were satisfied with the FM. Their study further demonstrated that the 26 building-performance requirements have a significant relationship to a building's overall user satisfaction.

II.4.1.4 ***Sustainability Management***

Lützkendorf and Lorenz (2005) examined the capability of meeting current and forthcoming challenges posed by sustainable development. They determined that the environmental and building-research community plays an important role in the standardization of sustainable terminology and in maximizing the exchange of ideas between financial and environmental research disciplines. The simultaneous consideration of economic, environmental, and social issues can offer FM more profound knowledge about a building's characteristics and its associated performance. Ihuah (2015) developed a conceptual framework for the sustainable (SU) management of social (public) housing estates in the Niger Delta region of Nigeria. The study identified: 1) 14 factors that negatively affect SU housing-estate management and the effectiveness of its maintenance approach; 2) 6 reasons for the non-involvement of stakeholders; and 3) 7 factors for enhancing sustainability (SUS) in a social (public) housing estate. Implementation of their developed Sustainable Social (Public) Housing Estates Management (SSPHEM) framework ensures improvements in the current social (public) housing estates' quality and conditions, with a significant appreciation for the benefits thus gained.

Gibberd (2015) analyzed an elective methodology that allows conceptualizing. The same study also determined that a nature-based domain may be formed, thereby establishing the groundwork for a new evaluation device. By using a built environment sustainability tool (BEST), the researcher can define these SFM configurations and characteristics by measuring the extent to which the required configurations and characteristics exist within FM.

II.4.1.5 *Construction and Sustainability*

Wong et al. (2009) suggested a basic SUS benchmark utilizing a 5-star rating framework for power and fuel gas utilization for private buildings. Their work concluded that the 5-star rating framework is a useful application in a straightforward SUS benchmark model for power and fuel gas utilization by private buildings. This model might be appropriate for promoting the approach of SB homes without the need for comprehensive estimations.

Muhey (2012) created an FM model for a maintenance and repair (M&R) program for office structures. This Model is a flexible and allows building owners and managers to practice their experience and, while offering SB the opportunity to act on their knowledge and information. In this work, Muhey showed that FMs need to know the operation and maintenance (O&M) expenses report year by year in advance in order to set their own O&M strategies according to the allocated budget. This report should be based on accurate historical data and statistical uncertainty in terms of activities and costs.

Andrews and Dong (2017) examined applications incorporating occupant behavior into building simulations. They concluded that user's satisfaction modeling offers a number of valuable aspects and important applications. The range of purposes and contexts illustrated in their work confirmed that occupant behavior plays an important role in FM consideration in most building-simulation modeling efforts.

II.4.1.6 *Building Design and Sustainability*

Langevine and Allouche (2006) produced a fabricating choice supportive network in order to model and screen building frameworks and components, to elaborate on the remaining administration terms for components, and to prioritize building frameworks and parts maintenance. A building maintenance decision support system (BMDSS) has been developed to help FM to address the deterioration of building systems and components, to forecast the remaining service life of components, and to prioritize building systems and components. Xia et al. (2008) investigated the “design by simulation” concept in building design. the methodology of applying the building simulation in the building’s conceptual design stage is the main theme discussed in Xia et al. (2008) paper. The principle finding from this paper is that it determines how to help FM make the right decisions in the conceptual design stage, as well as providing a better knowledge base for energy-efficient design in the next stage by means of the building-simulation tool.

Eweda (2012) developed an integrated condition-assessment model for academic buildings that considers their physical and environmental conditions. This model promised to assist owners and facility managers in the condition assessment of an asset. It decomposes buildings into spaces in which each “space” represents a principal element of the evaluation process. The multi-attribute utility theory (MAUT) was employed to evaluate the physical and environmental conditions of each space, and K-mean clustering was conducted to assess the integrated condition of each space. The input for the model was collected using questionnaires that gathered expert judgment in order to assign relative weights for each model’s attribute using analytical network process (ANP) and analytical hierarchy process (AHP) techniques.

II.4.1.7 *Urban Development*

Xia et al. (2016) determined the best FM that can be realized in a real-world sustainable community project so that it can be replicated in the future. The researchers identified the green technologies and strategies used in FM. The social considerations of FM are also recognized in providing comfort, convenience, and safety for residents.

Mohan et al. (2017) examined the mega-project strategies for the sustainable best value of stakeholders. They discovered that insufficient FM engagement has resulted in numerous procedural confusions and problematic results in recent mega-projects. An organized approach concentrating all of the basic information and providing an incentive from the beginning is developed to accomplish improved and more-feasible mega-project results. Particular suggestions include adjusting mega-project partner goals with provincial or even national needs and focusing on jointly identifying basic incentives through early partner inclusion in the arranging of constructed foundation mega-projects.

Arumsari and Rarasati (2017) proposed an elective upkeep methodology for open-leased private structures in Indonesia, recognizing the FM factors that influence the formation of ghetto creation, with the goal that important upkeep needs can be conveyed by the office in control. Their research found that the overwhelming elements in maintenance management that impact the production of ghetto conditions in broad daylight in leased private buildings are the level of harmful conditions and the decay in building materials in addition to the amount of funding available for building upkeep.

II.4.1.8 Benefits of Green Buildings

Amaratunga (2001) investigated using fabricating principles for estimating sustainable building execution via FM associations. Applying administrative standards will provide a framework for evaluating different perspectives in execution estimation in FM associations. His approach also identified execution-estimation instruments and instruments that offer exciting execution procedures. The identified instruments were assessed utilizing a questionnaire that offered to FM professionals in the UK. The outcomes of the questionnaire highlighted execution-estimation constructs that may be categorized according to four perspectives: customer, FM inward courses, FM input and development, and budgetary FM. At each level, the FM association should strive to make execution estimation a valuable step, especially by developing new execution-estimation constructs. The hypothesis thus created may be approved utilizing the master judgment of FM professionals in the field. The discoveries from claiming this research incorporate both a qualitative and a quantitative appraisal of the execution by using an estimation methodology that generally relies on extensive background information, as well as information from an FM association. As with experience, the learning process contributes extensively to the execution estimation, incorporating suggestions from an FM association. On the other hand, a commitment produced for a director will be judged by the association's stakeholders utilizing a wide range of criteria, including both budgetary and non-financial considerations. FM can influence the execution of an office building in distinct directions utilizing vital planning, resource control, service-quality levels, supply chain, and overall economic considerations as well as the quality of cash dissection.

In 2013, the United Nations (UN) allocated dedicated funds to its agencies and adopted greener operational practices at UN facilities worldwide. The program titled Sustainable United Nations (SUN) was established to improve energy-efficiency measures and to promote an organizational culture with sustainable procurement practices. The SUN program provides a practical guide that helps UN FM to reduce GHG emissions and increase energy efficiency in both leased and owned UN facilities worldwide.

The Energy Information Administration (EIA) in the United States provides energy for heating, air conditioning, and lighting in buildings. The UNEP-SKANSKA (2013) asserts that management represents the key to energy efficiency in SB. FM should establish an energy-use baseline as its first priority and then, if required, implement cost-effective measures to control energy use in UN (and other) facilities as much as possible. The most cost-effective measures are categorized as follows:

1. No-cost measures that are free and need little time to be implemented;
2. Low-cost measures that pay for themselves within six months; and
3. Moderate-cost measures that pay for themselves within two years.

The UNEP-SKANSKA (2013) evaluates several actions that can be used to assist FM in reducing energy costs and GHG emissions of a facility. The top 10 actions most commonly taken to monitor and reduce energy use in UN facilities are listed in Table II.11. Each of these actions receives a Why–How "WH" assessment in Table II.11, with the 'why' or predicted benefit(s) of each action, the 'how' (the means), and its relative cost. This assessment investigates the reasons, strategies, and circumstances related to the implementation of each action (UNEP-SKANSKA 2013).

Table II.11 Top Ten measures for Cost-effective Energy Use. *(UNEP-Skanska, 2013)*

Top 10 Actions	
Establishment of current energy usage by checking bills and costs (no cost)	Incorporation of energy efficiency into maintenance activities (no-cost)
Exclusion of draughts (low cost)	Increasing the energy efficiency of water heating systems (low cost)
Improvement of the efficiency of air conditioning/ventilation systems (low cost/no-cost)	Improvement of the efficiency of lighting systems (low cost)
Installing or updating loft/roof space insulation (ow cost)	Improvement of the efficiency of lighting systems (low cost)
Increasing the efficiency of space heating systems (low cost)	Use of double or triple glazed windows (medium cost)

There are several strategies for reducing the amount of energy consumed by buildings, including the use of renewable energy; co-generation technology, also known as combined heat and power (CHP); and trigeneration technology. It should be noted that renewable energy sources only become cost effective if one or more measures have been installed to reduce demand. The use of a micro wind turbine or solar photovoltaic (PV) panels represents the commitment of an organization to sustainability. It should also be noted that co-generation is used mainly when heating is the primary goal, while trigeneration technology is used in places where cooling has a greater value then heating.

Brown et al. (2010) asserted that green building strategies have been linked to occupant comfort, organizational success, the enhancement of occupant–stakeholder relations, and the improvement of the overall livability of a community (Brown et al. 2010; Heerwagen 2000). They also confirmed that occupants' workplace perspectives may increase employee productivity. Previous works have focused on workplace design from an organizational perspective. Therefore, it was necessary to link workplace design and organizational culture in the evaluation of a green building from the users' perspectives. In this respect, user perspective related to the workplace has been evaluated in the headquarters (i.e., both old and new) of an organization in Toronto, Ontario. This study used a building use studies (BUS) occupant questionnaire to investigate the user perspective in each of the HQ. Two rounds, post-move (HQ2) and pre-move (HQ1), were used for this assessment of human and environmental performance in terms of occupant perspective in relation to the workplace design, comfort, productivity, health and well-being, and building-use performance. The user perspective related to specifications improved considerably from HQ1 to HQ2. In general, the move from HQ1 to HQ2 contributed to increasing the productivity of employees. However, it was observed that 22%, 12%, 12%, and 3% of employees perceived no increase; instead, they perceived a 10%, 20%, and 30% decrease in their productivity, respectively. These results indicate that a considerable number of participants (47%) perceived a decrease in their productivity of between 10 and 30%.

Table II.12 shows the classification of papers according to the taxonomy, related research disciplines, research topics, and methods used. Taxonomy classification was conducted through a preliminary review of the articles' abstracts. This review highlighted a set of eight different disciplines (see Table II.12). This set of disciplines is coherent with an earlier classification by Nenonen et al. (2014) that categorizes FM research in respect to impact, performance, management process, special considerations, and research overview. However, the classification of journals that published the articles included in this review was carried out according to the journals' disciplines as advertised on each journal's website.

Table II.12: The different disciplines according to which we classified the papers

#	Discipline Name	Definition	Example
1	**Building performance**	Most studies focus on measuring and improving the energy performance of buildings and use energy consumption and CO2 emissions as performance measures	(Höfler et al. 2015) (Azizi et al. 2014) (Huat and Akasah 2011) (Jawdeh 2013)
2	**Sustainable tools and standers**	focus on the analysis of sustainability tools, green building indicators and certifications, especially developing tools and measurement systems or analyzing tool performance.	(Lee and Kang 2013) (Kumara 2016) (Manewa et al. 2016) (Wong 2013) (Yunging 2011)
3	**Users perceptome, satisfaction and production**	focus on the results of employee satisfaction surveys and post-occupancy evaluations of green buildings	(abdul-Rahman et al. 2014) (Okoroh et al. 2003) (Leaman and Bordass 2001) (Choi 2011)
4	**Sustainability management**	A focus on environmental aspects predominates, and a few articles specifically address the need to adapt to climate change and extreme weather events	(Lützkendorf and Lorenz 2005) (Gibberd 2015) (Jensen and Gram-Hanssen 2008) (Ihuah 2015)
5	**Constriction and sustainable building materials**	focus on individual materials but also consider building products and elements, e.g., facades, with the purpose of documenting the effect of new construction and building materials.	(Wong et al. 2009) (Gupta et al.2017) (Andrew and Dong 2017) (Muhey 2012)
6	**Building design and sustainability**	The focus is logically on buildings or design. It is typical for these articles to focus not on a specific property type but on concepts. The studies represent a combination of qualitative, theoretical and conceptual studies.	(Langevine and Allouche 2006) (Xia et al. 2008) (Becker 2008) (Eweda and Zayed 2012)
7	**Urban development**	they address cities' needs for sustainable community development, affordable housing, attractive parks, climate adaptation, risk management (natural catastrophes) and integrating sustainability aspects into sector development (energy, utility, transport, construction).	(Xia et al. 2016) (Kumaraswamy et al. 2017) (Arumsari and Rarasati 2017)
8	**Benefits of green building**	The focus varies from the building to the building and its users, a green building as workplace with a cultural context, and the general risks and benefits of going green within existing buildings, including for the building, its processes and management	(Chang et al. 2015) (UNEP-SKANSKA 2013) (Brown et al. 2010) (Amaratunga 2001)

The classification of the papers according to method and research topic is subjective by nature; therefore, content analysis was conducted to provide a more rigorous classification process (Cumbie et al. 2005). A coding form was developed to classify the papers into eight categories using a pilot study of 81 (35%) pooled papers. In the pilot study, the abstracts were read and an open-coding technique (Neuman 1997) was used to identify the set of categories used to classify the papers in respect to the method used and topic of interest. The categories developed by Nenonen et al. (2014) served as the inspiration for the development of classification categories for this research topic. The pilot study allows for identifying new categories. A total of eight classification categories were identified and used to classify the papers related to this research topic, as shown in Table II.13

Table II.13: Methodology categories.

#	Methodology Categories	Definition
1	**Case study**	Papers reporting on studies involved with a single site or a few sites often over a certain period of time.
2	**Archival**	Papers using secondary data such as public records, existing data sets and statistics
3	**Survey**	Papers that gather data by means of questionnaires
4	**Experiment**	Includes papers using either laboratory or field experiments
5	**Descriptive**	Papers solely describing or arguing for a phenomenon, often very practical-oriented
6	**Combined**	Papers using a combination of the above-mentioned categories
7	**Not mentioned**	Papers that do not mention any methods either explicitly or implicitly

II.4.2 Overview of Applied Research Techniques

II.4.2.1 *Analytic Network Process (ANP)*

The ANP is an extension and generalization of the AHP developed by Saaty (1996). The ANP uses a network rather than a hierarchical structure and allows for both the dependence and independence of criteria. It has the ability to prioritize groups or clusters and to support a complex decision-making problem with various intangible criteria (Tsai et al. 2010). Its major drawback is the ignorance of its various effects among clusters (Wang 2012). The ANP has the ability to clarify all the relationships among different factors and sub-factors by considering all the interdependencies between the factors and sub-factors while building the hierarchy. It also has the ability to decrease the gap between the model and reality. By using pairwise comparison, the ANP can achieve a higher degree of precision that helps in directing attention to a given connection at a time (Ismaeel and Zayed 2016; Elchanati and Zayed 2014).

II.4.2.2 *Fuzzy Theory (FT)*

Fuzzy Theory was first introduced by Zadeh (1965) to incorporate the imprecision and vagueness associated with data (Balmat 2011). However, fuzzy theory has proven to be an effective Multi-Criteria Decision Analysis (MCDM) technique due to its ability to handle complex decision-making for problems that have imprecise data and incomplete information. It is a flexible technique and allows for the evolution of available knowledge. However, it has been considered to be difficult to develop, and it requires testing several times before it can be used in real-world applications (Velasquez and Hester 2013). FT has been selected to model the uncertainty associated with data input. In other words, FT has the ability to simulate uncertainty in the evaluation process, as human judgment is mostly uncertain and subjective (Ismaeel and Zayed 2016; Elchanati and Zayed 2014; and Mahmoud and Zayed 2017).

II.4.2.3 *The Pugh Matrix*

The Pugh Matrix is a multi-criteria decision-making and compromise solution. This method was introduced by Stuart Pugh, who was searching for a method to determine the best alternative(s) by ranking them according to the perspective level of a set of criteria that are weighted according to their respective importance. The compromise solution obtained using the Pugh Matrix can be accepted by decision-makers because it provides maximum group utility of the "majority" and minimum individual regret of the "opponent." The main advantages of the Pugh Matrix are its consideration of the decision-making process in addition to the outcome, its utilization of criteria that are more meaningful for decision-makers than simple utilities, its production of a set of efficient compromise solutions rather than one solution, and its interactivity that assists decision-makers not only in participating but also in controlling the decision-making process. Its major disadvantage is that it has no procedure for evaluating the weights and importance levels of criteria.

Table II.14 summarizes the advantages and disadvantages of the various techniques commonly used in the process of multi-criteria decision-making. This comparison differentiates among those techniques and allows for selecting the most suitable combination of MCDM techniques for the current problem. In other words, prior to the selection of MCDM techniques, it is necessary to correctly formulate the current problem: the assessment of FM in a sustainable building from the users' perspective. The multi-attribute utility theory (MAUT) (Keeney 1977) has been the most commonly utilized MCDM method. MAUT allows for incorporating risk preferences and uncertainty into a multi-criteria decision-making support system (Loken 2007). It assigns a utility to every possible consequence and calculates the best possible utility (Konidari and Mavrakis 2007). MAUT has the ability to account for uncertainty and to incorporate the preferences of each consequence. However, its major disadvantage is that it is extremely data-extensive and requires precise input of the decision-makers' preferences.

The analytical hierarchy process (AHP), introduced by Saaty (1977) to deal with hierarchical problems, uses pairwise comparison. Rather than prescribing a definitive decision, the AHP indicates the decision that best suits the preferences of decision-makers and meets their goals. It provides a comprehensive and rational framework for solving a decision-making problem. The AHP framework illustrates the hierarchical structure of the problem, thereby allowing for the quantification of components (i.e., weights), the modeling of interrelations among criteria, the evaluation of various alternatives, and the selection of the alternative that best meets the decision-maker's goal. Despite criticism of the AHP as an exhibitor of the rank reversal effect, its use dominates that of other MCDM techniques (Mardani et al. 2015).

Case-based reasoning (CBR) was introduced by Daengdej et al. (1999) as an MCDM method that allows a specific problem to be solved based on similar cases found in a database. The application of CBR requires little effort in terms of data acquisition and requires no maintenance, as long as the database is updated. CBR can be improved over time, especially as more cases are added to the database. It is sensitive to data inconsistency, which may result in invalid responses. Data envelopment analysis (DEA) was introduced by Charnes et al. (1978). It is defined as a mathematical-programming method that provides a new way of obtaining empirical estimates of extreme relations that are a cornerstone of modern economics. DEA attempts to determine the productive efficiency of decision-making units with multiple inputs and outputs. Relative efficiency is calculated as the ratio of total weighted output to total weighted input. DEA has a number of advantages including the ability to handle multiple inputs and outputs, the capability of its analysis and its quantification of efficiency, and its ability to uncover relationships among criteria that may be hidden. The technique for order of preference by similarity to ideal solutions (TOPSIS) method was introduced by Hwang and Yoon (1981) to select the alternative that is the farthest from the negative ideal solution and closest to the positive ideal solution in a finite alternative set. TOPSIS has numerous advantages; it is simple and easy to use, it is programmable, and the number of steps is fixed regardless of the number of attributes (Ic, 2012). Its main disadvantage is that its use of Euclidean distance does not consider the correlation of attributes. TOPSIS also has difficulty in weighting attributes and maintaining a consistency of judgment in cases that involve additional attributes.

The Simple Multi-Attribute Rating SMART technique is based on a linear additive model and is considered the simplest MCDM method. It calculates an overall value of a given alternative as the total sum of the performance score (value) of each criterion (attribute) multiplied by the weight of that criterion. The ratings of alternatives are assigned directly and separately from the weighting of criteria. However, SMART cannot deal with various scales of criteria, and therefore decision-makers are requested to mathematically convert them into one common scale. Edwards and Barron (1994) introduced a simplified form of SMART called SMARTER (SMART Exploiting Ranks) that allows decision-makers to rank the criteria in order of importance and then assigns surrogate weights according to the criteria ranking (Roberts and Goodwin 2002).

Grey relational analysis (GRA), developed by Deng (1982), has been widely applied in many fields. The term "grey," interpreted here as a color, is intended to suggest the amount of known information in control theory. GRA, derived from grey-system theory, is particularly useful when dealing with poor, incomplete, and uncertain information. It is suitable for solving problems with complex interrelationships between factors and variables (Morán et al. 2006).

Goal programming (GP) was introduced by Charnes and Cooper (1961) as an extension of linear programming that allows multiple objective functions. Goal programming and linear programming are widely used to derive the weight priorities of interval preference relations. One major criticism of GP is that it can produce inefficient solutions if the target values are set too pessimistically. This has led several authors to argue against the use of GP (Zeleny, 1982) and has also led to various GP variants and extensions, such as the method developed by Hannan (1980) and the RPM, discussed in Section 3 (Wierzbicki 1982).

Simple additive weight (SAW) is the least-complicated method among the MCDM techniques. In SAW, the overall score of an alternative is determined by the weighted sum of all attribute values (Afshari et al. 2010). SAW is a common aggregation method that does not consider the different preferential ranks for each decision-maker in the assessment of alternatives. This method is considered too intuitive to achieve the consensus and commitment required for group-decision aggregation.

ELimination and Choice Expressing Reality ELECTRE was first introduced by Roy (1968) and used to select the best action(s) from a given set of actions. The method has become widely known, and various evolutions have been introduced: ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE IS and ELECTRE TRI. The major advantage of ELECTRE is that it considers uncertainty and vagueness. Its main disadvantage is that its outcomes are difficult to explain in layman's terms. In addition, due to the way preferences are incorporated, the lowest performances under certain criteria are not displayed. The outranking method results in the strengths and weaknesses of the alternatives not being identified directly or the results and impacts not being verified (Konidari and Mavrakis 2007).

The preference ranking organization method for enrichment evaluations (PROMETHEE) was introduced by Brans and Vincke (1985). It improves upon ELECTRE by using a different method for pairwise comparison. The PROMETHEE family of outranking methods includes PROMETHEE I for partial ranking of alternatives, PROMETHEE II for the complete ranking of alternatives, PROMETHEE III for interval-based ranking, PROMETHEE IV for ranking alternatives based on the continuity of viable solutions, PROMETHEE V for problems with segmentation constraints, and PROMETHEE VI for representation of the human brain (Behzadian et al. 2010). Its main disadvantages are that PROMETHEE does not provide a clear method by which to assign weights, and it requires the assignment of values but does not provide a clear method by which to assign those values.

Table II.14 Comprehensive review of MCDM Techniques.

MCDM Methods	MAUT (Keeney, 1977)	AHP (Saaty, 1980)	ANP (Saaty and Brady, 2009)	FT (Zadeh, 1965)	CBR (Daengdej et al., 1999)	DEA (Charnes et al., 1978)	TOPSIS (Hwang and Yoon, 1981)	Pugh Matrix	SMART (Olson, 1996)	GP (Charnes and Cooper, 1961)	SAW (Zionts and Wallenius, 1983)	ELECTRE (Roy, 1968)	PROMETHEE (Brans and Vincke, 1985)
Consider Uncertainty	✓			✓					✓			✓	
Incorporate Preferences	✓	✓	✓					✓	✓			✓	✓
Comprehensive	✓			✓					✓	✓			✓
Handle interdependencies			✓			✓							
Easy to use		✓	✓		✓		✓		✓	✓	✓		✓
Individual Assessment				✓									
Effective				✓				✓					
Handle Complex Problems			✓	✓		✓	✓	✓		✓			✓
Based on Similarity					✓		✓	✓					
Self-learning				✓	✓								
Consistent		✓	✓	✓			✓	✓		✓			
Expandable			✓		✓					✓			
Measure Efficiency						✓		✓					
Handle imprecise data				✓	✓			✓				✓	✓
Handle various criteria units								✓			✓		
Ranking of Alternatives	✓	✓	✓			✓	✓	✓			✓	✓	✓
Weighting of Coefficients		✓	✓			✓			✓		✓		✓
Simple computation	✓						✓	✓		✓	✓		
Handle correlation		✓	✓			✓							✓

II.4.3 Literature review findings

In this section, the findings of the literature review are presented in respect to the questions formulated in section 2: (1) How many peer-reviewed publications have been published each year? (2) How has the field evolved; which journals have published FM peer-reviewed publications? (3) Which journals have published the highest number of publications? Which authors have contributed?

II.4.3.1 *Publications and Journals*

The total number of peer-reviewed journal publications included in the literature review is 232. Figure II.5 shows the number of papers published each year from 2007 up to 2016. The largest number of published papers (36) was reached in 2011. Thereafter, the number of publications in 2012 through 2015 was 26, 18, 25, and 32 respectively. The increase in the number of SFM publications in 2011 was due to the introduction of new SFM-related journals and to growing interest in implementing SFM by developing countries.

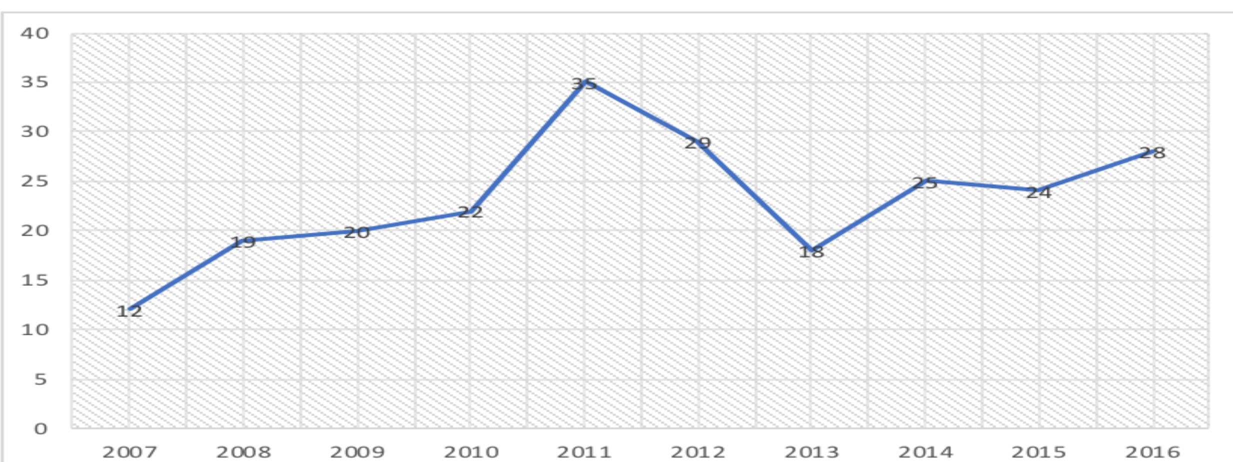


Figure II.5: Number of SFM journal publications per year.

The distribution of published SFM research papers indicates that 42 peer-reviewed journals published SFM papers from 2007 to 2016. The average number of SFM papers published in each journal and their percentage of the total number of papers over the period from 2007 to 2016 are shown in figures II.6 and II.7. The eight journals that published the most SFM papers are presented in Table II.15 and Figure II.8. Of the eight journals, three published more than 50% of the papers: *Advances in Building Energy Research* (43), *Advances in Environmental Accounting* (43) and the American Society of Civil Engineers (34). The remaining five journals each published 19 to 25 papers.

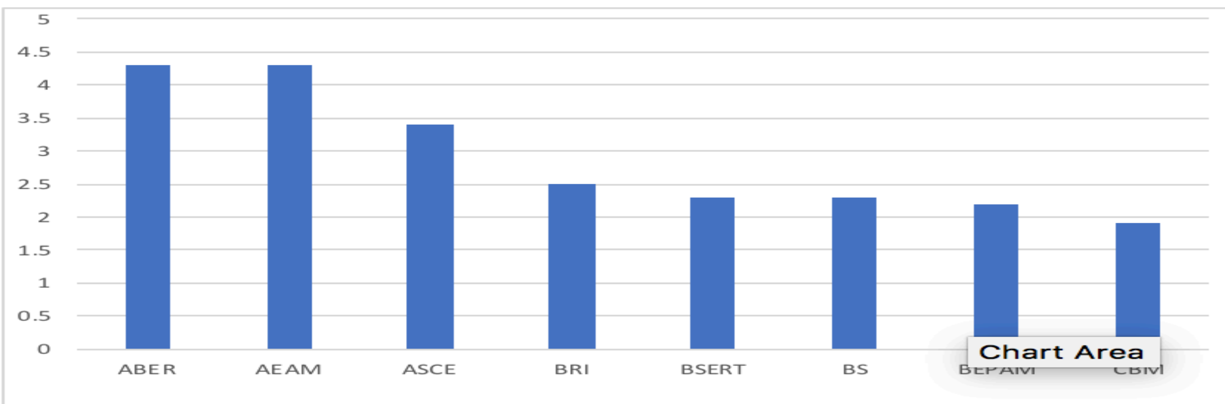


Figure II.6: Average in each publication journal over entire time.

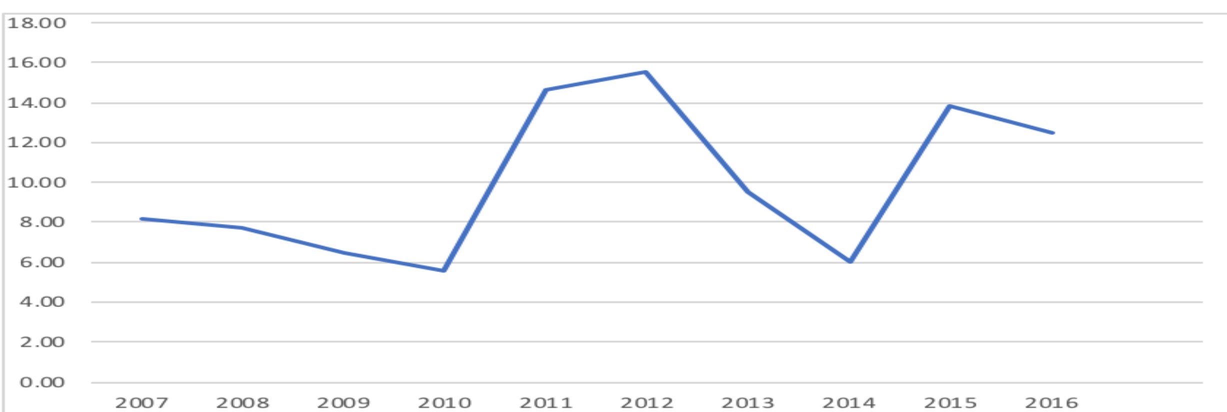


Figure II.7: Percentage average of publication for each year (2007 to 2016).

Table II.15: Publication in the ten most SFM publishing journals from 2007-2016.

#.	Journals Name		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	%	total	AV.
1	**Advances in building energy research (ABER)**	#	1	13	2	3	3	7	0	0	7	7	43	**18.53**	**42**	**19**
		%	2.3	30.2	4.7	7.0	7.0	16.3	0.0	0.0	16.3	16.3	100.00			
2	**Advances in Environmental Accounting and Management (AEAM)**	#	2	2	5	4	9	6	4	0	5	6	43	**18.53**		
		%	4.7	4.7	11.6	9.3	20.9	14.0	9.3	0.0	11.6	14.0	100.00			
3	**American Society of Civil Engineers (ASCE)**	#	0	0	0	0	7	6	8	0	5	8	34	**14.65**		
		%	0.0	0.0	0.0	0.0	20.6	17.6	23.5	0.0	14.7	23.5	100.00			
4	**Building research and information (BRI)**	#	0	0	2	0	3	5	3	4	5	3	25	**10.77**		
		%	0.0	0.0	8.0	0.0	12.0	20.0	12.0	16.0	20.0	12.0	100.00			
5	**Building services engineering research & technology (BSERT)**	#	13	1	1	2	3	0	1	0	1	1	23	**9.91**		
		%	56.5	4.3	4.3	8.7	13.0	0.0	4.3	0.0	4.3	4.3	100.00			
6	**Building simulation (BS)**	#	1	0	3	2	4	0	1	5	5	2	23	**9.91**		
		%	4.3	0.0	13.0	8.7	17.4	0.0	4.3	21.7	21.7	8.7	100.00			
7	**Built Environment Project and Asset Management (BEPAM)**	#	1	1	1	0	2	11	0	3	1	2	22	**9.48**		
		%	4.5	4.5	4.5	0.0	9.1	50.0	0.0	13.6	4.5	9.1	100.00			
8	**Construction & building materials (CBM)**	#	1	1	1	2	3	1	5	2	3	0	19	**8.18**		
		%	5.3	5.3	5.3	10.5	15.8	5.3	26.3	10.5	15.8	0.0	100.00			
Sum			**19**	**18**	**15**	**13**	**34**	**36**	**22**	**14**	**32**	**29**	**232**	**100**		
%			**8.19**	**7.76**	**6.47**	**5.60**	**14.66**	**15.52**	**9.48**	**6.03**	**13.79**	**12.50**				
Average %			**10.00**													

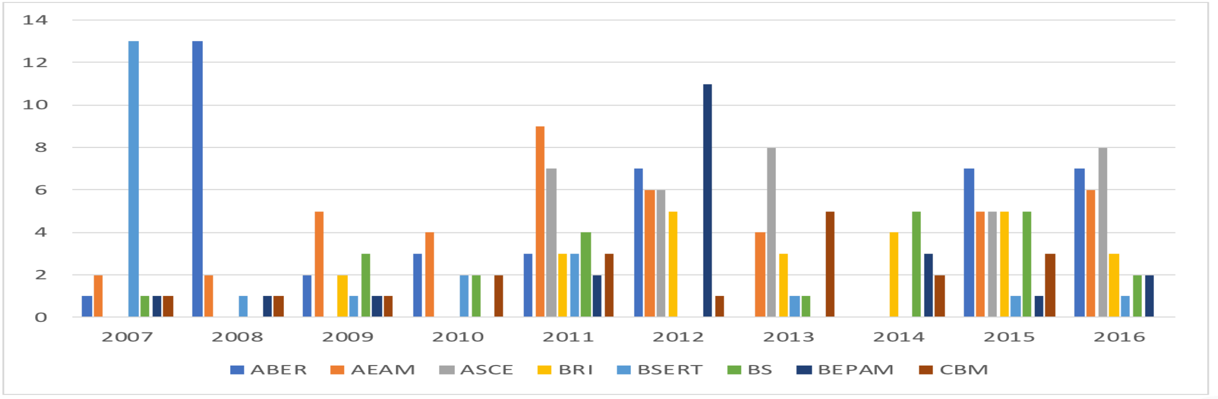


Figure II.8: Journals over time.

II.4.3.2 *Research Topics*

The research focusing on SFM addresses eight different research topics as follows: building performance (BP), sustainable tools and standers (S&S), users perceptome satisfaction and production (US&P), sustainability management (SM), constriction and sustainable building materials (C&SBM), building design and sustainability (BD&S), urban development (UD), and benefits of green building (BGB). Sustainable facility management (SM), building performance (BP), users perceptome satisfaction and production (US&P), and sustainable tools and standards (S&S) are those that have contributed the most to the discipline, as shown in Table II.16 and Figure II.9, which received 18.1%, 13.79%, 13.36% and 12.9% of the papers respectively, as shown in Figure II.10.

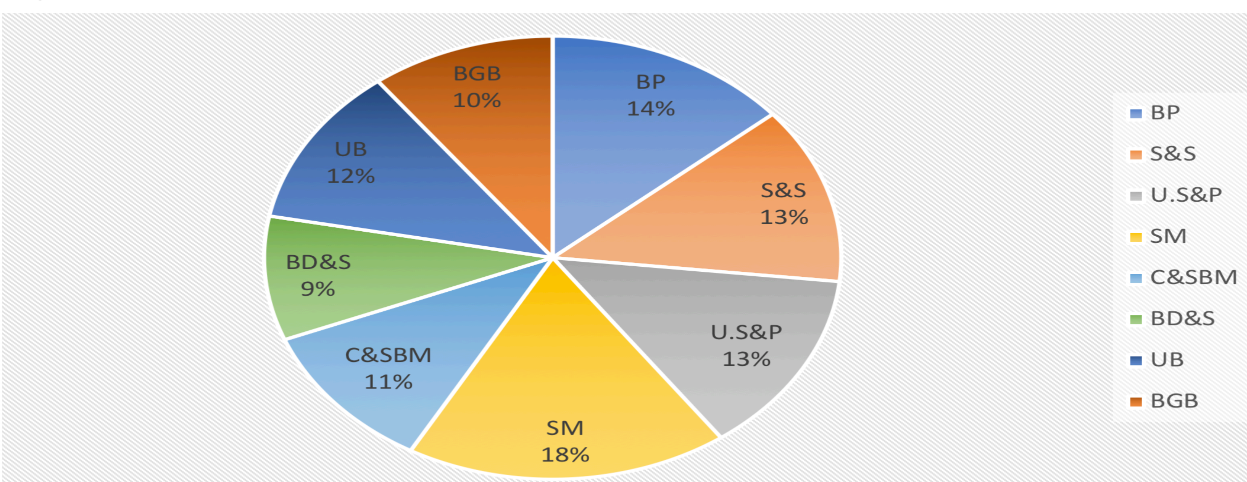


Figure II.10: Percentage of papers published in different disciplines over 10 years (2007 to 2016).

Table II.16: Number of papers in each discipline over time.

#	Topics		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Tota l	%
1	**Building Performance (BP)**	#	2	1	1	6	7	0	1	2	8	4	32	14
		%	*6.2*	*3.1*	*3.1*	*18*	*21*	*0.0*	*3.1*	*6.2*	*25*	*12*	*100*	
2	**Sustainable tools and standers (S&S)**	#	0	5	4	5	4	2	2	1	5	2	30	13
		%	*0.0*	*16.*	*13*	*16*	*13*	*6.6*	*6.6*	*3.3*	*16*	*6.6*	*100.*	
3	**Users perceptome, satisfaction and production (U, S&P)**	#	3	4	6	3	1	4	0	6	1	3	31	13
		%	*9.6*	*12*	*19*	*9.6*	*3.2*	*12*	*0.0*	*19*	*3.2*	*9.6*	*100*	
4	**Sustainability management (SM)**	#	3	2	3	1	8	4	5	5	4	7	42	18
		%	*7.1*	*4.7*	*7.1*	*2.3*	*19*	*9.5*	*11*	*11*	*9.5*	*16*	*100*	
5	**Constriction and sustainable building materials (C&SBM)**	#	0	0	1	5	6	4	3	2	0	4	25	11
		%	*0.0*	*0.0*	*4*	*20*	*24*	*16*	*12*	*8.0*	*0.0*	*16*	*100*	
6	**Building design and sustainability (BD&S)**	#	0	2	2	0	3	6	3	2	2	1	21	9
		%	*0.0*	*9.5*	*9.5*	*0.0*	*14*	*28*	*14*	*9.5*	*9.5*	*4.7*	*100*	
7	**Urban development (UD)**	#	3	5	1	2	1	3	1	5	0	6	27	12
		%	*11*	*18*	*3.7*	*7.4*	*3.7*	*11*	*3.7*	*18*	*0.0*	*22*	*100*	
8	**Benefits of green building (BGB)**	#	*1*	*0*	*2*	*0*	*5*	*6*	*3*	*2*	*4*	*1*	*24*	10
		%	4.1	0.0	8.3	0.0	20	25	12	8.3	16	4	100	
Sum.			12	19	20	22	35	29	18	25	24	28	232	100

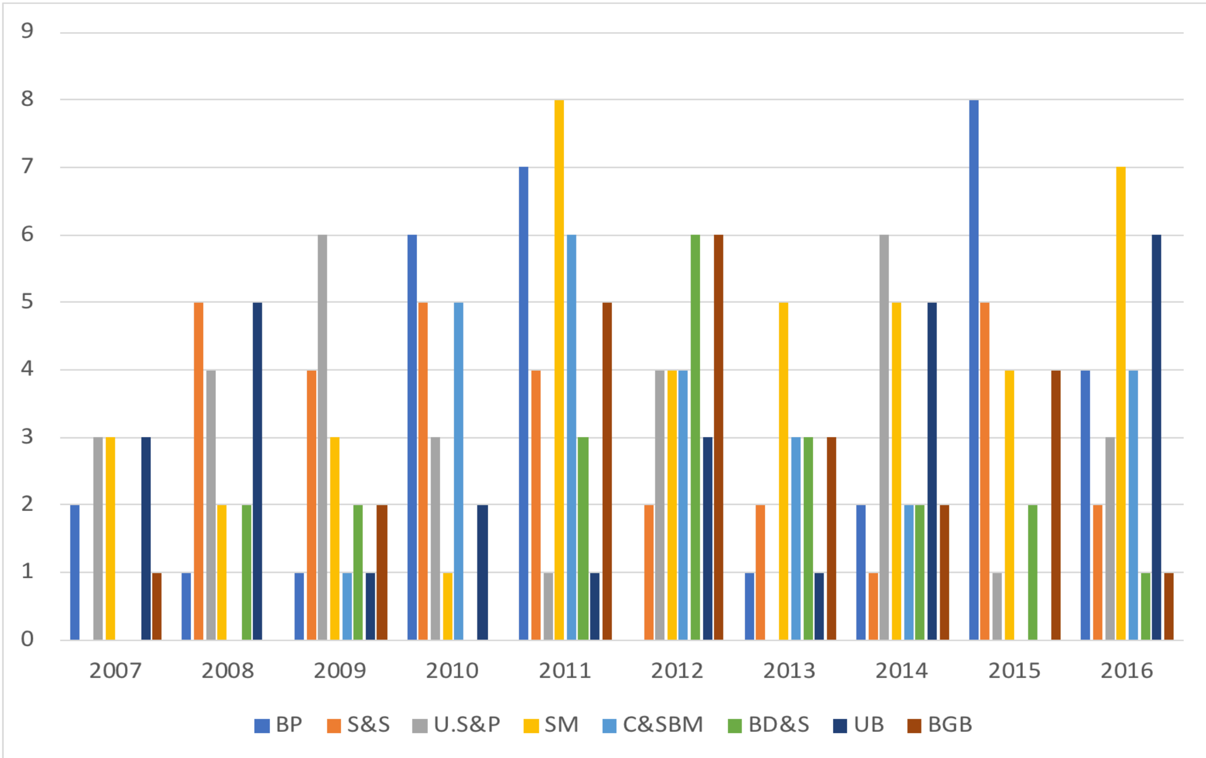


Figure II.9: Discipline over time (Numbers).

II.4.3.3 Research Methods as Regards Methods Used

Several classification methodologies were used in SFM articles published from 2007 to 2016. Most of these publications' methodologies can be classified into six categories as shown in Figure II.11: case studies, archival, surveys, experiments, descriptive, and combined, as well as unclassified or no method. The largest category of publication was classified as case studies (23.71%), followed by archival (17.24%), experiments (16.38%), and a combination of different methods (15.95%), and then surveys (11.64%), descriptive (10.78%), and unclassified (4.31%), as shown in Figure II.11 and Table II.17.

The use of classification methods has changed over time, with the most remarkable change taking place in the “case study(ies),” “survey,” and “experiment” categories, as shown in Figure II.11. It was noted that in 2007 and 2013, only 1.82% of the published papers utilized the case study method, but in 2010, that percentage rose to 16.36% and averaged 15% during the period from 2014 to 2016. Similarly, from 2007 to 2013, 7.41% (or even fewer) papers utilized survey data, whereas in the period 2015 to 2016, this percentage increased to 18%. The percentage of published papers that used experimental data in 2007 and 2009 was 8%, a percentage that increased in the period from 2013 to 2016 to 10% (please refer to Table II.17 and Figures II.12 and II.13).

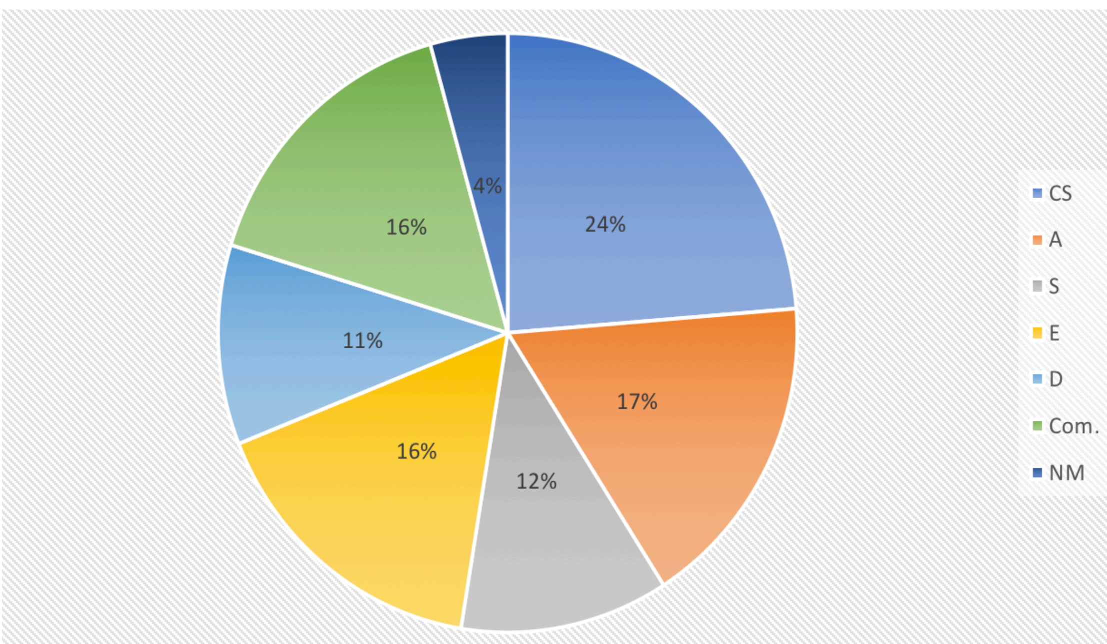


Figure II.11: Percentage of papers based on different methods.

Table II.17: Research methods over time.

#	Methodology Categories		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	%
1	**Case study(ies) (CS)**	**#**	1	5	4	9	4	7	1	9	7	8	55	**23.70**
		%	1.82	9.09	7.27	16.36	7.27	12.73	1.82	16.36	12.73	14.55	100	
2	**Archival (A)**	**#**	2	5	4	1	5	6	4	3	7	3	40	**17.24**
		%	5.00	12.50	10.00	2.50	12.50	15.00	10.00	7.50	17.50	7.50	100	
3	**Survey (S)**	**#**	2	1	2	2	2	2	2	3	6	5	27	**11.63**
		%	7.41	3.70	7.41	7.41	7.41	7.41	7.41	11.11	22.22	18.52	100.00	
4	**Experiment (E)**	**#**	3	4	3	4	2	3	6	4	6	3	38	**16.37**
		%	7.89	10.53	7.89	10.53	5.26	7.89	15.79	10.53	15.79	7.89	100.00	
5	**Descriptive (D)**	**#**	2	0	3	3	5	0	2	3	4	3	25	**10.77**
		%	8.00	0.00	12.00	12.00	20.00	0.00	8.00	12.00	16.00	12.00	100.00	
6	**Combined (Com.)**	**#**	2	5	3	4	4	1	4	5	3	6	37	**15.94**
		%	5.41	13.51	8.11	10.81	10.81	2.70	10.81	13.51	8.11	16.22	100.00	
7	**Not mentioned (NM)**	**#**	1	1	0	1	2	1	0	1	2	1	10	**4.31**
		%	10.00	10.00	0.00	10.00	20.00	10.00	0.00	10.00	20.00	10.00	100.00	
Total			**13**	**21**	**19**	**24**	**24**	**20**	**19**	**28**	**35**	**29**	232	**100**

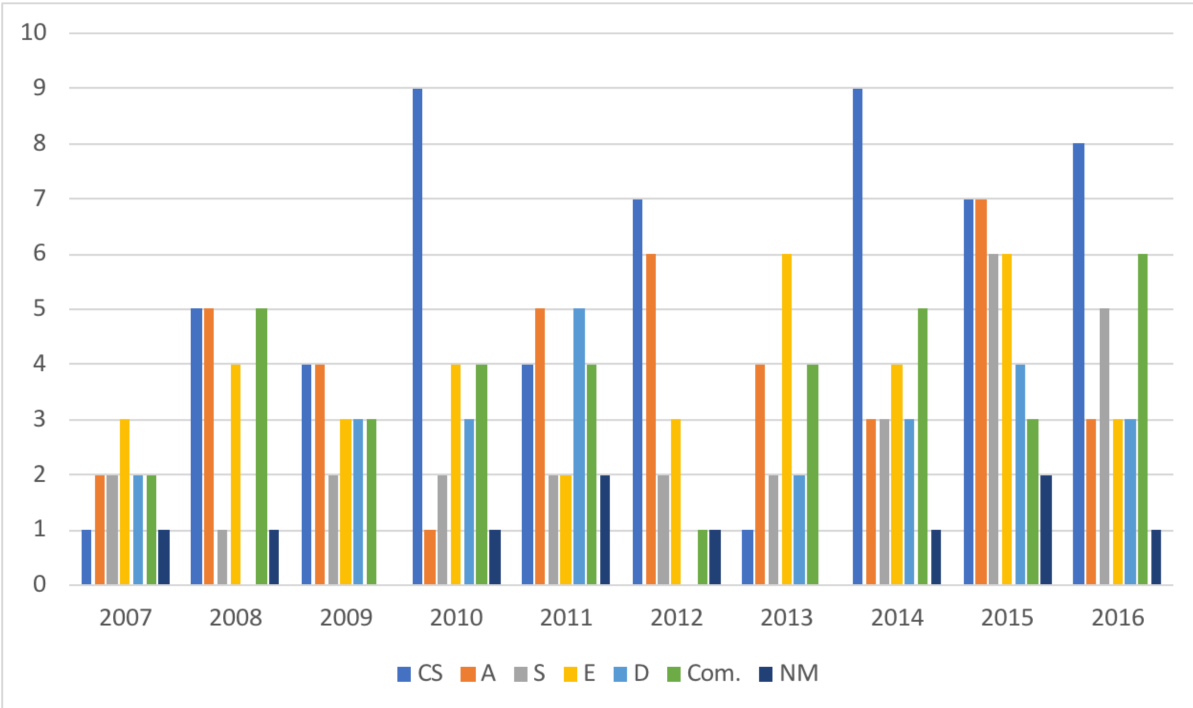


Figure II.12: Methods over time (numbers).

