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Development of Sustainability Assessment Tool for Existing Buildings

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ABSTRACT: Under climate change impacts, the world is becoming one village. This motivated the application of sustainability rating systems of buildings away from their origins which is hindered by the different attributes and weights. Hence, this study developed a global sustainability rating tool for existing buildings, considering the regional variations through proposing sustainability assessment attributes and determining their weights utilizing fuzzy logic. Data was collected through Canadian and Egyptian experts'questionnaires to stand for the impact of the regional variations on the weight values. Fuzzy topsis was implemented to overcome the uncertainties inherent when considering opinions of individuals. Consequently, the assessment model and the ranking scheme were developed. In addition to questionnaires, the model was implemented using BIM modeling and energy simulations for two cases in the Canadian and Egyptian environments. The results showed that weights vary from country to another, however, energy criteria deemed to have nearly the same weight in both countries. Also, the results showed the ability of the proposed model to address the regional variations through the developed multi-level weight model. The model was validated by applying sensitivity analysis. The developed sustainability assessment model is a step towards a globally working sustainability rating tool that can address regional variations.

KEYWORDS: *Sustainable rating systems, sustainability ranking, BREEAM, LEED, CASBEE.*

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1 INTRODUCTION

The building industry accounts for 32% of global energy consumption, more than a third of material global resource consumption, global energy consumption, and 12% of all fresh water use, in which these percentages contribute to an estimated 40% of global solid waste generation and 40% of CO_2 emissions and (IIASA, 2012; IPCC, 2007; IPCC, 2014; Mckinsey, 2009; Urge-Vorsatz et al., 2007; UNEP, 2009; UNEP, 2011; UNEP, 2016; WEC, 2013). Hence, the sustainable buildings are crucially needed to help in decreasing GHG emissions and their related side effects, assist in reducing air pollution, improve health and quality of life, increase productivity, create employment and new business opportunities, improve social welfare and poverty alleviation, and increase energy security (IPCC, 2007; UNEP, 2009). Consequently, understanding the sustainability of buildings is vital, which highlights the need of sustainability rating tools to assess the performance of buildings, to reduce their harmful impacts on the environment, and to encourage the facility managers and investors to improve the performance of their buildings by taking into consideration economic, environmental and social aspects (Al-Waer and Sibley, 2005). Therefore, Fowler and Rauch (2006) define the sustainability rating tools as "*tools that examine the performance or expected performance of a 'whole building' and translate that examination into an overall assessment that allows for comparison against other buildings*.".

Furthermore, the impacts of buildings occur throughout the stages of their life cycle especially the operation and maintenance phase that accounts for 70% - 90% of all impact of buildings on the environment through their whole life cycle such as global warming potentials, including acidification, eutrophication, photochemical ozone creation potential, and human toxicity (Seppo, 2004; UNEP, 2009). Therefore, this research is concerned with the sustainability of existing buildings in which the operational phase has the leading role.

Many rating systems had been established in different countries around the globe such as LEED USA, BREEAM UK, HK-BEAM Hong Kong, Green Mark Singapore, Green Building Index Malaysia, Greenship Indonesia, CASBEE Japan, … etc (BCA, 1986; BRE, 2015; HK GBC, 2012; GBC Indonesia, 2012; GBI, 2011; JaGBC, 2008; USGBC, 2009). Each of these tools varies in its assessment attributes, assessment model, and weighting scheme according to the regional variations of its country of origin; these variations can be addressed as climate change, type of building stocks, geographical features, government policy (Banini et al., 2013; Reed et al., 2011). These variations handicap the use of these tools efficiently apart from their country of origin (Alyami and Rezgui, 2012; Xiaoping et al., 2009), because there are noticeable differences between the same grade in different rating systems, for example, BREEAM Excellent, LEED Platinum, and a 6-Star Green Star office building are not equivalent in terms of sustainability assessment and impacts on the environment (Schwartz and Raslan, 2013). These arguments make it difficult for buildings' stakeholders such as facility managers, sustainability experts, and property investors who purchase buildings in different countries, to compare and assess the sustainability of their buildings on a consistent basis (Dixon et al., 2008). Hence, three of the well-known rating tools, which are BREEAM, LEED, Green star, have been seeking to develop a globally working sustainability rating tool that will help international property investors to compare their properties in different cities using a consistent international language (Kennett, 2009), which indicates the significance of the concept of this study. However, the idea of developing a globally working rating tool still unestablished, as it is hindered by different gaps in which this study intends to highlight and cover.