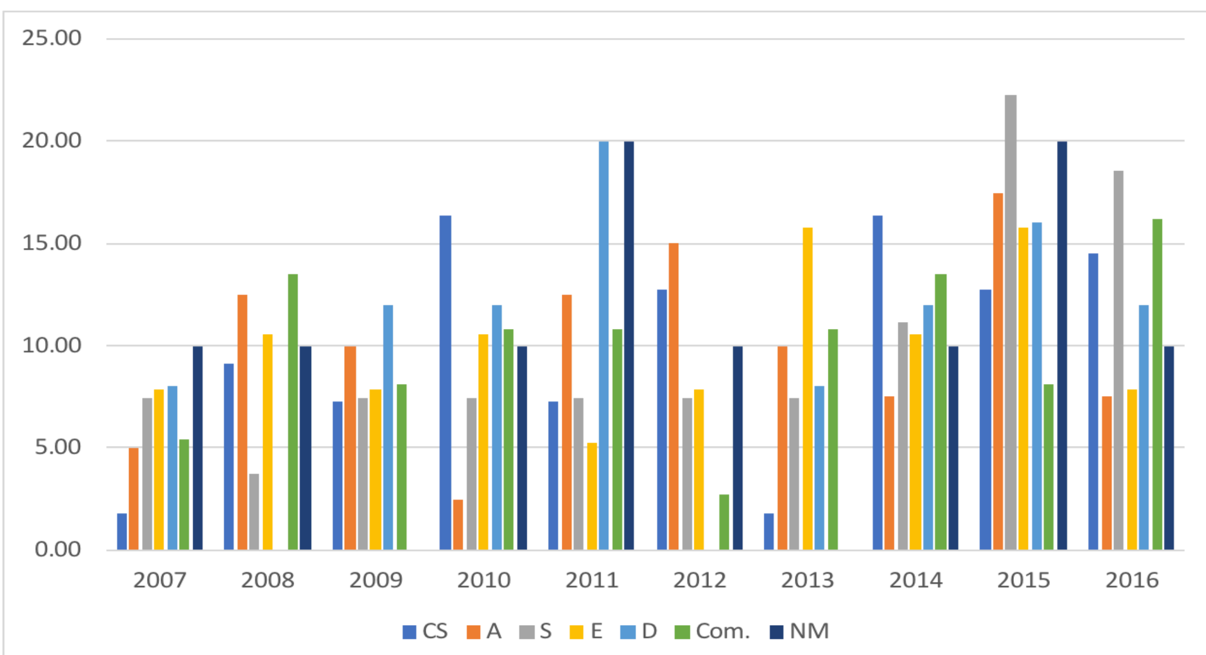


Figure II.13: Methods over time (Percentage).

II.5 THE LIMITATIONS OF FACILITY MANAGEMENT WITHIN USERS' PERSPECTIVES IN SUSTAINABLE BUILDINGS

Social, environmental, and economic aspects reliably indicate the successful integration of sustainability into a building's management system. The goal of sustainability can be achieved only after a comprehensive understanding of the interrelationship between the environment and users' satisfaction in sustainable buildings.

Most of the sustainable FM research (Che-Ani et al. 2010; Waly and Helal 2010; Jensen et al. 2009) have limitations that hinder their effectiveness and usefulness. These limitations include but are not limited to the following: a lack of the optimum selection of user-satisfaction indicators, the non-identification of users' needs, the non-consideration of the variations in users' needs, ineffective modeling of the complexity associated with user satisfaction, and unaddressed difficulties associated with the development of weighting schemes and measurement scales. However, many research studies have discussed and analyzed the limitations associated with meeting users' needs efficiently (Ding 2008; Khalil and Nawawi 2008; Meir et al. 2009).

As stated earlier, incorporating user-satisfaction assessment tools at an early stage (e.g., in a feasibility study) facilitates the implementation of users' satisfaction-based SFM at later stages of a project. However, such assessment is usually conducted only after design completion (Crawly and Aho 1999). In this regard, the incorporation of user satisfaction must include early intervention with users' needs and utilizing a design tool that allows early collaboration among designers and facility managers (Junghans and Olsson 2014). Delays or later alterations in considering users' needs may incur excessive costs, inconvenient implementation, environmental damage, unnecessary natural-resource consumption, and high maintenance or remedial costs (Ventovuor et al. 2007; Okoli and Schabram 2010).

Existing FM methods evaluate the sustainability of buildings from an organizational perspective and neglect the user's perspective (Edward 2006; Noor and Piee 2009; Vanier 2000). Furthermore, the factors affecting the evaluation of building sustainability from the user's perspective are yet to be identified, evaluated, and incorporated into an upgraded framework that guides the updating of conventional buildings into sustainable ones. Incorporating the user's needs in the evaluation and upgrading frameworks depends upon the type of building (e.g., commercial, academic, or residential) as well as on a wide spectrum of aspects such as indoor environmental quality (IEQ), the functional aspects of space, energy efficiency, and others. Indoor environmental quality aims to provide occupants with good air quality, a minimum amount of daylight and views, and pleasant acoustic conditions. IEQ also provides for an efficient control system that allows occupants to have control over their lighting as well as their thermal comfort. The functional aspects of space measure the accessibility and ratio of space in terms of the number of occupants. In a way, IEQ and functional aspects are correlated; however, their importance from the user perspective differs from one building to another. Therefore, the assessment procedure should consider the user perspective in a dynamic manner that allows for the customizing of the sustainability-assessment criteria for each building type while preserving key assessment criteria and attributes (Isa et al. 2016; Andersen et al. 2012).

A significant number of studies have focused on assessing the role of FM in sustainable buildings from different perspectives, including energy efficiency (Wisner et al. 2006; Dixit et al. 2016; Chotipanich and Lertariyanun 2011), GHG emissions (Patrick et al. 2014; Wilkinson and Reed 2006), and economic performance (Grussing and Marrano 2007; Grussing 2013). Considerably less work has focused on FM in sustainable buildings from the user perspective, and none of these works considered building types and their effects on the user-satisfaction assessment procedure.

A sustainability rating is a measure of three major aspects: economic, ecological, and social; however, the current rating tools (e.g., BREEAM, HK-BEAM, LEED, and BEPAC) do not consider users' needs or satisfaction in their assessment frameworks (Paula et al. 2017; Hodges 2005; Kumara et al. 2016; Aaltonen et al. 2013). It should be noted that the primary objective of any project is to satisfy the end users as well as the owners. Only a few studies have dealt with user satisfaction in a general way that identifies the special needs of a sustainable-building type to achieve a high level of user satisfaction (Gopikrishnan and Paul 2017; Grum 2017; Babatunde and Perera 2017; Hebert 2012; Lai and Lai 2013; Thomsen et al. 2013). However, such assessment procedures are inefficient and incapable of achieving the goal of sustainability in respect to user satisfaction in various types of buildings. Due to their variability, different sets of characteristics distinguish each type of building from another; these include thermal comfort, air quality, aesthetics, amenities, and upkeep as well as individual control over windows, blinds, and temperature.

In addition, the majority of existing rating systems cover sustainable buildings without considering the architectural factors that affect user satisfaction since the analysis data are based on internal factors such as indoor air quality (IAQ), temperature, and lighting (Wu and Low 2010; Chokor et al. 2015; Deniz 2017). Several studies analyze user satisfaction utilizing questionnaire methods without considering the uncertainty associated with the different interpretations of respondents or the accuracy and/or reliability of their responses (Gou and Lau 2013; Driza and Park 2014; Talib et al. 2013; Lo et al. 2014; Ali and Alfalah 2010). Furthermore, the majority of the evaluation processes focus on sustainability from organizational, operational, and economic perspectives and omit the user satisfaction perspective (Kyrö and Junnila 2012; Alwaer and D.J 2010).

Furthermore, analysts of SFM have an extraordinary opportunity to increase the value of an organization's sustainability agenda. More work needs to be done on sustainability agendas in organizations to allow them to manage similar critical issues such as staff productivity, adaptable working conditions and hours, and even biodiversity. By most accounts, a significant part of the emphasis today is on efficient or wasteful administration and reuse and carbon impression. One explanation could be that FM associations expect a consistent approach (Holton et al. 2010), and consequently, they emphasize supportability arrangements and obligations.

Interestingly, legislation is viewed as a key element for encouraging facilities to apply practical, sustainable practices. Thus, more and better-coordinated work towards sustainable legislation combined with the enactment powers of associations and diverse facilities would encourage the adoption of reasonable (especially cost-effective) sustainable-building measures, both in new buildings and in building upgrades. For example, consistently fixing the enactment of the carbon outflow-related issues would require building managers to progressively take responsibility for carbon discharges (Shah 2007; Holton et al. 2010). Enactment is the key driver, especially now that legislative bodies are expanding pressure on associations to agree to administrative structures (KPMG 2008), particularly in terms of the administration of carbon outflows. The logical (and desired) outcome will be for office-administration systems to continue to emphasize controlled ecological perspectives such as carbon outflow, carbon impression, and vitality utilization (Sioshansi 2011), neglecting the adjusted approach that over-analyzes the more extensive social aspects of manageability.

II.6 SUMMARY

According to the literature review, various issues hinder the efforts to achieve an accurate assessment of the level of user satisfaction in sustainable buildings. The most crucial issues are related to differences in building types, such as thermal comfort and air quality; aesthetics; amenities and upkeep; individual control over windows, blinds, and temperature; design and flexibility; and lighting and acoustics. Briefly, as illustrated in this literature review, some issues are regarded as limitations for both the existing rating systems and for the developed research, as summarized in the following points.

Worldwide, a large number of rating systems assess sustainability, but there is no unified concept or definition of user perspective that can be utilized to express the key aspects of user satisfaction. Hence, when a single building is assessed using a sustainability rating tool, some degree of user dissatisfaction will result. This dissatisfaction can be attributed to the rating system, as it does not take the user's needs into consideration after the building has been occupied.

To date, no rating system for sustainable building considers the dynamism and the importance of the assessment of the attributes of user perspective. Therefore, all the assessment attributes are deemed to have a constant weight regardless of the variations of different building types, i.e., the importance of acoustics in an academic building differs from its importance in other types of buildings, such as industrial buildings. Furthermore, the weighting system for user perspective is vague in most of the existing studies, which results in a lack of transparency and consistency. Thus, there is an urgent need to introduce a dynamic weighting scheme for the user perspective to express its importance according to building type.

Sustainability involves an integration of environmental, economic, and social aspects. However, some sustainable buildings do not consider the social aspects in their building's assessment. A building designed according to environmental aspects exclusively may be "green," but it cannot be truly sustainable. In addition, many sustainable buildings do not take the whole life-cycle approach into consideration, which means assessing the building throughout its entire life span beginning with the feasibility study, design stage, and construction and moving onto the operational and maintenance phase, including user satisfaction, and its eventual re-use or demolition/disposal.

Most of the studies of sustainable buildings do not provide decision-makers with a sustainability-based rehabilitation model with which to improve the sustainability of their buildings to meet their users' satisfaction. This model is crucial to the concept of user perspective itself, as not all alternatives that can improve user perspective are affordable. Indeed, only those options that increase user satisfaction and comply with time and cost limitations can be considered sustainable. Therefore, establishing a user-perspective model that can provide decision-makers for facilities management with a group of affordable alternatives for improving their building's sustainability from their users' perspectives would thus be quite valuable.

Chapter III: RESEARCH METHODOLOGY

III. 1. CHAPTER OVERVIEW

As illustrated in the previous chapter, a sustainable building presents a significant impact on users' satisfaction, productivity and health. Moreover, the operation and maintenance stage in the sustainable building life cycle has the highest impact on the users' perspective compared to the other stages. The only way to mitigate these impacts on users that occupy sustainable buildings is to adopt the users' perspective concept. The design of these buildings considers many aspects that help to decrease their negative impacts by achieving healthier built environments, including reducing users' perspective hazards (i.e. assuring thermal comfort and air quality, considering aesthetics, amenities and upkeep, design and flexibility...etc.).

The main objective of this chapter is to propose a methodology to establish a generic rating system for the users' perspective in sustainable buildings. This chapter will also introduce various aspects such as: 1) the variation of building aspects from one type of building to another, and which can significantly affect the evaluation process; 2) integration of the main assessment attributes that affect building sustainability; 3) establishing a user's perspective scale with which to apply a user's perspective measurement in sustainable buildings, depending upon building type; and 4) proposing a re-assessment of a users' perspective model based on sustainability to help decision makers in selecting the best options to achieve a higher degree of users' perspective within a predefined budget and timeframe.

III.2. DETAILED RESEARCH METHODOLOGY

A number of factors affect FM in sustainable buildings. The first challenge is to identify all the factors and sub-factors that affect the FM assessment procedure from a user's perspective. Twenty-one criteria have been identified and grouped into four groups: 1) Thermal comfort and air quality; 2) Aesthetics, amenity and upkeep; 3) Design and flexibility; and 4) Lighting and acoustics. This division illustrates the criteria that affect the users' perspective in regards to four attributes (i.e. Group of factors). Considering this structure, the assessment of user perspective in sustainable buildings represents a single-objective (i.e. Goal) decision making problem: Maximizing the user perspective.

Maximizing the user perspective in sustainable buildings requires the selection of one or more multi-criteria decision-making techniques that satisfy the following problem-dependent criteria:

1. Allows for the weighting of criteria and sub-criteria;
2. Allows for modelling the interrelations among criteria and sub-criteria;
3. Provides a set of solutions instead of one solution;
4. Handles imprecision and ambiguity in the input values; and
5. Allows the assessment of various alternatives.

By considering the aforementioned criteria, the developed method shown in Figure III.1 integrates the fuzzy set theory (FST) to model the uncertainty associated with data input. In this respect, FST collects the importance factor of each criterion from the perspective of each user. It is also used to collect the relative perspective weights of each sub-criterion in respect to each criterion. It integrates the analytic network process (ANP) that allows for the modelling of the interrelations of criteria and of users' feedbacl. Based on interrelations and feedback, the ANP allows the calculation of the overall importance of criteria and of the overall perspective level of each sub-criterion.

Finally, the developed method utilizes a Pugh Matrix for ranking the possible solutions (i.e. alternatives) and to identify the solution that maximizes the user perspective based on the importance factors of the criteria and the perspective level of sub-criteria calculated using the ANP. Considering that information, the developed method integrates fuzzy set theory (FST) with the analytic network process (ANP) and multi-criteria optimization and compromise solutions (Pugh Matrix). Figure III.1 shows the framework of developed method for evaluating the user perspective in respect to FM in sustainable building.

III.2.1. Identification of Users' Perspective Assessment Attributes

Comparisons and integrations were performed based on the literature review (described in the next chapter), resulting in four factors. These factors will be considered the primary attributes that have a significant influence on users' perspective in sustainable buildings: 1) Thermal comfort and air quality; 2) Aesthetics, amenity and upkeep; 3) design and flexibility; and 4) lighting and acoustics. Each criterion comprises a factor, used to subdivide and assess each criterion in different aspects.

III.3 ASSESSMENT OF FM IN SUSTAINABLE BUILDINGS FROM THE USERS' PERSPECTIVE:

The users' perspective model developed to assess the users' perspective in sustainable buildings was assessed according to a developed users' perspective scale. Figure III.1 shows that the development methodology consists of four phases: 1) Model Development, 2) Assessment of User perspective, 3) Upgrading of Sustainability and 4) Post-upgrading assessment.

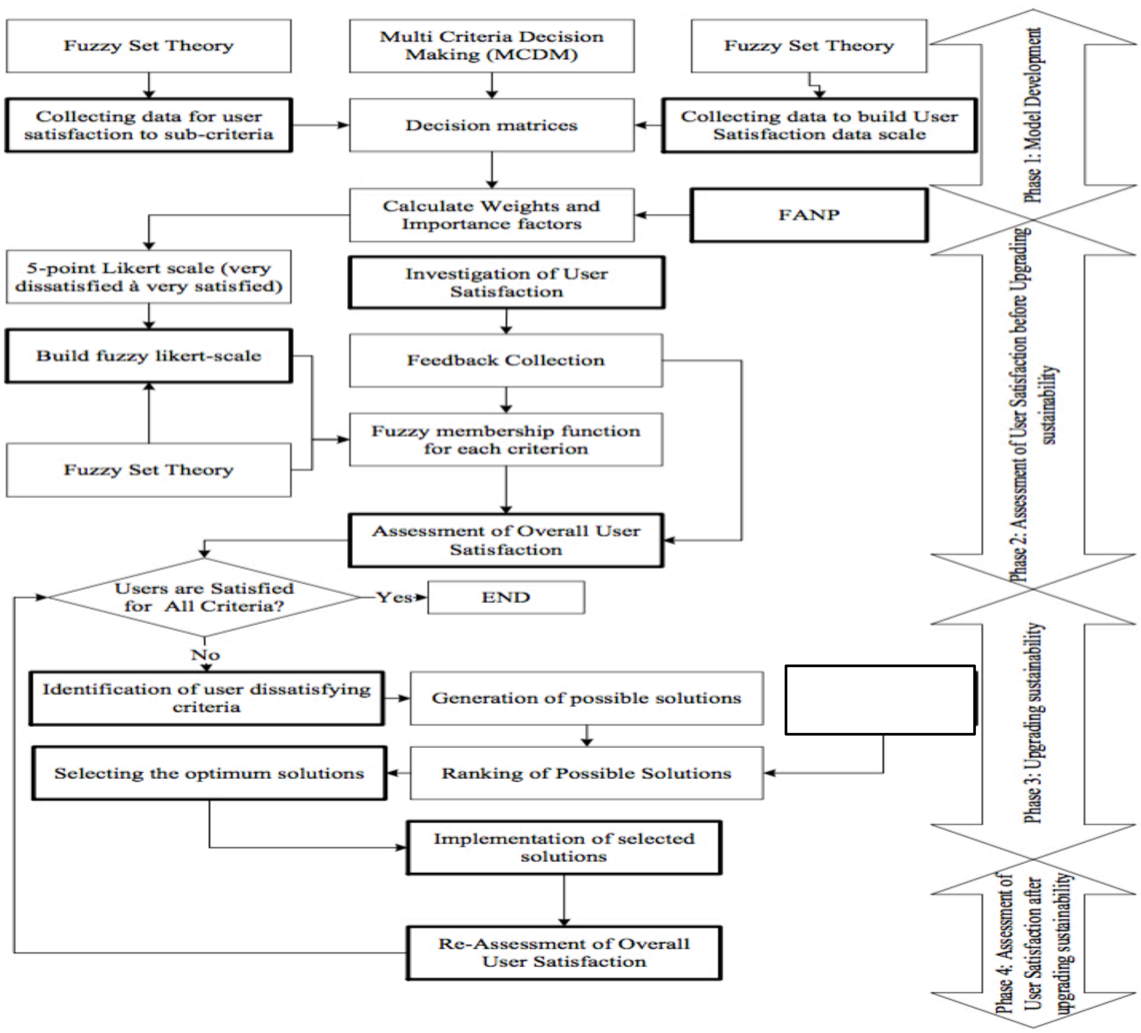


Figure III.1 Framework of the developed Method.

III.4. MODEL DEVELOPMENT FOR SUSTAINABLE EDUCATION BUILDINGS

As shown in figure III.2, the model development phase consists of three steps: 1) calculation of the relative weights of criteria and sub-criteria; 2) development of a user perspective scale for building sustainability, criteria and sub-criteria; and 3) database development.

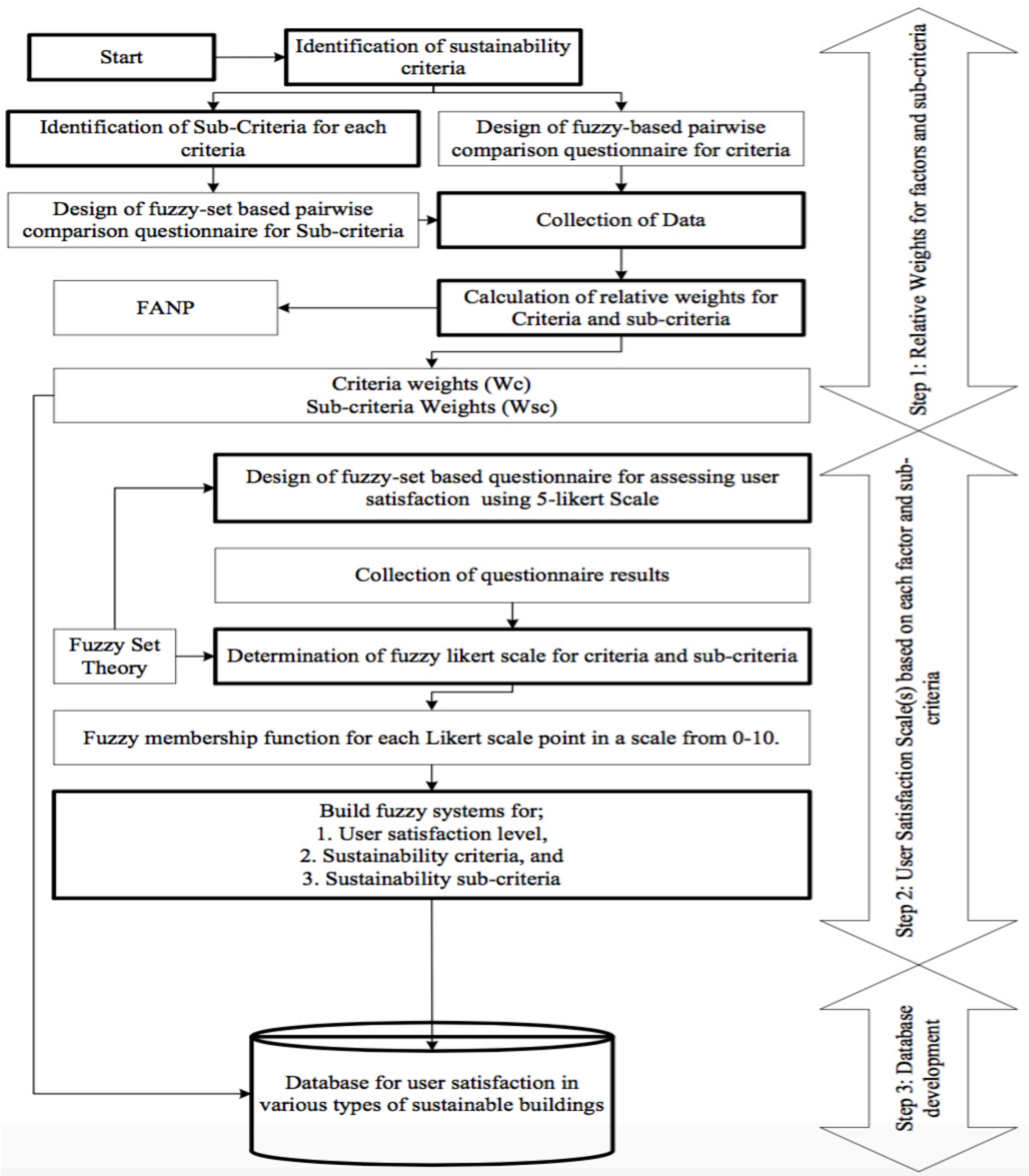


Figure III.2 Model Development for each type of sustainable building.

III.4.1. Calculation of the Relative Weights of Factors and Sub-factors

In this step, N number of criteria "i" and ni number of sub-criteria "k" associated with each sub-criterion are identified from the literature and from interviews with sustainability experts and FM personnel. After the identification of the criteria and their respective sub-criteria, two sets of fuzzy-based questionnaires (Appendices A and B) are distributed among experts in sustainability and FM to evaluate the importance of each criteria and sub-criteria from the sustainability perspective as well as from a FM perspective. Each expert "j" is requested to evaluate the importance of each sub-criterion in respect to their parent criterion using a fuzzy set-based pairwise comparison using a 3-state importance scale: less important (LI), equally important (EI) and more important (MI). Each state is represented by a fuzzy membership function. Figure III.3 shows an example of this 3-state fuzzy membership function that can be used to evaluate the relative importance of each sub-criterion in respect to their parent criteria.

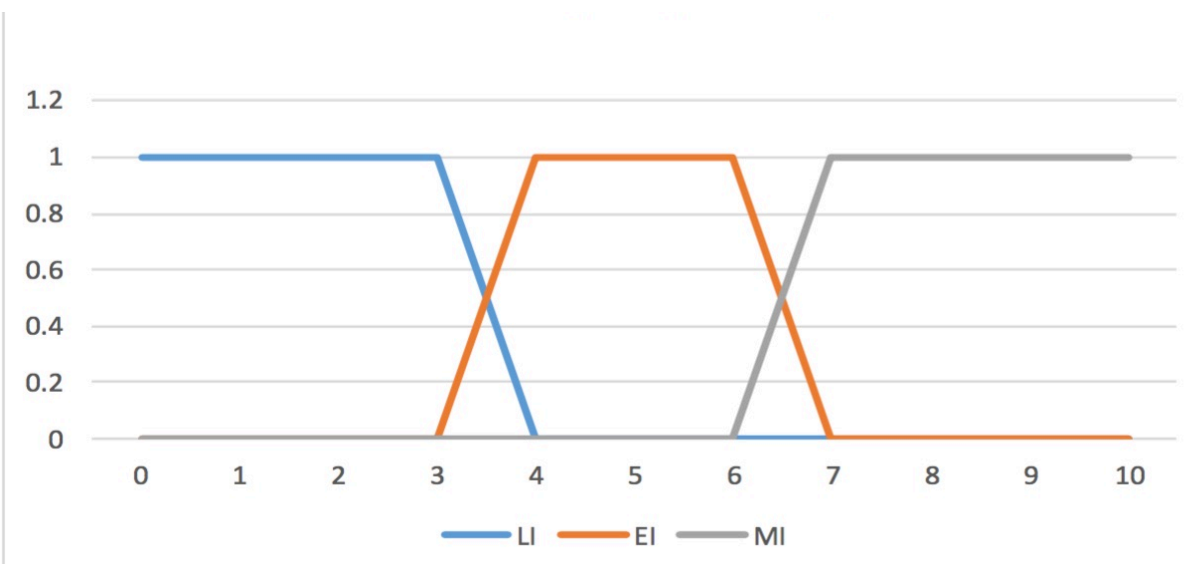


Figure III.3 Example of a 3-state membership function.

It should be noted that the fuzzy expert system (FES) is organization-dependent, which means that each organization builds their own FES based on their sustainability practices. Figure III.4 shows an example of a 5-state Fuzzy membership function, with the 5 states delineated as: Not Important (NI), Less Important (LI), Equally Important (EI), More Important (MI) and Extremely Important (EI). Similar pairwise comparisons are made by experts and FM practitioners to evaluate the importance of criteria in respect to the users' perspective.

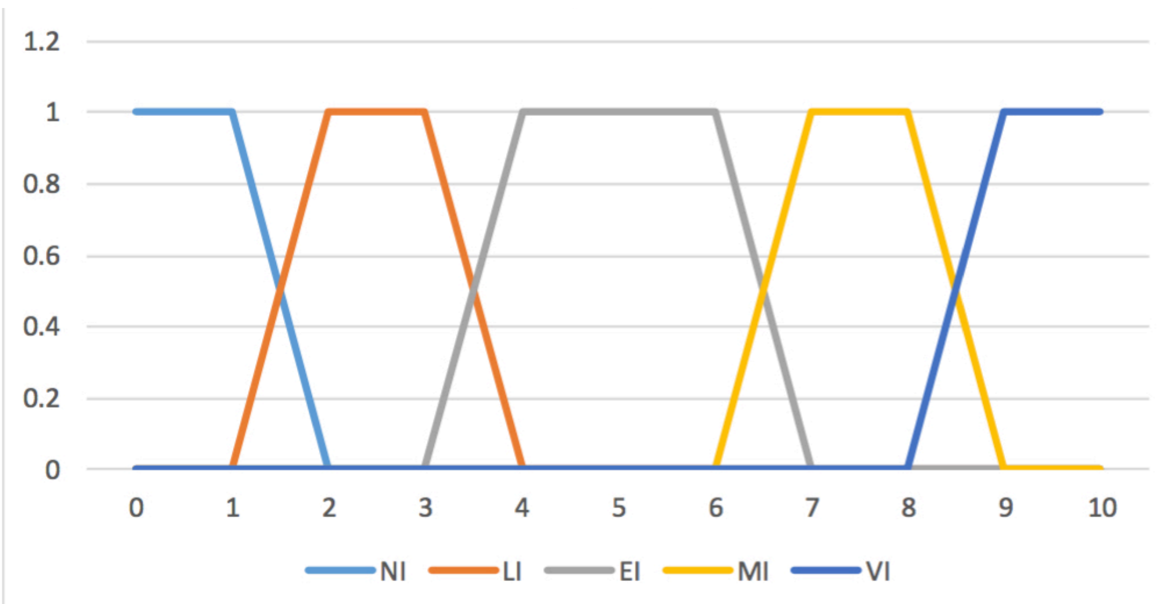


Figure III.4 Example of 5-state membership function.

After the pairwise comparison, a set of matrices that reflect the experts' opinions in respect to criteria and sub-criteria is generated, as shown in equation (III-1):

$$\tilde{A} = \begin{pmatrix} \widetilde{c_{11}} & \cdots & \widetilde{c_{1m}} \\ \vdots & \ddots & \vdots \\ \widetilde{c_{m1}} & \cdots & \widetilde{c_{mm}} \end{pmatrix} \qquad \text{(III-1)}$$

The fuzzy analytic network process (FANP) is then used to calculate the fuzzy importance factor (IFc) of each criterion (c) and the weight (Wsc) of each sub-criterion (sc). After each of the matrices has been resolved, the output of this step is two vectors that represent the fuzzy importance factors and the fuzzy weights of the criteria and sub-criteria, respectively. These importance factors and weight vectors are shown below as equations (III-2) and (III-3):

$$\tilde{C} = [\widetilde{IF}_{c1} \quad \dots \quad \widetilde{IF}_{cN}] \qquad \text{(III-2)}$$

$$\widetilde{SC}_i = [\widetilde{W}_{Sc,1} \quad \dots \quad \widetilde{W}_{Sc,n_i}] \qquad \text{(III -3)}$$

where

C represents the vector of importance factor (IF) of criteria (c);

SCi represents the vector of sub-criteria weights in respect to criteria “i”;

N represents the number of criteria; and

ni represents the number of sub-criteria in respect to criteria “i”.

III.4.2. Development of a User Perspective Scale for Building Sustainability Factors and Sub-factors:

In this step, fuzzy experts’ systems will be generated using the opinions of experts and FM practitioners to represent the user perspective criteria in respect to each factor and sub-factor. In other words, this process discovers the circumstances in which a user will be considered satisfied in respect to each factor. Figure III.5 shows an example of a 5-state fuzzy system that reflects temperature comfort and indicates how the generated fuzzy systems represent the user’s perspective in respect to each criterion and sub-criterion.

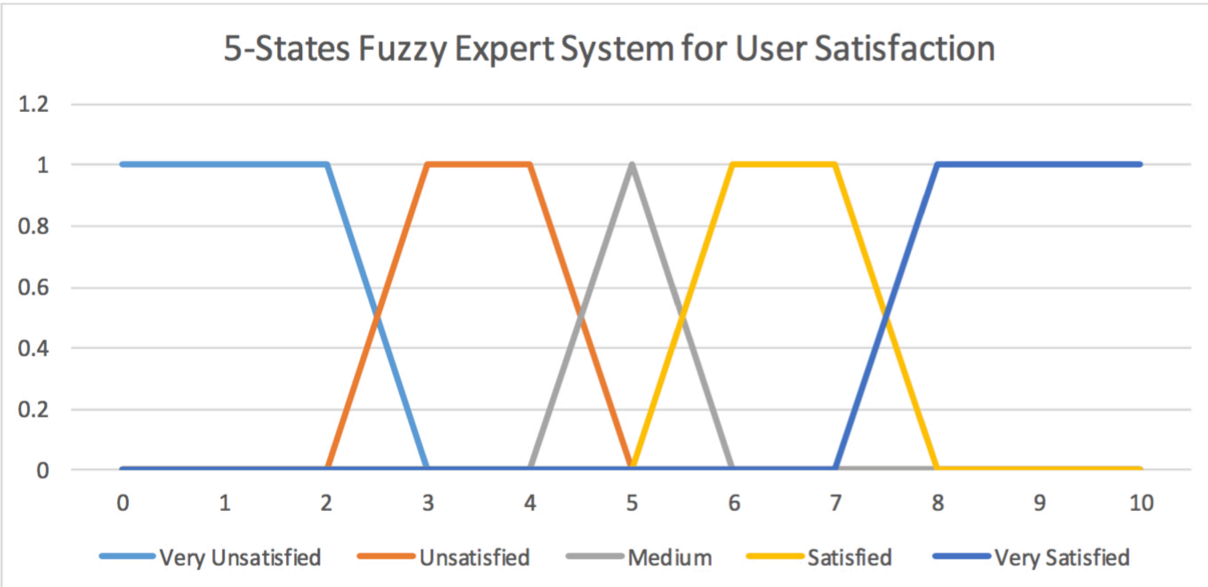
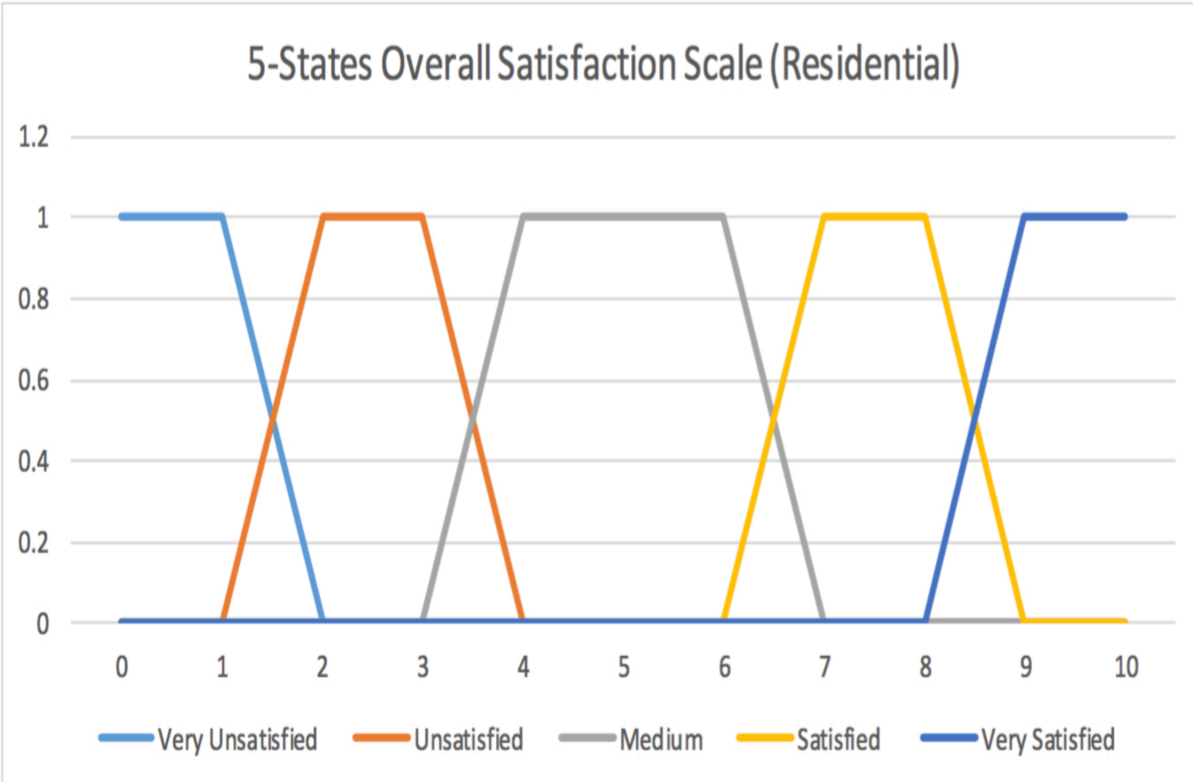


Figure III.5 Example of the user's perspective in respect to temperature comfort criteria.

Similarly, an overall user perspective scale (OSS) is generated to represent the user's perspective in respect to the sustainability of the building being considered. The OSS is useful for evaluating the sustainability of each building based on its respective set of criteria and sub-criteria. Figure III.6 shows an example of an OSS that represent the overall perspective scale in buildings. It should be noted an OSS needs to be generated for each type of building (e.g. commercial, educational etc.).



Label	Correction Action Categories	Users Perspective Numbers
Very Unsatisfied	Absolutely necessary to take corrective action(s)	$X \geqq 1.5$
Unsatisfied	Necessary to take corrective action(s)	$3.5 \leqq X < 1.5$
Medium	High priority to take corrective action(s)	$6.5 \leqq X < 3.5$
Satisfied	Unnecessary to take corrective action(s)	$8.5 \leqq X < 6.5$
Very Satisfied	No corrective action is enquired	$X < 8.5$

Figure III.6 Example of Overall Perspective Scale (OSS) for sustainable buildings.

III.4.3. Database Development

A model database is generated to store the data input of the weights for each criterion and sub-criterion as well as the fuzzy systems that represent the user perspective in respect to each criterion and sub-criterion. Once the database is generated, the model is ready to be implemented to evaluate the user perspective in respect to a specific type of building (i.e. Residential, Commercial, Educational, etc.). However, since the criteria of user perspective in respect to sustainability depends largely on a building's type, a similar model development procedure will be used to generate the data input for each type of building to be stored in the model database.

III.5. ASSESSMENT OF THE USER PERSPECTIVE PHASE

The users' perspective is evaluated based on the type of the building being considered. After selecting the type of the building, the respective data will be loaded into the system so that the user's perspective can be evaluated in respect to the sustainability of that building. In Figure III.7 shows the 5-step assessment process of the user perspective: 1) data collection, 2) user perspective assessment in respect to sub-criteria, 3) evaluation of overall user perspective in respect to the criteria, 4) evaluation of user perspective in respect to building sustainability, and 5) upgrading of the decision-making information.

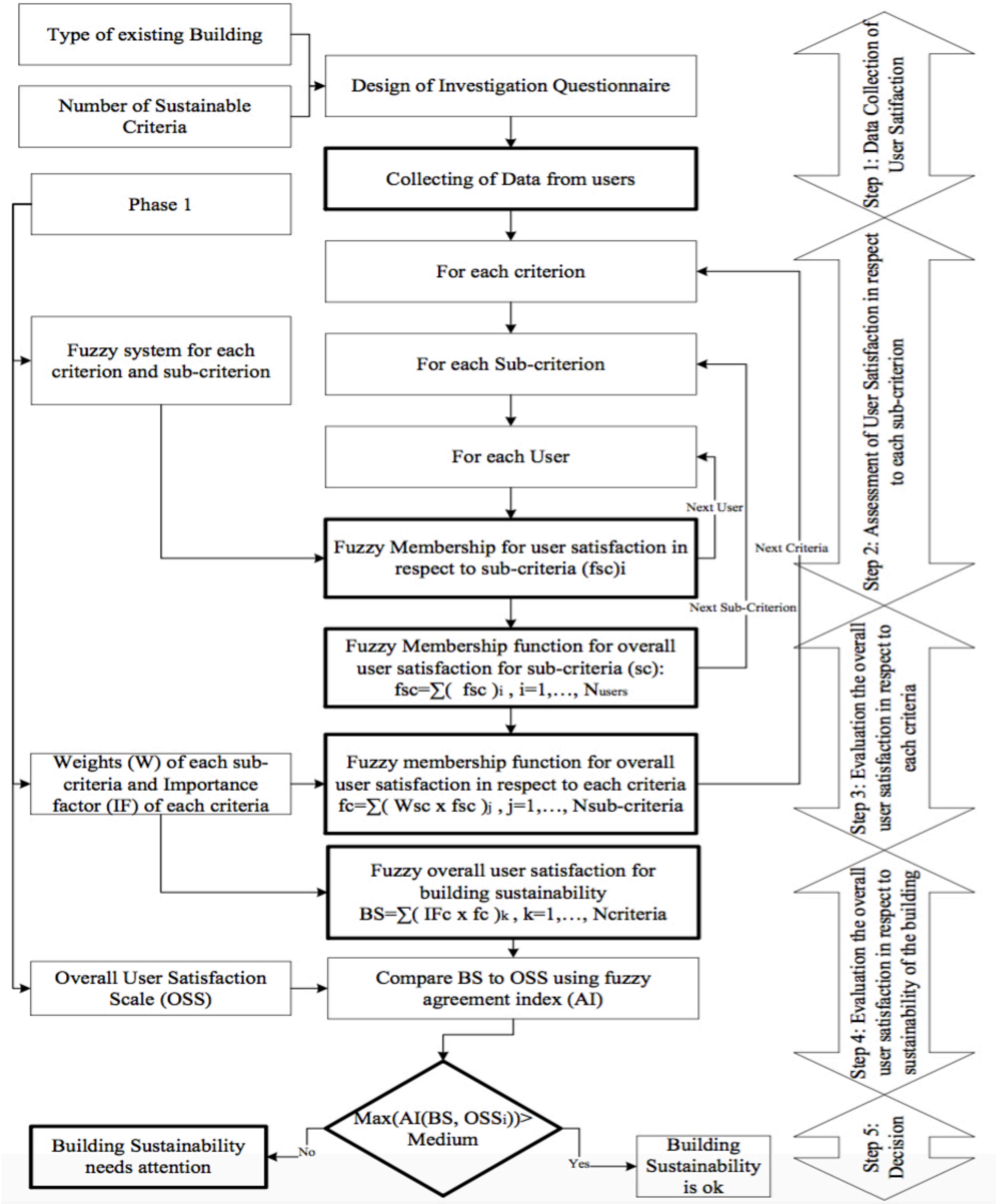


Figure III.7 Assessment of User perspective before upgrading building sustainability.

III.5.1. Data Collection of the Users' Perspective

The data is collected using a questionnaire that investigates the users' perspective in respect to each criterion and sub-criterion. Each user "i" evaluates their own perspective with the sustainability of the building being considered in respect to each sub-criterion (sc). The evaluations are based on a 5-point Likert perspective scale: (1) Very Unsatisfied (VU), (2) Unsatisfied (U), (3) Medium (M), (4) Satisfied (S), (5) Very Satisfied (VS). The outputs of this step are n evaluations for each sub-criterion (sc), where n represents the number of respondents (i.e users).

III.5.2. Assessment of User Perspective in Respect to Sub-factors:

The assessment of the user perspective process evaluates the perspective of users in respect to each sub-criterion. The linguistic evaluations of users collected in the first step are converted into numeric fuzzy membership functions using the scheme designed by experts and FM practitioners in the previous phase. Each sub-criterion (sc) receives N numeric fuzzy memberships (fsc)i evaluated by the users (i=1…, N users) of the building being considered. The user perspective in respect to the sub-criteria (sc) being considered is calculated using fuzzy arithmetic (summation arithmetic) as presented in Eq. (III-4).

$$\widetilde{f_{sc}} = \sum_{i=1}^{i=N_{users}} \left(\widetilde{f_{sc}}\right)_i \qquad \text{(III} - 4\text{)}$$

where:

fsc represents the fuzzy membership function of the sub-criteria (sc);

(fsc)i represents the fuzzy membership function of the sub-criteria (sc) evaluated by users "i"; and

N users represents the number of users participating in the evaluation process.

III.5.3. Assessment of User Perspective in Respect to Criteria

A fuzzy membership function that represents the evaluation of each criteria is generated using the fuzzy evaluations and fuzzy weights of its respective sub-criteria, as presented in Eq. (III-5).

$$\widetilde{f_c} = \sum_{j=1}^{j=N_{sc}} \widetilde{W_{sc}} \times \widetilde{f_{sc}} \qquad (\text{III}-5)$$

where:

fsc represents the fuzzy memberships of user perspective in respect to sub-criterion "sc";

Wsc represents the weight of sub-criterion "sc" in respect to criteria "c";

fc represents the fuzzy memberships of the user perspective in respect to criterion "c"; and

Nsc represents the number of sub-criteria (sc) that affect the criterion "c".

III.5.4. Assessment of User Perspective in Respect to Building Sustainability

The user perspective in respect to building sustainability (BS) is calculated as the sum of all the fuzzy memberships of sustainability criteria (fc) multiplied by their respective fuzzy importance factors (IFc). The fuzzy membership function that represents the user perspective in respect to BS is calculated using Eq. (III-6) as follows:

$$\widetilde{BS} = \sum_{k=1}^{k=N_c} \widetilde{IF_c} \times \widetilde{f_c} \qquad \text{(III-6)}$$

where:

fc represents the fuzzy memberships of user perspective in respect to criterion “c”;

IFc represents the importance factor of criterion “c” in respect to building sustainability;

Nc represents the number of criteria (c) that affect building sustainability; and

BS represents the fuzzy memberships of user perspective in respect to building sustainability.

After calculating the fuzzy building score (BS), the agreement indices (AI) with each state of the overall perspective scale of this type of building are calculated using Eq. (III-7) as follows:

$$AI\left(\widetilde{BS}, \widetilde{OSS_m}\right) = \frac{Area\left(\widetilde{BS} \cap \widetilde{OSS_m}\right)}{Area\left(\widetilde{OSS_m}\right)}, m = VU, U, M, S, VS \qquad (\mathrm{III}-7)$$

where:

AI represents the agreement index with two fuzzy membership functions;

BS represents the fuzzy membership building sustainability score;

OSSm represents the state m in the overall perspective scale; and

VU, U, M, S, and VS represent the five states of OSS.

The user perspective sustainability level (SL) is determined as the OSS state (m) that has the maximum agreement index with the BS score, as presented in Eq. (III-8).

$$SL_k = \begin{cases} Very\ Unsatisfied, & if \bigvee_{m=1}^{m=5} AI(BS, OSS_m) = AI_{VU} \\ Unsatisfied, & if \bigvee_{m=1}^{m=5} AI(BS, OSS_m) = AI_U \\ Medium, & if \bigvee_{m=1}^{m=5} AI(BS, OSS_m) = AI_M \\ Satisfied, & if \bigvee_{m=1}^{m=5} AI(BS, OSS_m) = AI_S \\ Very\ Satisfied, & if \bigvee_{m=1}^{m=5} AI(BS, OSS_m) = AI_{VS} \end{cases} \qquad (\text{III} - 8)$$

where:

SLk represents the perspective of users in respect to sustainability at level "k".

The perspective level can be measured at the sub-criteria (k=sc), criteria (k=c), and building (k=b) levels. If SLk ∈ {medium, satisfied, very satisfied} then the sustainability of the building being considered satisfies the user sustainability level (SL) and there is no need to upgrade that building's sustainability. Otherwise, the sustainability of the building being considered needs to be upgraded using one or more sustainable technologies.

III.6. UPGRADING SUSTAINABILITY PHASE

The upgrading sustainability phase is initiated in cases where the users of a building are not satisfied with the current sustainability level of that building. Figure III.8 shows the 4-step upgrading process: 1) identification of dissatisfying criteria, 2) identification of possible solutions for these dissatisfying criteria, 3) ranking and selection of optimum solutions, and 4) implementation of the selected solutions.

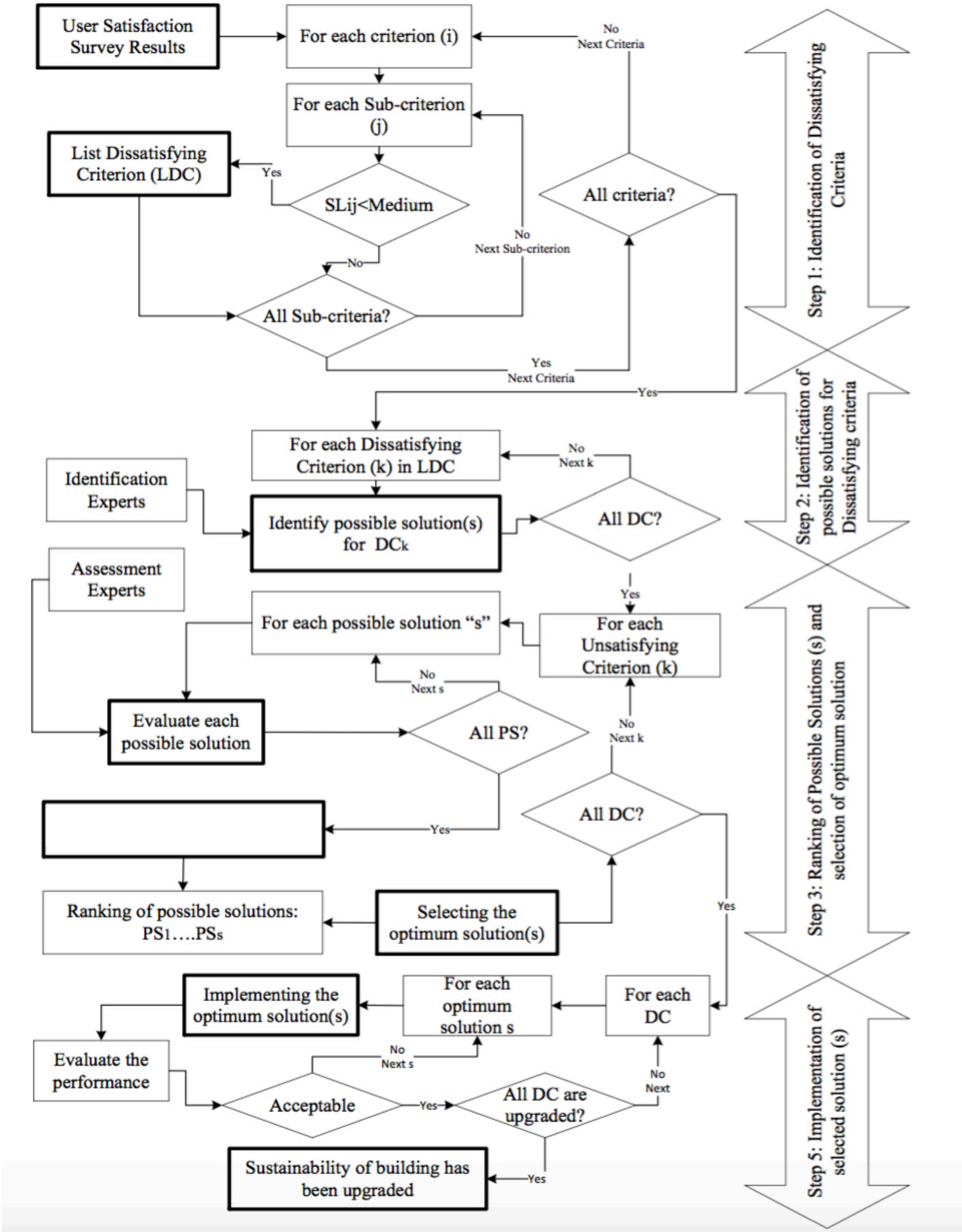


Figure III.8 Upgrading Sustainability.

III.6.1. Identification of Dissatisfying Factors:

The identification of dissatisfying criteria is based on the perspective level (SL) of users in respect to criterion “c”. If SLc is lower than medium, then “c” is considered as a dissatisfying criterion (DC) for users, which means that “c” contributes to the dissatisfaction of users in respect to the sustainability of the building being considered. The associated sub-criteria are investigated to identify the list of dissatisfying sub-criteria in respect to each criterion “c”. Such investigation generates a list of dissatisfying criteria (LDC) that contains all of the associated dissatisfying sub-criteria.

III.6.2. Identification of Possible Solutions for DCs

The expert judgement method is employed here to identify the possible solutions that can elevate the user perspective in respect to each DC. Increasing the user perspective in respect to sub-criteria subsequently elevates the user perspective both in respect to specific criteria as well as in respect to the sustainability of the building being considered. Each expert “j” provides a list of possible solutions for each sub-criterion on the LDC. An ultimate list of possible solutions (LPS) that combines all of the lists of possible solutions (LPSjk) generated by expert “j” for each dissatisfying criterion “k” is then produced, as presented in Eq. (III-9).

$$LPS_k = \bigcup_{j=1}^{j=N} LPS_{kj} \qquad (\mathrm{III}-9)$$

where

LPSk represents the ultimate list of possible solutions for dissatisfying criterion “k”;

LPSkj represents the list of possible solutions for dissatisfying criterion “k” generated by expert “j”; and

N represents the number of experts.

III.6.3. Assessment, Ranking and Selection of Optimum Solutions

The Pugh matrix technique for a fuzzy environment is used to evaluate, rank and select the most optimum solutions for each sub-criterion. The application of the Pugh Matrix method consists of the following eight steps:

- Identify the possible solutions (PS) or alternatives for each criterion:

The possible solutions were identified in a previous step; however, another round of screening can be performed to finalize the list of possible solutions for each sub-criterion on the LDC.

- Identify the evaluation criteria:

Once the possible solutions list is finalized, a list of evaluation criteria must be generated (e.g. cost, time, etc.).

- Assess the alternatives and criteria based on the selected criteria:

Expert judgements are used to obtain the aggregated fuzzy weights of the criteria and thus the aggregated fuzzy ratings of the possible solutions. If the fuzzy rating and importance weight of the kth expert are as given in equations (III-10) and (III-11):

$$\tilde{x}_{ijk} = (x_{ijk1}, x_{ijk2}, x_{ijk3}, x_{ijk4}) \quad \text{(III-10)}$$

$$\widetilde{w}_{jk} = (w_{jk1}, w_{jk2}, w_{jk3}, w_{jk4}) \quad \text{(III-11)}$$

then the aggregated fuzzy ratings ($\widetilde{x_{ij}}$) of alternatives with respect to each criterion can be calculated as shown in equations (III-12) and (III-13):

$$\tilde{x}_{ij} = \left[\min_k(x_{ijk1}), \frac{1}{K}\sum_{k=1}^{k=K} x_{ijk2}, \frac{1}{K}\sum_{k=1}^{k=K} x_{ijk3}, \max_k(x_{ijk1})\right] \quad (\text{III} - 12)$$

$$\widetilde{w}_j = \left[\min_k(w_{jk1}), \frac{1}{K}\sum_{k=1}^{k=K} w_{jk2}, \frac{1}{K}\sum_{k=1}^{k=K} w_{jk3}, \max_k(w_{jk4})\right] \quad (\text{III} - 13)$$

The selection problem can be expressed in a matrix format as shown in equations (III-14) and (III-15):

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \ddots & \ldots & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \vdots & \vdots & \ldots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \cdots & \tilde{x}_{nn} \end{bmatrix} \quad \text{(III-14)}$$

$$W = [\widetilde{w}_1, \widetilde{w}_2, \ldots, \widetilde{w}_n] \quad \text{(III-15)}$$

where $\tilde{x}_{ij}$ represents the fuzzy rating of alternatives Ai in respect to criteria Cj, and wj is the importance weight of the jth criterion.

- Normalize the assessment scores of the selected criteria

- Assign weights of importance for the assessment criteria (i.e. time = 50%, cost = 50%)
- Use weighted-sum method to compute the score of each alternative

$$\sum_{i=1}^{i=n}\left[\widetilde{W}_i \times \widetilde{x_{ij}}\right]$$

w is the weight of the criteria,

j is the counter of criteria,

n is the total number of criteria,

x is the score of the criteria, and

i is the alternative number

- Rank the possible solution in ascending order based on the resulting score

  (Less time is better and faster, less cost is more economical)

- Identify the improvement factor of the selected solution/alternative in fuzzified scale (VS, S, M, U, VU)
- Select the first ranked possible solution

III.6.4 Implementation of Selected Solution (s)

The optimum solutions selected in the 8-step process described above are implemented to elevate the user perspective in respect to each dissatisfying criterion on the LDC. If the implementation of the first optimum solution did not elevate the user perspective to an acceptable (Medium or above) level, the next optimum solution is implemented. The building sustainability in respect to each dissatisfying criterion is considered completed if the perspective level of users is rated as medium or above in respect to that criterion. Upgrading all of the dissatisfying criterion on the LDC upgrades the sustainability of the building being considered.

III.7. SUSTAINABILITY UPGRADING USING A GENETIC ALGORITHM

According to the relevant literature, the GA approach performs very well, even among other effective strategies on comprehending budget and time optimization issues for two main reasons (Chan et al. 1994; Liu et al. 1997). First, the GA perform better from the conventional mathematics way specially in huge search spaces. Second, the GA can reach the optimum solution set in relatively smaller times. Therefore, the GA approach will be utilized here to clarify the budget and time allotment model. The GA optimization of FM is illustrated in figure III.9. The budget and the times are allocated in light of the execution indices obtained from the SP overhaul model. Those budget and time values are allocated in the entire EV building. Based on the calculations for each part within the process, the activities for overhauling each element will be selected in light of the BS value, and the calculation of each component are then processed in light of the OSS model.

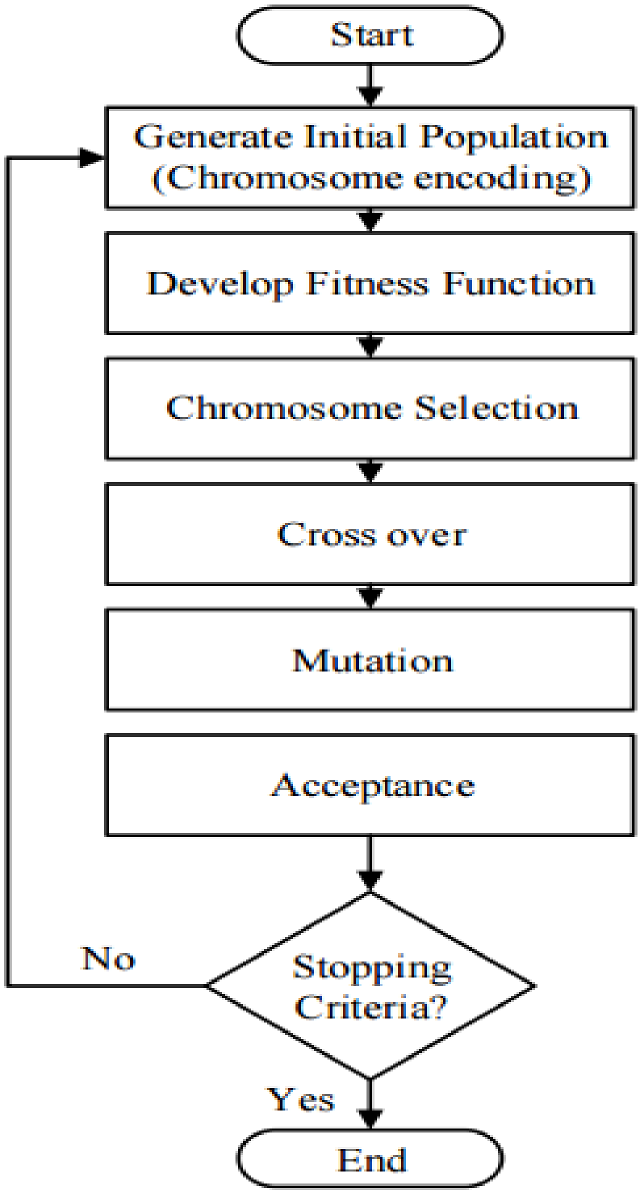


Figure III.9: GA Optimization of FM in Sustainable Buildings from the User Perspective (Abouhamad, 2015)

The fundamental goal of the model is to expand the execution list of the building's overhaul items from the users' perspective, as stated by the users' index of the BS fabricating list. Selecting the actions can also be ranked according to if they are easily allowable, their twelve-month cost, and the choice of variables based on a binary representation where (1) indicates "undertaking an intervention/maintenance" and (0) indicates "do nothing". This model should have the option to be connected via Skyline to a FM expert over a particular run for a specified time period. The decision variables for the different building components along with their corresponding times and costs can be presented as in Table III.1. The mathematical formulation of the model can be displayed as in the equations (III-23) below:

$$\text{Decision Variables} = \begin{bmatrix} M_n \\ \cdot \\ \cdot \\ M_N \end{bmatrix} \tag{III.23}$$

For $M_N = 0, 1$ (maintenance actions)

n = 1, 2, … N (building components)

With an objective function:

$$Max\ f(x) = \sum_{i=1}^{i=n} W_i * PI_i \tag{III.24}$$

subject to the following constraints:

$$\sum_{i=1}^{i=n} \sum_{j=1}^{j=k} C_{ij} \leq C_{max} \qquad \text{(III.25)}$$

Where, Wi= $Weight\ of\ importance\ of\ each$ sub-factor;

PIi= Each sub-factor's performance index;

Ci=_$Cost\ of\ rehabilitation\ strategies\ j\ applied\ to$ sub-factors' $i\ components$; and

$$C_{max} = max.\,allowable \frac{budget}{year}, \qquad \text{(III.26)}$$

Where $Cmax$=_$max.\ allowable\ budget\ year$, and

i= sub−factors= 1,2, 3,…n .

The model inputs are:

1) The unit cost of each update action for the different sub-factors;
2) The unit time of each update action for the different sub-factors;
3) The amount of work required for each sub-factor; and
4) The performance indices' calculations.

The output of this problem is a budget and time allocation plan close to that of the optimal solution, which is accepted here due to the complexity of the problem, the numerous levels within the network and the various actions required for each component. The actions selected vary from the simplest and least costly (e.g. preventive action or cement lining) to the most complicated and costly (e.g. replacement). The GA is composed of several steps, as indicated in the literature review chapter.

Table III.1: The decision variables for the different building components along with their corresponding time and cost

#	Main Criteria	Sub-Criteria	Alternatives	Unit of Measurment	Unit Tim	Unit Cos	Tim	Cost
1	Thermal comfort (TC)	Heating/cooling system that is responsive to changes in temperature (HCSR)	Improve air-conditioner or heat pump	BTU	8	$ 1,635.00	48	$ 9,810.00
		Functions at a comfortable humidity (CH)	Maintaine Humidity Levels	BTU	8	$ 3,324.00	40	$ 16,620.00
		Feels well ventilated (WV)	control of airborne contaminants	BTU	16	$ 3,425.00	112	$ 23,975.00
		How much control users have over their environment (CU)	Switch controlled HVAC	BTU	8	$ 3,221.00	48	$ 19,326.00
		Functions at a comfortable temperature (CT)	reduce air infiltration	BTU	16	$ 4,521.00	96	$ 27,126.00
2	Design and flexibility (DF)	Visually appealing (VA)	Shapes	M2	24	$ 12.00	-	$ -
		Tidy in appearance (TA)	welcom appearance	M2	24	$ 14.00	-	$ -
		Containing up-to-date IT services (CITS)	Devise a plan for standardizing production systems to the same version and application software	M2	16	$ 12.00	-	$ -
		Having good quality common amenities (GQ)	good furnetures	M2	8	$ 23.00	-	$ -
		Having enough storage at their desk for personal items (S)	cabinets	M2	20	$ 18.00	-	$ -
		Degree of noise (DN)	Noise Friendly Flooring	M2	14	$ 18.00	-	$ -
3	Aesthetics (A)	The flexibility of the spaces (FA)	creative zones based on function	M2	21	$ 12.00	-	$ -
		Conversational privacy in the office (CP)	meeting room	M2	14	$ 13.00	-	$ -
		The circulation of the building (CB)	ignoring boring path	M2	18	$ 32.00	-	$ -
		Interaction with different colleagues (IDC)	Use effective communications	M2	14	$ 32.00	-	$ -
		ability to meet needs (AMN)	interaction with users	M2	10	$ 13.00	-	$ -
		openness and views to outside (OV)	direction of openning biews	M2	12	$ 23.00	-	$ -
4	Lighting and acoustics (LA)	Good distribution of sound to all the space (GDS)	good Component Selection	Unit	10	$ 122.00	500	$ 6,100.00
		Proper reverberation times throughout all frequencies (PRT)	panels that hang from the ceiling or attach to walls at an angle	M2	11	$ 342.00	814	$ 25,308.00
		Natural sound diffusion and envelopment (NSDE)	Install foam panels	M2	12	$ 341.00	1,020	$ 28,985.00
		A sense of intimacy for the audience (SIA)	Confirming the Vision	Unit	15	$ 143.00	690	$ 6,578.00
		Brightness (B)	CONTROLLING TOO MUCH LIGHT	M	17	$ 74.00	170	$ 740.00
		Contrast (CON)	Exterior elements such as overhangs or vertical fins	Unit	18	$ 65.00	1,152	$ 4,160.00
		Glare (G)	landscaping to shade east and west exposures	M	25	$ 143.00	1,325	$ 7,579.00
		Diffusion (D)	Rearranging furniture and seating positions	Unit	12	$ 74.00	780	$ 4,810.00
		Color (COL)	White	M2	22	$ 12.00	4,642	$ 2,532.00
			Gray	M2	22	$ 12.00	7,524	$ 4,104.00

III.7.1 Population Initialization

For each population, a number of chromosomes are required for every generation. For a higher degree of assurance, a higher number of chromosomes should further boost the BS (Goldberg 1989). The sub-factors include the investment into the cost and time of the output solution provided by the illustration chromosomes.

III.7.2. Chromosome Encoding

Throughout the encoding process, each sub-factor inside the whole building may be addressed by a number of genes, each of whose segments represent an opportunity to be redesigned. Thus, the chromosome encoding could similarly characterize each sub-factor for the genes. The overhaul movements thus represent the encoding for the genes. Figure III.10 shows the encoding for the developed model.

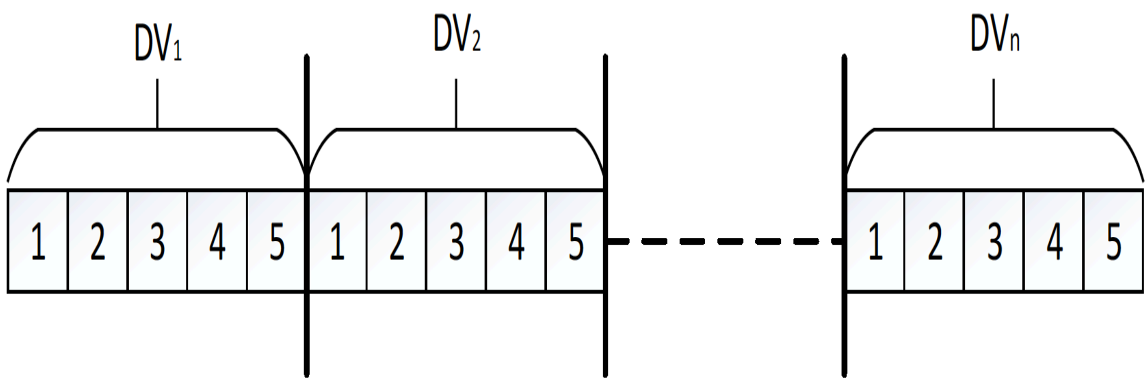


Figure III.10: Encoding for the developed model

III.7.3 Fitness Calculation

After initializing the population, a fitness function will be computed for every chromosome in light of its qualities, thereby ensuring it fits the streamlining objective as well as its own imperatives. The best chromosomes with higher fitness function values, i.e. higher execution indexes, would be acknowledged to the following generation; allowing for for a minimum amount of attention to those aspects in the following generation.

III.7.4 Executing Genetic Algorithms

When running the model, the initial population comprises "do nothing" solutions for the building items until it derives a relation between the building components and the building. However, during the 2nd generation, the maintenance actions start to appear on some of the building components. Those actions represent the genes of the new population. Following the same process, the GA continues to change the variables to achieve the pre-set objective through the pre-set crossover and mutation rates, assumed as 80% and 20%, respectively in this study.

III.7.5 Stopping Criteria

The stopping criteria of this model was a combination between progress-based and time-based stopping criteria. The stopping criteria was set as not requiring any progress (0%) for a certain amount of time (4 hours).

III.8 ASSESSMENT OF USER PERSPECTIVE AFTER UPGRADING SUSTAINABILITY PHASE

This phase evaluates the user perspective level after a building's sustainability has been upgraded. As shown in the flowchart of figure III.11, it consists of four steps: 1) Data collection, 2) Re-consideration of upgrading sustainability, 3) Re-implementation of selected solutions and 4) A continuous sustainability upgrading cycle.

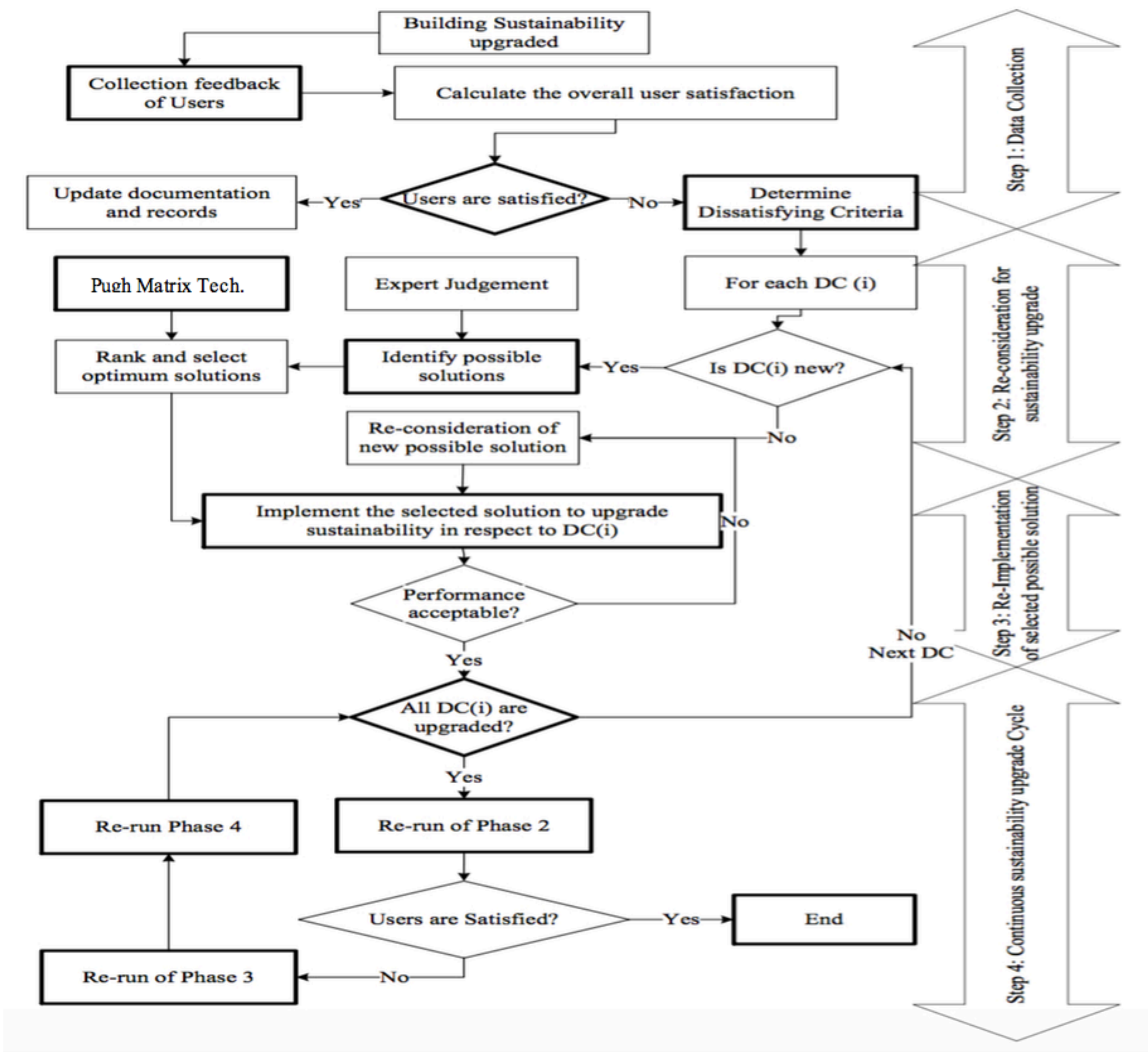


Figure III.11 Assessment of User perspective after upgrading sustainability.

III.8.1 Data Collection

Users' feedback is collected to re-evaluate their perspective level in respect to the sustainability of the building being considered. If the users are satisfied with the upgraded sustainability, then no further action is required. Otherwise, the dissatisfying criteria are identified similar to step 1 of phase 3

III.8.2. Reconsideration of the Sustainability Upgrade

The possible solutions are identified, ranked and selected to elevate the sustainability of the building in respect to the dissatisfying criteria (DC), similar to step 2 and step 3 in phase 3 (using the Pugh Matrix technique). The output of this step is a list of new possible solutions for each DC.

III.8.3. Re-implementation of Optimum Solutions

The selected optimum solutions are implemented to elevate the user perspective level in respect to the newly identified dissatisfying criteria. If the performance is acceptable after upgrading all of the DCs, then cyclic monitoring is initiated.

III.8.4. Continuous Sustainability Upgrade Cycle

This step represents the continuous monitoring systems. This system follows a cyclic procedure as described below:

1. Collect the user feedbacks after upgrading the building sustainability;
2. Evaluate the user perspective in respect to the building sustainability;
3. Identify the dissatisfying criteria if the perspective level is lower than medium;
4. Identify, evaluate, rank and select the optimum solutions for each DC;
5. Implement the optimum solution to elevate the user perspective;
6. Evaluate the performance of each DC after the implementation of optimum solutions; and
7. Upgrade the building's sustainability level.

III.9. SUMMARY

This chapter presented the proposed research methodology. Three models were integrated with each other in order to develop the sustainability assessment model for buildings from the users' perspective. This assessment and improvement process consist of three phases. First, model development: This phase evaluates the importance level of each criterion and sub-criterion in respect to the user perspective. Pairwise comparisons for criteria and sub-criteria are generated and used to calculate the weights of each criteria and sub-criteria using the analytic network process (ANP). Second, assessment of the users' perspective before upgrading the sustainability level. This phase evaluates the user perspective level in a sustainable building using the user responses collected on a 5-point Likert scale: very dissatisfied, dissatisfied, medium, satisfied and very satisfied. The collected responses are aggregated using fuzzy set theory and multiplied by the weights and importance levels of the sub-criteria and criteria to calculate the overall perspective of users in the sustainable building being considered. It should be noted that if the overall perspective of users is equal to satisfied or higher, no action is required. Otherwise, phase 3 is initiated to upgrade the sustainability of the building being considered to elevate the overall user perspective level. Third, upgrading sustainability: The criteria that cause user dissatisfaction are identified; each criterion or sub-criterion that has a perspective level lower than medium will be considered for upgrade. Once these criteria are identified, a set of possible solutions will be identified and the Pugh Matrix (criteria-based) technique employed to evaluate and rank those solutions and select the highest-ranked options. These selected solutions are then implemented to elevate the user perspective in respect to that criterion and its related sub-criteria.

Chapter IV: Data Collection and Case study

IV.1. CHAPTER OVERVIEW

The previous chapter illustrated the research methodology in detail, including the users' perspective assessment model and the reassessment of users' overall perspective model. Each of these models requires a different type of data. Both require the identification of the users' perspective assessment attributes, such as the criteria and sub-factors utilized to evaluate the current users' perspective of a sustainable building, and the users' perspective index must be utilized to update the users' sustainable building perspective. The weight of each of criterion and of each of the sub-factors must be estimated to accurately represent the importance of each of the assessment attributes according to the building type.

This chapter addresses the procedures followed to select the assessment attributes based on a literature review. Every criterion and its related sub-factor(s) is illustrated, as well as its objective. This chapter also provides a detailed description of the questionnaire employed to gather the information related to the importance of each attribute, and in turn, explains how this information is used to estimate their weights. An illustration of the strategies applied to establish a users' perspective assessment scale to measure the degree of the users' perspective in sustainable buildings completes this chapter.

IV.2 IDENTIFICATION OF USERS' PERSPECTIVE ASSESSMENT ATTRIBUTES:

The identification of the users' perspective assessment attributes (factors and sub-factors) was based on reviewing many different studies (Zagreus et. al 2004, Abbaszadeh et. al 2006, Roulet et. al 2006, Edwards 2006) that dealt with developing users' satisfaction and efficient FM based on various regional contexts. This review made it possible to identify some limitations and advantages. Based on these limitations and lacking some of the important attributes, a list of attributes was assembled; attributes that were considered to have a significant impact on the users' perspective in SFM and that can help to assess the users' perspective based on the three pillars of sustainability. Furthermore, different interviews and questionnaires were conducted based on the developed list of attributes. This step contributed to forming a hierarchy through which to make the final modifications; resulting in the final list of the attributes.

The factors derived from the literature review focus on the users' perspective and allow these factors to be compared to each other. These factors were selected to highlight some of the (generally) overlooked attributes, and to be sure to include the most crucial ones that affect the overall users' perspective on sustainable buildings. Table IV.1 illustrates the comparison between the literature review factors that focus on users' perspective and those that emerge from SFM. This comparison was performed to spotlight the overlooked attributes and the most crucial ones that affect the users' perspective and the SFM of existing buildings. The information thereby acquired thus helps achieve the underlying goal of increasing the level of users' perspective in SFM and to reduce the environmental impact of buildings throughout the whole building lifecycle from design and construction, throughout the operational phase including adaptations, to the end of the lifecycle when deconstruction and recycling can be undertaken (Reed and Wilkinson 2005; Redman and Wilkinson 2009).

Table IV.1: Comparison conducted via a literature review focused on users' perspective and SFM.

Title	Authors	Categories											
		Air Quality	Thermal Comfort	Acoustics	Lighting	Building Design	Building Services	Flexibility	Safety & Security	Cleanliness	Well being	Privacy	Productivity
Green building performance, A Post occupancy evaluation of 22 Gsa buildings	(Fowler et al. 2010)	×	×	×	×					×			
Sustainable Architectural Applications in the Gulf States-Post Occupancy Evaluation Case Study of Kingdom of Saudi Arabia	(Ali and Alfalah 2010)	×	×	×	×	×		×	×	×			
User Satisfaction in Sustainable Office Buildings: A Preliminary Study.	(Wilkinson et al. 2011)		×	×	×			×			×	×	
Facility Management Indicators for High-Rise Residential Property in Malaysia.	(CHE-ANI et al. 2010)	×	×						×	×		×	
Evaluating user experience in green buildings in relation to workplace culture and context.	(Brown et al. 2010)					×	×		×		×		×
The Impact of Facility Management on Office Buildings Performance in Egypt.	(Waly and Helal 2010)	×	×	×	×	×	×	×	×	×		×	×

Green Facility Management in a Shanghai Office Building A Case Study of the "Asia Building	(Yunqing 2011)	×	×	×	×		×		×		×		
Listening to the occupants: a Web-based indoor environmental quality survey	(Zagreus et al. 2004)			×	×	×	×			×		×	×
Occupant satisfaction with indoor environmental quality in green buildings	(Abbaszadeh et al. 2006)	×	×		×			×	×				
Perceived health and comfort in relation to energy use and building characteristics	(Roulet et al. 2007)	×		×	×	×		×		×		×	×
Benefits of green offices in the UK: analysis from examples built in the 1990s	(Edwards 2006)		×	×		×	×	×	×	×			
Design, Productivity and Well Being	(Heerwagen 1998)	×	×	×	×	×		×			×		×
Post-occupancy evaluation correlated with building occupants' satisfaction: An approach to performance evaluation of government and public buildings	(Nawawi and Khalil 2008)		×		×	×			×	×	×	×	
Post-occupancy evaluation: how to make buildings work better	(Preiser 1995)		×	×	×	×		×		×		×	

Post Occupancy Evaluation: A Multifaced Tool for Building Improvement" ,	(Vischer 2002)	×		×		×	×		×		×		
Using end-user surveys to enhance facilities design and management	(Hebert 2012)		×		×	×	×	×		×	×		
Evaluating user satisfaction: case studies in Australasia	(Leifer 1998)		×	×	×	×		×		×		×	
Post-occupancy evaluation of postgraduate hostel facilities	(Adewunmi et al. 2011)		×			×				×			
Framework model for post-occupancy evaluation of school facilities	(Hassanain and Lftikhar 2015)	×		×		×	×	×	×		×		
Examining the perception of tenants in sustainable office buildings	(Jailani et al. 2015)		×	×	×	×		×		×		×	×
Occupant satisfaction in LEED-certified higher education buildings	Driza and Park 2014)		×	×				×		×	×		
Energy performance and occupancy satisfaction: A comparison of two closely related buildings	(Sawyer et al. 2008)	×		×	×	×	×		×	×		×	

Improving safety performance through post occupancy evaluations (POE): A study of Malaysian low-cost housing	(Husin et al. 2018)		×		×	×		×		×			×
Parameters contributing to occupants' satisfaction: Green and conventional residential buildings	(Agnieszka 2014)		×	×	×			×		×			×
Sustainable workplaces and building user comfort and satisfaction	(Smith and Pitt 2011)		×	×		×	V	×	×	×	×	×	
Impact of sustainable office bui ldings on occupant's comfort and productivity	(Feige et al. 2013)	×		×	×	×		×		×			×
Green offices in Australia: a user perception survey	(Armitage et al. 2011)	×	×	×	×		×	×			×	×	×
Total		**13**	**20**	**19**	**21**	**17**	**16**	**18**	**12**	**19**	**11**	**12**	**10**

Many of the factors and sub-factors of sustainable buildings are linked to energy conservation, especially in terms of burning fuel for electricity with its associated greenhouse gas emissions and their influence on climate change and global warming. Sustainable building design makes it possible to reduce energy consumption by proper building orientation and siting, as well as by the sizing and placement of appropriate windows to reduce excessive solar gain during summer months and heat loss during the winter months. Operational energy consumption is extremely important, as a sustainable building may be occupied for many years before any adaptations are made, and operational energy can substantially exceed the construction energy and embodied energy levels. Specifying the use of building materials that have low embodied energy and that do not include deleterious materials such as volatile organic compounds (VOCs) or formaldehydes is key to both reducing the overall energy consumption and for human comfort. These particular building materials can adversely affect human health through allergic and sensitivity reactions, causing eye, skin and respiratory problems (Douglas 2006).

Furthermore, the factors and sub-factors should take into consideration the operational phase of a sustainable building; thus, the emphasis on maintenance practices to ensure that the principles of sustainability are routinely incorporated. Building services and IEQ are important aspects of sustainable buildings due to their role in operational energy consumption; for example, increased importance is being placed on adopting natural ventilation over air conditioning systems. An important theme in the uptake of sustainability in sustainable buildings is to maintain and increase sustainability whilst maintaining and enhancing the comfort levels of the buildings' users.

Finally, transport-related emissions should also be considered. For example, transport emissions typically account for one-quarter of Australia's total greenhouse gas emissions, and therefore any reduction in these emissions would be a significant contribution to Australia's total emission levels (Davis-Langdon 2008). Sustainable buildings can encourage occupants to use public transit systems such as trains, subways, trams or buses as credited under the rating tools, and they can encourage active transport, like cycling, by incorporating amenities such as showers and secure, weather-protected bike racks.

In summary, a number of factors affect FM in sustainable buildings. The first challenge is to identify all the factors and sub-factors that affect the assessment procedure of FM from the users' perspective. Twenty-one criteria have been identified and grouped into four groups:

1) Thermal comfort and air quality;

2) Aesthetics, amenity and upkeep;

3) Design and flexibility; and

4) Lighting and acoustics.

Figure IV.1 shows the hierarchical structure of FM assessment from a user's perspective. This hierarchy illustrates the criteria that affect the perspective of users in respect to five attributes (i.e. Group of factors). Considering this structure, the assessment of a user's perspective in sustainable buildings represents a single objective (i.e. Goal) decision-making problem: Maximizing the user's perspective.

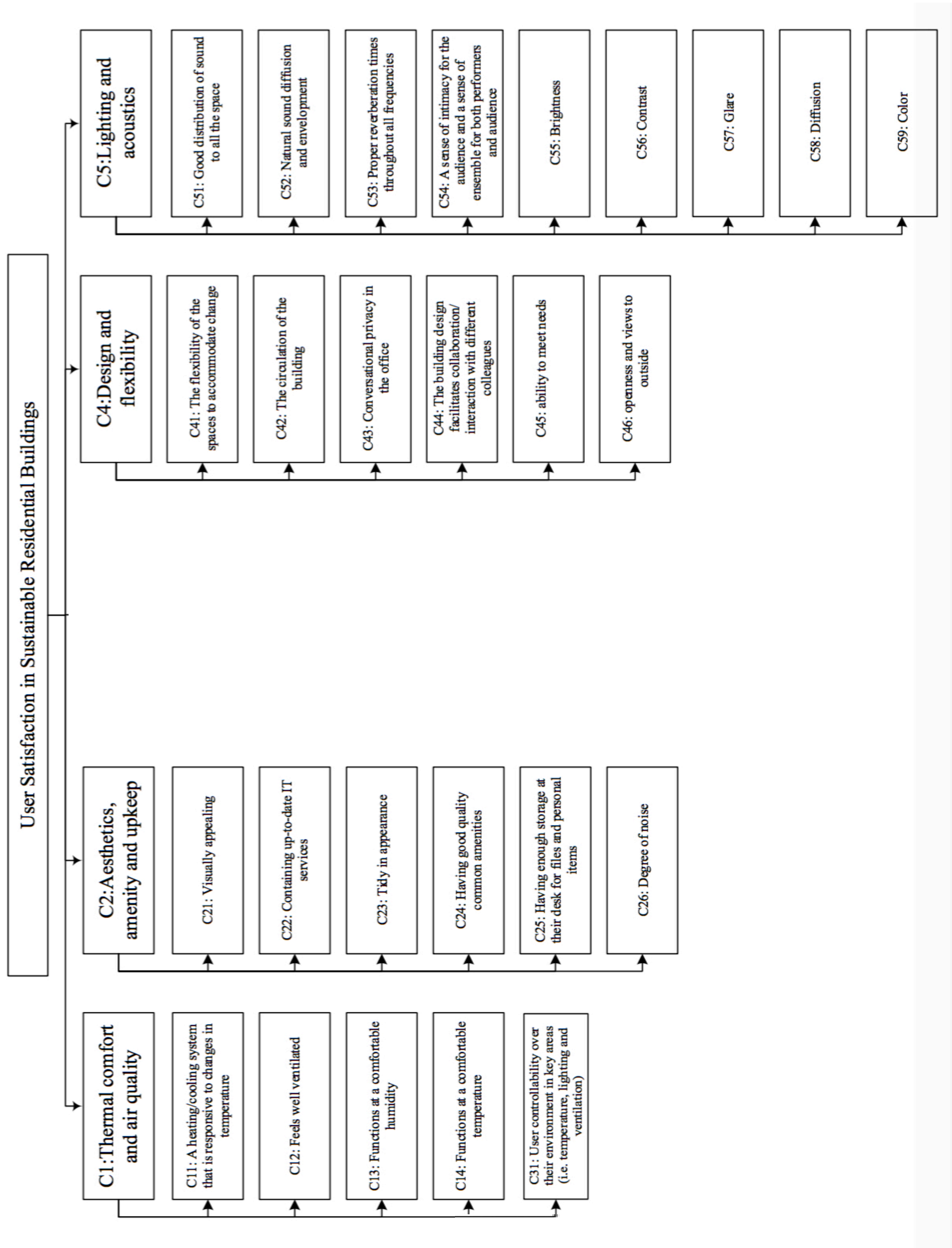


Figure IV.1 Hierarchy presentation of user perspective assessment in sustainable residential buildings

IV.2.1 Thermal Comfort and Air Quality:

Thermal comfort is a condition of mind that expresses satisfaction with the local thermal environment. Due to its subjectivity, thermal comfort is different for every individual; maintained as the heat generated by a body's metabolism is allowed to dissipate at a rate that maintains thermal equilibrium within the body. Any heat gain or loss beyond this equilibrium leads to substantial discomfort. Essentially, to maintain thermal comfort, heat produced must equal heat lost. It has been long recognized that the sensation of feeling hot or cold is dependent on more than just air temperature (ASHRAE 2010). It embraces five sub-factors as follows. Fist, a responsive heating/cooling system (RHCS) that provides a control framework should control the operation of a warming/ventilating framework. Second, how well is an area maintained at a comfortable humidity (CH) level, which can be defined as the water vapor portion of air that can be used for condensation, communicated as a rate. Third, how well ventilated (WV) does the air seem, i.e., are users provided with adequate ventilation while preventing the amassing of critical amounts of vapor-air mixtures over one-fourth of the easier combustible limit. Fourth, how much control do users have over their environment (CU), i.e., to what degree has a method been designed so that that individuals can manipulate and adjust appliances within their work or living spaces. Fifth, to what degree can a comfortable temperature (CT) be maintained, which can be determined as a maximum of 78 F (summer), a minimum of 68 F (winter) and relative humidity (RH) of 30% - 60%. Ideal conditions are temperatures between 68-78 F and 45% RH year-round.

IV.2.2 Aesthetics:

Excellence and taste are philosophical concepts. These can be closely identified with theories about art, and as such are concerned with how symbolization and ideas translate into expectations (Scruton and Munro 2017). It is a very important that aesthetics is considered as one of the sustainable factors. Due to the sustainability warrants an aesthetic philosophy and that such a theory must be comprehended as far as how facility managers is planned and made with a specific end goal to accomplish the execution results that are the premise of manageability. Setting up manageability as the tasteful inspiration driving building configuration will be the premise of another worldview for the act of facility managers.

Aesthetics embraces six sub-factors as follows. First, the flexibility of the spaces (FA), which means that there is a method for innovative organizational improvement, including offering freelancers to plan the use of such spaces Bringing adaptability into physical space management could allow them to shrink or expand according to the work needs (Tayyebi 2012). Second, assuring conversational privacy (CP) in the office, a key aspect that offers users a feeling of security. This CP is often linked to a defined physical space. Third, the building circulation (BC) which refers to how people move throughout a building, including how BC allows for more interaction and cooperation. Fourth, the conditions for interaction with different colleagues (IDC), which refers to how the design plan helps to create opportunities for realistic interaction among a variety of colleagues. These can include work and break times, socializing and eating areas, and even recreational and physical training facilities. Fifth, a measure of a building's ability to meet needs (AMN). The last factor is the degree of openness and the access to outside views (OV) which rates the openness of the spaces in terms of natural light as well as fresh air.

IV.2.3 Design and Flexibility:

Design and flexibility are utilized to implement different qualities in building frameworks. In the field of designing frameworks, this to all the plans that might need to be adjusted when outer progressions happen (Srivastava and Bansal 2013). It is a very important to be considered as one of the sustainability factors that effect on user's perspective because the role of the adaptability of buildings in facilitating a realistic response to the challenges of user's perspective. A building has flexible design in order to respond to changes of user perspective in the environment can reflect more their perspective and it will make the building interact more with users

It embraces six sub-factors as follows. First, visually appealing (VA). which is a rating based on the reasons for user's interest in and alternately gravitation towards clients that utilize the separate spaces. Second, tidy in appearance (TA), which emphasizes the need to offer simple, serene and systematic spatial courses of action, made easier by uncluttered spaces. This aspect also includes rearrangements of the inner portions for a purpose that makes it possible to achieve some crucial quality, and to avoid lavishness. Third, containing up-to-date IT services (CITS), which can be considered as the degree of being dependent upon the dates of all of the provision from claiming office to overseeing the economy. This aspect also refers to protecting the various structures in the creation, management and streamlining areas, keeping attackers from claiming or having access to the majority of the data and fabricating procedures. Fourth, having good quality (GQ) common amenities that help users in many ways, such as library resources or sports facilities offered for the users' convenience, enjoyment, and sometimes for personal solace. Fifth, assuring that there is enough storage at users' desks for personal items (S) which mean that users have enough personal storage: at their desk, either 1) Below their desk's mobile cabinet; 2) Below-desk storage for personal emergencies, and in lockers: 1) On-floor lockers for personal items and storage; and 2) Nearby shower facilities and storage for clothing and personal hygiene items, and/or on-floor team storage: 1) Lockable cabinets; and2) Shared high-density storage; and central in-building storage: 1) Central file and records storage for the agency, often managed by a records team, as well as on-site storage or archive material, records and files.

IV.2.4 Lighting and Acoustics

Lightning and acoustics are the science and engineering aspects of achieving good sound and lighting within a building (Arieff 2011). These embrace seven sub-factors, listed below. First, assuring a good distribution of sound to all the space (GDS), defined as a system that office administrators take after enriching the caliber of callous dissemination inside diverse spaces in structures. Second, the proper reverberation times (PRT) throughout all frequencies, which is part of the study of room acoustics/resonation influences and whose best approach is via space resonance. A helter-skelter resonation time camwood could result in a space that is noisy and/or not conducive to normal conversation. In a room full of reverberation, a helter-skelter resonation occurs, making reasonable discourse callous and muted. Rooms intended for discourse are therefore commonly designed for low resonation time: ≤1 second. Third, Natural sound diffusion and envelopment (NSDE), which we understand as a measure of how individuals should experience indoor sounds. This aspect begins with the configuration plan (architectural determinism), as social sciences have been used to evaluate how humans are profoundly affected by their surrounding spaces. The fourth aspect is brightness (B), based on visual observation and which evaluates how well light is reflected and perceived, inspired by the luminance of a visual target, but not in direct proportion to luminance. Fifth, contrast (CON), which is the distinction over luminance or color that makes an item (or its representation in a picture or display) recognizable. The sixth aspect is glare (G), a phenomenon that creates difficulty for people to perceive their desired views, often under strong light for example, such as reflected daylight or the light from auto headlamps at night., Diffusion (D) indicates the level of light dispersion (light diffusion) essentially diminishing glare. The eight and last aspect is color (COL) which not only indicates the color but also includes how each color influences human temperament. Light treatment investigations have discovered that distinctive light shades influence moods and heart rates and even Circassia rhythms.

IV.3 QUESTIONNAIRES:

There is a considerable number of specialists in FM field in Canada. Be that as it may, the correct number of the number of populations in those FM specialists is difficult to be evaluated. Along these lines, when the sample size is to be chosen, two components ought to be mulled over which is degree of confidence and margin of error. The degree of confidence speaks to the level of right outcomes will be acquired out of the survey that will be the same. If the degree of confidence is 90%, this implies the genuine outcomes out of various examples in a similar populace will get genuine outcome that matches the confidence level. The margin of error speaks to the passable blunder that can be gotten out of sample results, so, the greater the margin of error the less confidence is the experiment or the results out of the sample. The sample size can be identified by using Figure IV.2, by indenify the population size, the confidence level, and the margin of error (Research Advisors, 2006). Therefore, the population size of facility management experts was assumed to be 150, so based on the previous figure the sample size was selected to be 100. The value in Figure IV.2 is based on equation (5.1) (Krejcie and Morgan, 1970).

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

Where,

n = required sample size

X2 = table value of chi-square for one degree of freedom at desired confidence level (3.841)

N = population size

P = population proportion (assumed 0.5); and

d = degree of accuracy (0.05).

Required Sample Size[†]

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

Figure IV.2: Sample Size Determination (Research Advisors, 2006)

IV.3.1 Overall Users' Perspective Scale

For OSS, several user's satisfaction aspects in sustainable buildings surveys were reviewed in an effort to select the most appropriate user perspective scale. Adapting widely-used surveys enables a comparison of the results across similar studies completed earlier. The questionnaire also underwent many modifications to modify the time required to respond the questionnaire so that it can be taken in 10 to 15 minutes.

In addition, how the questions were developed in the questionnaire was adjusted several times to achieve the optimal clarity, directness, and reliability. One hundred experts in the FM, construction, and sustainability fields were contacted by email (25 for each type of building: commercial, residential, industrial, and education) and requested to fill in the questionnaire. The survey requests the FM experts to suggest ways to update buildings to become sustainable buildings and to develop an OSS for FM with which to assess and enhance the sustainability of existing buildings from the user's perspective in commercial, residential and industrial buildings. These 100 FM experts had different levels of experience in updating buildings from conventional to sustainable, with randomly-selected participants from each type of building.

The experts were asked to identify the OSS from the user's perspective on the basis of a 5-point Likert scale: Very Unsatisfied, Unsatisfied, Medium, Satisfied and Very Satisfied [from 1 (very dissatisfied) to 5 (very satisfied)] as shown in figure IV.2. The average OSSs of the 5-point Likert scale were then calculated by using the fuzzy expert system as shown in table IV.2 for industrial buildings, and similar steps were conducted for the other two types of buildings. Respondents were categorized into one of the following three main groups on the basis of their number of years of experience (less the 5 years, between 5 and 15 and more than 15), level of education (Bachelor, Master and PhD) and if they had upgraded a sustainable rating system (LEED, Green Globes and BREEAM).

Example:

In the table below, consider evaluating "Very Unsatisfied" level:

User Level	Range			
	N1	N2	N3	N4
Very Unsatisfied (VU)	0	0	1	3
Unsatisfied (U)				
Medium (M)				
Satisfied (S)				
Very Satisfied (VS)				

If you consider the start point of very unsatisfied is 0

If you consider the second (N2) point of very unsatisfied is 0

If you consider the third (N3) point of very unsatisfied is 1

If you consider the fourth (N4) point of very unsatisfied is 3

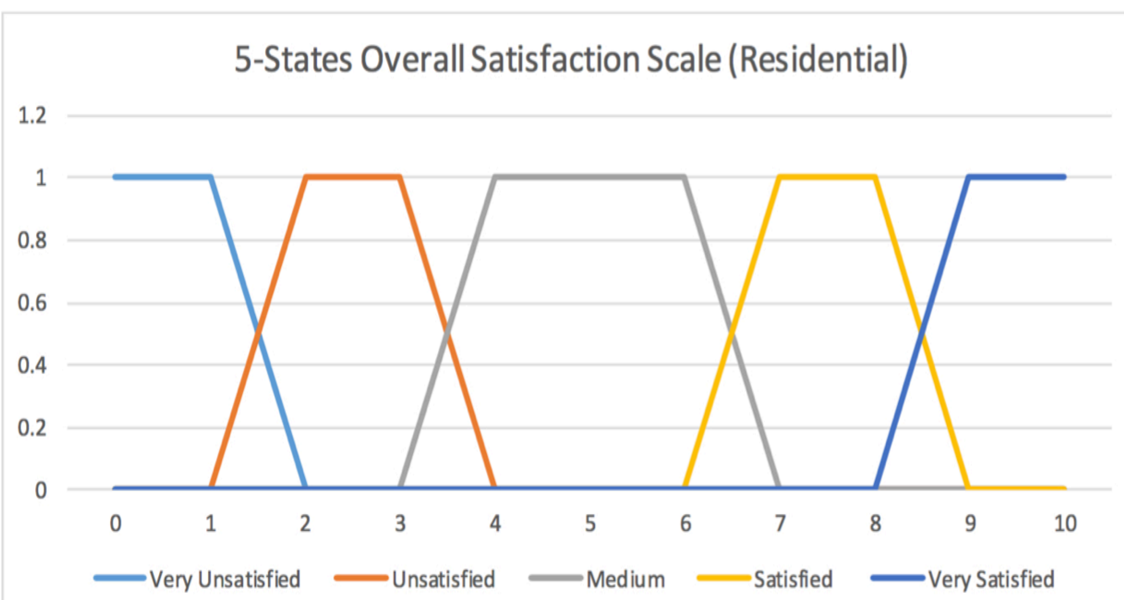


Figure IV.2 Expressing linguistic scale as triangular fuzzy numbers.

IV.4. WEIGHT DETERMINATION

The first part of the questionnaire is shown below in Figure IV.3, in which the respondent is asked to enter some general information that indicates his/her profession and years of experience, which helps in assessing the reliability of the answers. The second part of the questionnaire requests a pairwise comparison of the various factors and sub-factors, with an example for illustration. Next, Figure IV.4 shows how these respondents are requested to insert the degree of importance of each criterion of the four criteria with respect to the overall assessment of the users' perspective. In the same part of the questionnaire, especially in the second question shown in Figure IV.4, the respondents are also requested to enter the degree of importance of each sub-factor concerning the criterion it represents, based on their own experience in the field. The mean of the responses is then calculated to estimate the conversion scale utilized to transform the data from a linguistic scale into a triangular fuzzy number.

PART (1): GENERAL INFORMATION

1) How do you describe your occupation?

- ☐ Civil Engineer
- ☐ Architect
- ☐ Mechanical/Electrical Engineer
- ☐ Others ____________________

2) Which best describes your working experience?

- ☐ Less than 5 years
- ☐ 5 – 15 years
- ☐ 15 – 20 years

3) Level of education

- ☐ Bachelor
- ☐ Master
- ☐ PhD

4) Experience of Rating system

- ☐ LEED
- ☐ Green Globes
- ☐ BREEAM

Figure IV.3: Respondent self-information.

PART (2): Pairwise comparison between factors:

The Information Gathered from this part of the survey will be used to model the importance of each indicator (Level 1) and sub-indicator (Level2) relative to the whole set of indicators and sub-indicators respectively. The following questions require a pair-wise comparison between the different indicators (Levels 1&2) using the importance scale shown below. The indicators are shown in tables-matrices; using the scale of importance, kindly fill the tables in the following pages by ticking (✓) in the appropriate box from your point of view:

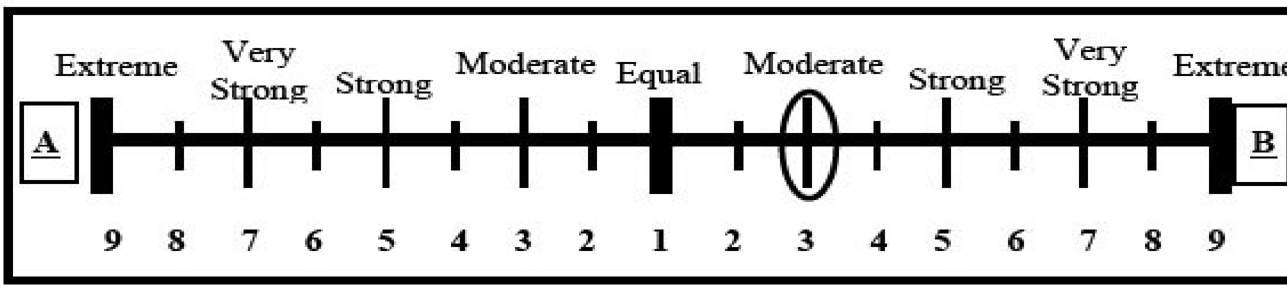


Figure IV.4: Degree of importance of each criterion.

Users perspective Performance Index

Criterion (X)	(9) Absolute	(7) Very Strong	(5) Strong	(3) Moderate	(1) Equal	(3) Moderate	(5) Strong	(7) Very Strong	(9) Absolute	Criterion (Y)
	← Degree of Importance →									
Thermal comfort										Aesthetics
										Personal control
										Design and flexibility
										Lighting and acoustics

If you consider that thermal comfort is more important than Personal control and the degree of this importance is Strong then tick (✓) here

If you consider that both the Thermal and Personal control have Equal importance, then tick (✓) here

If you consider that Personal control is more important than Thermal and the degree of this importance is Absolute then tick (✓) here

Table IV.2: Degree of importance of each factor and sub-factor

#	Sub-Criteria	Number of Respondents (N)				
		VU	U	M	S	VS
1	A responsive heating/cooling system responding (RHCS)					
2	Functions at a comfortable humidity (CH)					
3	Feels well ventilated (WV)					
4	How much control users have over their environment (CU)					
5	Functions at a comfortable temperature (CT)					
1	Visually appealing (VA)					
2	Tidy in appearance (TA)					
3	Containing up-to-date IT services (CITS)					
4	Having good quality common amenities (GQ)					
5	Having enough storage at their desk for personal items (S)					
6	Degree of noise (DN)					
1	The flexibility of the spaces (FA)					
2	Conversational privacy in the office (CP)					
3	The circulation of the building (CB)					
4	Interaction with different colleagues (IDC)					
5	Ability to meet needs (AMN)					
6	Openness and views to outside (OV)					
1	Good distribution of sound to all the space (GDS)					
2	Proper reverberation times throughout all frequencies (PRT)					
3	Natural sound diffusion and envelopment (NSDE)					
4	A sense of intimacy for the audience (SIA)					
5	Brightness (B)					
6	Contrast (CON)					
7	Glare (G)					
8	Diffusion (D)					
9	Color (COL)					

IV.5. CASE STUDY: CONCORDIA UNIVERSITY E.V. BUILDING

Concordia University’s EV Building is located in the SGW Campus at Concordia University in Montreal, Quebec, Canada (see figure IV.5). Construction work began in September 2005. Housing the departments of Engineering, Computer Science and Visual Arts, it is comprised of 17 stories and contains research and graduate teaching labs, specialized labs, conference rooms, meeting rooms and administrative offices. the E.V. building is an actually case study and it is represented the educational buildings type. It is very essential in order to obtained the overall users perspective scale, weighting for factors and sub-factors, the different possible solutions to upgrade the user’s perspective in the education buildings, the cost and time for different possible solutions to upgrade the user’s perspective, and a user’s perspective of the current status.

Figure IV.5: Concordia University, E.V. Building

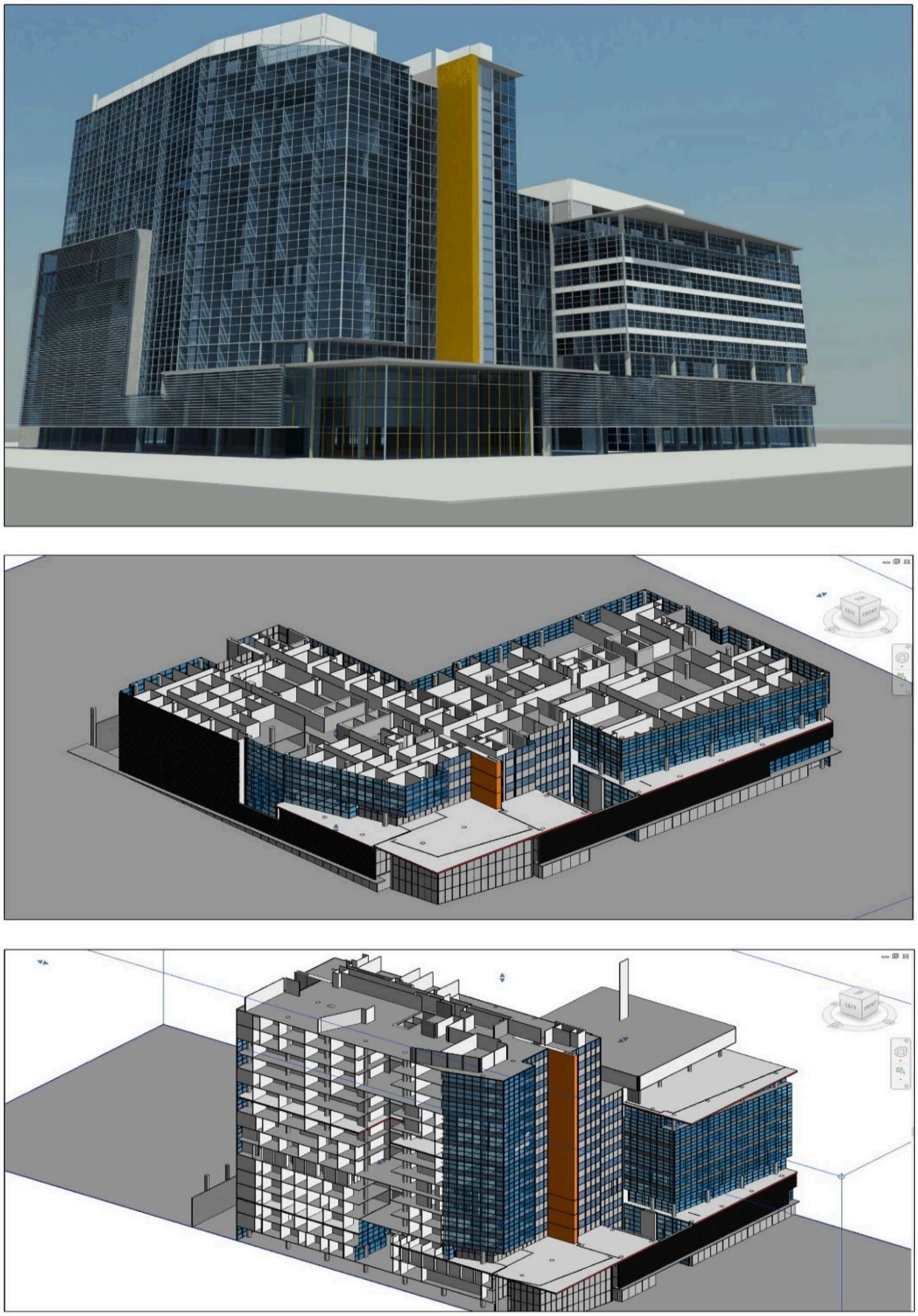


Figure IV.6: Façade, Plan Details and Floor Heights

Figure IV.7: E.V. Interior Spaces

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

Chapter V: MODEL IMPLEMENTATIONS

V.1 INTRODUCTION

This chapter introduces the procedures for determining the weight of factors and sub-factors implemented by applying the fuzzy ANP technique, as well as illustrates several ways to check data reliability and consistency. It also explains the assessment scale and procedures for developing the threshold for overall users perspective scale OSS , describes the BIM models of the case studies, and presents the data collected using those models. After detailing the procedures for determining scores and allocating points to each subfactor, the chapter closes by explaining how the user's perspective model was implemented on buildings and their contexts in the case studies.

V.2. OVERALL USER PERSPECTIVE SCALE (OSS):

To develop the overall user's perspective scale (OSS), several aspects of user's satisfaction from sustainable building surveys were reviewed for their relevance to the case studies. Experts in sustainable facility management (SFM) were asked to rate aspects of the OSS from a user's perspective on a 5-point Likert scale (1 = *very dissatisfactory*, 5 = *very satisfactory*). Next, the averages of their responses were calculated by using a fuzzy expert system (Tables V.1A–C). Respondents were categorized into three groups according to their years of experience with SFM (i.e., fewer than 5 years, 5–15 years, and more than 15 years), academic degree in sustainable development (i.e., bachelor's degree, master's degree, and doctoral degree), and their experience with upgrades with Leadership in Energy and Environmental Design (LEED), the Green Globe system, and the Building Research Establishment Environmental Assessment Method (BREEAM), as shown in Tables V.2A–C.

Table V.1.A: Fuzzy Expert System respondents for Industrial building.

#	Very Unsatisfied				Unsatisfied				Medium				Satisfied				Very Satisfied			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1	0	0.25	1.25	1.5	1.25	1.5	4	4.5	4	4.5	5.75	6.5	5.75	6.5	7.5	8.15	7.5	8.15	9.75	10
2	0	0.5	1	1.15	1	1.1	3.1	3.5	3.1	3.5	7.15	7.75	7.15	7.75	8.35	8.5	8.35	8.5	9.15	10
3	0	0.5	1.75	2	1.75	2.15	3.15	4	3.15	4	6.5	7	6.5	7	8	8.5	8	8.5	9.55	10
4	0	0	1.5	1.75	1.5	1.75	4.25	4.75	4.25	4.75	6.5	7.15	6.5	7.15	8.15	8.5	8.15	8.5	9.85	10
5	0	0	1	1.5	1	1.5	3.15	3.75	3.15	3.75	5.15	6	5.15	6	7	7.25	7	7.25	9.3	10
6	0	0.1	1.15	1.5	1.15	1.3	3.5	4.15	3.5	4.15	5.75	6.5	5.75	6.5	7.5	8	7.5	8	9.5	10
7	0	0	1.5	1.8	1.75	2	3.15	3.5	3.15	3.5	6.15	7	6.15	7	8	8.25	8	8.25	9.75	10
8	0	0.25	1.75	2	1.8	2.15	3.5	3.75	3.5	3.75	6.75	7.25	6.75	7.25	8.5	8.75	8.5	8.75	9.95	10
9	0	0	1.15	1.5	1.15	1.35	2.35	3	2.35	3	5.85	6.5	5.85	6.5	7.5	7.75	7.5	7.75	9.25	10
10	0	0	1	1.1	1	1.15	2.5	3.1	2.5	3.1	4.9	5.5	4.9	5.5	6.5	6.85	6.5	6.85	9	10
11	0	0.2	1.2	1.5	1.2	1.5	3.25	3.5	3.25	3.5	6.75	7.5	6.75	7.5	8.5	8.75	8.5	8.75	9.75	10
12	0	0	1.3	1.5	1.3	1.5	2.75	3.5	2.75	3.5	6.15	7	6.15	7	8	8.55	8	8.55	10	10
13	0	0	1	1.35	1.15	1.3	2.5	3.13	2.5	3.13	5.15	6	5.15	6	7	7.5	7	7.5	9.15	10
14	0	0.1	1.75	2	1.75	2.15	3.5	4.1	3.5	4.1	6.25	7	6.25	7	8	7.25	8	7.25	9.75	10
15	0	0	1	1.5	1	1.5	3	4	3	4	6.5	7.15	6.5	7.15	8	7.55	8	7.55	9.85	10
16	0	0	1.5	2	1	2.0	3	3.5	3	3.5	6	6.6	6	6.6	7.50	8	7.5	8	10	10
17	0	0	1	1.25	1	1.25	2.5	3	2.5	3	5	6.25	5	6.25	7.35	7.55	7.35	7.55	9	10
18	0	0	1.25	1.5	1.25	1.5	2.25	3.15	2.25	3.15	4.5	6	4.5	6	7	7.25	7	7.25	10	10
19	0	0	1	1.15	1	1.15	2	2.5	2	2.5	4	4.5	4	4.5	5.5	5.75	5.5	5.75	8	10
20	0	0	0.5	1	0.5	1	2	2.55	2	2.55	4.25	5	4.25	5	6.5	7	6.5	7	9.5	10
21	0	0	0.75	1.15	0.75	1.15	2.15	3	2.15	3	6	6.75	6	6.75	8.15	8.5	8.15	8.5	10	10
22	0	0	1	1.25	1	1.25	2.5	3.1	2.5	3.1	5	5.55	5	5.55	6.75	7	6.75	7	9	10
23	0	0	1.25	1.5	1.25	1.5	2.75	3.5	2.75	3.5	5	6.1	5	6.1	7	7.15	7	7.15	9.5	10
24	0	0	1	1.75	1	1.75	3	3.55	3	3.55	5.5	6.5	5.5	6.5	7.15	7.5	7.15	7.5	10	10
25	0	0	0.75	1.5	0.75	1.5	2.5	3.5	2.5	3.5	6	6.5	6	6.5	7.5	8	7.5	8	9.75	10
average	**0**	**0**	**1**	**2**	**1**	**2**	**3**	**4**	**3**	**4**	**6**	**6.5**	**6**	**6.5**	**7**	**8**	**7**	**8**	**10**	**10**

Table V.1.A: Fuzzy Expert System respondents for Residential building.

#	Very Unsatisfied				Unsatisfied				Medium				Satisfied				Very Satisfied			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1	0.0	1.0	2.0	3.2	2.0	3.2	5.0	7.0	5.0	7.0	7.8	8.0	7.8	8.0	9.0	9.5	9.0	9.5	10.0	10.0
2	0.0	0.0	1.5	2.3	1.5	2.3	5.2	7.2	5.2	7.2	8.0	8.2	8.0	8.2	9.5	9.8	9.5	9.8	10.0	10.0
3	0.0	0.0	1.8	3.0	1.8	3.0	4.6	7.5	4.6	7.5	8.0	8.5	8.0	8.5	9.2	9.5	9.2	9.5	10.0	10.0
4	0.0	0.5	1.0	2.1	1.0	2.1	4.5	6.9	4.5	6.9	7.5	8.0	7.5	8.0	8.8	9.8	8.8	9.8	10.0	10.0
5	0.0	0.0	1.5	2.2	1.5	2.2	4.2	6.8	4.2	6.8	7.6	8.3	7.6	8.3	9.0	9.2	9.0	9.2	10.0	10.0
6	0.0	1.0	3.0	3.5	3.0	3.5	5.8	7.5	5.8	7.5	8.0	8.2	8.0	8.2	9.2	9.5	9.2	9.5	10.0	10.0
7	0.0	0.5	2.8	3.5	2.8	3.5	4.6	6.3	4.6	6.3	7.0	7.3	7.0	7.3	8.5	9.3	8.5	9.3	10.0	10.0
8	0.0	0.0	1.3	2.5	1.3	2.5	3.8	6.2	3.8	6.2	7.2	7.5	7.2	7.5	8.8	9.6	8.8	9.6	10.0	10.0
9	0.0	0.6	1.6	2.3	1.6	2.3	3.9	6.0	3.9	6.0	7.0	7.1	7.0	7.1	8.0	9.8	8.0	9.8	10.0	10.0
10	0.0	0.0	1.0	1.8	1.0	1.8	3.0	5.0	3.0	5.0	6.0	6.5	6.0	6.5	7.8	9.2	7.8	9.2	10.0	10.0
11	0.0	0.0	0.6	1.5	0.6	1.5	3.5	5.0	3.5	5.0	7.5	8.0	7.5	8.0	8.8	9.8	8.8	9.8	10.0	10.0
12	0.0	0.3	1.3	2.2	1.3	2.2	4.0	6.0	4.0	6.0	7.9	8.0	7.9	8.0	9.0	9.6	9.0	9.6	10.0	10.0
13	0.0	0.0	1.6	2.5	1.6	2.5	4.2	5.0	4.2	5.0	6.6	7.0	6.6	7.0	8.0	9.2	8.0	9.2	10.0	10.0
14	0.0	0.0	1.8	2.3	1.8	2.3	4.3	5.5	4.3	5.5	7.0	7.5	7.0	7.5	8.0	9.6	8.0	9.6	10.0	10.0
15	0.0	1.2	2.5	3.0	2.5	3.0	5.5	7.0	5.5	7.0	8.0	8.1	8.0	8.1	8.5	9.3	8.5	9.3	10.0	10.0
16	0.0	0.0	1.6	2.3	1.6	2.3	4.0	5.5	4.0	5.5	7.3	7.5	7.3	7.5	8.5	9.5	8.5	9.5	10.0	10.0
17	0.0	1.0	2.0	3.0	2.0	3.0	5.2	7.5	5.2	7.5	8.5	8.8	8.5	8.8	9.0	9.6	9.0	9.6	10.0	10.0
18	0.0	0.0	1.0	2.0	1.0	2.0	5.5	7.2	5.5	7.2	8.0	8.1	8.0	8.1	8.6	9.3	8.6	9.3	10.0	10.0
19	0.0	0.0	1.8	3.0	1.8	3.0	4.9	6.8	4.9	6.8	7.5	7.8	7.5	7.8	8.0	9.0	8.0	9.0	10.0	10.0
20	0.0	0.0	1.0	2.0	1.0	2.0	4.0	6.8	4.0	6.8	8.0	8.3	8.0	8.3	8.6	9.2	8.6	9.2	10.0	10.0
21	0.0	1.0	1.9	2.5	1.9	2.5	4.5	6.5	4.5	6.5	7.0	7.4	7.0	7.4	7.8	9.5	7.8	9.5	10.0	10.0
22	0.0	0.0	1.0	1.6	1.0	1.6	3.8	6.0	3.8	6.0	7.3	7.5	7.3	7.5	7.9	9.6	7.9	9.6	10.0	10.0
23	0.0	1.3	2.0	3.2	2.0	3.2	5.3	6.5	5.3	6.5	7.0	7.5	7.0	7.5	8.0	9.5	8.0	9.5	10.0	10.0
24	0.0	0.0	2.0	3.0	2.0	3.0	5.2	6.8	5.2	6.8	7.5	8.0	7.5	8.0	8.5	9.8	8.5	9.8	10.0	10.0
25	0.0	1.0	2.0	3.2	2.0	3.2	5.5	7.5	5.5	7.5	8.0	8.3	8.0	8.3	9.0	9.8	9.0	9.8	10.0	10.0
average	**0**	**0**	**2**	**3**	**2**	**3**	**5**	**6.5**	**5**	**6.5**	**7**	**8**	**7**	**8**	**9**	**9.5**	**9**	**9.5**	**10**	**10**

Table V.1.C: Fuzzy Expert System respondents for Commercial building.

#	Very Unsatisfied				Unsatisfied				Medium				Satisfied				Very Satisfied			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1	0.0	0.0	1.5	3.2	0.2	1.3	3.5	4.2	3.5	4.2	5.0	5.3	4.8	5.3	6.0	6.3	6.0	6.3	10.0	10.0
2	0.0	0.1	1.5	3.5	0.8	3.8	4.2	5.2	4.3	5.2	6.0	6.2	6.0	6.2	7.0	7.2	7.0	7.2	10.0	10.0
3	0.0	0.0	2.0	3.3	2.0	3.5	4.5	4.7	4.8	4.8	5.5	5.8	5.2	5.8	6.2	6.5	6.3	6.5	9.5	10.0
4	0.0	0.0	0.3	2.0	0.2	2.3	3.5	4.2	4.0	4.2	5.0	5.2	4.8	5.2	5.8	6.0	5.8	6.0	10.0	10.0
5	0.0	0.0	1.3	2.8	1.0	3.0	3.3	3.8	3.3	3.8	4.2	4.5	4.2	4.5	5.5	5.8	5.5	5.8	9.3	10.0
6	0.0	0.1	1.0	4.0	0.5	4.2	4.8	5.0	4.8	5.0	5.5	5.8	5.5	5.8	6.5	6.8	6.5	7.0	9.5	10.0
7	0.0	0.0	1.5	3.5	2.0	4.0	5.0	6.0	5.5	6.0	6.8	7.0	6.8	7.0	7.8	8.0	7.8	8.0	10.0	10.0
8	0.0	0.0	0.5	2.8	0.5	3.0	4.6	4.8	4.6	4.8	6.2	6.5	6.5	6.5	7.5	7.8	7.5	8.2	10.0	10.0
9	0.0	0.0	2.0	4.5	1.5	4.0	4.5	5.0	4.8	5.0	5.5	5.8	5.5	5.8	6.5	6.8	6.5	7.0	9.3	10.0
10	0.0	0.0	1.5	2.5	1.5	2.5	3.0	4.0	3.0	4.0	5.0	5.2	4.2	5.2	6.2	6.5	6.2	6.8	10.0	10.0
11	0.0	0.2	0.5	3.5	0.5	3.3	4.3	4.5	4.3	4.5	5.0	5.2	5.1	5.2	6.5	6.7	6.5	7.0	9.8	10.0
12	0.0	0.0	0.8	2.0	1.0	1.5	2.0	2.2	2.2	2.2	3.0	3.2	3.3	3.2	4.8	5.0	4.8	7.5	10.0	10.0
13	0.0	0.0	0.5	3.0	1.8	2.0	2.8	3.5	2.8	3.5	4.0	4.3	3.5	4.3	5.5	5.8	5.5	6.0	10.0	10.0
14	0.0	0.1	0.8	2.8	1.0	4.3	5.0	5.3	5.2	5.3	5.8	6.0	5.0	6.0	7.5	7.8	7.5	8.0	10.0	10.0
15	0.0	0.0	1.0	2.0	0.8	3.0	4.5	5.0	4.5	5.0	6.2	6.5	6.2	6.5	8.0	8.3	8.0	8.5	10.0	10.0
16	0.0	0.0	1.1	2.5	1.1	2.5	3.0	4.5	3.0	4.5	5.5	5.8	5.5	5.8	6.5	7.0	6.5	7.0	8.5	10.0
17	0.0	0.0	0.5	3.5	0.5	3.5	4.5	6.0	4.5	6.0	7.5	7.3	5.0	7.3	8.0	8.3	8.0	8.3	10.0	10.0
18	0.0	1.0	1.0	2.0	1.0	2.0	3.3	4.5	3.3	4.5	5.5	5.8	5.5	5.8	6.5	6.8	6.5	6.8	8.0	10.0
19	0.0	0.0	2.0	2.5	2.0	2.5	3.0	4.2	3.0	4.2	5.5	5.8	5.5	5.8	6.3	6.5	6.3	6.5	8.5	10.0
20	0.0	0.0	0.8	1.5	0.8	1.5	3.5	5.0	3.5	5.0	6.0	6.2	6.0	6.2	6.9	7.0	6.9	7.0	9.5	10.0
21	0.0	0.5	0.5	2.5	0.5	2.5	3.5	4.5	3.5	4.5	5.5	5.8	5.5	5.8	6.5	6.8	6.5	6.8	9.0	10.0
22	0.0	0.0	0.5	1.0	0.5	1.0	2.0	3.0	2.0	3.0	4.0	4.3	4.0	4.3	5.5	5.9	5.5	5.9	8.0	10.0
23	0.0	0.0	1.0	2.0	1.0	2.0	3.0	3.8	3.0	3.8	4.8	5.0	4.8	5.0	5.5	6.0	5.5	6.0	10.0	10.0
24	0.0	1.0	0.5	2.8	0.5	2.8	3.5	4.2	3.5	4.2	5.0	5.2	5.0	5.2	6.5	6.2	6.5	6.2	9.0	10.0
25	0.0	0.0	1.0	2.3	1.0	2.3	3.8	4.8	3.8	4.8	5.5	5.8	5.5	5.8	6.8	7.3	6.8	7.3	10.0	10.0
average	**0**	**0**	**1**	**3**	**1**	**3**	**4**	**4.5**	**4**	**4.5**	**5**	**5.5**	**5**	**5.5**	**6**	**7**	**6.5**	**7**	**10**	**10**

Table V.2. A: Categorization of respondents for Industrial building.

Experts	Industrial Buildings			
	Experience (Years)	Speciality in Building Type	Level of Education	Sustainable Rating system feature
1	3	Industrial	bachelor	Green Globes
2	4	Industrial	Master	LEED
3	2	Industrial	bachelor	Green Globes
4	7	Industrial	Master	LEED
5	9	Industrial	Master	Green Globes
6	8	Industrial	PhD	LEED
7	10	Industrial	bachelor	Green Globes
8	12	Industrial	bachelor	BREEAM
9	5	Industrial	Master	LEED
10	16	Industrial	Master	LEED
11	10	Industrial	Master	LEED
12	14	Industrial	Master	LEED
13	6	Industrial	bachelor	LEED
14	8	Industrial	Master	LEED
15	4	Industrial	Master	LEED
16	2	Industrial	PhD	LEED
17	4	Industrial	Master	LEED
18	3	Industrial	Master	LEED
19	17	Industrial	bachelor	LEED
20	14	Industrial	Master	BREEAM
21	7	Industrial	bachelor	LEED
22	5	Industrial	Master	BREEAM
23	3	Industrial	bachelor	LEED
24	7	Industrial	Master	LEED
25	3	Industrial	bachelor	Green Globes

Table V.2. B: Categorization of respondents for Commercial building.

Experts	Commercial Buildings			
	Experience (Years)	Speciality in Building Type	Level of Education	Sustainable Rating system feature
1	6	Commercial	Master	LEED
2	4	Commercial	Master	LEED
3	7	Commercial	bachelor	Green Globes
4	3	Commercial	Master	LEED
5	8	Commercial	Master	LEED
6	4	Commercial	bachelor	LEED
7	3	Commercial	bachelor	Green Globes
8	8	Commercial	bachelor	BREEAM
9	7	Commercial	Master	LEED
10	9	Commercial	bachelor	BREEAM
11	7	Commercial	Master	LEED
12	6	Commercial	bachelor	LEED
13	6	Commercial	Master	BREEAM
14	8	Commercial	Master	LEED
15	15	Commercial	Master	Green Globes
16	2	Commercial	bachelor	LEED
17	4	Commercial	Master	LEED
18	17	Commercial	bachelor	Green Globes
19	3	Commercial	Master	LEED
20	15	Commercial	Master	BREEAM
21	7	Commercial	bachelor	LEED
22	14	Commercial	Master	BREEAM
23	3	Commercial	Ph.D.	LEED
24	7	Commercial	Master	LEED
25	17	Commercial	Master	LEED

Table V.2. C: Categorization of respondents for Industrial building.

Experts	Residential Buildings			
	Experience (Years)	Speciality in Building Type	Level of Education	Sustainable Rating system feature
1	3	Residential	bachelor	Green Globes
2	4	Residential	Master	LEED
3	2	Residential	bachelor	Green Globes
4	3	Residential	bachelor	LEED
5	6	Residential	Master	Green Globes
6	4	Residential	bachelor	LEED
7	3	Residential	bachelor	Green Globes
8	2	Residential	bachelor	BREEAM
9	2	Residential	Master	LEED
10	4	Residential	bachelor	BREEAM
11	5	Residential	Master	LEED
12	6	Residential	bachelor	Green Globes
13	6	Residential	bachelor	BREEAM
14	8	Residential	Master	LEED
15	4	Residential	Master	Green Globes
16	2	Residential	bachelor	LEED
17	4	Residential	Master	BREEAM
18	3	Residential	bachelor	Green Globes
19	3	Residential	bachelor	LEED
20	4	Residential	Master	BREEAM
21	7	Residential	bachelor	LEED
22	5	Residential	bachelor	BREEAM
23	3	Residential	bachelor	LEED
24	7	Residential	Master	LEED
25	3	Residential	bachelor	Green Globes

V.2.1. Overall User Perspective Scale (OSS) Determination:

This section presents the findings of data collection in relation to how they can help to answer the following research questions: (1) How many SFM systems have evolved by upgrading from conventional buildings to sustainable ones?, (2) What kinds of a SFM rating system can best represent the user's perspective on sustainable upgrades?, (3) What are the different ranges of the 5-point Likert scale in OSSs for facility managers (FMs) to assess and enhance the sustainability of existing commercial, residential, and industrial buildings from a user's perspective?, and (4) At what level are aspects of sustainable buildings dissatisfying from the user's perspective in relation to building type?

Regarding the first question, only 75 of 200 FMs (37%) had evolved with sustainable upgrades from conventional to sustainable buildings (Figure V.1). That result reflects that SFM concerns more generic objects of supporting and maintaining buildings to meet standards.

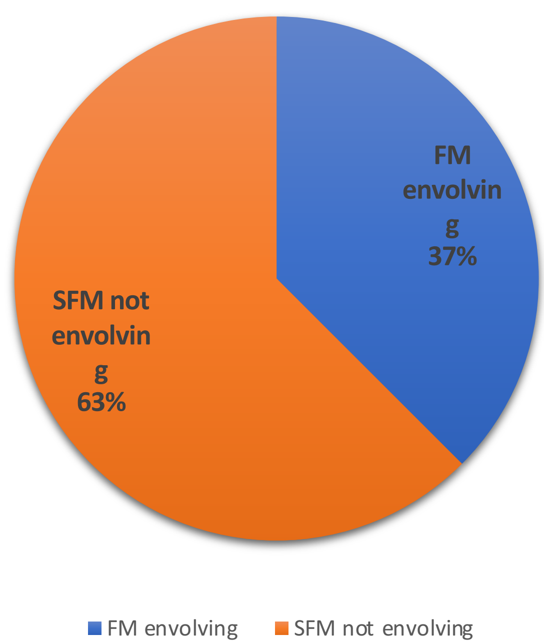


Figure V.1: Facility management expert involved to sustainable facility management upgrade.

Figure V.2 shows that only 36%, 64%, and 32% of FMs (33 of 75 total) with fewer than 5 years of experience had evolved with SFM upgrades for industrial, residential, and commercial buildings, respectively. By contrast, 56%, 36%, and 60% of FMs (38 of 75 total) with 5–15 years of experience with SFM upgrades had evolved with SFM upgrades for those respective building types, whereas only 2% of FMs (four of 75 total) of FMs with more than 15 years of experience had evolved with SFM upgrades for industrial and commercial buildings. As results for FMs with 5–15 years of experience suggest, increased experience has better familiarized those experts with users' perceptions and perspectives while performing SFM upgrades.

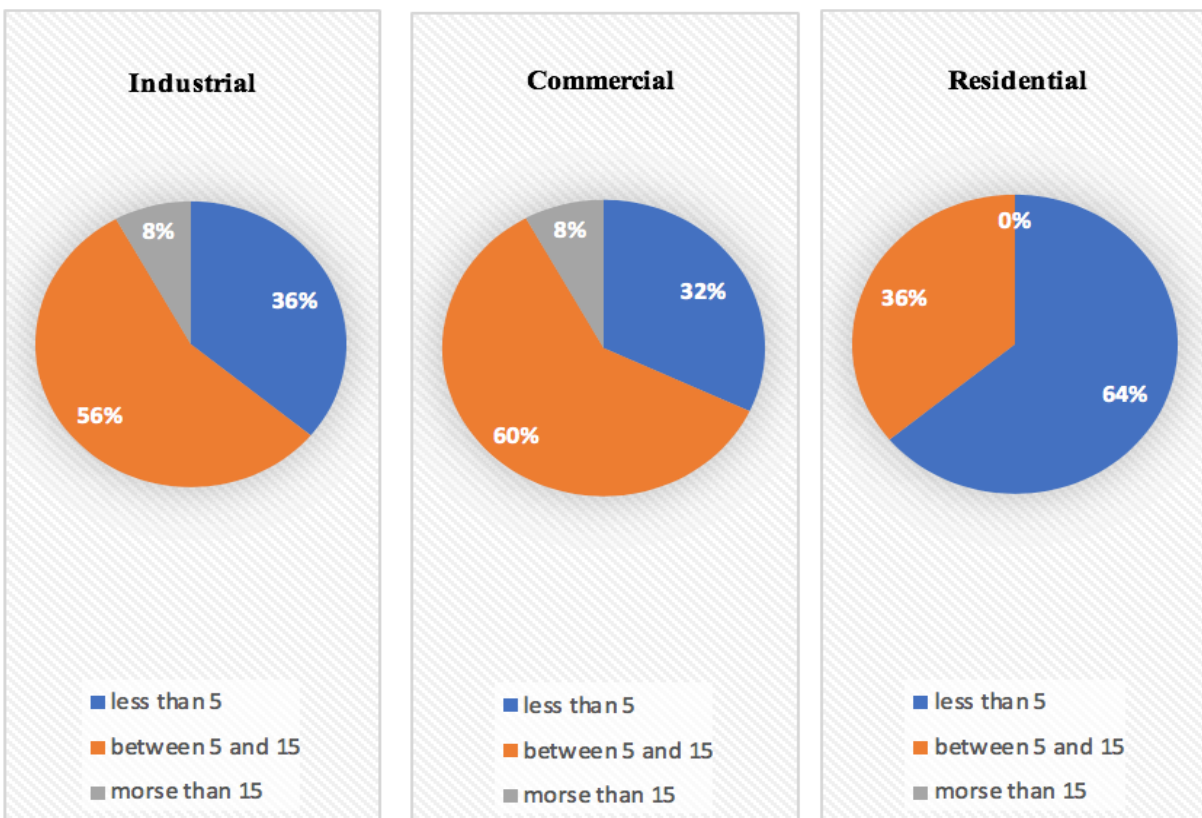


Figure V.2: Evolving of facility management in sustainable facility management upgrade in term of year of experience in different building type (Industrial, Residential and Commercial).

Increased level of education, measured as academic degree earned in sustainable development, has also helped FMs to expand their perspectives on SFM upgrades (Figure V.3). Of 25 FMs in industrial buildings, 14 FMs (56%) had a master's degree in sustainable development, whereas only two FMs (8%) in industrial buildings had a doctoral degree in the field. Similarly, of 25 FMs in commercial buildings, 15 FMs (60%) had a master's degree in sustainable development. However, of 25 FMs in residential buildings, only nine FMs (36%) had a master's degree in the field, whereas 16 FMs (64%) had a bachelor's degree.

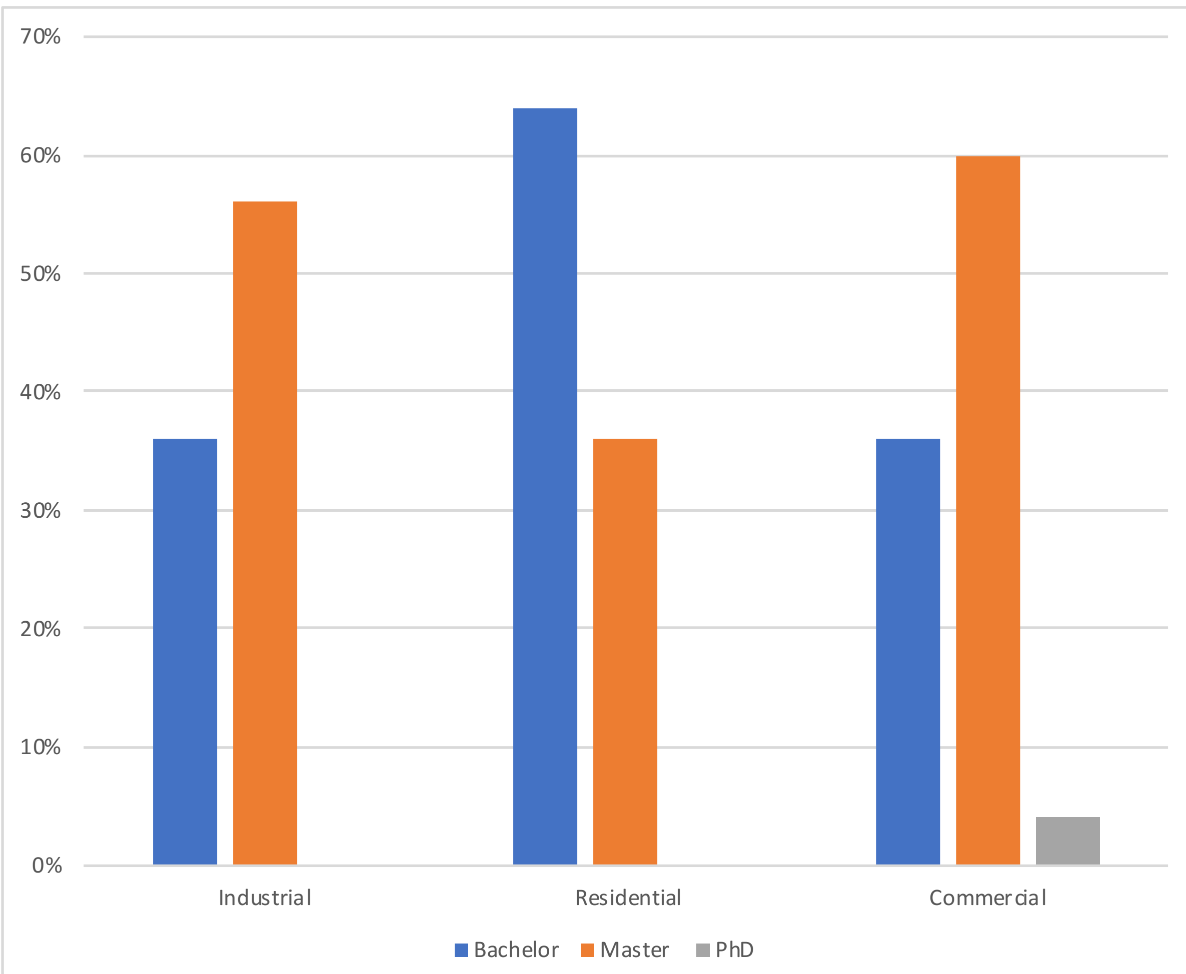


Figure V.3: Respondents based on the level of education in each type of buildings.

To answer the second question, regarding what kinds of SFM rating systems can best represent the user's perspective on sustainable upgrades, the use of three SFM rating systems employed in SFM upgrades were evaluated—namely, LEED, the Green Globe system, and BREEAM. As Figure V.4 shows, LEED, used by 17 of 25 FMs (68%), was the most popular SFM rating system in industrial buildings in North America, whereas the Green Globe system and BREEAM were used by five (20%) and three (12%) FMs, respectively. Moreover, SFM rating systems varied by building type, and the most remarkable differences were observed with LEED; 11 FMs (44%) used LEED for residential buildings, whereas 16 FMs (64%) used it in commercial buildings. With a smaller range, eight FMs (32%) and five FMs (20%) used the Green Globe system in residential and industrial buildings, respectively; concerning commercial building, the number dropped to only four FMs (16%). Last, five FMs (20%), three FMs (12%), and six FMs (24%) used BREEAM in commercial, industrial, and residential buildings, respectively.

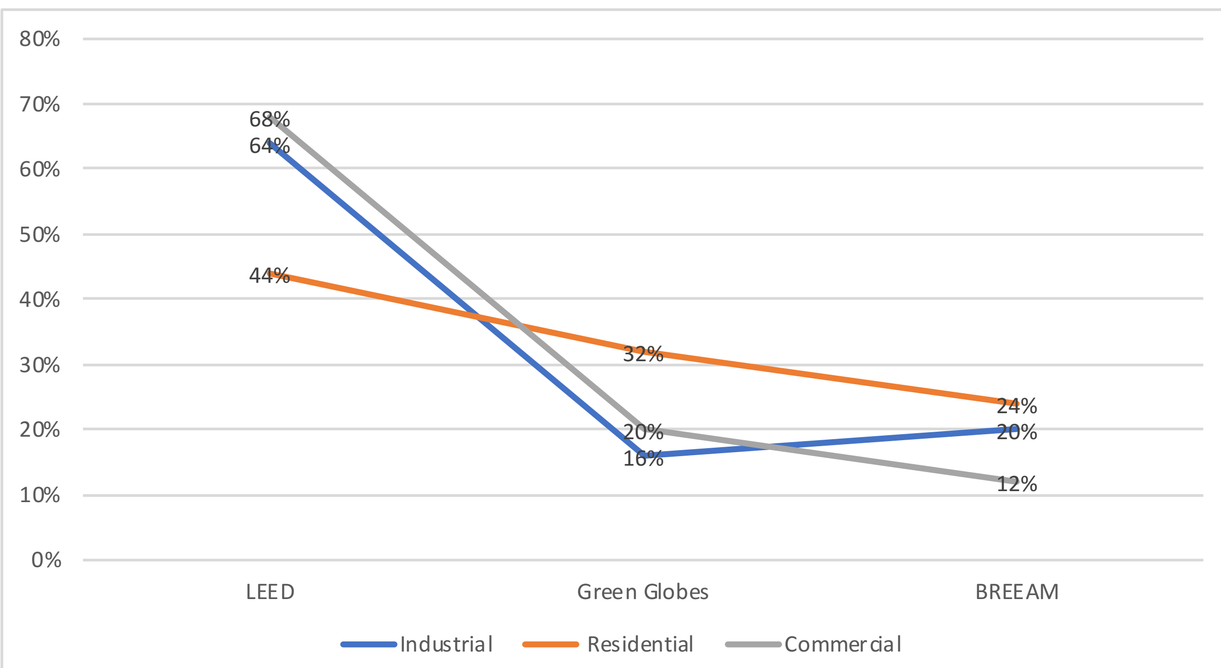


Figure V.4: Percentage of rating system have been used in sustainable facility management upgrade.

To answer the third question, with reference to the experts' responses to the questionnaire, the different OSSs for FMs to assess and enhance sustainability upgrades of existing buildings from a user's perspective in commercial, residential, and industrial buildings were compared by fuzzification—that is, by converting linguistic variables to fuzzy numbers. Seventy-five of 200 (37%) of respondents answered the portion of the questionnaire with the numerical representation of linguistic variables, and the final trapezoidal fuzzy numbers were determined as the average of all responses in each column (Tables V.3A–C). Figures V.5–7 indicate the frequency of the five linguistic variables (i.e., *very dissatisfactory*, *dissatisfactory*, *neither dissatisfactory nor satisfactory*, *satisfactory*, and *very satisfactory*) in numerical ranges when represented as trapezoidal fuzzy numbers for the three building types.

Table V.3.A: Five linguistic variables for each type of buildings.

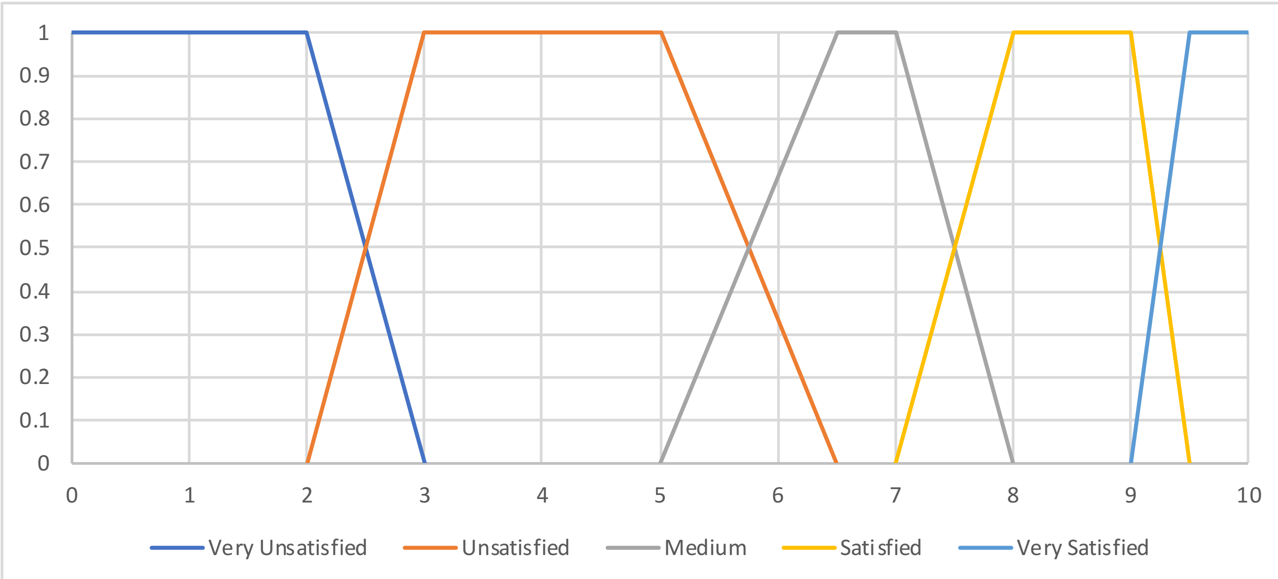
	VU	U	M	S	VS
Overall Satisfaction Scale in Industrial	0	1	3	6	7
	0	2	4	6.5	8
	1	3	6	7	10
	2	4	6.5	8	10

Table V.3.B: Five linguistic variables for each type of buildings.

	VU	U	M	S	VS
Overall Satisfaction Scale in Commercial Buildings	0	1	4	5	6
	0	3	4.5	5.5	7
	1	4	5	6	10
	3	4.5	5.5	7	10

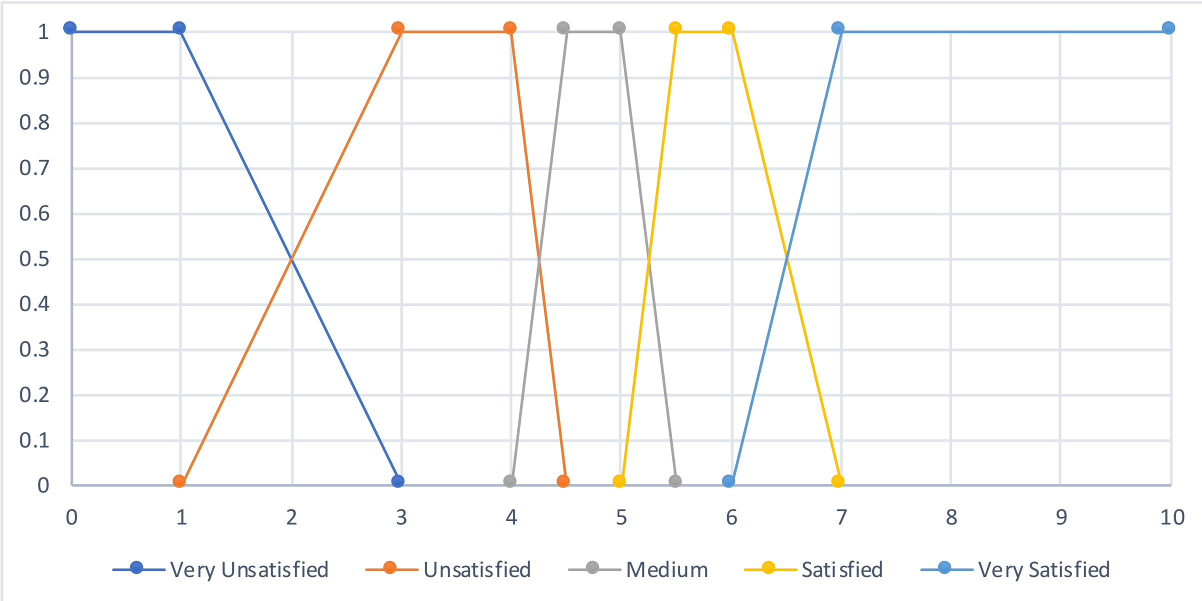
Table V.3.C: Five linguistic variables for each type of buildings.

	VU	U	M	S	VS
Overall Satisfaction Scale in Residential Buildings	0	2	5	7	9
	0	3	6.5	8	9.5
	2	5	7	9	10
	3	6.5	8	9.5	10



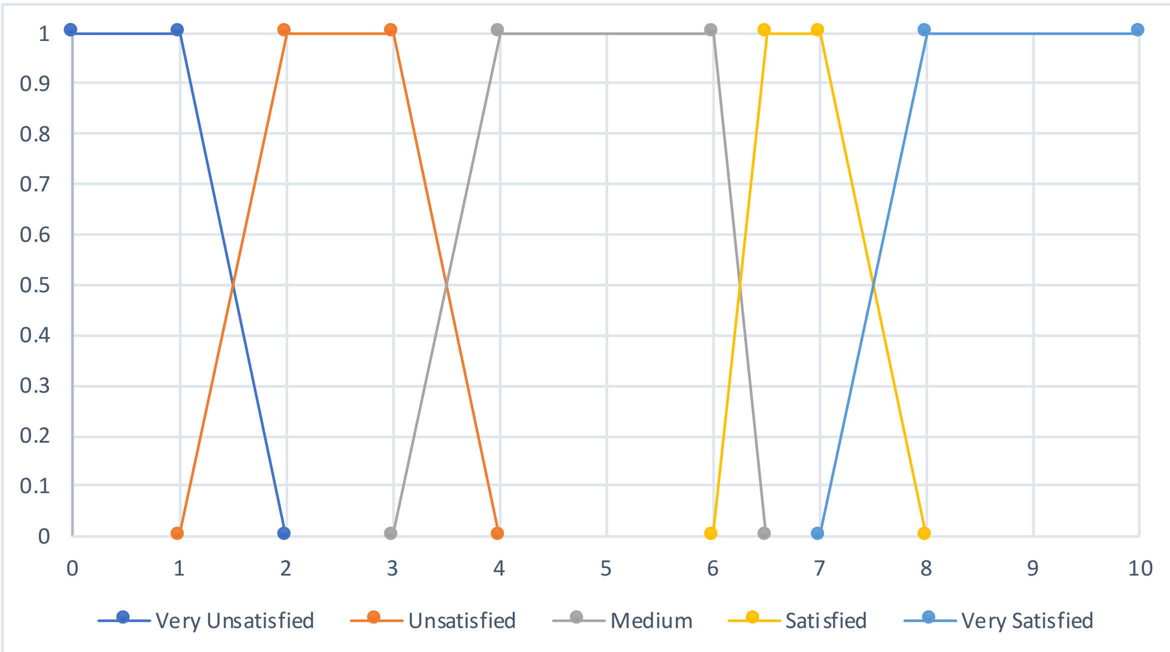
Label	Correction Action Categories	Users Perspective Numbers
Very Unsatisfied	Absolutely necessary to take corrective action(s)	X ≧2.5
Unsatisfied	Necessary to take corrective action(s)	5.75 ≦ X < 2.5
Medium	High priority to take corrective action(s)	7.5 ≦ X < 5.75
Satisfied	Unnecessary to take corrective action(s)	9.25 ≦ X < 6.5
Very Satisfied	No corrective action is enquired	X < 9.25

Figure V.5 Five linguistic variables for Residential buildings.



Label	Correction Action Categories	Users Perspective Numbers
Very Unsatisfied	Absolutely necessary to take corrective action(s)	X ≧ 2
Unsatisfied	Very necessary to take corrective action(s)	4.25 ≦ X ＜ 2
Medium	Necessary to take corrective action(s)	5.25 ≦ X ＜ 4.25
Satisfied	High priority to take corrective action(s)	6.5 ≦ X ＜ 5.25
Very Satisfied	No corrective action is enquired	X < 6.5

Figure V.6: Five linguistic variables for Commercial buildings.



Label	Correction Action Categories	Users Perspective Numbers
Very Unsatisfied	Absolutely necessary to take corrective action(s)	X ≧ 1.5
Unsatisfied	Necessary to take corrective action(s)	3.5 ≦ X < 1.5
Medium	High priority to take corrective action(s)	6.25 ≦ X < 3.5
Satisfied	Unnecessary to take corrective action(s)	7.5 ≦ X < 6.25
Very Satisfied	No corrective action is enquired	X < 7.5

Figure V.7: Five linguistic variables for Industrial buildings.

Last, the fourth question, regarding the dissatisfaction level of users with aspects of SFM, was answered with reference to the replies of FM experts for each building type. If the dissatisfaction level with the OSSs was *very dissatisfactory* or *dissatisfactory*, for example, then the building was considered to be dissatisfactory from the user's perspective. Figure V.8 shows the calculated dissatisfaction levels for each building type. For residential buildings, 56% FMs reported that if OSS scores were less than *neither dissatisfactory nor satisfactory*, then the building was considered to be dissatisfactory from the user's perspective. The same result was found for commercial buildings, whereas, for industrial buildings, the number shifted to 60% FMs. Figure V.9 allows the easy comparison of the levels of dissatisfaction in each building type

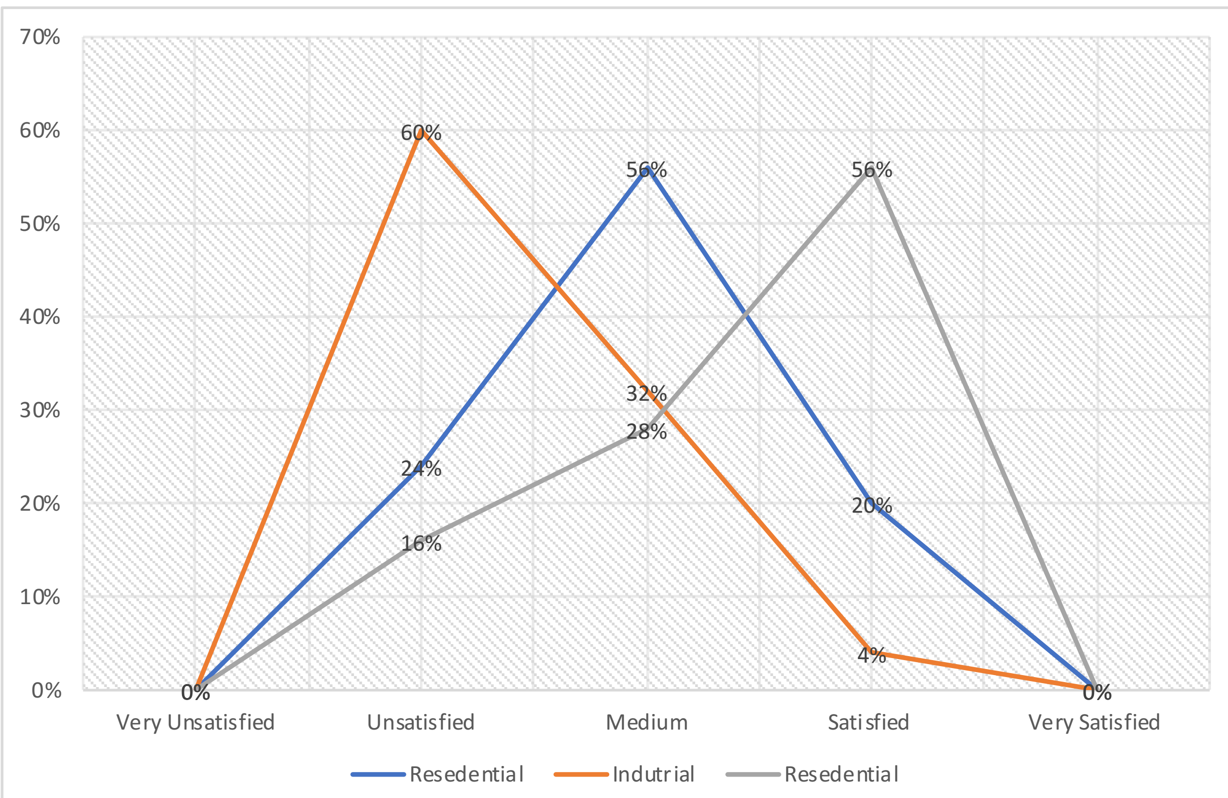


Figure V.8: Comparison between the dissatisfaction level in each type of building.

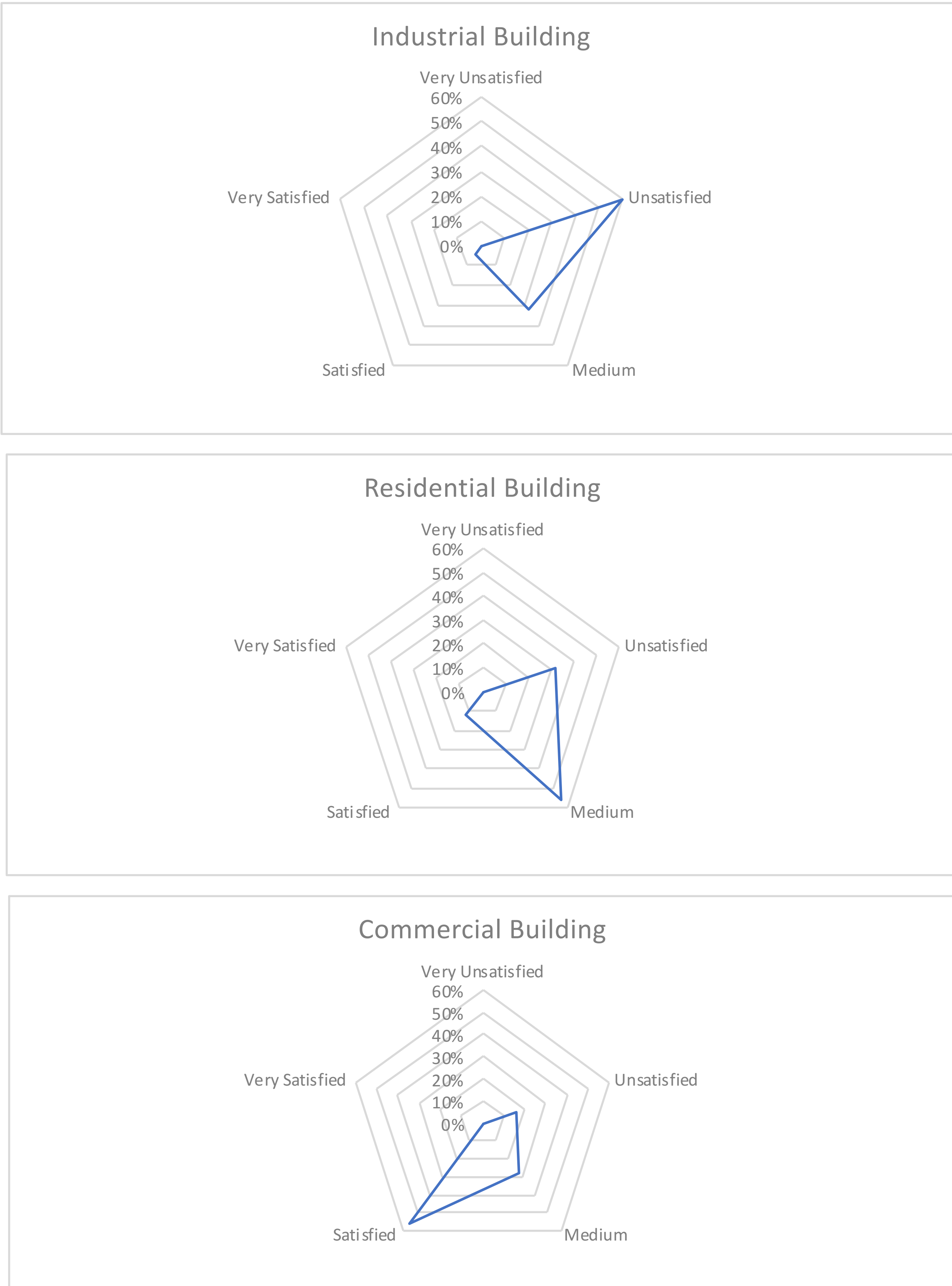


Figure V.9: Level of dissatisfaction for Industrial, Commercial and Residential Buildings.

From those results, two questions arose: (1) From a user's perspective, have SFM upgrades matured?, and (2) Why do differences exist in the OSSs in the three building types?. A conceptual framework was developed to highlight important topics in SFM and guide discussions about the usefulness of a structured methodological framework in analyzing specific aspects of SFM.

In answer to the first question, the fundamental problem that prevents FMs from performing sustainable upgrades is their lack of technical knowledge and expertise in SFM upgrades for different building types. Any FM who wants to perform sustainable upgrades needs to have experience in the field because SFM upgrades require knowledge about more generic means and ends of support and maintenance to meet preset standards. However, results also showed that the lack of engagement in sustainable upgrades by entire FM organizations generally stemmed from a lack of understanding about the importance of providing comprehensive SFM upgrades. Furthermore, neither explicit guidelines nor requirements for SFM upgrades exist for each building type. Nevertheless, such guidelines could be used to measure the satisfaction of users and the quality of SFM by FM companies, as well as to standardize the practice and implementation of SFM.

To address the second question, the level of dissatisfaction for users from their perspectives and by building type (i.e., residential, industrial, and commercial) were analyzed. Findings revealed that current methods of evaluating the sustainability of buildings prioritize the organizational perspective and neglect the perspective of users. Furthermore, factors that affect the user's perspective on sustainability updates remain unidentified, unevaluated, and unincorporated into the framework for upgrading conventional buildings into sustainable ones according to building type. After all, users' needs vary according to the type of building that they manage, and each building type has its own level of user's (dis)satisfaction. A comprehensive understanding of users' needs depending upon building type and the ability to evaluate their perspectives from various angles, including in terms of indoor environmental quality (IEQ), is thus a requirement for FMs. IEQ refers to all environmental aspects that provide occupants with good air quality, at least a minimal amount of daylight and views, pleasant acoustic conditions, and control over lighting and thermal comfort. It also encompasses the functional aspects of space in terms of accessibility and the ratio of the amount of space for each occupant. Design, flexibility and lighting, acoustics, and aesthetics, amenities, and upkeep are all parts of IEQ that FMs have to consider in order to identify the (dis)satisfaction level of users according to the type of building that they manage. In a sense, those aspects are correlated; however, their importance to users differs from one building to another. Consequently, the procedures for assessing the understandings of users about building sustainability should vary considerably from one building type to another yet invariably retain key assessment criteria and address identical attributes in order to ensure consistency.

V.3. USER PERSPECTIVE IN RESPECT TO BUILDING SUSTAINABILITY:

To create a building user's perspective index from a user's perspective, factors and subfactors that affect user's satisfaction with sustainable buildings needed to be identified. Table V.4 lists the four factors derived from the literature review that focus on the user's perspective; the factors were selected to highlight some overlooked attributes and to include the most crucial ones that affect the overall user's perspective on sustainable buildings. The four factors judged as having the most influence on users' perspectives were thermal comfort and air quality, design and flexibility, lighting and acoustics, and aesthetics, amenities, and upkeep.

The underlying goal of factors and sub-factors was to increase user's satisfaction with sustainable education buildings. Surveys were conducted with FM experts and building users over a period of 2 years to collect data needed to develop an OSS about education buildings and a user's perception index regarding sustainable education buildings.

Table V.4: the five main factors and its sub-factors.

Factors	Factors Definition	Sub-Factors
Thermal comfort and air quality	The state from claiming personality that communicates fulfillment with those warm nature's domain. (ASHRAE 2010)	A heating/cooling system responding (HCSR)
		Functions at a comfortable humidity (CH)
		Feels well ventilated (WV)
		How much control users have over their environment (CU)
		Functions at a comfortable temperature (CT)
Aesthetics, amenity and upkeep	Those philosophical contemplate of excellence and taste. It will be nearly identified with those theory of art, which will be concerned with those way for symbolization and the ideas As far as which distinct meets expectations of specialty would translated What's more assessed. (Scruton and Munro 2017)	The flexibility of the spaces (FA)
		Conversational privacy in the office (CP)
		The circulation of the building (CB)
		Interaction with different colleagues (IDC)
		ability to meet needs (AMN)
		openness and views to outside (OV)
Design and flexibility	To utilize Similarly as a trait for different sorts of frameworks. In the field about designing frameworks design, it alludes all the to outlines that might adjust when outside progressions happen. (Srivastava and Bansal 2013)	Visually appealing (VA)
		Tidy in appearance (TA)
		Containing up-to-date IT services (CITS)
		Having good quality common amenities (GQ)
		Having enough storage at their desk for personal items (S)
		Degree of noise (DN)
Lighting and acoustics	is the science and engineering of achieving a good sound and lighting within the building. (Arieff 2011)	Good distribution of sound to all the space (GDS)
		Proper reverberation times throughout all frequencies (PRT)
		Natural sound diffusion and envelopment (NSDE)
		A sense of intimacy for the audience (SIA)
		Brightness (B)
		Contrast (CON)
		Glare (G)
		Diffusion (D)
		Color (COL)

Before taking its final form, the questionnaire underwent many modifications, especially to adjust the time taken to respond to the questionnaire, which was aimed to be limited to 10–15 min. Additionally, the questions were modified several times to achieve clarity, directness, and reliability. One-hundred experts in the building, construction, and sustainability fields and 120 users were contacted by email and requested to complete the questionnaire. Ultimately, 25 respondents were FM experts and 40 were building users, with percentages of 25% and 33%, respectively. Figures V.10 and V.11 show the diversity of respondents for both samples of experts and users. The experts included civil engineers, mechanical or electrical engineers, sustainability experts, FMs, and architects, whereas the users consisted of students, faculty, and staff at Concordia University.

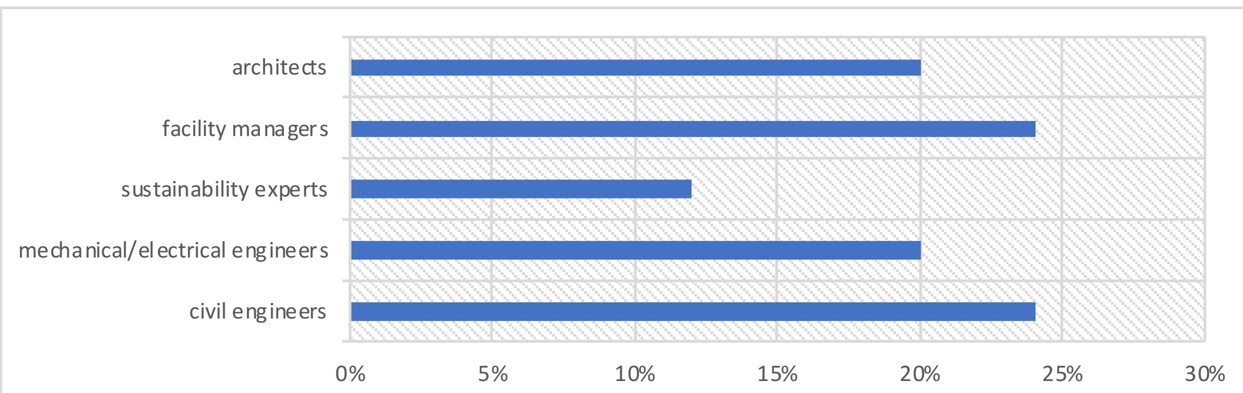


Figure V.10: Diversity of respondents for experts.

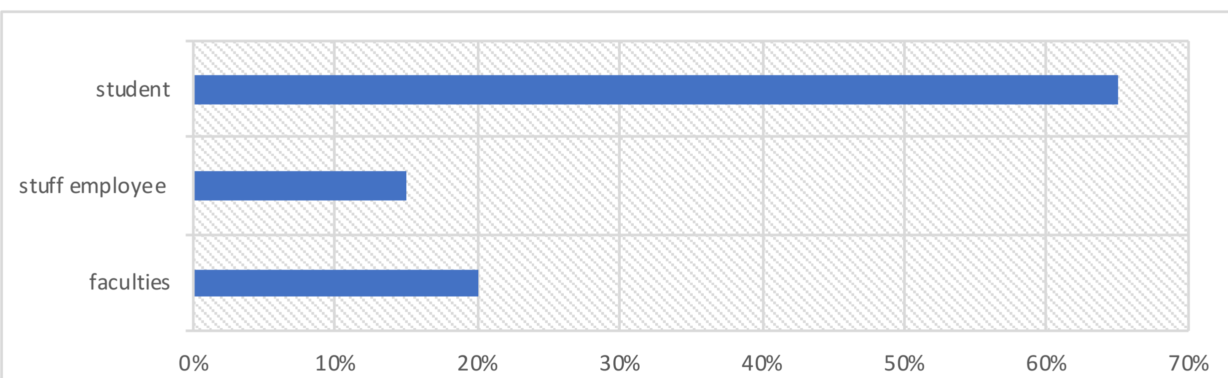
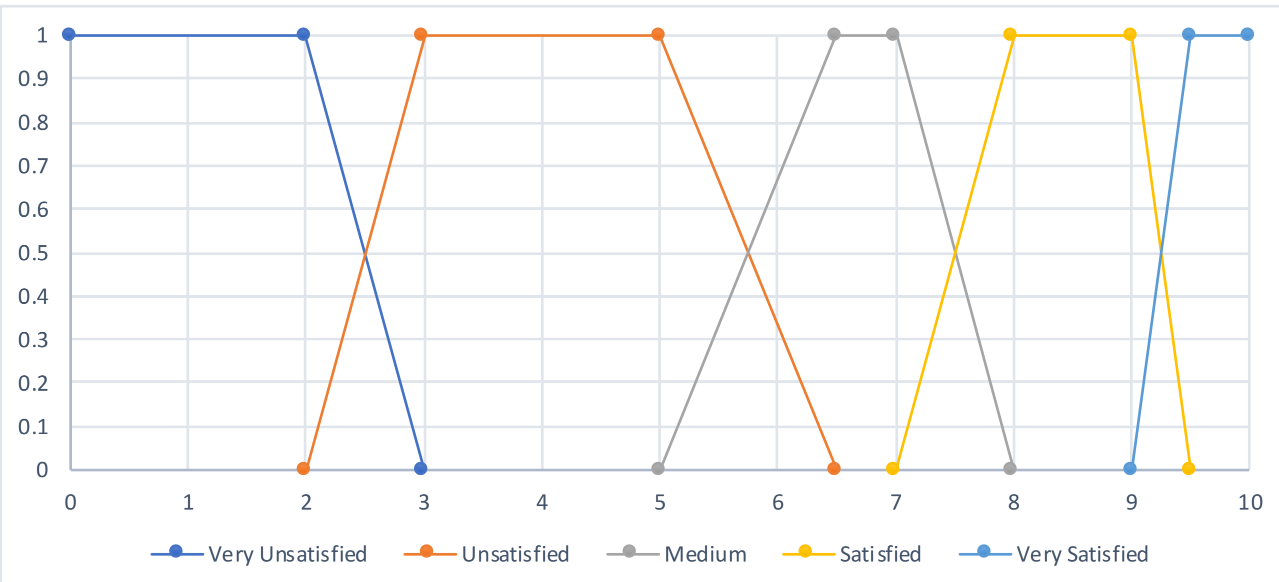


Figure V.11: Diversity of respondents for users.

V.3.1 Weight Determination:

V.3.1.1 Fuzzification Scale:

First, to develop the OSS for education buildings, fuzzification was accomplished by interpreting the responses to the second part of the questionnaire (Figure V.12). Twenty-five of 100 respondents answered the part of the questionnaire with the numerical representation of linguistic variables, and the final trapezoidal fuzzy numbers were determined as the averages of all responses in each column (Table V.5).



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Label	Correction Action Categories	Users Perspective Numbers
Very Unsatisfied	Absolutely necessary to take corrective action(s)	X ≧2.5
Unsatisfied	Necessary to take corrective action(s)	5.75 ≦ X < 2.5
Medium	High priority to take corrective action(s)	7.5 ≦ X < 5.75
Satisfied	Unnecessary to take corrective action(s)	9.25 ≦ X < 7.5
Very Satisfied	No corrective action is enquired	X < 9.25

Figure V.12: Five linguistic variables for education buildings

Table V.5: Final trapezoidal fuzzy numbers for the five linguistic variables.

	VU	U	M	S	VS
Overall Satisfaction Scale in Education Buildings	0	1	4	6	8
	0	3	5	7	9
	1	4	6	8	10
	3	5	7	9	10

As shown in Figure V.13, the five linguistic variables (i.e., *very dissatisfied*, *dissatisfied*, *neither dissatisfied nor satisfied*, *satisfied*, and *very satisfied*) varied in their numerical ranges when represented as trapezoidal fuzzy numbers. Most (60%) FM experts said that if OSS scores were *dissatisfactory* or *very dissatisfactory*, then the building should be deemed unsatisfactory from the user's perspective. However, 24% and 16% of the FM experts said that if OSS scores were *neither dissatisfactory nor satisfactory* or *satisfactory*, respectively, then the building should be deemed unsatisfactory from the user's perspective. As the result, average responses of *unsatisfactory* or less were considered to be the minimum of user's satisfaction from the user's perspective in education buildings that require updates.

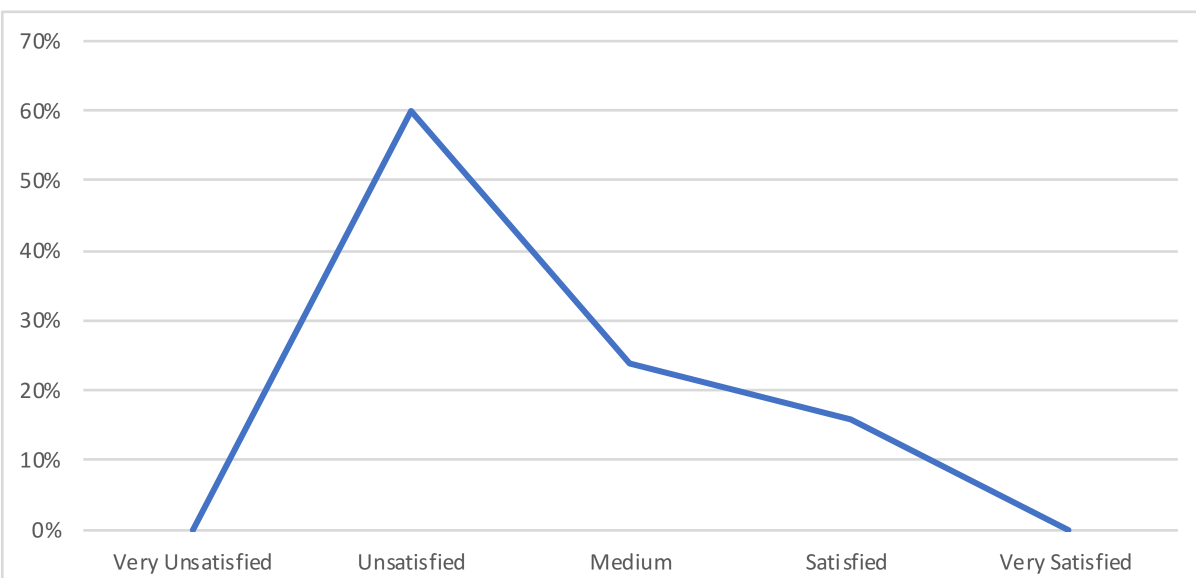


Figure V.13: Unsatisfied level in education building that request update.

V.3.1.2 Fuzzy Analytical Network Process

Second, to calculate the relative weights of the defined factors and subfactors, the fuzzy analytical network process (FANP), which comprises a series of calculations, was used. On the questionnaire, experts were asked about the relative importance of identified factors and subfactors, and a pairwise comparison (i.e., the most probable pairwise comparison or matrix) was built using the output of the questionnaires based on the Saaty scale to obtain the lower and upper matrices (Figure V.14). After creating the pairwise comparisons, they were fuzzified for all factors and subfactors (Tables V.6–10).

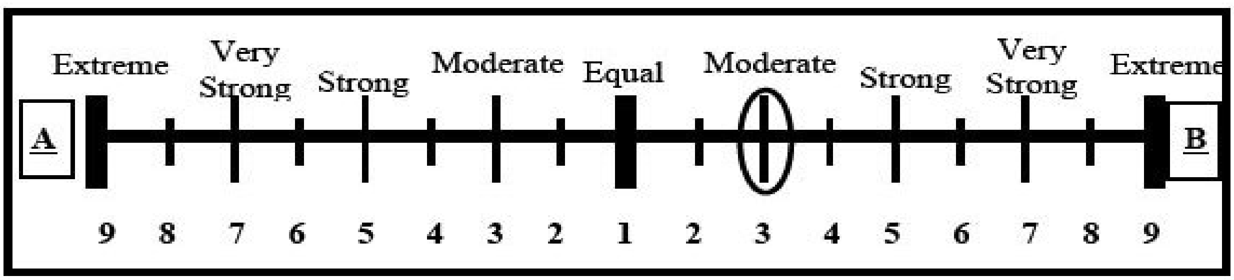


Figure V.14: Saaty scale. (Saaty 1989)

Table V.6: Indicators categories pairwise comparison with respect to the overall performance.

	Thermal comfort	Aesthetics	Design and flexibility	Lighting and acoustics
Thermal comfort	1	2	3	1
Design and flexibility	0.5	1	4	3
Aesthetics	0.3	0.2	1	2
Lighting and acoustics	1	0.3	0.5	1
Sum.	**2.8**	**3.5**	**8.5**	**7**

Table V.7: Thermal comfort indicators pairwise comparison.

	A heating/cooling system responding	Functions at a comfortable humidity.	Feels well ventilated.	How much control users have over their environment	Functions at a comfortable temperature.
A heating/cooling system responding	1	1	3	2	1
Functions at a comfortable humidity.	1	1	2	4	3
Feels well ventilated.	0.3	0.5	1	2	3
How much control users have over their environment	0.5	0.2	0.5	1	1
Functions at a comfortable temperature.	1	0.3	0.3	1	1
Sum.	**3.8**	**3**	**6.8**	**10**	**9**

Table V.8: Aesthetics indicators pairwise comparison.

	Visually appealing.	Tidy in appearance.	Containing up-to-date IT services.	Having good quality common amenities.	Having enough storage at their desk for personal items.	Degree of noise
Visually appealing.	1	3	2	4	1	2
Tidy in appearance.	0.3	1	4	3	2	3
Containing up-to-date IT services.	0.5	0.2	1	4	2	3
Having good quality common amenities.	0.2	0.3	0.2	1	4	2
Having enough storage at their desk for personal items.	1	0.5	0.5	0.2	1	3
Degree of noise	0.5	0.3	0.3	0.5	0.3	1
Sum.	**3.5**	**5.4**	**8**	**12.7**	**10.3**	**14**

Table V.9: Design and flexibility indicators pairwise comparison.

	The flexibility of the spaces	Conversational privacy in the office.	The circulation of the building.	Interaction with different colleagues.	ability to meet needs	openness and views to outside
The flexibility of the spaces	1	2	1	2	3	4
Conversational privacy in the office.	0.5	1	3	4	7	5
The circulation of the building.	1	0.3	1	3	3	4
Interaction with different colleagues.	0.5	0.2	0.3	1	2	4
ability to meet needs	0.3	0.1	0.3	0.5	1	2
openness and views to outside	0.2	0.2	0.2	0.2	0.5	1
Sum.	3.5	3.9	5.9	10.7	16.5	20

Table V.10: Lighting and acoustics indicators pairwise comparison

	distribution of sound	Proper reverberation	Natural sound diffusion	A sense of intimacy	Brightness.	Contrast.	Glare.	Diffusion.	Color.
Good distribution of sound	1	2	4	3	5	3	4	5	3
Proper reverberation	0.5	1	5	4	2	3	4	5	3
Natural sound diffusion	0.2	0.2	1	4	5	2	3	4	3
A sense of intimacy	0.3	0.2	0.2	1	3	3	4	3	1
Brightness.	0.2	0.5	0.2	0.3	1	3	4	3	2
Contrast.	0.3	0.3	0.5	0.3	0.3	1	3	4	3
Glare.	0.2	0.2	0.3	0.2	0.2	0.3	1	2	3
Diffusion.	0.2	0.2	0.2	0.3	0.3	0.2	0.5	1	4
Color.	0.3	0.3	0.3	1	0.5	0.3	0.3	0.2	1
Sum.	**3.4**	**5**	**11.8**	**14.2**	**17.4**	**15.9**	**23.8**	**27.2**	**23**

V.3.1.3 Indicators' relative weights

All calculations were performed with Excel sheets in order to calculate the unweighted matrix from normalization. Results of normalization were used as inputs, whereas the output was an unweighted super matrix located automatically in the Excel sheet (Table V.11). After the unweighted super matrix was calculated, the weighted super matrix was calculated by normalizing the unweighted one. Normalization was performed to make values in each column equal 1 by obtaining the sum of each column and dividing each cell within that column by the sum (Table V.12). Next, the limited matrix (Table V.13) was calculated by raising the weighted super matrix to a larger power in a continuous process until an output matrix equaled the one before it. That limited matrix calculation process was performed with an Excel sheet by multiplying weighted super matrix up to 256 times by itself. As a result, the FANP relative global weight for factors and subfactors was obtained from the first column of the limited matrix (Table V.14).

Table V.11: Unweighted super matrix

	##	C	TC	DF	A	LA	HCSR	CH	WV	CU	CT	VA	TA	CITS	GQ	S	DN	FA	CP	CB	IDC	AMN	OV	GDS	PRT	NSDE	SIA	B	Con	G	D	Col
1	Criteria ©	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Thermal comfort (TC)	0.35	0.00	1.18	0.50	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Design and flexibility (DF)	0.34	0.63	0.00	0.35	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Aesthetics (A)	0.15	0.26	0.64	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Lighting and acoustics (LA)	0.16	0.11	0.36	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	A heating/cooling system responding (HCSR)	0.00	0.27	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Functions at a comfortable humidity (CH)	0.00	0.32	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Feels well ventilated (WV)	0.00	0.19	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	How much control users have over their environment (CU)	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Functions at a comfortable temperature (CT)	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Visually appealing (VA)	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Tidy in appearance (TA)	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Containing up-to-date IT services (CITS)	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Having good quality common amenities (GQ)	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Having enough storage at their desk for personal items (S)	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Degree of noise (DN)	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	The flexibility of the spaces (FA)	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Conversational privacy in the office (CP)	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	The circulation of the building (CB)	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Interaction with different colleagues (IDC)	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	ability to meet needs (AMN)	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	openness and views to outside (OV)	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Good distribution of sound to all the space (GDS)	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Proper reverberation times throughout all frequencies (PRT)	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Natural sound diffusion and envelopment (NSDE)	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
26	A sense of intimacy for the audience (SIA)	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
27	Brightness (B)	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
28	Contrast (CON)	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
29	Glare (G)	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
30	Diffusion. (D)	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
31	Color (COL)	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
	Sum.	**1**	**2**	**3.177777778**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table V.12: Weighted super matrix

#	##	C	TC	DF	A	LA	HCSR	CH	WV	CU	CT	VA	TA	CITS	GQ	S	DN	FA	CP	CB	IDC	AMN	OV	GDS	PRT	NSDE	SIA	B	Con	G	D	Col
1	Criteria ©	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Thermal comfort (TC)	0.35	0.00	0.37	0.25	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Design and flexibility (DF)	0.34	0.32	0.00	0.17	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Aesthetics (A)	0.15	0.13	0.20	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Lighting and acoustics (LA)	0.16	0.05	0.11	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	A heating/cooling system responding (HCSR)	0.00	0.13	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Functions at a comfortable humidity (CH)	0.00	0.16	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Feels well ventilated (WV)	0.00	0.09	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	How much control users have over their environment (CU)	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Functions at a comfortable temperature (CT)	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Visually appealing (VA)	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Tidy in appearance (TA)	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Containing up-to-date IT services (CITS)	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Having good quality common amenities (GQ)	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Having enough storage at their desk for personal items (S)	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Degree of noise (DN)	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	The flexibility of the spaces (FA)	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Conversational privacy in the office (CP)	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	The circulation of the building (CB)	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Interaction with different colleagues (IDC)	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	ability to meet needs (AMN)	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	openness and views to outside (OV)	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Good distribution of sound to all the space (GDS)	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Proper reverberation times throughout all frequencies (PRT)	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Natural sound diffusion and envelopment (NSDE)	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
26	A sense of intimacy for the audience (SIA)	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
27	Brightness (B)	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
28	Contrast (CON)	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
29	Glare (G)	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
30	Diffusion. (D)	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
31	Color (COL)	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Sum.		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table V.13: Limited super matrix

#	##	C	TC	DF	A	LA	HCSR	CH	WV	CU	CT	VA	TA	CITS	GQ	S	DN	FA	CP	CB	IDC	AMN	OV	GDS	PRT	NSDE	SIA	B	Con	G	D	Col
1	Criteria ©	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Thermal comfort (TC)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Design and flexibility (DF)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Aesthetics (A)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Lighting and acoustics (LA)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	A heating/cooling system responding (HCSR)	0.11	0.17	0.08	0.06	0.06	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Functions at a comfortable humidity (CH)	0.13	0.21	0.10	0.07	0.07	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Feels well ventilated (WV)	0.07	0.12	0.06	0.04	0.04	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	How much control users have over their environment (CU)	0.04	0.06	0.03	0.02	0.02	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Functions at a comfortable temperature (CT)	0.05	0.08	0.04	0.03	0.03	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Visually appealing (VA)	0.06	0.04	0.11	0.03	0.03	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Tidy in appearance (TA)	0.05	0.04	0.10	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Containing up-to-date IT services (CITS)	0.04	0.03	0.07	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Having good quality common amenities (GQ)	0.03	0.02	0.05	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Having enough storage at their desk for personal items (S)	0.03	0.02	0.05	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Degree of noise (DN)	0.01	0.01	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	The flexibility of the spaces (FA)	0.06	0.04	0.05	0.15	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Conversational privacy in the office (CP)	0.07	0.05	0.06	0.19	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	The circulation of the building (CB)	0.04	0.03	0.04	0.11	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Interaction with different colleagues (IDC)	0.02	0.02	0.02	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	ability to meet needs (AMN)	0.01	0.01	0.01	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	openness and views to outside (OV)	0.01	0.01	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Good distribution of sound to all the space (GDS)	0.04	0.02	0.02	0.02	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Proper reverberation times throughout all frequencies (PRT)	0.03	0.01	0.02	0.02	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Natural sound diffusion and envelopment (NSDE)	0.02	0.01	0.01	0.01	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
26	A sense of intimacy for the audience (SIA)	0.02	0.01	0.01	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
27	Brightness (B)	0.01	0.01	0.01	0.01	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
28	Contrast (CON)	0.01	0.01	0.01	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
29	Glare (G)	0.01	0.00	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
30	Diffusion. (D)	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
31	Color (COL)	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Sum.		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table V.14: Factors and sub-factors global and relative weight.

FACTORS	Weight	Sub-Factors	Weights
Thermal comfort	**40%**	A heating/cooling system responding	11%
		Functions at a comfortable humidity.	13%
		Feels well ventilated.	7%
		How much control users have over their environment	4%
		Functions at a comfortable temperature.	5%
Aesthetics	**22%**	Visually appealing.	6%
		Tidy in appearance.	5%
		Containing up-to-date IT services.	4%
		Having good quality common amenities.	3%
		Having enough storage at their desk for personal items.	3%
		Degree of noise	1%
Design and flexibility	**21%**	The flexibility of the spaces	6%
		Conversational privacy in the office.	7%
		The circulation of the building.	4%
		Interaction with different colleagues.	2%
		ability to meet needs	1%
		openness and views to outside	1%
Lightening and acoustics	**16%**	Good distribution of sound to all the space.	4%
		Proper reverberation times throughout all frequencies.	3%
		Natural sound diffusion and envelopment	2%
		A sense of intimacy for the audience	2%
		Brightness.	1%
		Contrast.	1%
		Glare.	1%
		Diffusion.	1%
		Color.	1%
TOTAL			**100%**

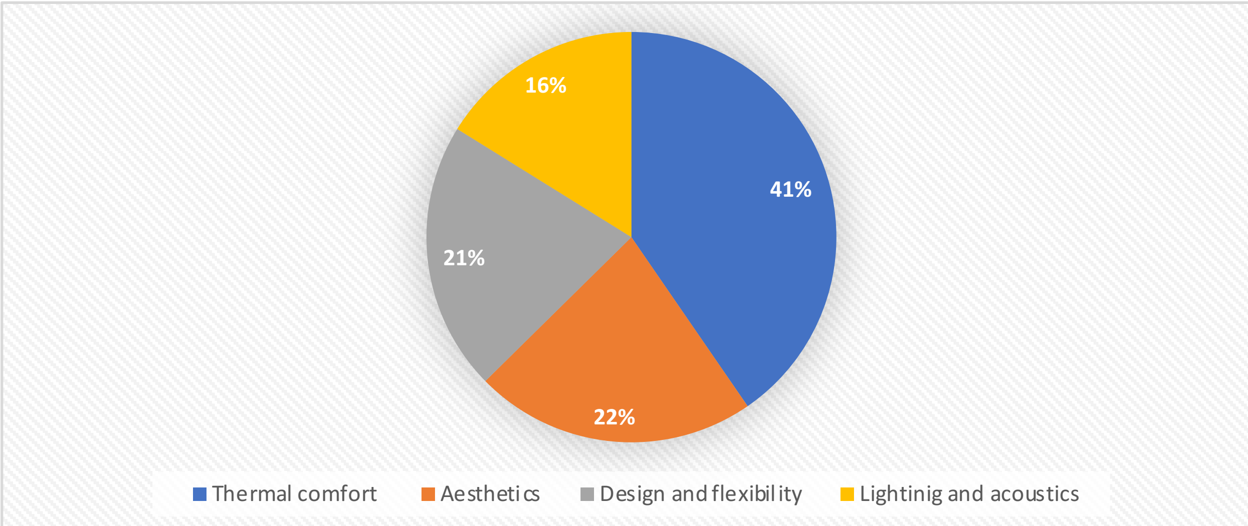


Figure V.15: Relative weight for the main four factors.

In terms of thermal comfort (Figure V.16), the highest relative weights were functions of comfortable humidity (13%), followed by a responsive heating and cooling system (11%) and the feeling of proper ventilation (7%). Concerning aesthetics, Figure V.17 indicates that the weights were nearly identical to the relative weights and that visual appeal (6%) and tidiness in appearance (5%) contributed most to overall performance. Conversely, design and flexibility contributed least to user satisfaction (Figure V.18) compared to thermal comfort, aesthetics, and lighting and acoustics. Such results could be explained by the fact that experts do not consider design and flexibility to be highly influential, for both aspects are nearly constant for each building and because ways to redesign the buildings to ameliorate those aspects are unavailable.

Figure V.19 shows that a good distribution of sound throughout the entire space had the greatest impact on user's satisfaction among lighting and acoustic factors. Accordingly, sound in education buildings should be the chief focus of FM experts to achieve user's satisfaction. Proper reverberation times throughout all frequencies (3%) and natural sound diffusion and envelopment (2%) were the next two most impactful subfactors on the satisfaction with lighting and acoustics among users.

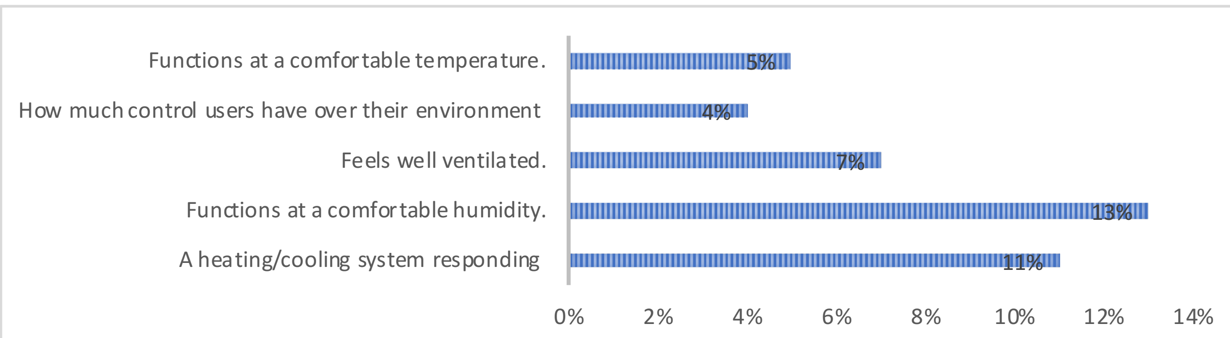


Figure V.16: Relative weight for the sub0fators of thermal comfort.

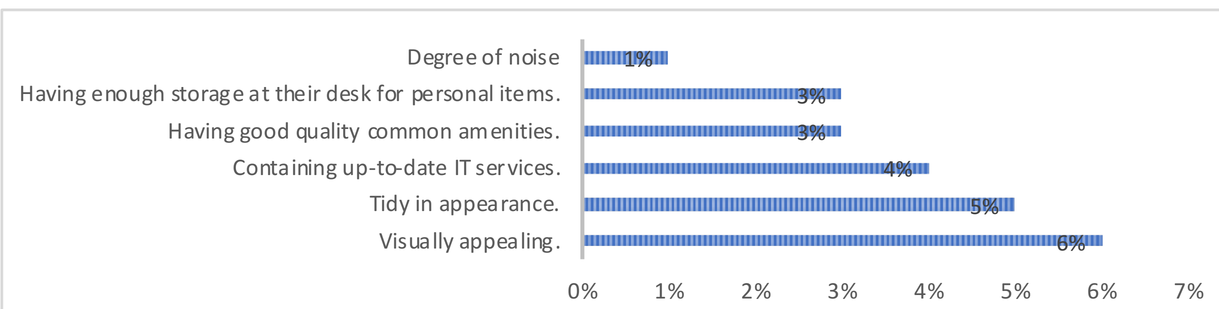


Figure V.17: Relative weight for the sub-factors of Aesthetics.

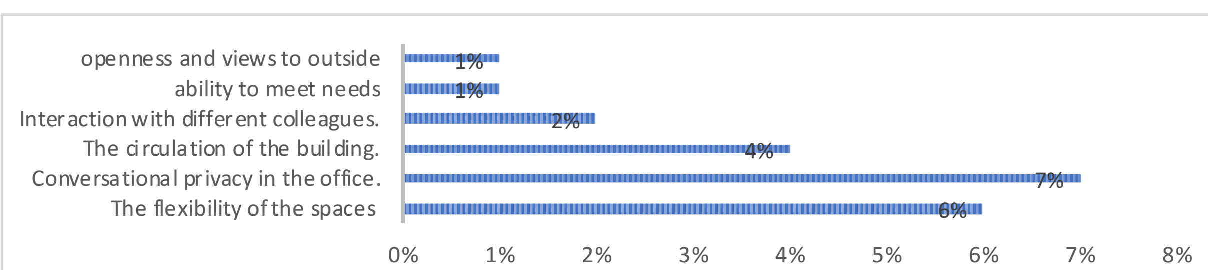


Figure V.18: Relative weight for the sub-factors of Design and flexibility

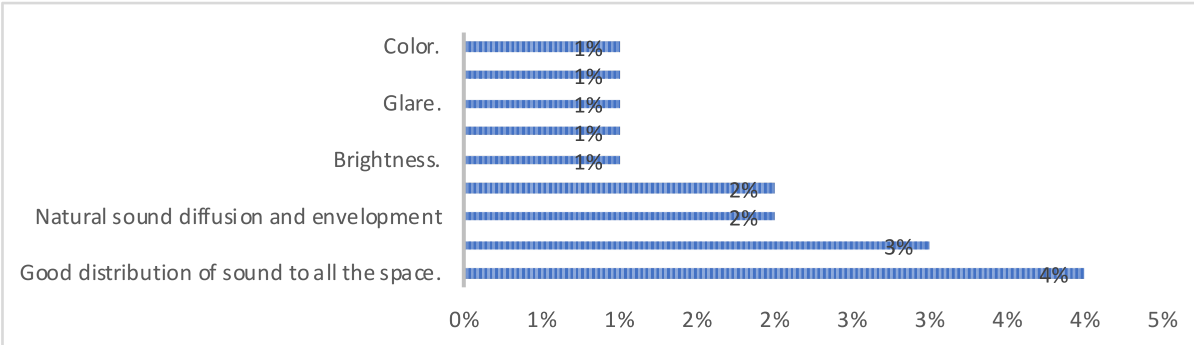


Figure V.19: Relative weight for the sub-factors of lightening and acoustic.

Once the OSS and weights for the factors and subfactors were determined, users' responses were evaluated in relation to the OSS and the relative weights to develop the building index and determine whether the buildings were satisfactory for users. The threshold value was unified among all factors deemed to be *dissatisfactory* by respondents. Table V.15 shows the scores for the factors and subfactors, as well as that factors and subfactors deemed *dissatisfactory* or *very satisfactory* generally indicated dissatisfaction. The table also indicates that, regarding thermal comfort, three subfactors achieved the dissatisfaction of users: a responsive heating and cooling system, a feeling of proper ventilation, and the degree of control that users have over their environment. By contrast, regarding lightening and acoustics, most subfactors were dissatisfactory from the user's perspective, except for proper reverberation times throughout all frequencies, brightness, and color.

Table V.15: Factors and sub-factors that achieve unsatisfied level or less in overall users' preventive scale.

#	Factors	Decision score (SL)	Sub-Factors	Decision score (SL)
1	**Thermal comfort (TC)**	**U**[1]	A heating/cooling system responding (HCSR)	**U**
			Functions at a comfortable humidity (CH)	**M**
			Feels well ventilated (WV)	**U**
			How much control users have over their environment (CU)	**U**
			Functions at a comfortable temperature (CT)	**M**
2	**Design and flexibility (DF)**	**M**	Visually appealing (VA)	**S**
			Tidy in appearance (TA)	**S**
			Containing up-to-date IT services (CITS)	**S**
			Having good quality common amenities (GQ)	**S**
			Having enough storage at their desk for personal items (S)	**S**
			Degree of noise (DN)	**S**
3	**Aesthetics (A)**	**M**	The flexibility of the spaces (FA)	**S**
			Conversational privacy in the office (CP)	**S**
			The circulation of the building (CB)	**S**
			Interaction with different colleagues (IDC)	**S**
			ability to meet needs (AMN)	**S**
			openness and views to outside (OV)	**S**
4	**Lighting and acoustics (LA)**	**U**	Good distribution of sound to all the space (GDS)	**U**
			Proper reverberation times throughout all frequencies (PRT)	**M**
			Natural sound diffusion and envelopment (NSDE)	**U**
			A sense of intimacy for the audience (SIA)	**U**
			Brightness (B)	**M**
			Contrast (CON)	**U**
			Glare (G)	**U**
			Diffusion (D)	**U**
			Color (COL)	**M**

[1] Orange color: indicted that either factors or sub-factors are not satisfied with users' prepositive

The findings of the data collection are discussed in what follows with the objective of answering two questions: (1) If a building is considered to be sustainable, then the users will be satisfied, and (2) How can the satisfaction of users with sustainable buildings be assessed?

A conceptual framework was developed to highlight important topics in SFM and guide discussions about the usefulness of a structured methodological framework in analyzing specific aspects of SFM.

To answer the first question, a model was developed to explain the kinds of attributes that influence the satisfaction of users of education buildings from their perspective. The findings showed that the economic and environmental aspects of SFM were strong predictors of the perceived importance of SFM. The activities of users, particularly their more complex behaviors, inside buildings should receive considerable attention by FMs as they consider implementing upgrades. FMs need to do more than use natural resources economically; they have to also achieve the user's satisfaction so that human resources can contribute to, instead of impede, a building's sustainability (Weiss et al. 2004).

To answer the second question, this chapter presents some unpredictable aspects of users' experiences of buildings related the qualities of buildings and the evaluation of a broad range of variables, including work environment configuration.

V.4 SUSTAINABLE USERS PERSPECTIVE UPGRADING PHASE:

After determining the dissatisfactory factors and subfactors, a Pugh matrix was used to select an alternative for each subfactor based on rational argument instead of subjective preferences. Briefly, the Pugh matrix affords a means to select the best option from multiple available options. To prepare the matrix, a list of alternatives was constructed to compare alternatives within each factor. Each alternative needed to be an objectively quantifiable measure. For example, three alternatives were possible for each subfactor of thermal comfort (Table V.16), whereas three separate alternatives were possible for the subfactor of having a heating and cooling system that is responsive to changes in temperature: upgrading all HVAC systems to high efficiency (i.e., with a 10-kW package unit), improve the air conditioner or heat pump, and improve chilling efficiency. For the functions of the subfactor of comfortable humidity, three different alternatives were possible: type of humidification, principles of indoor condensation, and humidity maintenance. Tables V.17–19 present the alternatives for all other factors and subfactors.

Table V.16: Alternatives for each sub-factor within thermal comfort

Factors	Sub-Criteria	#	Alternatives
Thermal comfort (TC)	Heating/cooling system that is responsive to changes in temperature (HCSR)	1	Upgrade all HVAC systems to high efficiency (Package unit 10 kw)
		2	Improve air-conditioner or heat pump
		3	Improve chiller efficiency
	Functions at a comfortable humidity (CH)	1	Humiliation Type
		2	Principles of Indoor Condensation
		3	Maintained Humidity Levels
	Feels well ventilated (WV)	1	control of airborne contaminants
		2	Install Air-To-Air heat exchange
		3	introduction and distribution of adequate ventilation air
	How much control users have over their environment (CU)	1	Personal control of thermal conditions
		2	More efficient air-conditioning
		3	Switch controlled HVAC
	Functions at a comfortable temperature (CT)	1	reduce heat conduction through celling, roofs, walls and floors
		2	reduce heat conduction, solar gain and long-wave radiation through dlazing areas
		3	reduce air infiltration

Table V.17: Alternatives for each sub-factor within Design and flexibility

Factors	Sub-Criteria	#	Alternatives
Design and flexibility (DF)	Visually appealing (VA)	1	Grabbing Attention
		2	Shapes
		3	Comfortable Content
	Tidy in appearance (TA)	1	welcome appearance
		2	perfect architecture language
		3	interactive
	Containing up-to-date IT services (CITS)	1	Develop an up-to-date inventory of all production systems
		2	Devise a plan for standardizing production systems to the same version and application software
		3	Compare reported vulnerabilities against your inventory/control list.
	Having good quality common amenities (GQ)	1	good furniture
		2	up to date technology
		3	interactive feedback team
	Having enough storage at their desk for personal items (S)	1	cabinets
		2	enough disk surface
		3	Personalize thoughtfully
	Degree of noise (DN)	1	Acoustic Wall Panels
		2	Innovating in zones Layout
		3	Noise Friendly Flooring

Table V.18: Alternatives for each sub-factor within Aesthetics

Factors	Sub-Criteria	#	Alternatives
Aesthetics (A)	The flexibility of the spaces (FA)	1	moving partition
		2	creative zones based on function
		3	enough spaces
	Conversational privacy in the office (CP)	1	meeting room
		2	round table meeting
		3	quite areas
	The circulation of the building (CB)	1	ignoring boring path
		2	adding some catalysts
		3	enhance function relationship between different zones
	Interaction with different colleagues (IDC)	1	Use effective communications
		2	Provide zones for different work modes
		3	adding gathering areas
	ability to meet needs (AMN)	1	interaction with users
		2	Plan for solo and team Work
		3	Better accommodate technology
	openness and views to outside (OV)	1	adding more daylight
		2	direction of opening biers
		3	positive views

Table V.19: Alternatives for each sub-factor within Lighting and acoustics

Factors	Sub-Criteria	#	Alternatives
Lighting and acoustics (LA)	Good distribution of sound to all the space (GDS)	1	good Component Selection
		2	perfect Physical Installation
		3	high Calibration
	Proper reverberation times throughout all frequencies (PRT)	1	Remove hard surfaces and things that vibrate from the room.
		2	panels that hang from the ceiling or attach to walls at an angle
		3	redesign the room mode
	Natural sound diffusion and envelopment (NSDE)	1	cover all the walls with equally sized foam panels
		2	Use rolls and slabs of insulation as absorbers
		3	Install foam panels
	A sense of intimacy for the audience (SIA)	1	Considering Seat Distribution and Room Shape
		2	Confirming the Vision
		3	Control and Systems Integration
	Brightness (B)	1	controlling too much range of luminance
		2	shading
		3	controlling too much light
	Contrast (CON)	1	Use fixed overhangs on south-facing glass
		2	Interior glare control devices
		3	Exterior elements such as overhangs or vertical fins
	Glare (G)	1	landscaping to shade east and west exposures
		2	interval shading advises
		3	external shading advises
	Diffusion (D)	1	proper orientation of windows and skylights
		2	window treatments
		3	Rearranging furniture and seating positions
	Color (COL)	1	White
		2	Brown
		3	Gray

Assigning weights to factors is a critical component of upgrading. Because most of the identified factors had different levels of importance, a mechanism was required to weigh the relative importance of the factors. To that end, a proven method is to allow FM experts assign a relative weight to each criterion based on how important they think the factor is. Accordingly, each FM expert distributed a predetermined number of points among the factors to produce a factoring scale. Next, the factor weights of all FM experts were averaged to identify an overall factor weight to use in the final matrix. Percentages of 60% and 40% were determined for time and cost, respectively (Table V.20, Figure V.20). It is critical to determine the weights of factors before performing such an analysis, or else evaluators could be unconsciously biased toward one design and assign weights that benefit the criteria of that design.

Table V.20: Percentage of the time and cost

Criteria	Weight of importance (%)
Time	60%
Cost	40%

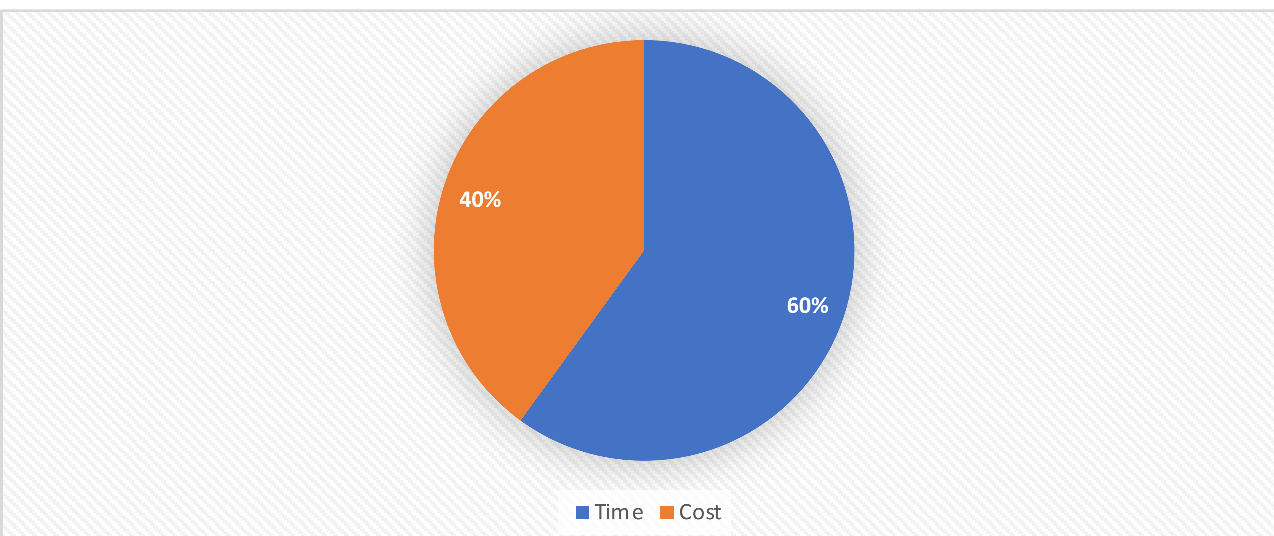


Figure V.20: Percentage of the time and cost

The required amount of work, units of measurement, cost of units, and times of units was determined for each alternative (Tables V.21 and V.22). Typically, when using a Pugh Matrix to select from among alternatives, design requirements can be used either in part or in whole and ideally should reflect both the user's perspective and sustainability.

Table V.21: An identification for amount of work, unit measurement, unit cost and unit time for dissatisfaction sub-factors with thermal comfort

Alternatives	Amount	Unit of Measurement	Unit Time	Unit Cost	Time	Cost
Upgrade all HVAC systems to high efficiency (Package unit 10 kw)	3	BTU	16	$ 5,344.00	48	$ 16,032.00
Improve air-conditioner or heat pump	6	BTU	8	$ 1,635.00	48	$ 9,810.00
Improve chiller efficiency	4	BTU	16	$ 4,352.00	64	$ 17,408.00
Humidication Type	5	BTU	8	$ 5,342.00	40	$ 26,710.00
Principles of Indoor Condensation	6	BTU	16	$ 2,311.00	96	$ 13,866.00
Maintained Humidity Levels	5	BTU	8	$ 3,324.00	40	$ 16,620.00
control of airborne contaminants	7	BTU	16	$ 3,425.00	112	$ 23,975.00
Instal Air-To-Air heat exchange	8	BTU	24	$ 2,142.00	192	$ 17,136.00
introduction and distribution of adequate ventilation air	9	BTU	16	$ 4,323.00	144	$ 38,907.00
Personal control of thermal conditions	8	BTU	16	$ 4,232.00	128	$ 33,856.00
More efficient air-conditioning	7	BTU	24	$ 4,113.00	168	$ 28,791.00
Switch controlled HVAC	6	BTU	8	$ 3,221.00	48	$ 19,326.00
reduce heat conduction through celling, roofs, walls and floors	5	BTU	32	$ 4,231.00	160	$ 21,155.00
reduce heat conduction, solar gain and long-wave radiation through dlazing areas	6	BTU	24	$ 3,211.00	144	$ 19,266.00
reduce air infiltration	6	BTU	16	$ 4,521.00	96	$ 27,126.00

Table V.22: An identification for amount of work, unit measurement, unit cost and unit time for dissatisfaction sub-factors with lightening and acoustics

Alternatives	Amount	Unit of Measurement	Unit Time	Unit Cost	Time	Cost
good Component Selection	50	Unit	10	$ 122.00	500	$ 6,100.00
perfect Physical Installation	100	Unit	20	$ 213.00	2,000	$ 21,300.00
high Calibration	40	Unit	25	$ 143.00	1,000	$ 5,720.00
Remove hard surfaces and things that vibrate from the room.	64	M2	24	$ 231.00	1,536	$ 14,784.00
panels that hang from the ceiling or attach to walls at an angle	74	M2	11	$ 342.00	814	$ 25,308.00
redesign the room mode	80	M2	16	$ 534.00	1,280	$ 42,720.00
cover all the walls with equally sized foam panels	76	M2	11	$ 422.00	836	$ 32,072.00
Use rolls and slabs of insulation as absorbers	47	M2	14	$ 423.00	658	$ 19,881.00
Install foam panels	85	M2	12	$ 341.00	1,020	$ 28,985.00
Considering Seat Distribution and Room Shape	43	Unit	23	$ 132.00	989	$ 5,676.00
Confirming the Vision	46	Unit	15	$ 143.00	690	$ 6,578.00
Control and Systems Integration	23	Unit	23	$ 423.00	529	$ 9,729.00
controlling too much range of luminance	80	M	21	$ 78.00	1,680	$ 6,240.00
shading	45	M	16	$ 89.00	720	$ 4,005.00
controlling too much light	10	M	17	$ 74.00	170	$ 740.00
use fixed overhangs on south-facing glass	35	Unit	13	$ 423.00	455	$ 14,805.00
interior glare control devices	44	Unit	22	$ 243.00	968	$ 10,692.00
exterior elements such as overhangs or vertical fins	64	Unit	18	$ 65.00	1,152	$ 4,160.00
landscaping to shade east and west exposures	53	M	25	$ 143.00	1,325	$ 7,579.00
interval shading advises	23	M	20	$ 324.00	460	$ 7,452.00
external shading advises	54	M	22	$ 423.00	1,188	$ 22,842.00
proper orientation of windows and skylights	35	Unit	12	$ 534.00	420	$ 18,690.00
window treatments	46	Unit	15	$ 153.00	690	$ 7,038.00
rearranging furniture and seating positions	65	Unit	12	$ 74.00	780	$ 4,810.00
white	211	M2	22	$ 12.00	4,642	$ 2,532.00
brown	231	M2	15	$ 43.00	3,465	$ 9,933.00
gray	342	M2	22	$ 12.00	7,524	$ 4,104.00

Once the lists of possible solutions list and evaluation criteria were finalized, an assessment of alternatives and of the criteria was performed by extracting the expert judgments to obtain the aggregated fuzzy weights of the criteria and of the possible solutions. That step allowed the aggregated fuzzy ratings of the alternatives to be calculated with respect to each criterion. Subsequently, the possible solutions were ranked according to their cost and time in order to select the optimal solution or solutions (Tables V.23 and V.24).

Table V.23: Ranking the possible solutions based on cost and time context for thermal comfort dissatisfaction sub-factor

Alternatives	Normalized Time	Normalized Cost	Alternative Score	Rank
Upgrade all HVAC systems to high efficiency (Package unit 10 kw)	0.67	0.77	0.71	3
Improve air-conditioner or heat pump	0.33	0.23	0.29	1
Improve chiller efficiency	0.67	0.62	0.65	2
Humidication Type	0.33	0.70	0.48	2
Principles of Indoor Condensation	0.67	0.30	0.52	3
Maintained Humidity Levels	0.33	0.43	0.37	1
control of airborne contaminants	0.40	0.53	0.45	1
Install Air-To-Air heat exchange	0.60	0.33	0.49	2
introduction and distribution of adequate ventilation air	0.40	0.67	0.51	3
Personal control of thermal conditions	0.50	0.57	0.53	2
More efficient air-conditioning	0.75	0.55	0.67	3
Switch controlled HVAC	0.25	0.43	0.32	1
reduce heat conduction through cellings, roofs, walls and floors	0.67	0.55	0.62	3
reduce heat conduction, solar gain and long-wave radiation through dlazing areas	0.50	0.42	0.47	2
reduce air infiltration	0.33	0.58	0.43	1

Table V.24: Ranking the possible solutions based on cost and time context for lightening and acoustics dissatisfaction sub-factor

Alternatives	Normalized Time	Normalized Cost	Alternative Score	Rank
good Component Selection	0.29	0.36	0.32	1
perfect Physical Installation	0.57	0.64	0.60	2
high Calibration	0.71	0.43	0.60	3
Remove hard surfaces and things that vibrate from the room.	0.69	0.30	0.53	2
panels that hang from the ceiling or attach to walls at an angle	0.31	0.45	0.37	1
redesign the room mode	0.46	0.70	0.55	3
cover all the walls with equally sized foam panels	0.44	0.55	0.48	2
Use rolls and slabs of insulation as absorbers	0.56	0.55	0.56	3
Install foam panels	0.48	0.45	0.47	1
Considering Seat Distribution and Room Shape	0.61	0.24	0.46	2
Confirming the Vision	0.39	0.26	0.34	1
Control and Systems Integration	0.61	0.76	0.67	3
controlling too much range of luminance	0.57	0.48	0.53	3
shading	0.43	0.55	0.48	2
controlling too much light	0.46	0.45	0.46	1
Use fixed overhangs on south-facing glass	0.37	0.87	0.57	2
Interior glare control devices	0.63	0.50	0.58	3
Exterior elements such as overhangs or vertical fins	0.51	0.13	0.36	1
landscaping to shade east and west exposures	0.56	0.25	0.43	1
interval shading advises	0.44	0.57	0.50	2
external shading advises	0.49	0.75	0.59	3
proper orientation of windows and skylights	0.44	0.88	0.62	3
window treatments	0.56	0.25	0.43	2
Rearranging furniture and seating positions	0.44	0.12	0.32	1
White	0.59	0.22	0.44	1
Brown	0.41	0.78	0.56	3
Gray	0.59	0.22	0.44	1

Table V.25 shows that concerning thermal comfort, an improved air conditioner or heat pump, better-maintained humidity levels, better control of airborne contaminants, a switch-controlled HVAC system, and reduced air infiltration were the best solutions to maximize the satisfaction of users. Those alternatives would cost $96,857 and require 344 h of work (Figures V.21 and V.22). Regarding lighting and acoustics (Table V.26), selecting good components, using panels that hang from the ceiling or attach to walls at an angle, using foam panels, confirming the vision, controlling for too much light, and using exterior elements (e.g., overhangs and vertical fins, landscaping to shade eastward and westward exposure, and white paint) would be optimal solutions to maximize the user's satisfaction. Those optimal alternatives would cost $90,896 and require 18,617 h of work (Figures V.23 and V.24).

Implementing the optimal solutions can prioritize the user's perspective in response to dissatisfaction with criteria on the LDC. If the implementation of the first optimal solution does not elevate the user's satisfaction to an acceptable level, then another optimal solution should be implemented. The sustainability of a building in respect to each dissatisfactory criterion is considered to be complete if users deem it to be at least *neither dissatisfactory nor satisfactory* overall. Upgrading all dissatisfactory criteria on the LDC can improve the sustainability of the building from the user's perspective.

Table V.25: Time and accost for each sub factors wither thermal comfort

Main Criteria	Sub-criteria	Chosen Alternative	Time	Cost
Thermal comfort (TC)	Heating/cooling system that is responsive to changes in temperature (HCSR)	Improve air-conditioner or heat pump	48	$ 9,810.00
	Functions at a comfortable humidity (CH)	Maintained Humidity Levels	40	$ 16,620.00
	Feels well ventilated (WV)	control of airborne contaminants	112	$ 23,975.00
	How much control users have over their environment (CU)	Switch controlled HVAC	48	$ 19,326.00
	Functions at a comfortable temperature (CT)	reduce air infiltration	96	$ 27,126.00

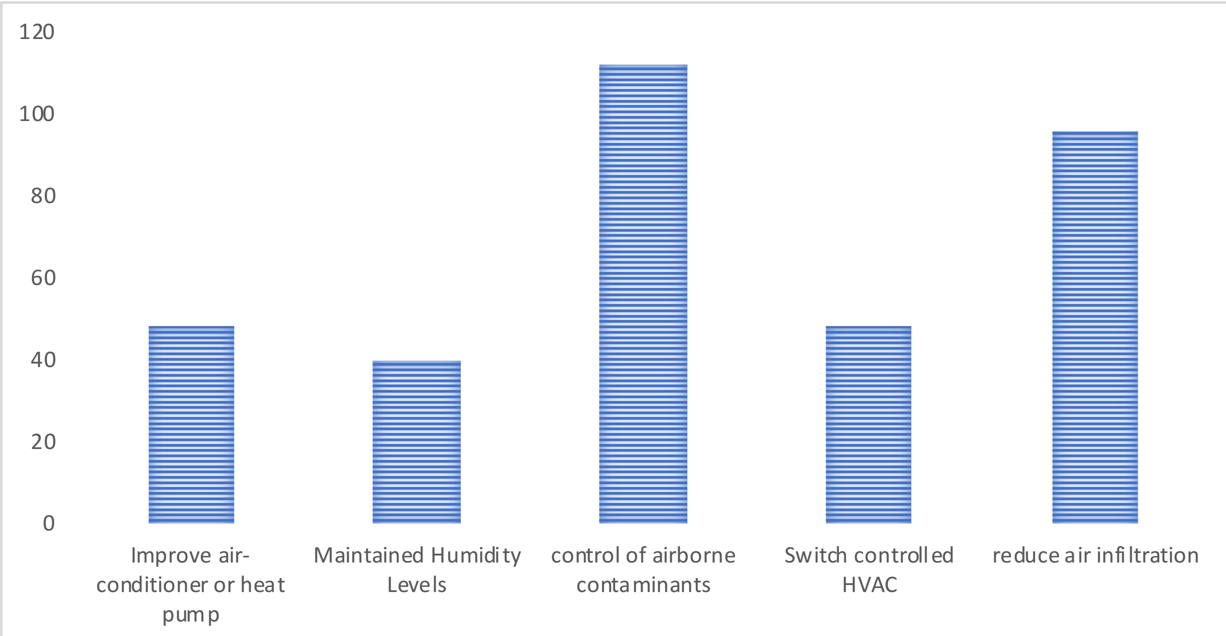


Figure V.21: Time need for upgrade each thermal comfort sub-factors

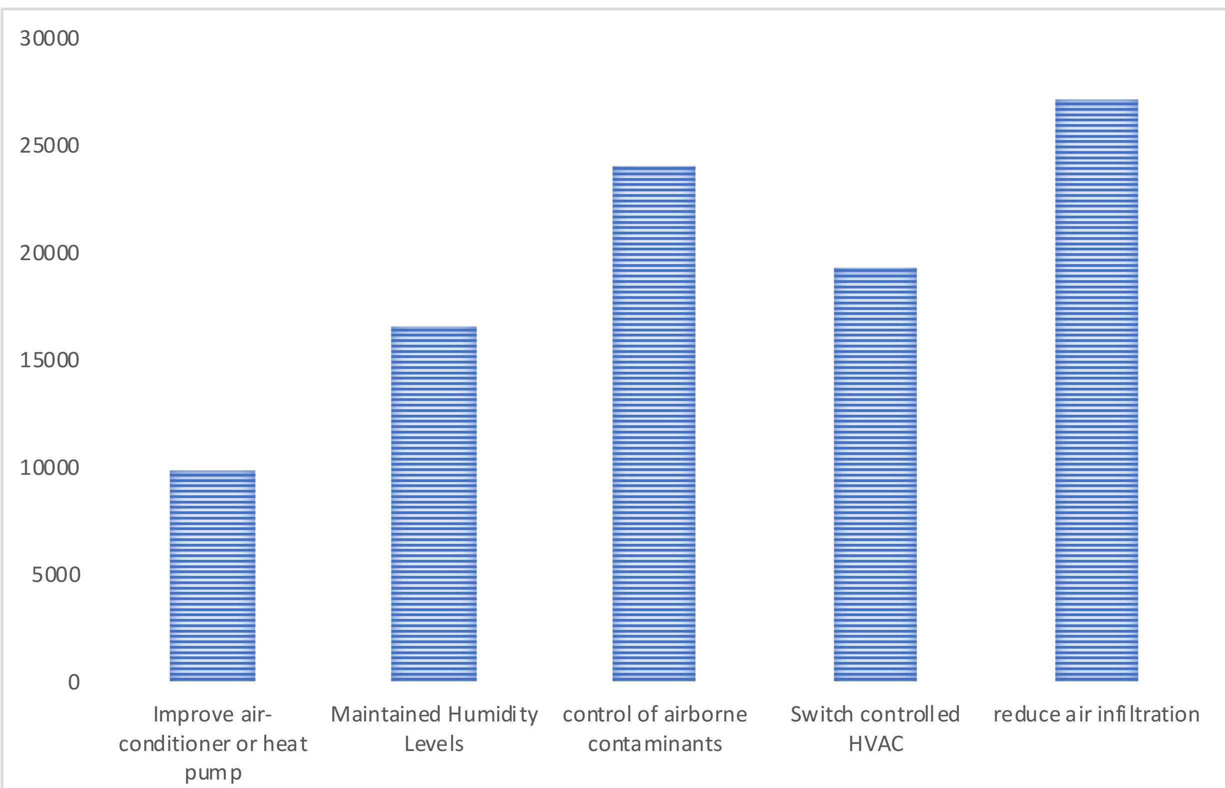


Figure V.22: Cost of upgrade each thermal comfort sub-factors

Table V.26: Time and accost for each sub factors wither Lighting and acoustics

<table>
<tr><th>Main Criteria</th><th>Sub-criteria</th><th>Chosen Alternative</th><th>Time</th><th>Cost</th></tr>
<tr><td rowspan="29">Lighting and acoustics (LA)</td><td rowspan="3">Good distribution of sound to all the space (GDS)</td><td>Good Component Selection</td><td>500</td><td>$ 6,100.00</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Proper reverberation times throughout all frequencies (PRT)</td><td></td><td></td><td></td></tr>
<tr><td>Panels that hang from the ceiling or attach to walls at an angle</td><td>814</td><td>$ 25,308.00</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Natural sound diffusion and envelopment (NSDE)</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Install foam panels</td><td>1,020</td><td>$ 28,985.00</td></tr>
<tr><td rowspan="3">A sense of intimacy for the audience (SIA)</td><td></td><td></td><td></td></tr>
<tr><td>Confirming the Vision</td><td>690</td><td>$ 6,578.00</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Brightness (B)</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Controlling Too Much Light</td><td>170</td><td>$ 740.00</td></tr>
<tr><td rowspan="3">Contrast (CON)</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Exterior elements such as overhangs or vertical fins</td><td>1,152</td><td>$ 4,160.00</td></tr>
<tr><td rowspan="3">Glare (G)</td><td>Landscaping to shade east and west exposures</td><td>1,325</td><td>$ 7,579.00</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Diffusion (D)</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Rearranging furniture and seating positions</td><td>780</td><td>$ 4,810.00</td></tr>
<tr><td rowspan="3">Color (COL)</td><td>White</td><td>4,642</td><td>$ 2,532.00</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Gray</td><td>7,524</td><td>$ 4,104.00</td></tr>
</table>

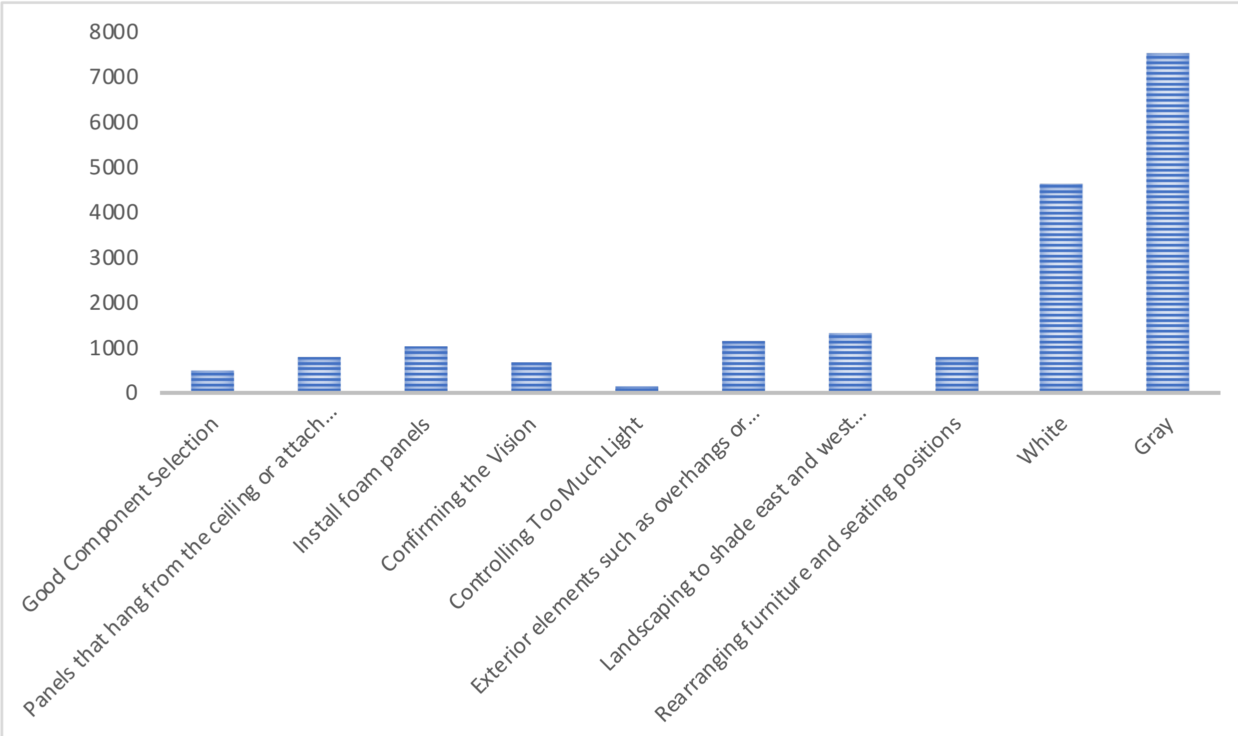


Figure V.23: Time need for upgrade each Lighting and acoustics sub-factors

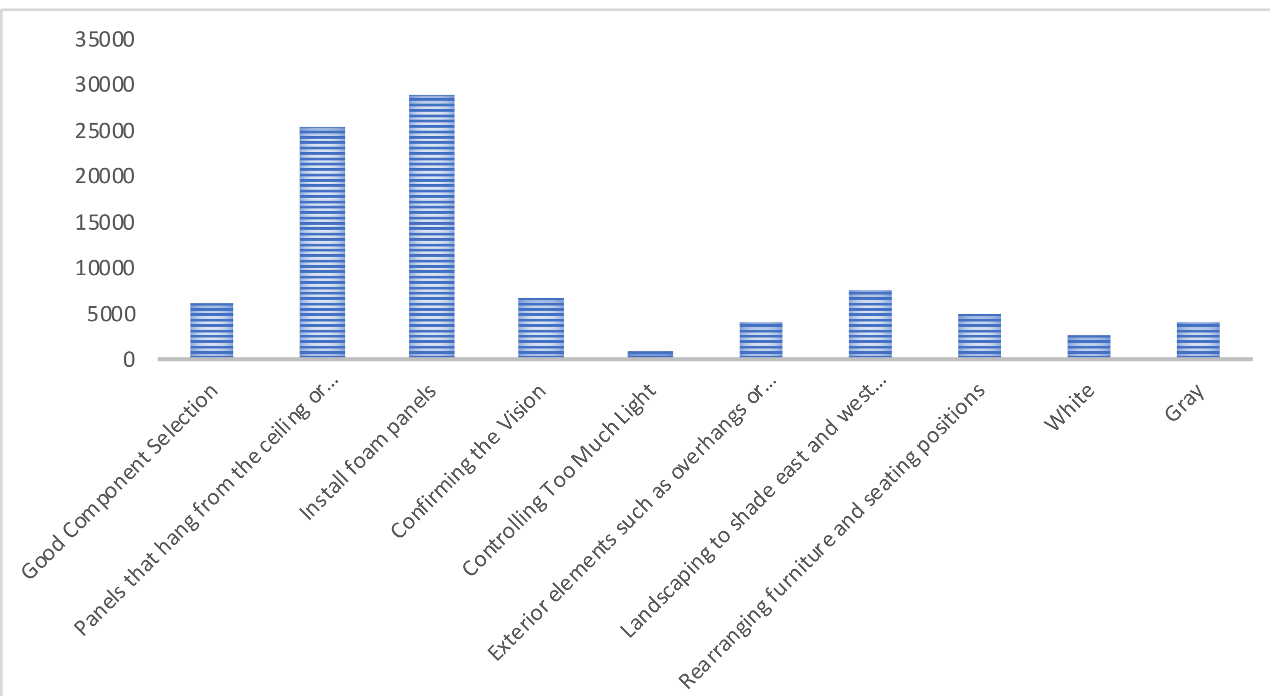


Figure V.24: Cost of upgrade each Lighting and acoustics sub-factors

V.5. SUSTAINABILITY UPGRADING USING A GENETIC ALGORITHM

All of the outputs from the user's perspective on sustainability upgrades were used as inputs in the model for allocating the budget and time. To optimize such allocation in order to achieve the best increased satisfaction of users, the software Evolved and genetic algorithm techniques were used. With performance as the objective, only two updating actions were specified: no action and total replacement. In the GA model, those actions are used as variables for decision making, with the chief constraint being the allowable annual budget and time. The primary inputs for the GA models were updating actions and the cost as well as time of units used in those actions. Tables V.25 and V.26 present the selection of the defined updating actions based on the performance indices. The models were also linked to the FANP model to incorporate the effect of the weights of each factor and subfactor. The available budget and time were distributed across the components of each factor and subfactor by taking into consideration the weight of each component in respect to factors of the overall user's perspective.

The allowable budget and time for upgrading the EV building was assumed with reference to the Department of Facilities Management at Concordia University in three scenarios (Table V.27, Figures V.25 and V.26): the pessimistic scenario ($100,000 and 8,000 h), the average scenario ($150,000 and 10,000 h), and the optimistic scenario ($180,000 and 15,000 h). Each scenario requires three stages: updating data for alternative solutions, maximizing user's satisfaction, and optimization. The first process was performed as part of the upgrading model, whereas the other two stages are performed automatically. An Al alternative was identified for each subfactor.

Table V.27: Three different scenarios

scenarios	Cost ($)	Time (Hr)
Pessimistic scenario	$ 100000	8000 hr
Average scenario	$ 150000	10000 hr
optimistic scenario	$ 180000	15000 hr

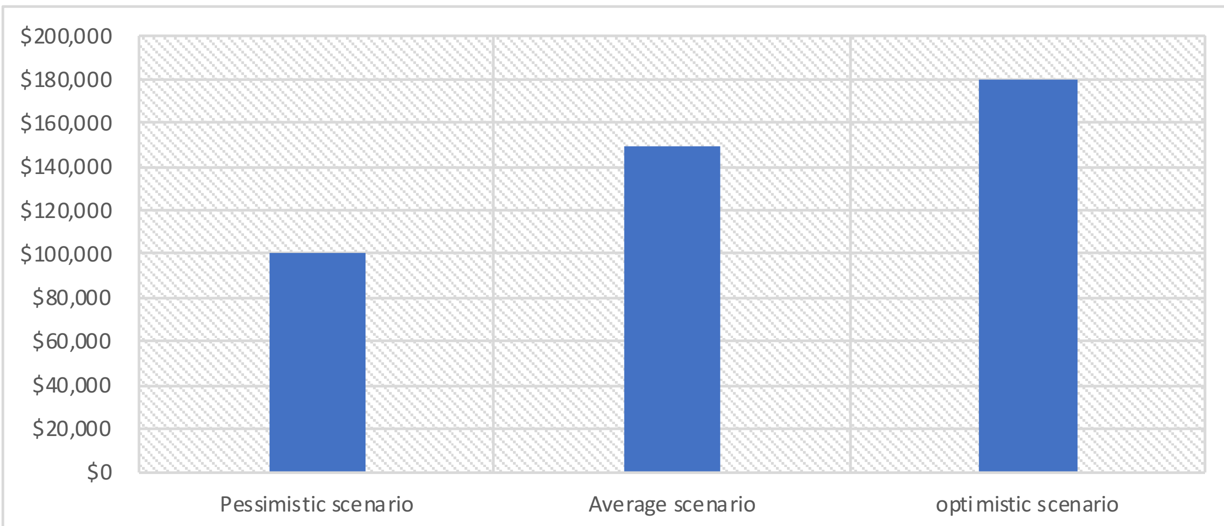


Figure V.25: Comparison chart for the three-different scenario for GA optimization (Cost)

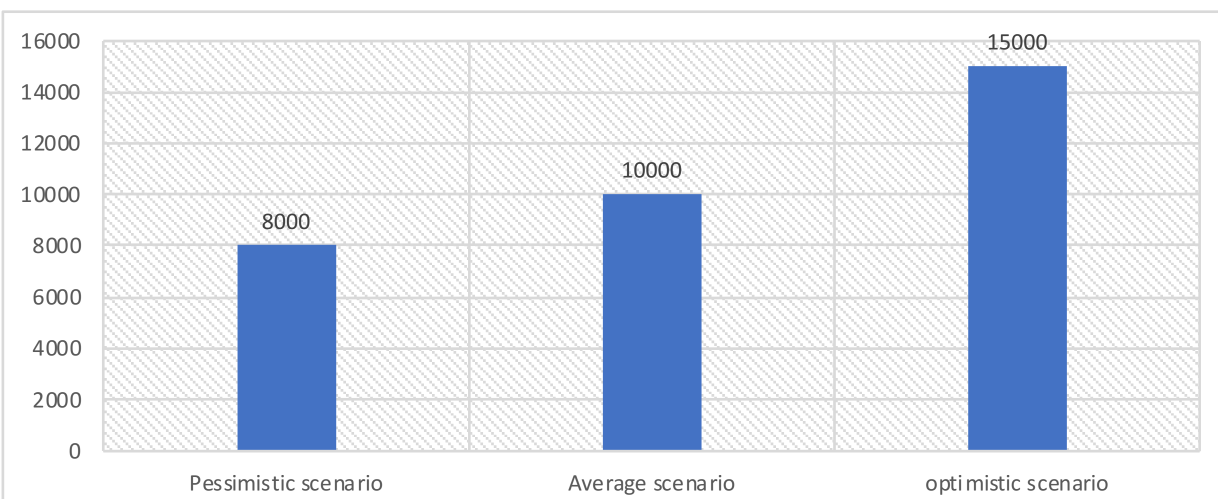


Figure V.26: Comparison chart for the three-different scenario for GA optimization (Time (HR))

V.5.1 Optimistic Scenario: The User's Perspective Assessment and Optimization Results Display:

Table V.28 shows the optimistic scenario with a budget of $180,000 and a work allotment of 15,000 h. The optimization model selected specific subfactors within factors that needed to be upgraded in order to improve the building index from the user's perspective within the allocated budget and time. For thermal comfort (Figure V.27), the optimization model selected a heating and cooling system that is responsive to changes in temperature, the feeling of proper ventilation, and the degree of control that users have over their environment; the corresponding actions for upgrading each subfactor were to improve the air conditioner or heat pump, control airborne contaminants, and use a switch-controlled HVAC system, respectively. For lighting and acoustics, the optimization model selected the subfactors of a sense of intimacy for the audience, glare, and diffusion; the corresponding actions for upgrading each subfactor were confirming the vision, landscaping to shade eastward and westward exposure, and rearranging the furniture and seating positions. The upgrades have a budget of $72,078 and a work allotment of 3,003 h and could improve the building index from 5.7 to 7.0 out of 10.0.

Figure V.27: Comparison between allocated cost and Time with original cost and time

Table V.28: Optimistic scenario

Main Factor	Sub- Factor	Decision Score (SL)	Upgrading Alternative	Old Index	Scenario upgrading time (Hrs)	Scenario upgrading cost ($)	Scenario Improvement scale	New Index
Thermal comfort (TC)	Heating/cooling system that is responsive to changes in temperature (HCSR)	**U**	Improve air-conditioner or heat pump	3	48	9,810.00	M	5.5
	Functions at a comfortable humidity (CH)	M		5.5	0			5.5
	Feels well ventilated (WV)	**U**	control of airborne contaminants	3	112	23,975.00	VS	9
	How much control users have over their environment (CU)	**U**	Switch controlled HVAC	3	48	19,326.00	S	7.5
	Functions at a comfortable temperature (CT)	M		5.5	0			5.5
Lighting and acoustics (LA)	Good distribution of sound to all the space (GDS)	**U**	good Component Selection	3	0			3
	Proper reverberation times throughout all frequencies (PRT)	M		5.5	0			5.5
	Natural sound diffusion and envelopment (NSDE)	**U**	Install foam panels	3	0			3
	A sense of intimacy for the audience (SIA)	**U**	Confirming the Vision	3	690	6,578.00	M	5.5
	Brightness (B)	M		5.5	0			5.5
	Contrast (CON)	**U**	Exterior elements such as overhangs or vertical fins	3	0			3
	Glare (G)	**U**	landscaping to shade east and west exposures	3	1325	7,579.00	S	7.5
	Diffusion (D)	**U**	Rearranging furniture and seating positions	3	780	4,810.00	S	7.5
	Color (COL)	M		5.5	0			5.5
Total				**5.7**	**3003**	**72078**		**7**

V.5.2 Average Scenario: The User's Perspective Assessment and Optimization Results Display:

Table V.29 illustrates the average scenario with a budget $150,000 and a work allotment of 10,000 h. The optimization model selected specific subfactors within the factors that needed upgrading in order to improve the building's index from the user's perspective with the allocated budget and time. For thermal comfort (Figure V.28), the optimization model selected a responsive heating and cooling system and offering users more control over their environment; the corresponding actions to upgrade each subfactor were to improve the air conditioner or heat pump and use a switch-controlled HVAC, respectively. For lighting and acoustics, the optimization model selected the subfactors of a good distribution of sound throughout the space, natural sound diffusion and envelopment, contrast, and glare; the corresponding actions to upgrade each subfactor were selecting good components, installing foam panels, and using exterior elements such as overhangs or vertical fins and landscaping to shade eastward and westward exposure. The upgrades have a budget of $75,960.00 and a work allotment of 4,093 h, and the building index could be improved from 5.7 to 6.5 out of 10.0 as a result of the upgrades.

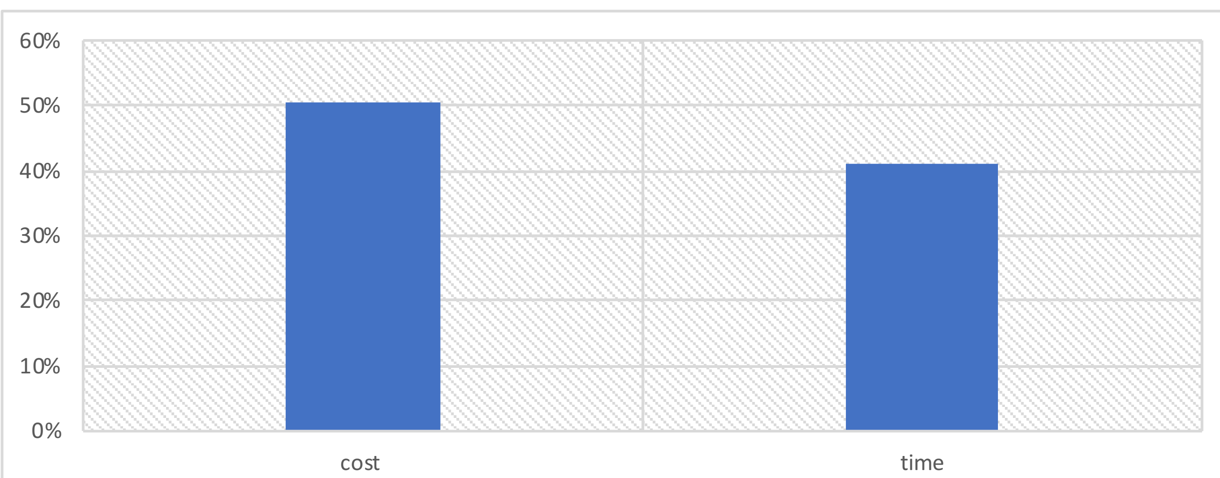


Figure V.28: Comparison between allocated cost and Time with original cost and time

Table V.29: Average scenario

Main Factor	Sub- Factor	Decision Score (SL)	Upgrading Alternative	Old Index	Scenario upgrading time (Hrs)	Scenario upgrading cost ($)	Scenario Improvement scale	New Index	Main Factor
Thermal comfort (TC)	Heating/cooling system that is responsive to changes in temperature (HCSR)	**U**	Improve air-conditioner or heat pump	M	3	48	9,810.00	M	5.5
	Functions at a comfortable humidity (CH)	M			5.5	0			5.5
	Feels well ventilated (WV)	**U**	control of airborne contaminants	VS	3	0			3
	How much control users have over their environment (CU)	**U**	Switch controlled HVAC	S	3	48	19,326.00	S	7.5
	Functions at a comfortable temperature (CT)	M			5.5	0			5.5
Lighting and acoustics (LA)	Good distribution of sound to all the space (GDS)	**U**	good Component Selection	S	3	500	6,100.00	S	7.5
	Proper reverberation times throughout all frequencies (PRT)	M			5.5	0			5.5
	Natural sound diffusion and envelopment (NSDE)	**U**	Install foam panels	S	3	1020	28,985.00	S	7.5
	A sense of intimacy for the audience (SIA)	**U**	Confirming the Vision	M	3	0			3
	Brightness (B)	M			5.5	0			5.5
	Contrast (CON)	**U**	Exterior elements such as overhangs or vertical fins	VS	3	1152	4,160.00	VS	9
	Glare (G)	**U**	landscaping to shade east and west exposures	S	3	1325	7,579.00	S	7.5
	Diffusion (D)	**U**	Rearranging furniture and seating positions	S	3	0			3
	Color (COL)	M			5.5	0			5.5
Total					**5.7**	**4093.00**	**75,960**		**6.5**

V.5.3 Pessimistic Scenario: The User's Perspective Assessment and Optimization Results Display:

Table V.30 shows the pessimistic scenario with a budget of $100,000 and a work allotment of 8,000 h. The optimization model selected specific subfactors within the factors that needed to be upgraded in order to improve the building index from a user's perspective within the allocated budget and time allotment. For thermal comfort (Figure V.29), the optimization model selected a responsive heating and cooling system and the degree of control users have over their environment; the corresponding actions to upgrade each subfactor were to improve the air-conditioner or heat pump and to install a switch-controlled HVAC, respectively. For lighting and acoustics, the optimization model selected a good distribution of sound throughout the space, natural sound diffusion and envelopment, contrast, and glare; the corresponding actions to upgrade each subfactor were to select good components, install foam panels, and incorporate exterior elements such as overhangs or vertical fins and landscaping to shade eastward and westward exposure. The upgrade has a budget of $91,066.00 and a time allotment of 3,160 h and can improve the building index from 5.7 to 6.7 out of 10.0.

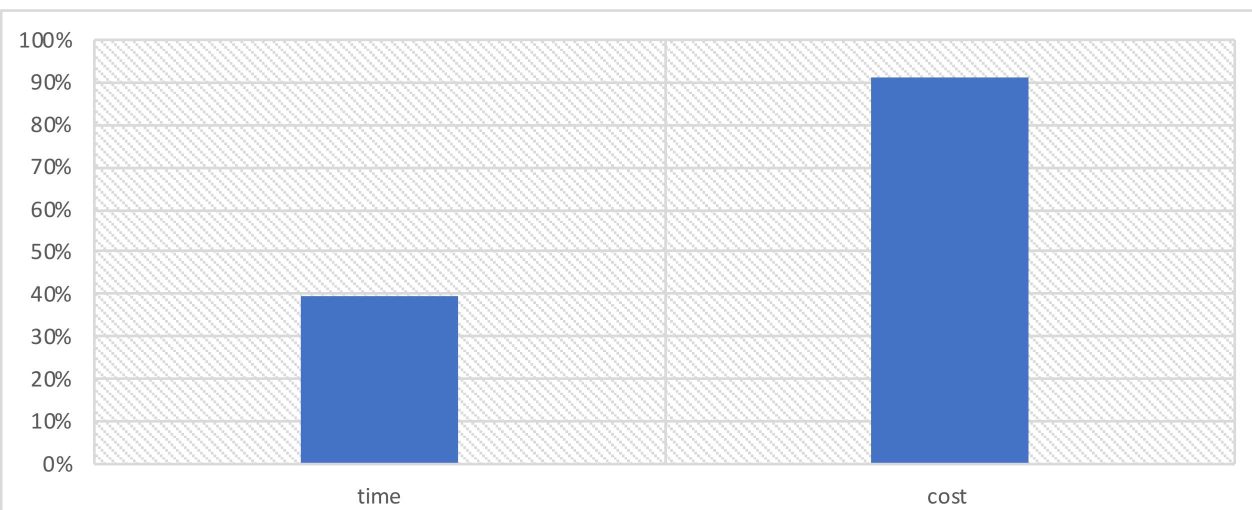


Figure V.29: Comparison between allocated cost and Time with original cost and time

Table V.30: Pessimistic scenario

Main Factor	Sub- Factor	Decision Score (SL)	Upgrading Alternative	Old Index	Scenario upgrading time (Hrs)	Scenario upgrading cost ($)	Scenario Improvement scale	New Index	Main Factor
Thermal comfort (TC)	Heating/cooling system that is responsive to changes in temperature (HCSR)	**U**	Improve air-conditioner or heat pump	M	3	48	9,810.00	M	5.5
	Functions at a comfortable humidity (CH)	M			5.5	0			5.5
	Feels well ventilated (WV)	**U**	control of airborne contaminants	VS	3	112	23,975.00	VS	9
	How much control users have over their environment (CU)	**U**	Switch controlled HVAC	S	3	48	19,326.00	S	7.5
	Functions at a comfortable temperature (CT)	M			5.5	0			5.5
Lighting and acoustics (LA)	Good distribution of sound to all the space (GDS)	**U**	good Component Selection	S	3	0			3
	Proper reverberation times throughout all frequencies (PRT)	M			5.5	0			5.5
	Natural sound diffusion and envelopment (NSDE)	**U**	Install foam panels	S	3	1020	28,985.00	S	7.5
	A sense of intimacy for the audience (SIA)	**U**	Confirming the Vision	M	3	0			3
	Brightness (B)	M			5.5	0			5.5
	Contrast (CON)	**U**	Exterior elements such as overhangs or vertical fins	VS	3	1152	4,160.00	VS	9
	Glare (G)	**U**	landscaping to shade east and west exposures	S	3	0			3
	Diffusion (D)	**U**	Rearranging furniture and seating positions	S	3	780	4,810.00	S	7.5
	Color (COL)	M			5.5	0			5.5
Total					**5.7**	**3160.00**	**91,066.00**		**6.717**

V.5.4. Comparisons between the Three Scenarios:

As shown in Figure V.30, the three scenarios—the pessimistic scenario ($100,000, 8,000 h), the average scenario ($150,000, 10,000 h), and the optimistic scenario ($180,000, 15,000 h)—varied in their time allotments and budgets. For the pessimistic scenario, the time allotment and cost would consume 40% and 91%, respectively, of the original budget and time allocated for a result of BS 6.7. With the average scenario (Figure V.30), the cost would consume 51% and the time allotment 41% of the original budget and time allocated for a result of BS 6.5. With the optimistic scenario, the time used would be only 20% of the time budgeted for a result of BS 7.0, and the cost would be only 40% of the total budget for a result of BS 7.0.

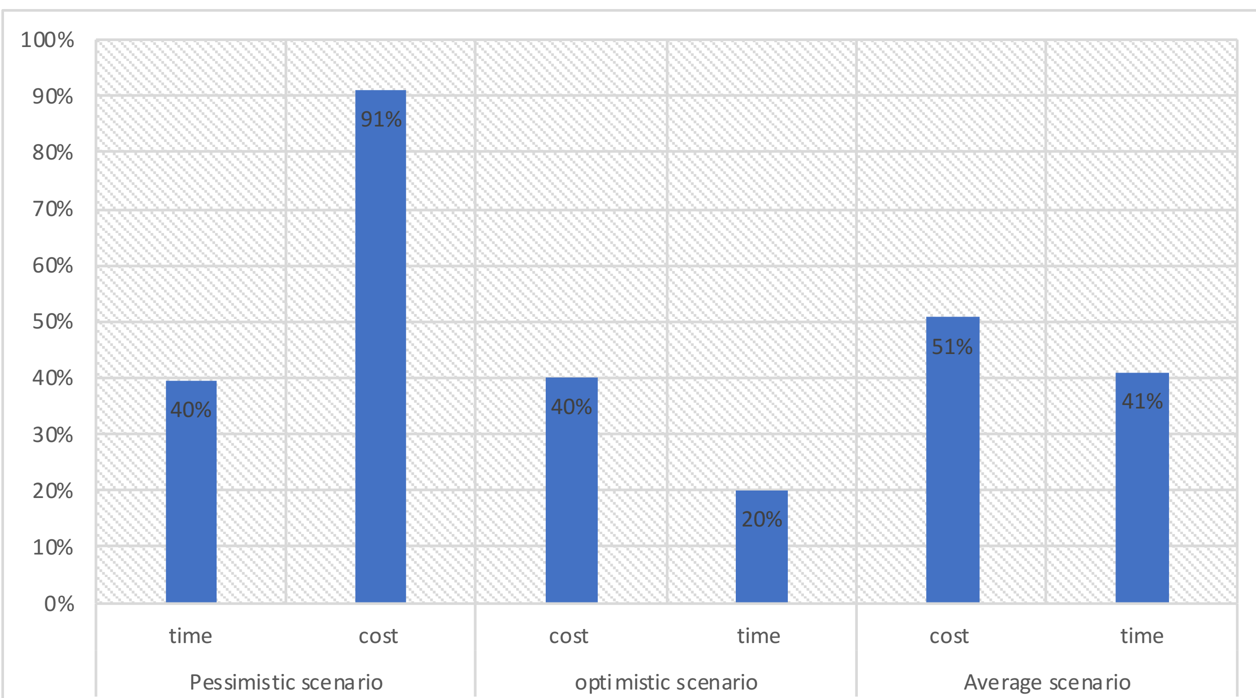


Figure V.30: Comparison between the three scenarios

The results of the upgrades for the three scenarios appear in Figure V.31. The optimistic scenario, costing $180,000 and with 23% upgrade in BS from the user's perspective compared to the original, is the best scenario, whereas the average scenario, costing $150,000 and with only a 14% upgrade in BS, is the worst. By contrast, the pessimistic scenario, costing $100,000 and with an 18% upgrade, became the actual average scenario in terms of the BS from the user's perspective.

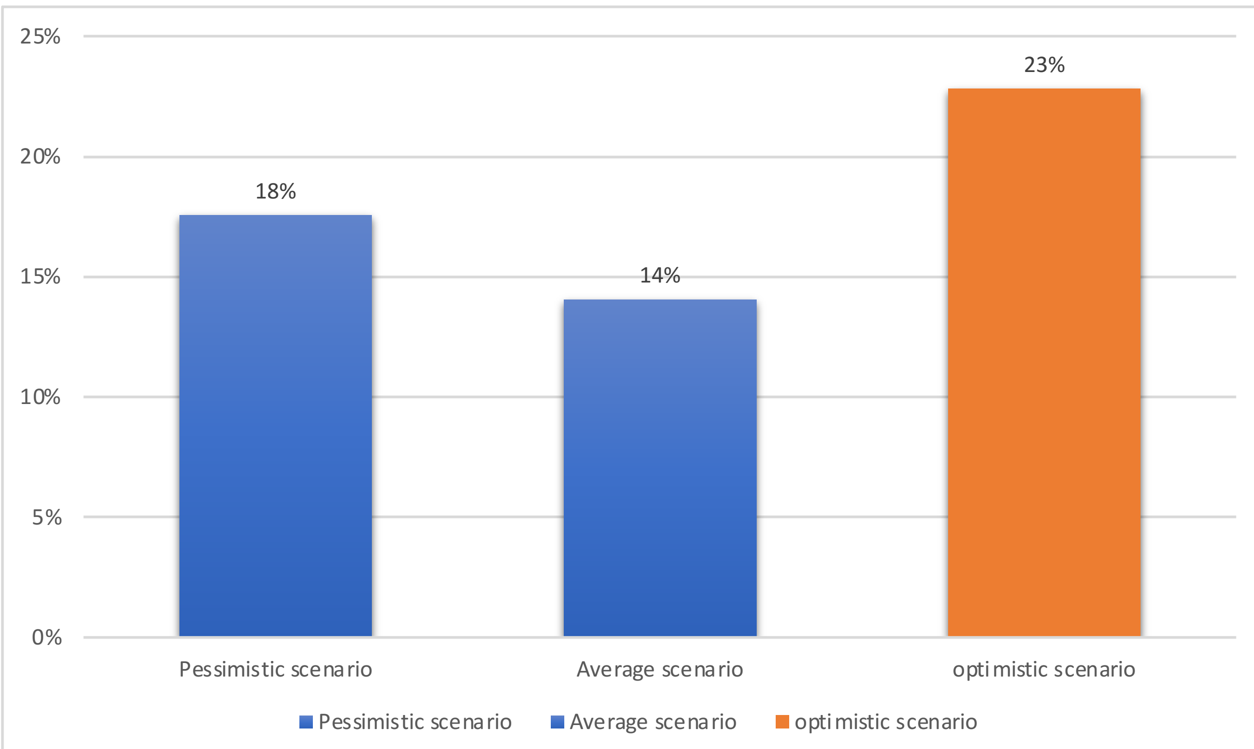


Figure V.31: Optimistic scenario is the best scenario

CHAPTER VI: AN AUTOMATED TOOL (USAUT)

VI.1 INTRODUCTION

This chapter demonstrates the development and the key features of the Integrated Users Perspective Assessment and Upgrade Tool (USAUT). The development of this tool is based on the user's perspective assessment model and user's perspective upgrade model illustrated in Chapters III and IV. The main aim for this tool is to allow decision-makers to: 1) assess the current users perspective of their building; 2) provide statistical charts related to the determined user's perspective of the building; and 3) provide an illustrative set of alternatives, including a detailed description of their decision variables to upgrade the user's perspective of their buildings to maximize the user's perspective. This chapter is comprised of five parts: 1) the tool's technical features; 2) its graphical user interface; 3) the users' perspective assessment process; 4) the optimization process; and 5) a result display.

VI.2 THE USAUT'S MAIN FEATURES

The USAUT is a standalone tool that is programmed utilizing visual basic.net. The tool integrates Excel software in its data entry, user's perspective assessment and optimization processing. The tool is divided into four tiers as follows:

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

2. User's perspective Assessment: After data has been entered into the spreadsheets, the current user's perspective is evaluated based on predefined equations and thresholds, as illustrated in Chapter V.

3. Optimization Process: The optimization is processed in Excel based on the data entry for the upgrade alternatives in the first tier and on the prewritten GA optimization using Evolver.

4. Output display: This displays two sets of outputs: 1) the user's perspective assessment, and 2) the optimization output.

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

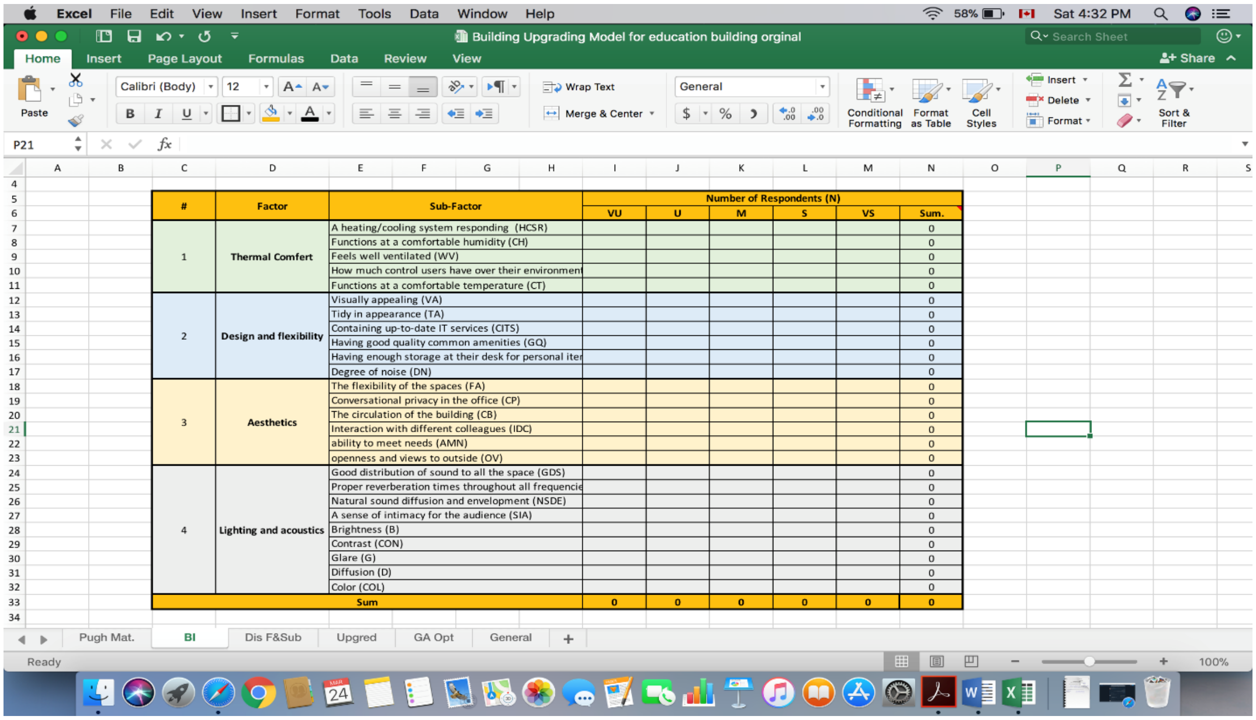
VI.3 USAUT GRAPHICAL USER INTERFACE GUI

USAUT's GUI allows the user to navigate through the tool's features, as illustrated in the previous section. The main window consists of three groups as shown in Figure VI.1 The first is the data entry for the user's perspective assessment. This process includes four keys, which allow the FM to access the predeveloped spreadsheets for each of the four factors: Thermal comfort (TC), Design and flexibility (DF), Aesthetics (A) and Lighting and acoustics (LA). The second is the optimization process in which the FM runs the optimization through Evolver. The third group is the output display for the user's perspective assessment and optimization.

Figure VI.1: Main window of USAUT

VI.3.1 The User's Perspective Assessment Process

The FM can navigate through the four assessment factors and open the Excel spreadsheet required for data entry as shown in Figure VI.2 Each factor's spreadsheet includes its related sub-factors, navigation tabs, dropdown menus and calculation tables for each sub-factor, as well as the score for its sub-factors.



#	Factor	Sub-Factor	Number of Respondents (N)					
			VU	U	M	S	VS	Sum.
1	Thermal Comfert	A heating/cooling system responding (HCSR)						0
		Functions at a comfortable humidity (CH)						0
		Feels well ventilated (WV)						0
		How much control users have over their environment						0
		Functions at a comfortable temperature (CT)						0
2	Design and flexibility	Visually appealing (VA)						0
		Tidy in appearance (TA)						0
		Containing up-to-date IT services (CITS)						0
		Having good quality common amenities (GQ)						0
		Having enough storage at their desk for personal iter						0
		Degree of noise (DN)						0
3	Aesthetics	The flexibility of the spaces (FA)						0
		Conversational privacy in the office (CP)						0
		The circulation of the building (CB)						0
		Interaction with different colleagues (IDC)						0
		ability to meet needs (AMN)						0
		openness and views to outside (OV)						0
4	Lighting and acoustics	Good distribution of sound to all the space (GDS)						0
		Proper reverberation times throughout all frequencie						0
		Natural sound diffusion and envelopment (NSDE)						0
		A sense of intimacy for the audience (SIA)						0
		Brightness (B)						0
		Contrast (CON)						0
		Glare (G)						0
		Diffusion (D)						0
		Color (COL)						0
Sum			0	0	0	0	0	0

Figure VI.2: Excel spreadsheet for the data entry of the four user's perspective assessment factors.

VI.3.1.1 *Threshold-Based Attribute*

The threshold attribute is dependent on calculation tables that are related to predefined equations, as illustrated in the user's perspective determination in Chapter III. As demonstrated in Figure VI.3, after the FM enters the data obtained from the users, the user's perspective calculation process for the threshold attribute starts. This button will lead to a calculation table that requires data entry from the FM, followed by an automated calculation for the identification of factors and sub-factors that do not meet the user's perspective level based on the OSS, expressed as either a percentage or a quantity according to the type of the attribute. The obtained dissatisfaction level is automatically compared with a predefined threshold to obtain the achieved user's perspective. Finally, the dissatisfaction level appears in red, to draw the FM's attention to them.

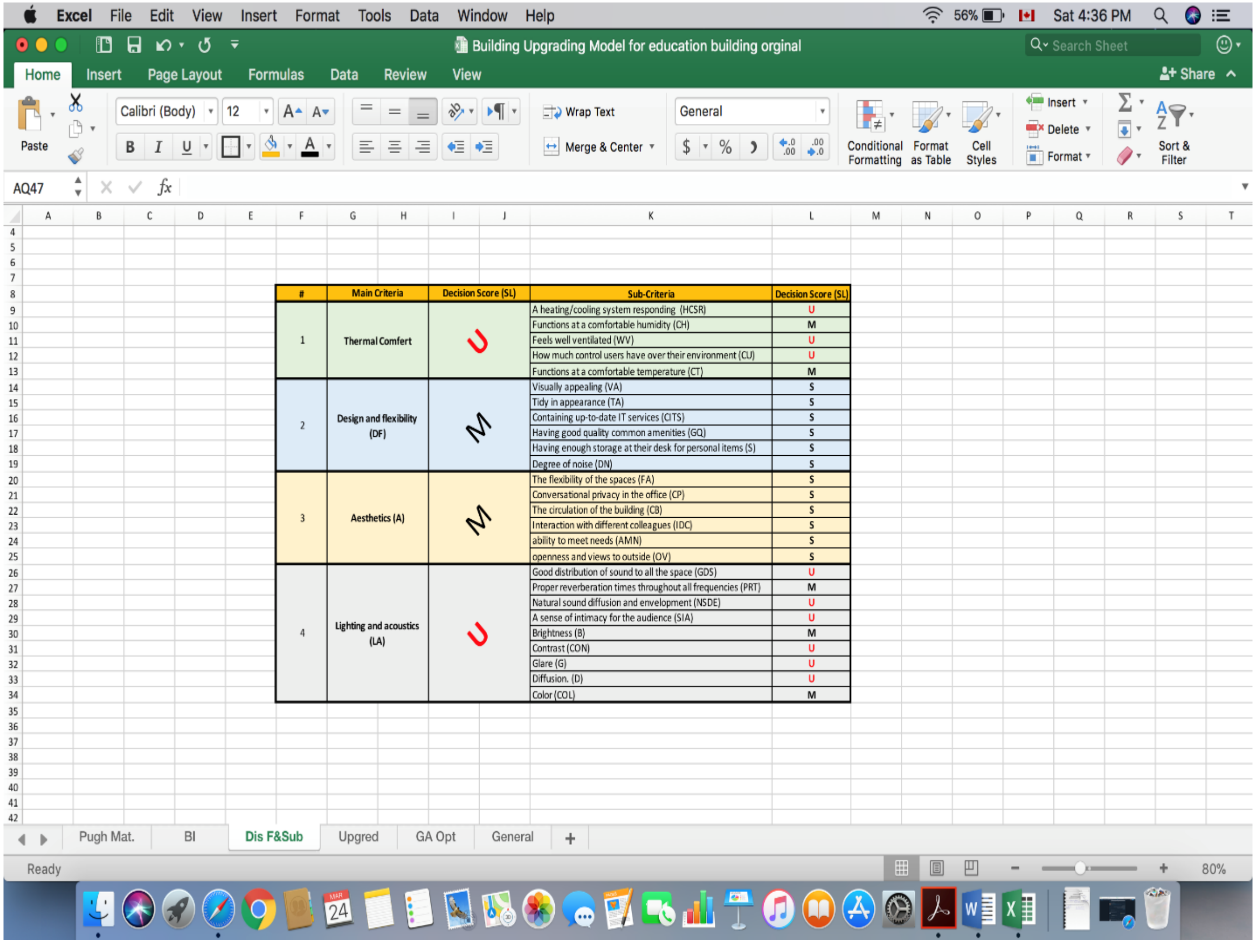


Figure VI.3: Obtained dissatisfaction level is automatically compared with a predefined threshold to obtain the user's perspective

VI.3.2 The Upgrade Process

The upgrade process in the tool passes through three stages: 1) the upgrade alternatives' data entry; 2) the amount of work, and 3) the amounts of cost and time required. The amount of work process is performed manually by means of the tool user in the predesigned spreadsheets, whereas the other three stages are performed automatically. The entire process is explained below.

VI.3.2.1 ***The Rehabilitation Alternatives' Data Entry***

There are 31 sub-factors covering the entire defined aspects of the user's perspective. Each sub-factor consists of three user's perspective-based upgrade alternatives, as shown in Figure VI.4. A button is located next to each sub-factor to direct the FM to the calculation tables, which determine the achieved percentage or the quantity for each sub-factor

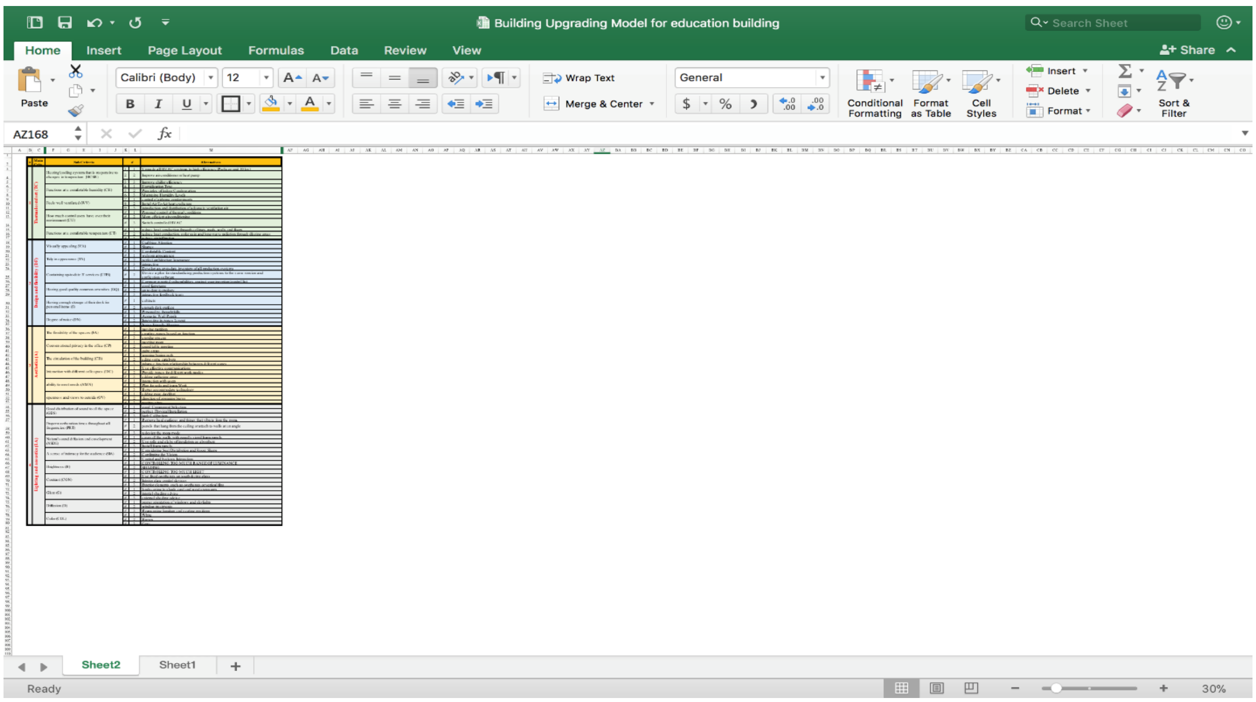
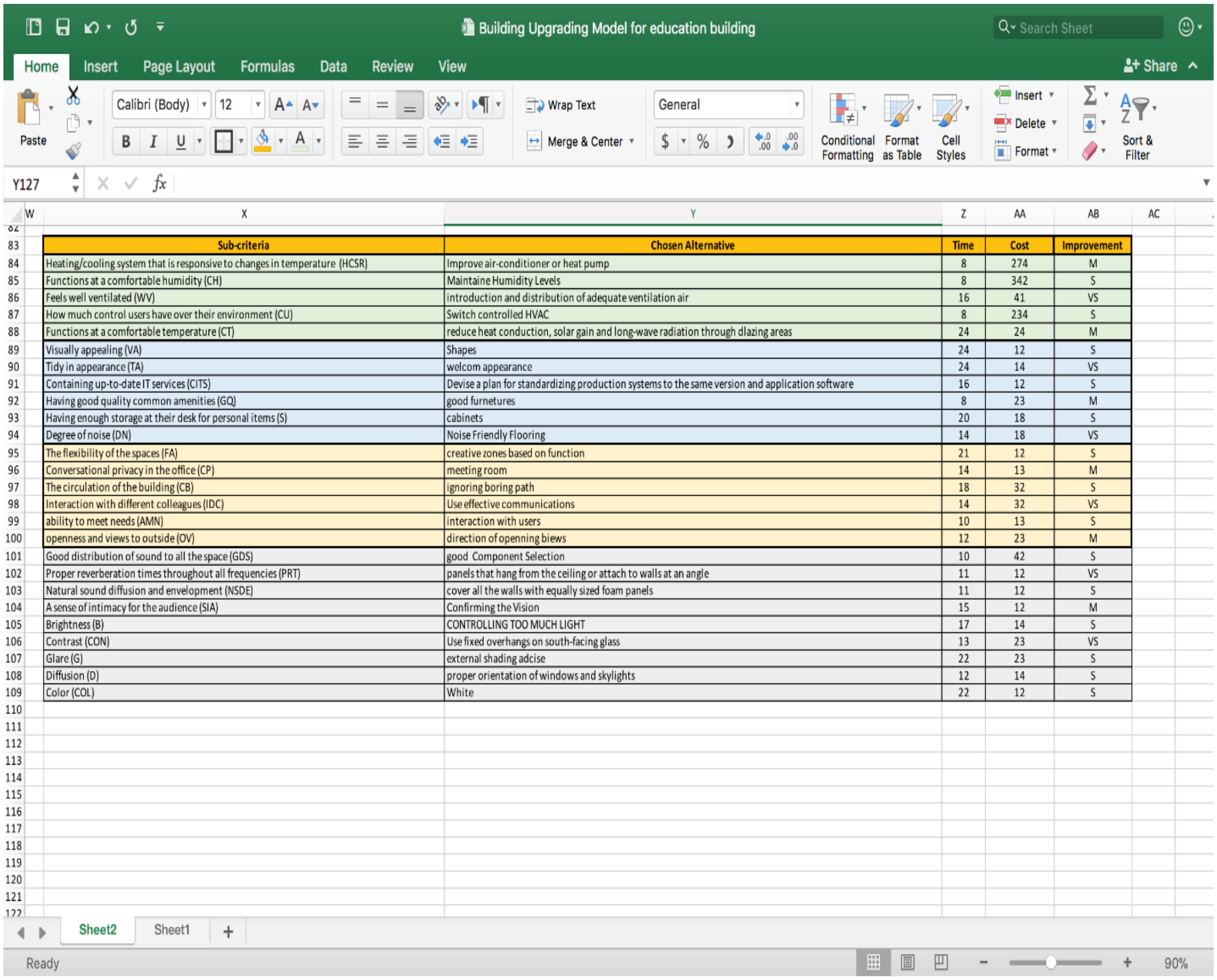


Figure VI.4: Three alternatives assigned to each sub-factor

VI.3.2.2 ***Amount of Work Required***

An identification of the unit cost and unit time has already been determined for each 17 out of 31 sub-factor's alternatives, as indicated in figure VI.5. Typically, when using the upgrade process, the USAUT will select the design requirements that can be used either in part or in whole from among a number of candidate alternative options. Ideally the design requirements should reflect both the user perspective.



Sub-criteria	Chosen Alternative	Time	Cost	Improvement
Heating/cooling system that is responsive to changes in temperature (HCSR)	Improve air-conditioner or heat pump	8	274	M
Functions at a comfortable humidity (CH)	Maintaine Humidity Levels	8	342	S
Feels well ventilated (WV)	introduction and distribution of adequate ventilation air	16	41	VS
How much control users have over their environment (CU)	Switch controlled HVAC	8	234	S
Functions at a comfortable temperature (CT)	reduce heat conduction, solar gain and long-wave radiation through dlazing areas	24	24	M
Visually appealing (VA)	Shapes	24	12	S
Tidy in appearance (TA)	welcom appearance	24	14	VS
Containing up-to-date IT services (CITS)	Devise a plan for standardizing production systems to the same version and application software	16	12	S
Having good quality common amenities (GQ)	good furnetures	8	23	M
Having enough storage at their desk for personal items (S)	cabinets	20	18	S
Degree of noise (DN)	Noise Friendly Flooring	14	18	VS
The flexibility of the spaces (FA)	creative zones based on function	21	12	S
Conversational privacy in the office (CP)	meeting room	14	13	M
The circulation of the building (CB)	ignoring boring path	18	32	S
Interaction with different colleagues (IDC)	Use effective communications	14	32	VS
ability to meet needs (AMN)	interaction with users	10	13	S
openness and views to outside (OV)	direction of openning biews	12	23	M
Good distribution of sound to all the space (GDS)	good Component Selection	10	42	S
Proper reverberation times throughout all frequencies (PRT)	panels that hang from the ceiling or attach to walls at an angle	11	12	VS
Natural sound diffusion and envelopment (NSDE)	cover all the walls with equally sized foam panels	11	12	S
A sense of intimacy for the audience (SIA)	Confirming the Vision	15	12	M
Brightness (B)	CONTROLLING TOO MUCH LIGHT	17	14	S
Contrast (CON)	Use fixed overhangs on south-facing glass	13	23	VS
Glare (G)	external shading adcise	22	23	S
Diffusion (D)	proper orientation of windows and skylights	12	14	S
Color (COL)	White	22	12	S

Figure VI.5: Amount of Work Required

VI.3.2.3 *Optimization*

All of the outputs from the user's perspective upgrade model are used as inputs in the optimization process, as shown figure in VI.6. The FM should enter the budget and time in order to utilize them in the optimization process. The user's perspective index is used as the objective. The optimization process will only deal with upgrade alternative that win in the upgrade model.

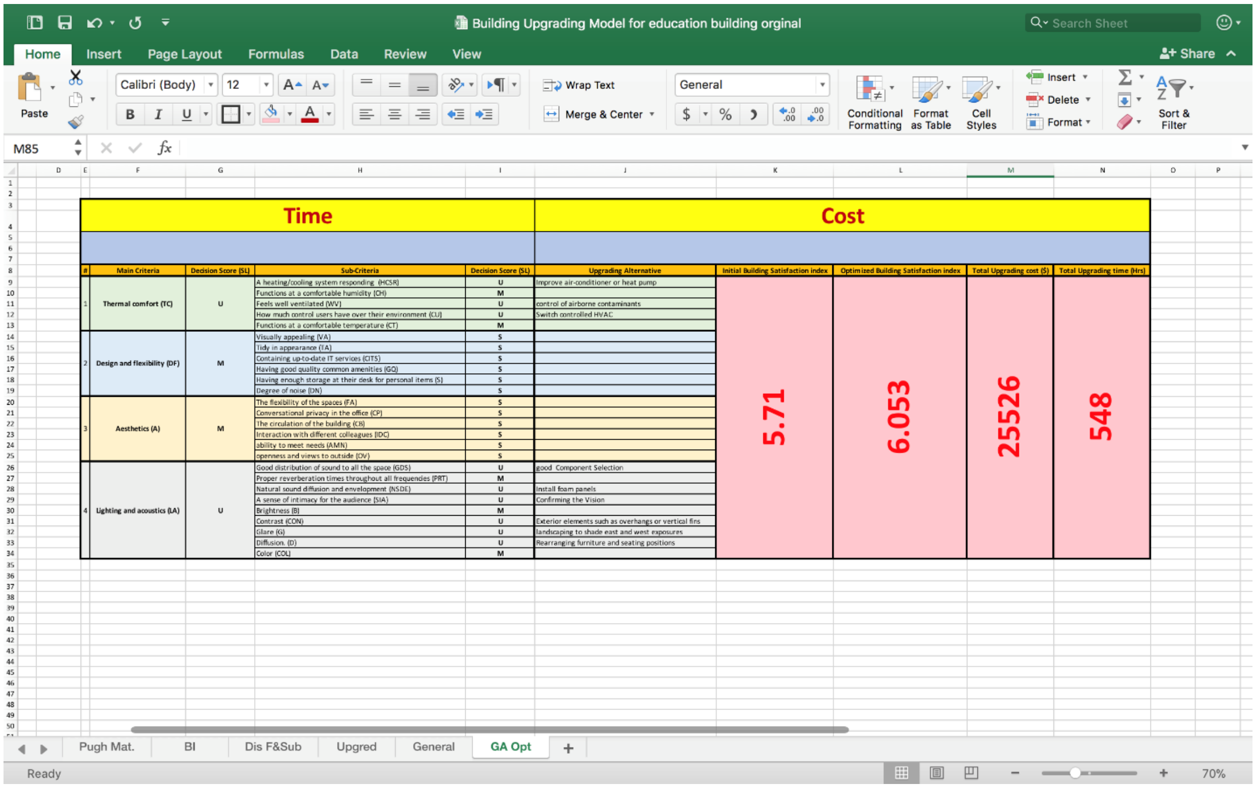


Figure VI.6: Users' perspective optimization button

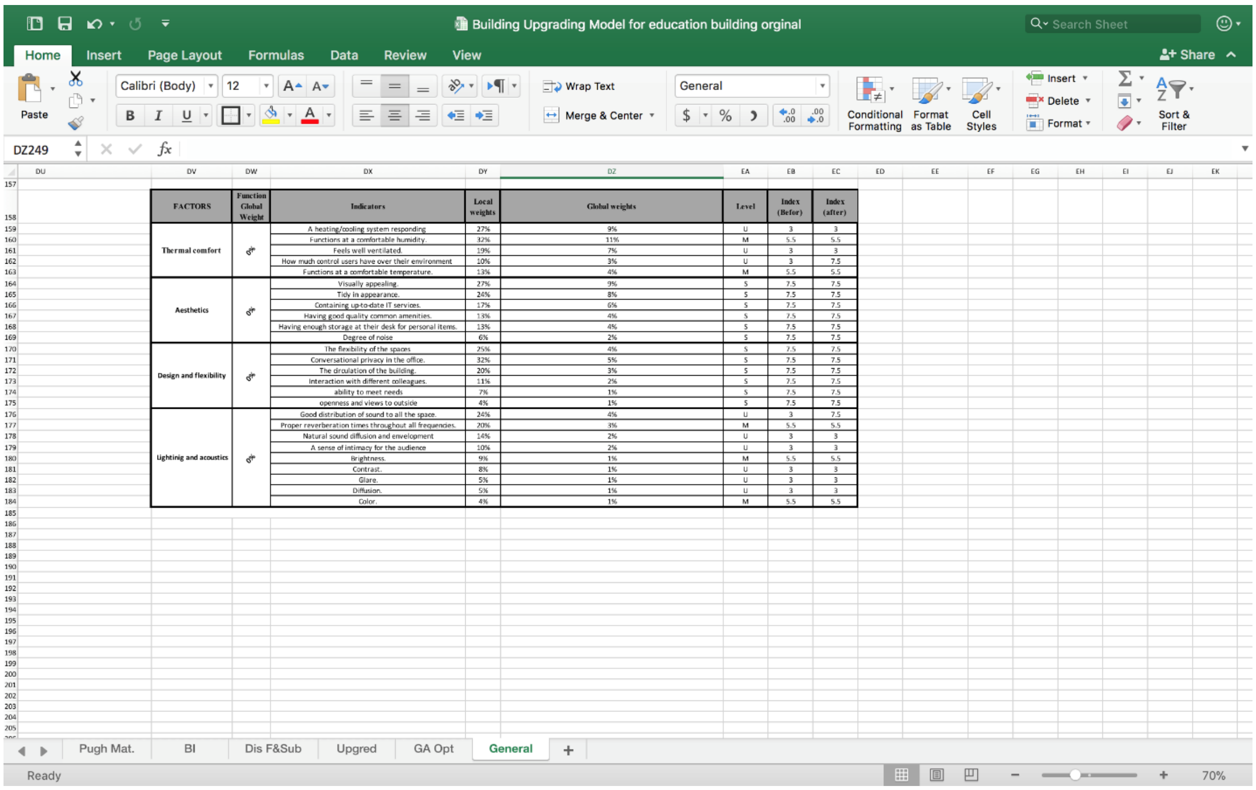
VI.3.3 The Users' Perspective Assessment and the Optimization Results Display

In this stage, the user displays some detailed results of the user's perspective assessment process and the optimization output as follows.

VI.3.3.1 *User's Perspective Assessment Display*

In this process, a new window is opened by the FM when the user's perspective results in the main window are pressed. This window provides the user with two options: 1) display a summary for the whole user's perspective assessment process, and 2) display different illustrative charts in Excel. The summary table, as shown in Figure 7, has five columns: 1) the user's perspective assessment attribute (factors and sub-factors); 2) the user's perspective level achieved for the factors and the sub-factors; 3) the local weight for the factors; 4) the global weights of the factors;

and 5) the factors' user's perspective index (BS). The second part of the display contains the illustrative charts, which show several types of graphs, such as the overall users' perspective scale, the chart of the weights for each factor and sub-factor, and comparisons of the cost and time for each upgrade alternative.



FACTORS	Function Global Weight	Indicators	Local weights	Global weights	Level	Index (Befor)	Index (after)
Thermal comfort	0%	A heating/cooling system responding	27%	9%	U	3	3
		Functions at a comfortable humidity.	32%	11%	M	5.5	5.5
		Feels well ventilated.	19%	7%	U	3	3
		How much control users have over their environment	10%	3%	U	3	7.5
		Functions at a comfortable temperature.	13%	4%	M	5.5	5.5
Aesthetics	0%	Visually appealing.	27%	9%	S	7.5	7.5
		Tidy in appearance.	24%	8%	S	7.5	7.5
		Containing up-to-date IT services.	17%	6%	S	7.5	7.5
		Having good quality common amenities.	13%	4%	S	7.5	7.5
		Having enough storage at their desk for personal items.	13%	4%	S	7.5	7.5
		Degree of noise	6%	2%	S	7.5	7.5
Design and flexibility	0%	The flexibility of the spaces	25%	4%	S	7.5	7.5
		Conversational privacy in the office.	32%	5%	S	7.5	7.5
		The circulation of the building.	20%	3%	S	7.5	7.5
		Interaction with different colleagues.	11%	2%	S	7.5	7.5
		ability to meet needs	7%	1%	S	7.5	7.5
		openness and views to outside	4%	1%	S	7.5	7.5
Lightinig and acoustics	0%	Good distribution of sound to all the space.	24%	4%	U	3	7.5
		Proper reverberation times throughout all frequencies.	20%	3%	M	5.5	5.5
		Natural sound diffusion and envelopment	14%	2%	U	3	3
		A sense of intimacy for the audience	10%	2%	U	3	3
		Brightness.	9%	1%	M	5.5	5.5
		Contrast.	8%	1%	U	3	3
		Glare.	5%	1%	U	3	3
		Diffusion.	5%	1%	U	3	3
		Color.	4%	1%	M	5.5	5.5

Figure VI.7: Summary table

VI.3.3.2 *Optimization Output Display*

After the optimization process is finished and the output is written to the corresponding sheets, the FM can display all the decision variables for each alternative. This display shows three different types of data: 1) the Initial Building Satisfaction index; 2) the Optimized Building Satisfaction index; and 3) the Total Upgrading cost ($) and Total Upgrading time (Hrs).

VI.4. VALIDATION OF THE DEVELOPED MODELS AND FRAMEWORK

The previous parts of this thesis describe the development of the user's perspective upgrade models in detail, as well as the selection framework. To further enhance these tools and to assure their viability, evaluation and validation procedures were applied to them. These validations were performed to confirm the results and to verify the data used. The evaluation procedures were divided into three parts:

1. Validation of the developed methodology
2. Validation of initial costs and time
3. Validation of the model

VI.4.1 Validation of the Developed Methodology:

In the absence of an integrated user's perspective assessment and upgrade tool that assesses the user's perspective of buildings and proposes set of optimal solutions to upgrade the user's perspective of the building, the validation procedures that was followed by Eweda (2012) is adopted to validate the developed research methodology. The validation method is divided into six validation criteria as illustrated in Moody et al. (2003) and as shown in Figure VI.8. These validation criteria are the actual efficiency, actual effectiveness, perceived ease of use, perceived usefulness, intention to use and actual usage.

The validation process was performed through a structured interview with facility managers of Concordia University and sustainability experts. The interview began with a presentation showing the objectives of the research, the developed user's perspective upgrade assessment, and the optimization model and its output results, and ended with the description of the developed tool and its various features. The presentation was followed by a session of questions in which the FMs asked technical questions concerning the inputs and outputs of the model as well as the data required for the assessment. The participants showed their interest in the methodology and the tool and illustrated their important role. A questionnaire was distributed among the attendees to investigate how the industry might react towards the developed methodology and to indicate the effectiveness of the developed models (illustrated in Figure VI.8). Each respondent to the questionnaire was asked to enter his or her perceptions about each of the six attributes ranging from "doesn't meet expectations" to "exceptional".

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

Figure VI.8: Questionnaire for Methodology Validation

The data collected from the respondents were analysed to predict the acceptance of the developed methodology and tool and the probability of its use in the future. After analysis, all six criteria scores achieved a score of 70%, which represents above expectations, and the criterion "perceived usefulness" achieved the highest score at 80% as shown in Figure VI.9.

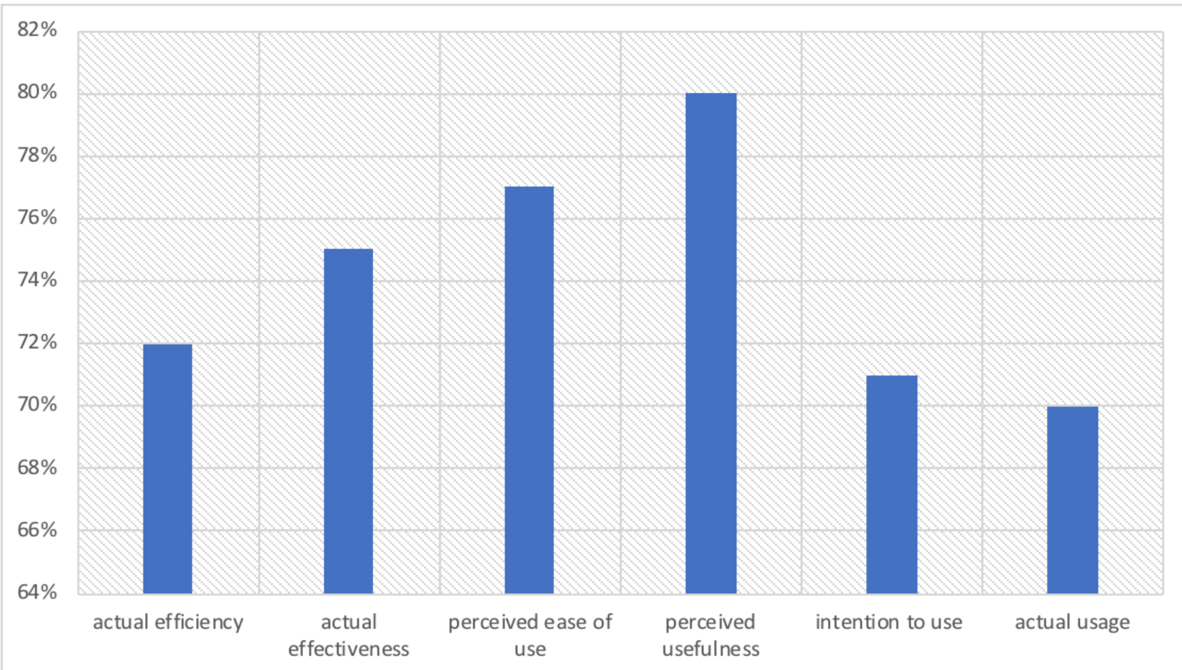


Figure VI.9: Methodology Validation Results

VI.4.2. Validation of initial costs and time:

Since the initial costs and time for the upgrade alternatives were computed using real market prices obtained from RS Means 2011, no further validation was required; nonetheless, a validation was performed to double check this data. The study interviewed close to 120 engineers, architects and facility management personnel. In addition, the research reviewed more than 900 work applications that focused on various alternatives and their time and cost. The keywords used in searching for appropriate papers were: "sustainable facility management" and "upgrade alternative".

VI.4.3 Validation of the Models

The factor most affected in the user's perspective is thermal comfort (Al-Geelawe and Mohsin 2015; Berardi 2012; Perez-Lombard et al. 2008; Schwartz and Raslan 2013); therefore, a comparison was performed concerning thermal comfort assessment among selected factors with the collaboration of the Facility management department in Concordia University. Users' feedback was collected to re-evaluate the thermal comfort and user's perspective level in respect to the sustainability of the building being considered

As table VI.1 A and B illustrate, the developed user's perspective upgrade assessment requires a fulfilment of a satisfied (S) level and above. The selected optimum solutions were therefore implemented to elevate the users' perspective level in respect to the identified dissatisfying criteria. The result shows that the user's perspective level is very satisfied (VS), which is above the established baseline. In addition, all the sub-factors that had been assessed as Unsatisfied level (U): A responsive heating/cooling system (RHCS), Feels well ventilated (WV) and How much control users have over their environment (CU) were upgraded to very satisfied (VS). In addition, the sub-factors that achieved a Medium level (M), which are Functions at a comfortable humidity (CH) and Functions at a comfortable temperature (CT) were upgraded to a very satisfied level (VS). These high levels of the users' perspective were measured after the upgrade alternative action.

Table VI.1 A: Users perspective levels before any upgrading

#	Factors	Decision score (SL)	Sub-Factors	Decision score (SL)
1	**Thermal comfort (TC)**	**U[2]**	A heating/cooling system responding (HCSR)	**U**
			Functions at a comfortable humidity (CH)	**M**
			Feels well ventilated (WV)	**U**
			How much control users have over their environment (CU)	**U**
			Functions at a comfortable temperature (CT)	**M**

Table VI.1 B: Users perspective levels after the upgrade.

#	Factors	Decision score (SL)	Sub-Factors	Decision score (SL)
1	**Thermal comfort (TC)**	**VS**	A heating/cooling system responding (HCSR)	**VS**
			Functions at a comfortable humidity (CH)	**VS**
			Feels well ventilated (WV)	**VS**
			How much control users have over their environment (CU)	**VS**
			Functions at a comfortable temperature (CT)	**VS**

In the case when an upgrade alternative action does not upgrade the user's perspective, the next possible solution could be the application of a Pugh Matrix to rank the upgrade alternative actions and then to implement the selected optimum solutions to elevate the user perspective level in respect to newly-identified dissatisfying criteria (DC). If the performance is acceptable after upgrading all the DCs, then cyclic monitoring is initiated as figure VI.10. The continuous monitoring systems is very important, and it follows the cyclic procedure listed below:

[2] Orange color: indicted that either factors or sub-factors are not satisfied with users' prepositive

1. Collect the user feedback after upgrading the building’s sustainability;
2. Evaluate the user perspective in respect to the building’s sustainability;
3. Identify the dissatisfying criteria if the perspective level is lower than medium;
4. Identify, evaluate, rank and select the optimum solutions for each DC;
5. Implement the optimum solution to elevate the user perspective;
6. Evaluate the performance of each DC after the implementation of the optimum solutions; and
7. Upgrade the building’s sustainability.

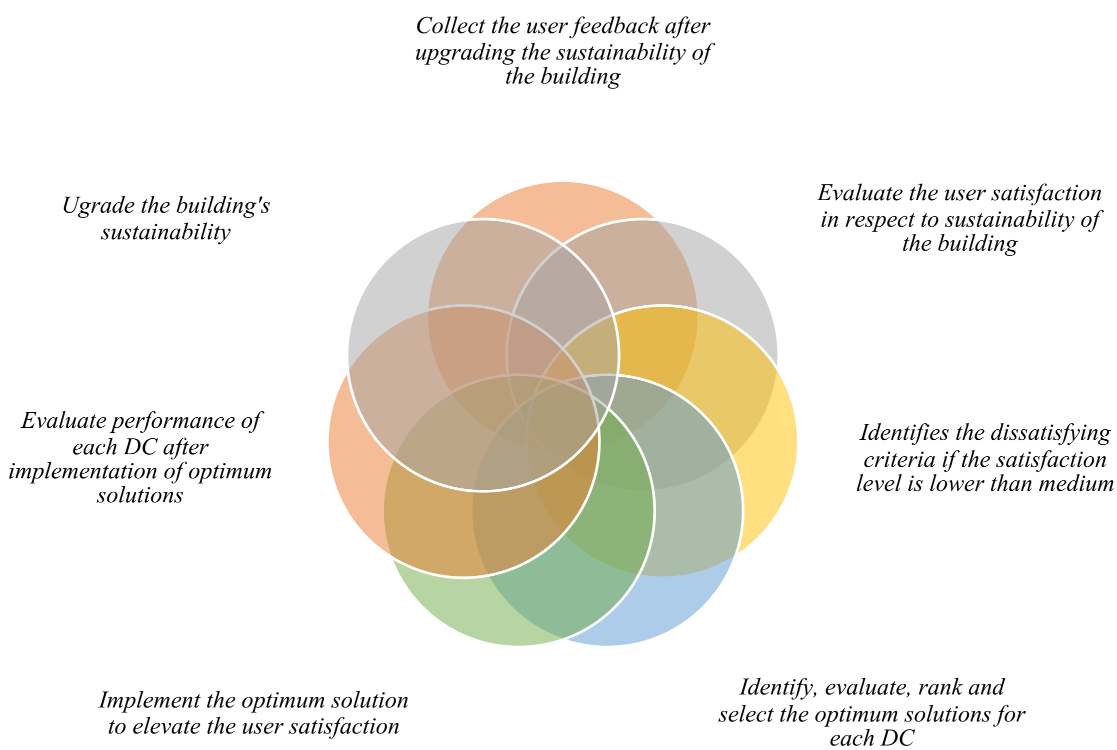


Figure VI.10: Cyclic Monitoring Procedure for Upgrading Building Sustainability in respect to user satisfaction

CHAPTER VII. CONCLUSIONS AND RECOMMENDATIONS

VII.1. RESEARCH CONCLUSIONS

This research proposes an integrated overall users' perceptive scale and user's satisfaction index for sustainable education buildings, which allows the user's perspective to be assessed both before and after a building upgrade. This framework takes into consideration the factors and sub-factors that affect user's satisfaction from the user's perspective, whose four main factors are 1) Thermal comfort and air quality, 2) Aesthetics, amenity and upkeep, 3) Design and flexibility, and 4) Lighting and acoustics. These four pillars are incorporated into the framework through an integrated user's satisfaction index developed through several stages, beginning with an extensive literature review. The framework can be considered as a two-tier decision-making tool for existing sustainable education buildings.

Several studies were reviewed for this work. Based on the literature review, it is clear that various issues hinder the efforts to achieve an accurate assessment of the level of users' satisfaction in sustainable buildings. The most crucial issues are related to differences of building type, such as thermal comfort and air quality, aesthetics, amenities and upkeep, individual control over windows, blinds, temperature control, design and flexibility and lighting and acoustics. Briefly, as detailed in the literature review, some of the issues regarded as limitations for both the existing rating systems and for the developed research are summarized in the following points.

The first tier is an overall users' perceptive scale model for education, commercial, industrial and residential sustainable buildings, based on a 5-point Likert scale as trapezoidal fuzzy numbers (TFN). For example, the OSS for industrial buildings was (VU: 0,0,1,2), (U: 1,2,3,4), (M: 3,4,6,6.5), (S: 6,6.5,7,8) and (VS: 7,8,10,10) while the OSS for commercial buildings was found to be (VU: 0,0,1,3), (U: 1,3,4,4.5), (M:4,4.5,5,5.5), (S: 5,5.5,6,7) and (VS: 6,7,10,10). The OSS for residential buildings was determined as (VU: 0,0,2,3), (U: 2,3,5,6.5), (M:5,6.5,7,8), (S: 7,8,9,9.5) and (VS: 9,9.5,10,10), and for education buildings (VU: 0,0,1,3), (U: 1,3,4,5), (M:4,5,6,7), (S: 6,7,8,9) and (VS: 8,9,10,10). All of these OSSs provide decision-makers with a holistic current user's satisfaction from the user's perspective, allowing them to verify if their properties are perceived as above the level of dissatisfaction or not.

The research also highlights the importance of building type variations according to the uses of a building. These variations must be expressed explicitly in a sustainable user's perspective upgrading process, without changing the consistency of the user's perceptive assessment attributes. The OSS model showed that for residential buildings, 56% per cent of the FM experts said that if the overall user perspective scale (OSS) score is at the Medium level or lower, then the building is considered as an unsatisfactory building from the user's perspective. The situation for commercial buildings is identical: 56% of FM experts indicated that OSS ratings at the Medium level and lower for commercial buildings mean that those buildings are considered to be unsatisfactory from the user's perspective. Even more FM experts (60%) agree that Medium and lower OSS ratings for industrial buildings indicate that their users consider their building as unsatisfactory. Furthermore, the unsatisfied level (U) and lower is considered the minimum level of user satisfaction from the user's perspective in education buildings that require an update.

A case study of the EV building at Concordia University in Montreal wsd utilized to implement the developed assessment model. The building's data were gathered from the Concordia Facility Management Office and the Concordia University website. The EV buildings were assessed to determine the impact of weighting and local context on the user perspective assessment. The weighting process was performed utilizing the fuzzy ANP technique. This technique has proved through many studies that it is capable, to some extent, of overcoming the uncertainty of collected data, as well as to transform linguistic data into numerical crisp values. The research revealed the differences in the weights for each user's perception assessment attribute (i.e. factors and sub-factors) between each type of building. For example, the weights for the main four factors were determined as: thermal comfort 40%, aesthetics 22%, design and flexibility 21% and lightening and acoustics 16%. Using these weights, we can calculate the second tier or the building index. For our case study example of a sustainable education building this was 5.7, which means that the building was located in the U zone when the researchers compared it with the OSS, and thus required an immediate user's perspective upgrade. The user's perspective building index (BS) will assist facility management to highlight the weaknesses and strengths of their buildings based on the factors and sub-factors and their needs for upgrading (or not) from the users' perspective.

This process successfully developed a users' perspective assessment model to assess the users' perspective in sustainable education buildings. The researcher identified a threshold value for the factors and sub-factors; if any factor or sub-factor reaches this level or below, it is considered to be unsatisfied. For the most significant factor, thermal comfort, there were three sub-factors considered to be unsatisfactory from the users' perspective: a responsive heating/cooling system, feels well-ventilated, and how much control users have over their environment. For lighting and acoustics, however apart from proper reverberation times throughout all frequencies, brightness and color, none of the sub-factors were satisfactory from the users' perspective.

After determining the dissatisfaction factors and sub-factors, a Pugh matrix technique was used to evaluate the alternatives for each sub-factor based on rational arguments instead of subjective preferences, with the Pugh matrix ranking indicating the optimum solutions. Within thermal comfort, the Pugh matrix ranking selected the options of improving the air-conditioner or heat pump, maintaining humidity levels, controlling airborne contaminants, installing a switch-controlled HVAC and reducing air infiltration as the optimum solutions to maximize users' satisfaction. These optimum alternatives will cost $ 96857 and take 344 hours. For lighting and acoustics (LA), the Pugh matrix technique selected good component selection, the installation of panels that hang from the ceiling or attach to walls at an angle, the installation of foam panels, steps to confirm the vision, ameliorating too much light exposure with exterior elements such as overhangs or vertical fins and adding landscaping to shade east and west exposures, as well as using white paint as the optimum solutions to maximize the user's satisfaction. These optimum alternatives will cost $ 90896 and incur18617 hours.

Next, an optimization algorithm was developed using artificial genetic optimization to provide decision-makers with sets of alternatives to upgrade the overall building's users' perspective. The optimization model includes different decision variables that cover all the possible upgrade actions for each criterion. The input of the model is the overall users' perspective scale and the time and cost of each alternative for each decision variable. The output of the model, as illustrated in CHAPTER VI, is three scenarios: a Pessimistic scenario with ($100000) and (8000 hr), 2) an Average scenario with ($150000) and (10000 hr), and 3) an Optimistic scenario with ($180000) and (15000 hr) that together cover a wide range of budgets and time values. Each solution contains different alternatives determined by the optimization model. These solutions provide information about the decisions to be made, including the different trade-offs, about the actions to be implemented to upgrade a building's sustainability and the level of user's perception.

VII.2. RESEARCH CHALLENGES

Certain challenges were encountered during the development phase of this research; these are summarized as follows:

- Lack of data for the accessories portion, which led to various assumptions.
- Unavailability of any software or of a reference code using an artificial immune system as an optimization engine.
- FANP weights are based on expert surveys that are numerically and geographically limited, and mostly only suitable for North America.
- There is a margin of error within the results, as the steps of the model are connected in a cycle and so an error can propagate from any step to the following steps.
- Lack of historical data, which affects the accuracy of the model.

VII.3. RESEARCH CONTRIBUTIONS

The main contribution of the present research can be presented in two main points:1) this work determines the current users' perspective level for four types of buildings and highlights the weak areas that require more attention from the users' perspective; and 2) it proposes various rehabilitation alternatives that upgrade the users' perspective in sustainable buildings as a step towards establishing a comprehensive global sustainability assessment framework for buildings from the users' perspective. Based on the developed models, the research contributions can be summarized as follows:

1. Identification of the users' perspective attributes that have a direct influence on the users' perspective in existing buildings. These assessment attributes cover most of the users' perspective areas in existing buildings. In addition, the identified attributes of the developed user's perspective tool were shown to be more comprehensive and to cover more areas compared to the well-known rating tools LEED, BREEAM and HK-BEAM. Furthermore, to date no rating system has addressed all of the determined attributes in a single assessment framework; these additional attributes can provide a holistic and comprehensive assessment of the user's perspective in existing buildings.

2. Development of a comprehensive weight-based user's perspective model, which can be tailored to the building type (education, commercial, industrial and residential) of the assessed building through the weight determination of each attribute. The assessment model also introduces a multi-level weighting scheme, which incorporates the criteria weights and the factors' weights to achieve a higher accuracy in addressing the impact of each building's variations. While most of the existing users' perspective tools utilize a single type of building weighting scheme, the developed model addresses the relativity of the user's perspective impact within different types of buildings by introducing four terminologies: the overall users' perspective scale (OSS), the building's users' perspective index (BS), the maximum building users' perspective level (SL) and the building users' perspective assessment ratio (BSAR). The benefits of BS is preserved the standard assessment's attributes and its maximum available scores to address the consistency among different types of buildings' assessments when changing the weight of each attribute according to its impact on the user's perspective according to building type.

3. Development of a users' perspective-based upgrade model, which provides facility managers with a set of alternatives that will upgrade the users' perspective of their buildings within allocated costs and timeframes. Additionally, the model is linked to a detailed calculation sheet that allows the user to introduce various upgrade alternatives for each decision variable. The Excel spreadsheet automatically calculates the score and the life cycle cost of each upgrade alternative based on the data entered. The calculation table for each alternative also allows the user to select the maintenance period or the changing frequency of each upgrade alternative, thereby offering more flexibility.

VII.4. RESEARCH LIMITATIONS

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

- The weights were determined for two levels (criteria and factors), but it would be better to determine the weight for the sub-factor level. The impact of the sub-factors on a user's perspective may change from one building type to another. However, introducing the weight of each sub-factor may increase the complexity of the assessment model.
- The weights of the respondents' reliability were constant in the fuzzy ANP calculations and did not change according to the years of experience in the sustainability field, as it was difficult to gather information concerning the years of expertise in the area of users' perspective in sustainable buildings. This type of question should be added to the questionnaire to determine reliability weights based on experts' experience.
- The economic aspects are embedded in calculation procedures in some of the assessment attributes, as is the case of the material criterion. It is better to introduce this item explicitly as a separate criterion and to note that the payback period is a factor in the economic criterion. This payback period addresses the savings that may result from energy and water saving measures.

- The planning horizon that is used in the calculation of the GA in the optimization model in respect to the present state is too short and needs to be extended to 50 or 60 years.

VII.5. RECOMMENDATIONS FOR FUTURE RESEARCH

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

- Increase the sample size of the data collected through questionnaires and thereby (very likely) improve the values of the determined weights. As indicated earlier, the responses were from Saudi Arabia and Canada. The reliability of the determined weights could be improved by gathering and analyzing more responses.
- Allow greater flexibility in the users' perspective-based update model to extend the planning horizon used to determine the LCC, as this will increase the reliability of the model. Extending the planning horizon to 50 or 60 years will allow the model to provide a more realistic output.
- The addition of a payback period analysis may enhance the structure of the user's perspective assessment model. A payback period will also be advantageous if introduced as a constraint in the optimization model to highlight the economic effect of the users' perspective upgrade.

- Integrating BIM software with the users' perspective may enhance the users' perspective of the developed tool. This integration can be performed by linking the BIM modelling software and the users' perspective tool along with the appropriate Excel spreadsheets to automatically collect the data required for assessment. This procedure will assure the accuracy of the data entry and may enhance the users' perspective in this process while preventing human error in the data acquisition process.

- Extending the weight determination to include additional factors and sub-factors for other centuries would enhance the dynamism of the assessment model. In this research, only weights from Canada and Saudi Arabia were utilized; to assure the efficiency of the developed assessment tool more weights from other countries should be introduced. Also, an extended analysis of and comparisons between the assessment results from other countries would broaden the potential impact of this model.
- More defining criteria for determining the weights of the users' perspective attributes need to be explored based on building type. While using experts' opinions is beneficial for weight determination, it may lead to bias in some cases. Therefore, more research is required in the area of weight determination to strive to eliminate biases.
- Offering the possibility to change the weights in the model based on predefined databases and a building's defining criteria will enhance the dynamism of the assessment model and minimize the time and the drawbacks inherent to the use of questionnaires in weight determination.

- Integrating BIM with the developed users' perspective assessment model is a new area to explore. This endeavor will likely speed up the process of the users' perspective assessment and improve the automation process of the data transfer. A huge amount of information and diverse types of data are required to perform a building's users' perspective assessment, and BIM modelling is capable of providing all sorts of data required for such an assessment. Coding the assessment model in BIM packages, especially in Revit, will therefore be a great contribution.
- Introducing life cycle impact assessment and users' perspective criteria will be advantageous in expressing the impacts of life cycle impact assessment and the users' perspective in different types of buildings.
- Extending the users' perspective assessment tool to include new constructions rather than only existing buildings would enhance the flexibility and usability of the tool. The developed tool is only concerned with the assessment attributes of existing buildings. Introducing other attributes that are concerned with the users' perspective assessment of the other phases, e.g. construction and demolition or recycling phases, will enhance the value of the tool and its contribution to the industry as well as to our environment.

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APPENDIX A: SAMPLE OF THE QUESTIONNAIRE

UNIVERSITÉ Concordia UNIVERSITY

Department of Civil, Building & Environmental Engineering

Adaptive Rating System for users' satisfaction in Sustainable Existing Buildings

Dear Sir/Madam

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

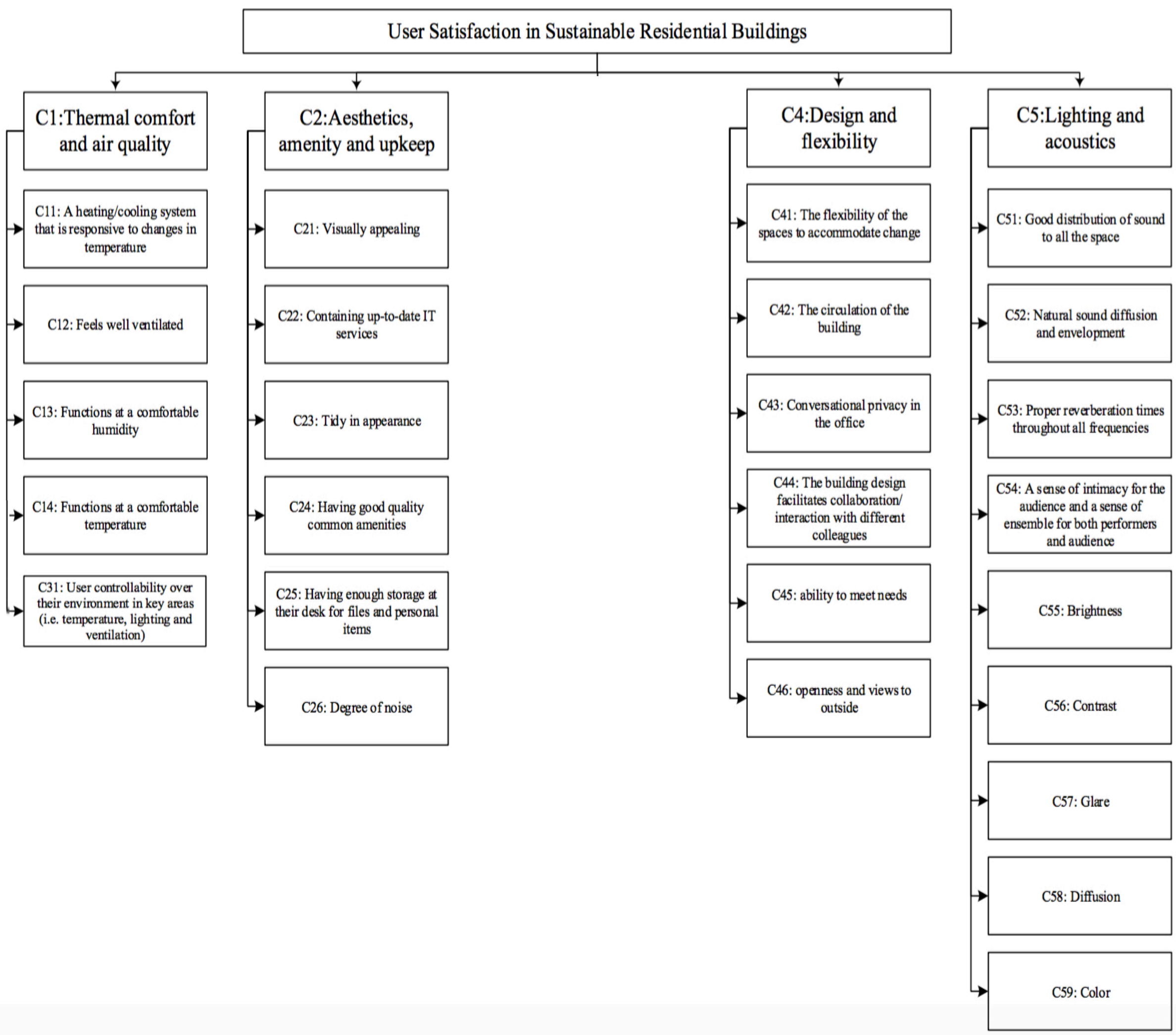


Figure 1: Factors affecting the users' satisfaction in sustainable building

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

PART (1): GENERAL INFORMATION

1) How do you describe your occupation?

Civil Engineer | Architect
Mechanical/Electrical Engineer | Others __________________

2) Which best describes your working experience?

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

PART (2): Overall Satisfaction Scale (OSS):

In order to determine the overall Satisfaction Scale (OSS), it is required to determine the ranges of each level of user satisfaction from 0 to 10. Each Level of User satisfaction should be rated with four boundaries (N) in a trapezoidal shape. As a result, kindly fill the following tables by identifying for each level:

Example:

In the table below, consider evaluating "Very Unsatisfied" level:

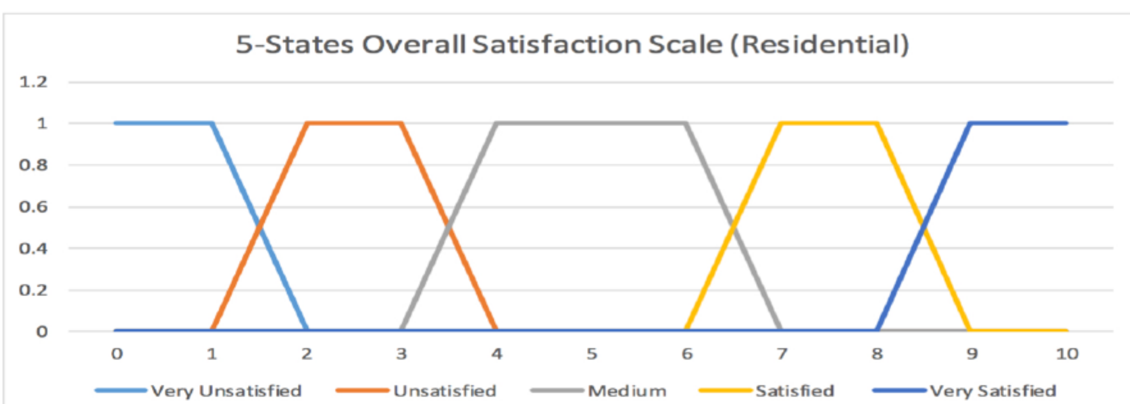
User Level	Range			
	N1	N2	N3	N4
Very Unsatisfied (VU)	0	0	1	3
Unsatisfied (U)				
Medium (M)				
Satisfied (S)				
Very Satisfied (VS)				

If you consider the start point of very unsatisfied is 0

If you consider the second (N2) point of very unsatisfied is 0

If you consider the third (N3) point of very unsatisfied is 1

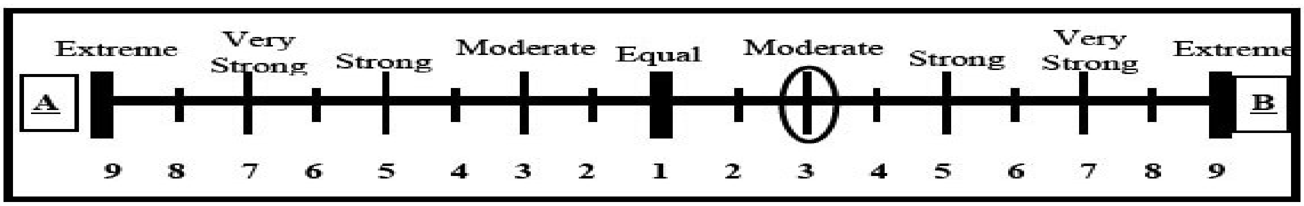
If you consider the fourth (N4) point of very unsatisfied is 3

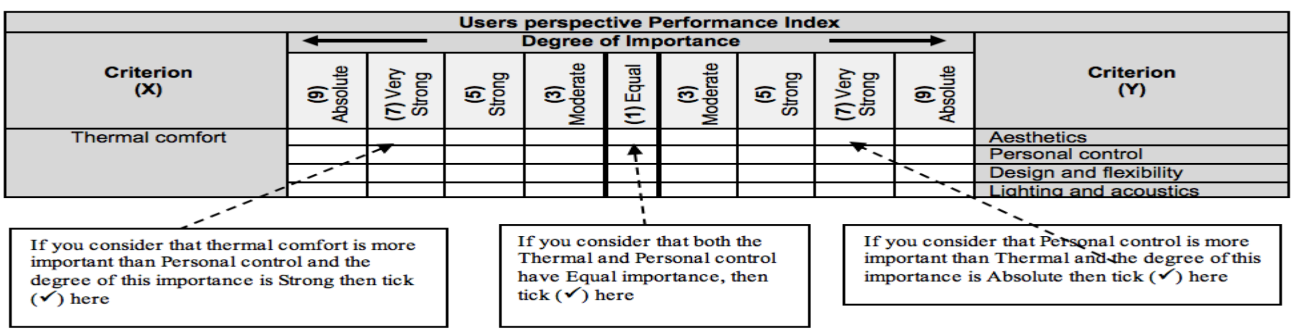


User Level	Range			
	N1	N2	N3	N4
Very Unsatisfied (VU)	0	0	1	3
Unsatisfied (U)				
Medium (M)				
Satisfied (S)				
Very Satisfied (VS)				

PART (2): Pairwise comparison between factors:

The Information Gathered from this part of the survey will be used to model the importance of each indicator. (Level 1) and sub indicators (Level2) relative to the whole set of indicators and sub indicators respectively. The following questions require a pair-wise comparison between the different indicators (Level 1&2) using the importance scale shown below. The indicators are shown in tables-matrices; using the scale of importance, kindly fill the tables in the following pages by ticking (✓) in the appropriate box from your point of view:





Users perspective Performance Index										
Criterion (X)	Degree of Importance									Criterion (Y)
	(9) Absolute	(7) Very Strong	(5) Strong	(3) Moderate	(1) Equal	(3) Moderate	(5) Strong	(7) Very Strong	(9) Absolute	
Main Factors										
Thermal comfort										Aesthetics
										Design and flexibility
										Lighting and acoustics
Design and flexibility										Aesthetics
										Lighting and acoustics
Aesthetics										Design and flexibility
1.Thermal comfort										
A heating/cooling system responding										Feels well ventilated.
										Functions at a comfortable humidity.
										How much control users have over their environment
										Functions at a comfortable temperature.
Functions at a comfortable humidity.										Feels well ventilated.
										How much control users have over their environment
										Functions at a comfortable temperature.
Feels well ventilated.										How much control users have over their environment
										Functions at a comfortable temperature.
How much control users have over their environment										Functions at a comfortable temperature.
2.Aesthetics										
Visually appealing.										Containing up-to-date IT services.
										Tidy in appearance.
										Having good quality common amenities.
										Having enough storage at their desk for personal items.
										Degree of noise
Tidy in appearance.										Containing up-to-date IT services.

										Having good quality common amenities.
										Having enough storage at their desk for personal items.
										Degree of noise
Containing up-to-date IT services.										Having good quality common amenities.
										Having enough storage at their desk for personal items.
										Degree of noise
Having good quality common amenities.										Having enough storage at their desk for personal items.
										Degree of noise
Having enough storage at their desk for personal items.										Degree of noise
3.Design and flexibility										
The flexibility of the spaces										The circulation of the building.
										Conversational privacy in the office.
										Interaction with different colleagues.
										ability to meet needs
										openness and views to outside
Conversational privacy in the office.										The circulation of the building.
										Interaction with different colleagues.
										ability to meet needs
										openness and views to outside
The circulation of the building.										Interaction with different colleagues.
										ability to meet needs
										openness and views to outside
Interaction with different colleagues.										ability to meet needs
										openness and views to outside
ability to meet needs										openness and views to outside
4.Lighting and acoustics										
										Natural sound diffusion and envelopment

Good distribution of sound to all the space.										Proper reverberation times throughout all frequencies.
										A sense of intimacy for the audience
										Brightness.
										Contrast.
										Glare.
										Diffusion.
										Color.
Proper reverberation times throughout all frequencies.										Natural sound diffusion and envelopment
										A sense of intimacy for the audience
										Brightness.
										Contrast.
										Glare.
										Diffusion.
										Color.
Natural sound diffusion and envelopment										A sense of intimacy for the audience
										Brightness.
										Contrast.
										Glare.
										Diffusion.
										Color.
A sense of intimacy for the audience										Brightness.
										Contrast.
										Glare.
										Diffusion.
										Color.
Brightness.										Contrast.
										Glare.
										Diffusion.
										Color.
Contrast.										Glare.
										Diffusion.
										Color.
Glare.										Diffusion.
										Color.

Diffusion.										Color.
Thermal comfort										Design and flexibility
Aesthetics										Lighting and acoustics
Aesthetics										Design and flexibility
Design and flexibility										Lighting and acoustics
Design and flexibility										Aesthetics
Thermal Comfort										Lighting and acoustics
Lighting and acoustics										Aesthetics
Thermal Comfort										Design and flexibility

APPENDIX B: WEIGHT DETERMINATION PROCEDURES

Table : Categorization of respondents for education building.

Experts	Education Buildings			
	Experience (Years)	**Speciality in Building Type**	**Level of Education**	**Sustainable Rating system feature**
1	8	Education	Master	LEED
2	4	Education	Master	LEED
3	2	Education	Bachelor	Green Globes
4	7	Education	Bachelor	LEED
5	6	Education	Master	Green Globes
6	4	Education	Master	LEED
7	3	Education	Bachelor	LEED
8	2	Education	Bachelor	BREEAM
9	7	Education	Master	LEED
10	4	Education	Bachelor	BREEAM
11	15	Education	Master	LEED
12	6	Education	Master	Green Globes
13	6	Education	Master	Green Globes
14	8	Education	Master	LEED
15	4	Education	Master	Green Globes
16	2	Education	Bachelor	LEED
17	17	Education	Master	Green Globes
18	6	Education	Master	LEED
19	3	Education	Bachelor	LEED
20	4	Education	Master	Green Globes
21	7	Education	Bachelor	LEED
22	5	Education	Master	BREEAM
23	3	Education	Bachelor	LEED
24	16	Education	Master	LEED
25	7	Education	Master	LEED

Table: Fuzzy Expert System respondents for overall user perspective scale (Education Building).

#	Very Unsatisfied				Unsatisfied				Medium				Satisfied				Very Satisfied			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	0	0	1	2	1	2	3	3.5	3	3.5	5	5.75	5	5.75	7	7.5	7	7.5	9	10
2	0	1	1.5	3.5	1.5	3.5	4.75	5.55	4.75	5.55	7	7.55	7	7.55	8.75	9	8.75	9	9.75	10
3	0	0	1	3	1	3	4.15	4.85	4.15	4.85	6	6.25	6	6.25	7.55	7.75	7.55	7.75	9	10
4	0	0	1	2.5	1	2.5	3.55	4.25	3.55	4.25	6.5	7	6.5	7	8.75	9	8.75	9	10	10
5	0	0	1.25	3.25	1.25	3.25	4.55	5	4.55	5	6.55	7.15	6.55	7.15	8.15	8.5	8.15	8.5	9.85	10
6	0	0.5	1.75	3.75	1.75	3.75	5	5.55	5	5.55	6.75	7.25	6.75	7.25	8.55	8.85	8.55	8.85	9.55	10
7	0	0	1	2.25	1	2.25	3.5	4.15	3.5	4.15	6.25	7.5	6.25	7.5	8.55	8.75	8.55	8.75	9.55	10
8	0	0	1	2	1	2	3.25	3.5	3.25	3.5	5.75	6.55	5.75	6.55	7.75	8	7.75	8	9.25	10
9	0	0	1	3	1	3	4	4.55	4	4.55	6.15	7	6.15	7	9.25	9.5	9.25	9.5	10	10
10	0	0	1	1.5	1	1.5	3	4	3	4	6	6.75	6	6.75	8.55	9	8.55	9	10	10
11	0	0	2	3	2	3	4.55	5.15	4.55	5.15	7.15	7.5	7.15	7.5	8.75	9.15	8.75	9.15	10	10
12	0	0	1	3	1	3	4.15	4.75	4.15	4.75	7	6.25	7	6.25	8.25	8.55	8.25	8.55	9.75	10
13	0	0	1	2.55	1	2.55	3.55	4.25	3.55	4.25	7.15	7.85	7.15	7.85	9.25	9.5	9.25	9.5	10	10
14	0	0.25	1	3	1	3	3.75	5.55	3.75	5.55	7	7.55	7	7.55	9.5	9.75	9.5	9.75	10	10
15	0	0	1	3	1	3	4.15	4.5	4.15	4.5	5.75	6.25	5.75	6.25	7.75	8	7.75	8	9.55	10
16	0	0	1	3.00	1	3	4	4.3	4	4.25	6.00	6.9	6	6.85	8.00	8.25	8	8.25	9.85	10
17	0	0	2	2.75	2	2.75	4.25	4.5	4.25	4.5	6.25	6.75	6.25	6.75	8.15	8.5	8.15	8.5	9.5	10
18	0	0	1	1.55	1	1.55	3	3.55	3	3.55	5.75	6.15	5.75	6.15	7.55	8	7.55	8	9.75	10
19	0	0	1	3	1	3	4.55	5	4.55	5	6.85	7.55	6.85	7.55	9.15	9.5	9.15	9.5	10	10
20	0	1	1	1.25	1	1.25	3	3.25	3	3.25	5.65	6.75	5.65	6.75	8.5	9	8.5	9	10	10
21	0	0	1	3	1	3	4.55	4.75	4.55	4.75	6.15	7	6.15	7	8.75	8.25	8.75	8.25	9.55	10
22	0	0	1	3	1	3	4.25	4.85	4.25	4.85	6.55	7.55	6.55	7.55	8.55	9	8.55	9	10	10
23	0	0	1	3.5	1	3.5	4.5	5	4.5	5	6.75	7.25	6.75	7.25	9	9.25	9	9.25	10	10
24	0	1	2	3	2	3	4	4.25	4	4.25	6.55	7.85	6.55	7.85	8.75	9	8.75	9	10	10
25	0	0	1	3.55	1	3.55	4.75	5	4.75	5	6.55	7	6.55	7	8	8.5	8	8.5	9.75	10

Main Factors

#		9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
1	Thermal comfort									2									Aesthetics
										3									Design and flexibility
										1									Lighting and acoustics
2	Design and flexibility									4									Aesthetics
										3									Lighting and acoustics
3	Aesthetics									2									Design and flexibility
Total										15									

Thermal Comfort

#		9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
1	A heating/cooling system responding									1									Feels well ventilated.
										3									Functions at a comfortable humidity.
										2									How much control users have over their environment
										1									Functions at a comfortable temperature.
2	Functions at a comfortable humidity.									2									Feels well ventilated.
										4									How much control users have over their environment
										3									Functions at a comfortable temperature.
3	Feels well ventilated.									2									How much control users have over their environment
										3									Functions at a comfortable temperature.
4	How much control users have over their environment									1									Functions at a comfortable temperature.
Total										22									

Aesthetics

#		9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
1	Visually appealing.									2									Containing up-to-date IT services.
										3									Tidy in appearance.
										4									Having good quality common amenities.
										1									Having enough storage at their desk for personal items.
										2									Degree of noise
2	Tidy in appearance.									4									Containing up-to-date IT services.
										3									Having good quality common amenities.
										2									Having enough storage at their desk for personal items.
										3									Degree of noise
3	Containing up-to-date IT services.									4									Having good quality common amenities.
										2									Having enough storage at their desk for personal items.
										3									Degree of noise
4	Having good quality common amenities.									4									Having enough storage at their desk for personal items.
										2									Degree of noise
5	Having enough storage at their desk for personal items.									3									Degree of noise
Total										42									

Design & Flexibility

#		9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
1	The flexibility of the spaces									2									The circulation of the building.
										1									Conversational privacy in the office.
										2									Interaction with different colleagues.
										3									ability to meet needs
										4									openness and views to outside
2	Conversational privacy in the office.									3									The circulation of the building.
										4									Interaction with different colleagues.
										7									ability to meet needs
										5									openness and views to outside
3	The circulation of the building.									3									Interaction with different colleagues.
										3									ability to meet needs
										4									openness and views to outside
4	Interaction with different colleagues.									2									ability to meet needs
										4									openness and views to outside
5	ability to meet needs									2									openness and views to outside
Total										49									

Lightning and Acoustics

#		9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
1	Good distribution of sound to all the space.									4									Natural sound diffusion and envelopment
										2									Proper reverberation times throughout all frequencies.
										3									A sense of intimacy for the audience
										5									Brightness.
										3									Contrast.
										4									Glare.
										5									Diffusion.
										3									Color.
2	Proper reverberation times throughout all frequencies.									5									Natural sound diffusion and envelopment
										4									A sense of intimacy for the audience
										2									Brightness.
										3									Contrast.
										4									Glare.
										5									Diffusion.
										3									Color.
3	Natural sound diffusion and envelopment									4									A sense of intimacy for the audience
										5									Brightness.
										2									Contrast.
										3									Glare.
										4									Diffusion.
										3									Color.
4	A sense of intimacy for the audience									3									Brightness.
										3									Contrast.
										4									Glare.
										3									Diffusion.
										1									Color.
5	Brightness.									3									Contrast.
										4									Glare.
										3									Diffusion.
										2									Color.
6	Contrast.									3									Glare.
										4									Diffusion.
										3									Color.
7	Glare.									2									Diffusion.
										3									Color.
8	Diffusion.									4									Color.
Total										121									

#		Thermal comfort	Aesthetics	Design and flexibility	Lighting and acoustics
1	Thermal comfort	1	2	3	1
2	Design and flexibility	0.5	1	4	3
3	Aesthetics	0.333333333	0.25	1	2
4	Lighting and acoustics	1	0.333333333	0.5	1
	Sum.	2.833333333	3.583333333	8.5	7

#		A heating/cooling system responding	Functions at a comfortable humidity.	Feels well ventilated.	How much control users have over their environment	Functions at a comfortable temperature.
1	A heating/cooling system responding	1	1	3	2	1
2	Functions at a comfortable humidity.	1	1	2	4	3
3	Feels well ventilated.	0.333333333	0.5	1	2	3
4	How much control users have over their environment	0.5	0.25	0.5	1	1
5	Functions at a comfortable temperature.	1	0.333333333	0.333333333	1	1
	Sum.	3.833333333	3.083333333	6.833333333	10	9

#		Visually appealing.	Tidy in appearance.	Containing up-to-date IT services.	Having good quality common amenities.	Having enough storage at their desk for personal items.	Degree of noise
1	Visually appealing.	1	3	2	4	1	2
2	Tidy in appearance.	0.333333333	1	4	3	2	3
3	Containing up-to-date IT services.	0.5	0.25	1	4	2	3
4	Having good quality common amenities.	0.25	0.333333333	0.25	1	4	2
5	Having enough storage at their desk for personal items.	1	0.5	0.5	0.25	1	3
6	Degree of noise	0.5	0.333333333	0.333333333	0.5	0.333333333	1
	Sum.	3.583333333	5.416666667	8.083333333	12.75	10.33333333	14

#		The flexibility of the spaces	Conversational privacy in the office.	The circulation of the building.	Interaction with different colleagues.	ability to meet needs	openness and views to outside
1	The flexibility of the spaces	1	2	1	2	3	4
2	Conversational privacy in the office.	0.5	1	3	4	7	5
3	The circulation of the building.	1	0.333333333	1	3	3	4
4	Interaction with different colleagues.	0.5	0.25	0.333333333	1	2	4
5	ability to meet needs	0.333333333	0.142857143	0.333333333	0.5	1	2
6	openness and views to outside	0.25	0.2	0.25	0.25	0.5	1
	Sum.	3.583333333	3.926190476	5.916666667	10.75	16.5	20

#		Good distribution of sound to all the space.	Proper reverberation times throughout all frequencies.	Natural sound diffusion and envelopment	A sense of intimacy for the audience	Brightness.	Contrast.	Glare.	Diffusion.	Color.
1	Good distribution of sound to all the space.	1	2	4	3	5	3	4	5	3
2	Proper reverberation times throughout all frequencies.	0.5	1	5	4	2	3	4	5	3
3	Natural sound diffusion and envelopment	0.25	0.2	1	4	5	2	3	4	3
4	A sense of intimacy for the audience	0.333333333	0.25	0.25	1	3	3	4	3	1
5	Brightness.	0.2	0.5	0.2	0.333333333	1	3	4	3	2
6	Contrast.	0.333333333	0.333333333	0.5	0.333333333	0.333333333	1	3	4	3
7	Glare.	0.25	0.25	0.333333333	0.25	0.25	0.333333333	1	2	3
8	Diffusion.	0.2	0.2	0.25	0.333333333	0.333333333	0.25	0.5	1	4
9	Color.	0.333333333	0.333333333	0.333333333	1	0.5	0.333333333	0.33333333	0.25	1
	Sum.	3.4	5.066666667	11.86666667	14.25	17.41666667	15.91666667	23.8333333	27.25	23

#		Thermal comfort	Personal control	Design and flexibility	Lighting and acoustics	Sum
1	Thermal comfort	0.352941176	0.558139535	0.352941176	0.142857143	1.406879031
2	Design and flexibility	0.176470588	0.279069767	0.470588235	0.428571429	1.35470002
3	Aesthetics	0.117647059	0.069767442	0.117647059	0.285714286	0.590775845
4	Lighting and acoustics	0.352941176	0.093023256	0.058823529	0.142857143	0.647645105
	Sum	**1**	**1**	**1**	**1**	**4**

#		A heating/cooling system responding	Functions at a comfortable humidity.	Feels well ventilated.	How much control users have over their environment	Functions at a comfortable temperature.	Sum
1	A heating/cooling system responding	0.260869565	0.324324324	0.43902439	0.2	0.111111111	1.335329391
2	Functions at a comfortable humidity.	0.260869565	0.324324324	0.292682927	0.4	0.333333333	1.61121015
3	Feels well ventilated.	0.086956522	0.162162162	0.146341463	0.2	0.333333333	0.928793481
4	How much control users have over their environment	0.130434783	0.081081081	0.073170732	0.1	0.111111111	0.495797707
5	Functions at a comfortable temperature.	0.260869565	0.108108108	0.048780488	0.1	0.111111111	0.628869272
	Sum	1	1	1	1	1	5

#		Visually appealing.	Tidy in appearance.	Containing up-to-date IT services.	Having good quality common amenities.	Having enough storage at their desk for personal items.	Degree of noise	Sum
1	Visually appealing.	0.279069767	0.553846154	0.24742268	0.31372549	0.096774194	0.142857143	1.63369543
2	Tidy in appearance.	0.093023256	0.184615385	0.494845361	0.235294118	0.193548387	0.214285714	1.41561222
3	Containing up-to-date IT services.	0.139534884	0.046153846	0.12371134	0.31372549	0.193548387	0.214285714	1.03095966
4	Having good quality common amenities.	0.069767442	0.061538462	0.030927835	0.078431373	0.387096774	0.142857143	0.77061903
5	Having enough storage at their desk for personal items.	0.279069767	0.092307692	0.06185567	0.019607843	0.096774194	0.214285714	0.76390088
6	Degree of noise	0.139534884	0.061538462	0.041237113	0.039215686	0.032258065	0.071428571	0.38521278
	Sum	1	1	1	1	1	1	6

#		The flexibility of the spaces	Conversational privacy in the office.	The circulation of the building.	Interaction with different colleagues.	ability to meet needs	openness and views to outside	Sum
1	The flexibility of the spaces	0.279069767	0.509399636	0.169014085	0.186046512	0.181818182	0.2	1.52534818
2	Conversational privacy in the office.	0.139534884	0.254699818	0.507042254	0.372093023	0.424242424	0.25	1.9476124
3	The circulation of the building.	0.279069767	0.084899939	0.169014085	0.279069767	0.181818182	0.2	1.19387174
4	Interaction with different colleagues.	0.139534884	0.063674955	0.056338028	0.093023256	0.121212121	0.2	0.67378324
5	ability to meet needs	0.093023256	0.036385688	0.056338028	0.046511628	0.060606061	0.1	0.39286466
6	openness and views to outside	0.069767442	0.050939964	0.042253521	0.023255814	0.03030303	0.05	0.26651977
	Sum	1	1	1	1	1	1	6

#		Good distribution of sound to all the space.	Proper reverberation times throughout all frequencies.	Natural sound diffusion and envelopment	A sense of intimacy for the audience	Brightness.	Contrast.	Glare.	Diffusion.	Color.	Sum
1	Good distribution of sound to all the space.	0.294117647	0.394736842	0.337078652	0.210526316	0.28708134	0.188481675	0.16783217	0.18348624	0.13043478	2.19377566
2	Proper reverberation times throughout all frequencies.	0.147058824	0.197368421	0.421348315	0.280701754	0.114832536	0.188481675	0.16783217	0.18348624	0.13043478	1.83154471
3	Natural sound diffusion and envelopment	0.073529412	0.039473684	0.084269663	0.280701754	0.28708134	0.12565445	0.12587413	0.14678899	0.13043478	1.2938082
4	A sense of intimacy for the audience	0.098039216	0.049342105	0.021067416	0.070175439	0.172248804	0.188481675	0.16783217	0.11009174	0.04347826	0.92075683
5	Brightness.	0.058823529	0.098684211	0.016853933	0.023391813	0.057416268	0.188481675	0.16783217	0.11009174	0.08695652	0.80853186
6	Contrast.	0.098039216	0.065789474	0.042134831	0.023391813	0.019138756	0.062827225	0.12587413	0.14678899	0.13043478	0.71441921
7	Glare.	0.073529412	0.049342105	0.028089888	0.01754386	0.014354067	0.020942408	0.04195804	0.0733945	0.13043478	0.44958906
8	Diffusion.	0.058823529	0.039473684	0.021067416	0.023391813	0.019138756	0.015706806	0.02097902	0.03669725	0.17391304	0.40919132
9	Color.	0.098039216	0.065789474	0.028089888	0.070175439	0.028708134	0.020942408	0.01398601	0.00917431	0.04347826	0.37838314
	Sum	1	1	1	1	1	1	1	1	1	9

APPENDIX C: USERS PERSPECTIVE FEEDBACK

Table : Importance of each factors and sub-factor from user's perspective.

#	Sub-Criteria	Number of Respondents (N)					
		VU	U	M	S	VS	Sum.
1	A heating/cooling system responding (HCSR)	13	25	1	1	0	40
2	Functions at a comfortable humidity (CH)	8	14	12	3	3	40
3	Feels well ventilated (WV)	17	20	0	2	1	40
4	How much control users have over their environment (CU)	19	19	0	2	0	40
5	Functions at a comfortable temperature (CT)	10	23	1	1	5	40
1	Visually appealing (VA)	1	9	11	18	1	40
2	Tidy in appearance (TA)	0	3	16	14	7	40
3	Containing up-to-date IT services (CITS)	2	4	15	15	4	40
4	Having good quality common amenities (GQ)	1	6	19	6	8	40
5	Having enough storage at their desk for personal items (S)	1	5	10	19	5	40
6	Degree of noise (DN)	2	8	12	15	3	40
1	The flexibility of the spaces (FA)	1	9	15	14	1	40
2	Conversational privacy in the office (CP)	1	8	14	14	3	40
3	The circulation of the building (CB)	2	3	13	14	8	40
4	Interaction with different colleagues (IDC)	2	6	17	13	2	40
5	ability to meet needs (AMN)	1	7	19	11	2	40
6	openness and views to outside (OV)	2	5	17	12	4	40
1	Good distribution of sound to all the space (GDS)	15	17	2	6	0	40
2	Proper reverberation times throughout all frequencies (PRT)	14	15	4	6	1	40
3	Natural sound diffusion and envelopment (NSDE)	15	19	5	1	0	40
4	A sense of intimacy for the audience (SIA)	16	20	4	0	0	40
5	Brightness (B)	12	19	3	6	0	40
6	Contrast (CON)	10	24	5	1	0	40
7	Glare (G)	13	21	4	1	1	40
8	Diffusion (D)	12	23	4	1	0	40
9	Color (COL)	14	17	3	6	0	40

#	Sub-Criteria	Number of Respondents (N)						W	Criteria	Fsc				Global weights
		VU	U	M	S	VS	Sum.							
1	A heating/cooling system responding (HCSR)	13	25	1	1	0	40	0.267	Thermal comfort (TC)	0.875	2.175	3.175	4.5	0.094
2	Functions at a comfortable humidity (CH)	8	14	12	3	3	40	0.322		2.6	3.75	4.75	5.875	0.113
3	Feels well ventilated (WV)	17	20	0	2	1	40	0.186		1	2.075	3.075	4.475	0.065
4	How much control users have over their environment (CU)	19	19	0	2	0	40	0.099		0.775	1.775	2.775	4.25	0.035
5	Functions at a comfortable temperature (CT)	10	23	1	1	5	40	0.126		1.825	3.15	4.15	5.275	0.044
1	Visually appealing (VA)	1	9	11	18	1	40	0.272	Design and flexibility (DF)	4.225	5.425	6.425	7.425	0.092
2	Tidy in appearance (TA)	0	3	16	14	7	40	0.236		5.175	6.25	7.25	8.075	0.080
3	Containing up-to-date IT services (CITS)	2	4	15	15	4	40	0.172		4.65	5.7	6.7	7.65	0.058
4	Having good quality common amenities (GQ)	1	6	19	6	8	40	0.128		4.55	5.675	6.675	7.5	0.043
5	Having enough storage at their desk for personal items (S)	1	5	10	19	5	40	0.127		4.975	6.075	7.075	7.975	0.043
6	Degree of noise (DN)	2	8	12	15	3	40	0.064		4.25	5.4	6.4	7.375	0.022
1	The flexibility of the spaces (FA)	1	9	15	14	1	40	0.254	Aesthetics (A)	4.025	5.225	6.225	7.225	0.038
2	Conversational privacy in the office (CP)	1	8	14	14	3	40	0.325		4.3	5.475	6.475	7.425	0.048
3	The circulation of the building (CB)	2	3	13	14	8	40	0.199		5.075	6.1	7.1	7.95	0.029
4	Interaction with different colleagues (IDC)	2	6	17	13	2	40	0.112		4.2	5.3	6.3	7.3	0.017
5	ability to meet needs (AMN)	1	7	19	11	2	40	0.065		4.125	5.275	6.275	7.25	0.010
6	openness and views to outside (OV)	2	5	17	12	4	40	0.044		4.425	5.5	6.5	7.45	0.007
1	Good distribution of sound to all the space (GDS)	15	17	2	6	0	40	0.244	Lighting and acoustics (LA)	1.525	2.575	3.575	4.95	0.039
2	Proper reverberation times throughout all frequencies (PRT)	14	15	4	6	1	40	0.204		1.875	2.9	3.9	5.225	0.033
3	Natural sound diffusion and envelopment (NSDE)	15	19	5	1	0	40	0.144		1.125	2.225	3.225	4.6	0.023
4	A sense of intimacy for the audience (SIA)	16	20	4	0	0	40	0.102		0.9	2	3	4.4	0.017
5	Brightness (B)	12	19	3	6	0	40	0.090		1.675	2.85	3.85	5.15	0.015
6	Contrast (CON)	10	24	5	1	0	40	0.079		1.25	2.6	3.6	4.85	0.013
7	Glare (G)	13	21	4	1	1	40	0.050		1.275	2.475	3.475	4.775	0.008
8	Diffusion (D)	12	23	4	1	0	40	0.045		1.125	2.4	3.4	4.7	0.007
9	Color (COL)	14	17	3	6	0	40	0.042		1.625	2.7	3.7	5.05	0.007

APPENDIX D: DETERMINATION OF THE DISSATISFACTION FACTORS

#	Main Criteria	Sub-Criteria	Fsc Score				Weighted score				Criteria's score (Fc) & (BC)			
			N1	N2	N3	N4	N1	N2	N3	N4	N1	N2	N3	N4
1	Thermal comfort (TC)	A heating/cooling system responding (HCSR)	0.875	2.175	3.175	4.5	0.23368264	0.58086829	0.84793416	1.20179645	1.56365655	2.746921019	3.74692102	5.01112368
		Functions at a comfortable humidity (CH)	2.6	3.75	4.75	5.875	0.83782928	1.20840761	1.53064964	1.89317193				
		Feels well ventilated (WV)	1	2.075	3.075	4.475	0.1857587	0.38544929	0.57120799	0.83127017				
		How much control users have over their environment (CU)	0.775	1.775	2.775	4.25	0.07684864	0.17600819	0.27516773	0.42142805				
		Functions at a comfortable temperature (CT)	1.825	3.15	4.15	5.275	0.22953728	0.39618764	0.5219615	0.66345708				
2	Design and flexibility (DF)	Visually appealing (VA)	4.225	5.425	6.425	7.425	1.15039386	1.47713295	1.74941552	2.02169809	4.66099944	5.780159	6.780159	7.69346586
		Tidy in appearance (TA)	5.175	6.25	7.25	8.075	1.22096554	1.47459606	1.71053143	1.90517811				
		Containing up-to-date IT services (CITS)	4.65	5.7	6.7	7.65	0.79899374	0.97941168	1.15123829	1.31447357				
		Having good quality common amenities (GQ)	4.55	5.675	6.675	7.5	0.5843861	0.72887716	0.85731367	0.96327379				
		Having enough storage at their desk for personal items (S)	4.975	6.075	7.075	7.975	0.63340115	0.77344964	0.90076646	1.01535159				
		Degree of noise (DN)	4.25	5.4	6.4	7.375	0.27285905	0.3466915	0.41089363	0.47349071				
3	Aesthetics (A)	The flexibility of the spaces (FA)	4.025	5.225	6.225	7.225	1.02325441	1.32832404	1.58254874	1.83677344	4.36716086	5.504168464	6.50416846	7.45423363
		Conversational privacy in the office (CP)	4.3	5.475	6.475	7.425	1.39578889	1.77719632	2.10179838	2.41017035				
		The circulation of the building (CB)	5.075	6.1	7.1	7.95	1.00981651	1.2137696	1.41274823	1.58188006				
		Interaction with different colleagues (IDC)	4.2	5.3	6.3	7.3	0.47164827	0.5951752	0.70747241	0.81976961				
		ability to meet needs (AMN)	4.125	5.275	6.275	7.25	0.27009445	0.34539351	0.41087096	0.47471147				
		openness and views to outside (OV)	4.425	5.5	6.5	7.45	0.19655833	0.24430979	0.28872975	0.33092872				
4	Lighting and acoustics (LA)	Good distribution of sound to all the space (GDS)	1.525	2.575	3.575	4.95	0.3717231	0.62766359	0.87141644	1.20657661	1.43995815	2.550991248	3.55099125	4.89350584
		Proper reverberation times throughout all frequencies (PRT)	1.875	2.9	3.9	5.225	0.38157182	0.59016441	0.79366938	1.06331346				
		Natural sound diffusion and envelopment (NSDE)	1.125	2.225	3.225	4.6	0.16172603	0.31985814	0.46361461	0.66127975				
		A sense of intimacy for the audience (SIA)	0.9	2	3	4.4	0.09207568	0.20461263	0.30691894	0.45014778				
		Brightness (B)	1.675	2.85	3.85	5.15	0.15047676	0.25603509	0.34587196	0.4626599				
		Contrast (CON)	1.25	2.6	3.6	4.85	0.09922489	0.20638777	0.28576769	0.38499258				
		Glare (G)	1.275	2.475	3.475	4.775	0.06369178	0.12363699	0.17359133	0.23853197				
		Diffusion. (D)	1.125	2.4	3.4	4.7	0.05114891	0.10911768	0.15458339	0.2136888				
		Color (COL)	1.625	2.7	3.7	5.05	0.06831918	0.11351494	0.15555752	0.21231499				
Sum			73.425	103.05	129.05	158.675	12.031775	16.5822397	20.5822397	25.052329	12.031775	16.58223973	20.5822397	25.052329

#	Main Criteria	Sub-Criteria	Criteria's score (BS)								Decision							Decision Score (SL)
			Low Range				High Range				Low range		Sum	High range		Sum	Max	
1	Thermal comfort (TC)	A heating/cooling system responding (HCSR) Functions at a comfortable humidity (CH) Feels well ventilated (WV) How much control users have over their environment (CU) Functions at a comfortable temperature (CT)	U	VU	VU	U	M	U	U	M	3.43634345	0	3.43634345	0	1.011123676	1.011123676	3.43634345	U
2	Design and flexibility (DF)	Visually appealing (VA) Tidy in appearance (TA) Containing up-to-date IT services (CITS) Having good quality common amenities (GQ) Having enough storage at their desk for personal items (S) Degree of noise (DN)	M	M	M	M	S	S	S	S	2.33900056	0	2.33900056	0	1.693465857	1.693465857	2.33900056	M
3	Aesthetics (A)	The flexibility of the spaces (FA) Conversational privacy in the office (CP) The circulation of the building (CB) Interaction with different colleagues (IDC) ability to meet needs (AMN) openness and views to outside (OV)	M	M	M	M	S	S	S	S	2.63283914	0	2.63283914	0	1.454233633	1.454233633	2.63283914	M
4	Lighting and acoustics (LA)	Good distribution of sound to all the space (GDS) Proper reverberation times throughout all frequencies (PRT) Natural sound diffusion and envelopment (NSDE) A sense of intimacy for the audience (SIA) Brightness (B) Contrast (CON) Glare (G) Diffusion. (D) Color (COL)	U	VU	VU	VU	VS	U	U	U	3.56004185	3.89350584	7.45354768	0	0	0	7.45354768	U

Sub-Criteria	Sub-Criteria's score (Fsc)								Decision							Decision Score (SL)
	Low Range				High Range				Low range		Sum	High range		Sum	Max	
A heating/cooling system responding (HCSR)	VU	U	U	M	U	M	M	S	2.125	0	2.125	0	4.125	4.125	4.125	U
Functions at a comfortable humidity (CH)	U	U	M	M	M	M	S	S	2.4	0	2.4	0	4.4	4.4	4.4	M
Feels well ventilated (WV)	U	U	U	M	U	M	M	S	4	3.475	7.475	4	4	8	8	U
How much control users have over their environment (CU)	VU	U	U	M	U	M	M	S	2.225	0	2.225	0	4.225	4.225	4.225	U
Functions at a comfortable temperature (CT)	U	U	M	M	M	M	S	S	3.175	0	3.175	0	5.175	5.175	5.175	M
Visually appealing (VA)	M	M	VS	VS	S	S	VS	VS	2.775	0	2.775	0	4.775	4.775	4.775	S
Tidy in appearance (TA)	M	VS	VS	VS	S	VS	VS	VS	1.825	0	1.825	0	3.825	3.825	3.825	S
Containing up-to-date IT services (CITS)	M	M	VS	VS	S	S	VS	VS	2.35	0	2.35	0	4.35	4.35	4.35	S
Having good quality common amenities (GQ)	M	M	VS	VS	S	S	VS	VS	2.45	0	2.45	0	4.45	4.45	4.45	S
Having enough storage at their desk for personal items (S)	M	VS	VS	VS	S	VS	VS	VS	2.025	0	2.025	0	4.025	4.025	4.025	S
Degree of noise (DN)	M	M	VS	VS	S	S	VS	VS	2.75	0	2.75	0	4.75	4.75	4.75	S
The flexibility of the spaces (FA)	M	M	VS	VS	S	S	VS	VS	2.975	0	2.975	0	4.975	4.975	4.975	S
Conversational privacy in the office (CP)	M	M	VS	VS	S	S	VS	VS	2.7	0	2.7	0	4.7	4.7	4.7	S
The circulation of the building (CB)	M	VS	VS	VS	S	VS	VS	VS	1.925	0	1.925	0	3.925	3.925	3.925	S
Interaction with different colleagues (IDC)	M	M	VS	VS	S	S	VS	VS	2.8	0	2.8	0	4.8	4.8	4.8	S
ability to meet needs (AMN)	M	M	VS	VS	S	S	VS	VS	2.875	0	2.875	0	4.875	4.875	4.875	S
openness and views to outside (OV)	M	M	VS	VS	S	S	VS	VS	2.575	0	2.575	0	4.575	4.575	4.575	S
Good distribution of sound to all the space (GDS)	U	U	U	M	M	M	M	S	3.475	3.95	7.425	0	5.475	5.475	7.425	U
Proper reverberation times throughout all frequencies (PRT)	U	U	U	M	M	M	M	S	3.125	0	3.125	0	5.125	5.125	5.125	M
Natural sound diffusion and envelopment (NSDE)	U	U	U	M	M	M	M	S	3.875	3.6	7.475	0	5.875	5.875	7.475	U
A sense of intimacy for the audience (SIA)	VU	U	U	M	U	M	M	S	2.1	0	2.1	0	4.1	4.1	4.1	U
Brightness (B)	U	U	U	M	M	M	M	S	3.325	0	3.325	0	5.325	5.325	5.325	M
Contrast (CON)	U	U	U	M	M	M	M	S	3.75	3.85	7.6	0	5.75	5.75	7.6	U
Glare (G)	U	U	U	M	M	M	M	S	3.725	3.775	7.5	0	5.725	5.725	7.5	U
Diffusion (D)	U	U	U	M	M	M	M	S	3.875	3.7	7.575	0	5.875	5.875	7.575	U
Color (COL)	U	U	U	M	M	M	M	S	3.375	0	3.375	0	5.375	5.375	5.375	M