The first gap is the lack of unified sustainability assessment attributes that can be considered the primary aspects of sustainability assessment that can be adopted in different regions to make consistent assessment and comparison among different regions (Baharetha et al., 2012; Banini et al., 2013; Warren et al., 2009). The regional variations hinder the direct use of a single tool in another country apart from its country of origin (Alyami and Rezgui, 2012; Xiaoping et al., 2009). Each regional context affects the importance and the priority of each assessment criterion in each rating system (Todd and Geissler, 1999), which leads to a variation in the criteria that are included in each rating system, as some criteria are considered important while others are of a lower priority (Ali and Al Nsairat, 2009; Berardi, 2012; Cole, 2005; Sev, 2009). The second gap as Ding (2008) stated that there is no consensus-based approach was applied to assign weights to the assessment criteria, the way the weight is calculated, and the reason behind its assigned values in the existing systems is not explicit and clear (Berardi, 2012). The weighting scheme is an essential part in the structure of the sustainability rating systems, which addresses the impact of the assessment attributes on the sustainability of a building (Cole, 1999; Cole, 2005; Lee et al., 2002; Todd and Geissler, 1999). Most of the rating systems were developed for the local use and did not admit regional variations; despite introducing weight can enhance the performance of these systems to be applied in different regions (Alyami and Rezgui, 2012; Ding, 2008).

Consequently, this research aims to develop a globally working sustainability rating tool for existing buildings and to illustrate the impact of regional variations on the sustainability assessment process. These two objectives will be covered through the following stages: 1) identify the sustainability assessment attributes for existing buildings, 2) establish a weight determination framework based on fuzzy multi-criteria decision-making method, 3) develop a sustainability assessment model; 4) establish a sustainability ranking, and 5) assess the impact of the regional context on the sustainability appraisal process.

The following sections will introduce a background that will illustrate the different classifications of sustainability rating tools and their assessment models, also it will discuss previous studies that are concerned with developing new rating tools. Moreover, the methodology utilized in this research will be explained in detail, which will cover the identification of sustainability assessment attributes, weight determination using Fuzzy logic, the development of an assessment model, and the determination of the ranking scheme. Moreover, the study will illustrate the model implementation procedures through two case studies, followed by results, analysis and ending with conclusions.

2 SUSTAINABILITY RATING SYSTEMS

There are several classifications for the sustainability assessment tools; some of these categorizations are based on the scope (i.e. single aspect or multi-aspects of assessment), while others are dependent on the performance (i.e. life cycle assessment or multi-attribute assessment tools), which will be illustrated. Crawley and Aho (1999) and Cole (2005) divided the assessment tools into Environmental Impact Assessment (EIA) and Life Cycle Assessment (LCA). The EIA assesses the impact of a building on the environment according to its site location and region, whereas the LCA assesses the impact regardless its location, time or usage. Another classification divided the assessment tools into cumulative energy demand (CED), Life Cycle Analysis (LCA), and Total Quality Assessment (TQA) (Berardi, 2012; Hastings and Wall, 2007). CED focuses on energy consumption, whereas TQA evaluates ecological, economic, and social aspects. Moreover, Fenner and Ryce (2008) categorized the assessment tools into 1) Knowledge-based tools that comprise manuals and information sources, which can be a reference for designers, 2) performance-based tools that utilize LCA, and 3) building rating tools, which consists of checklists and credit calculators. This research is concerned with building rating tools that may have different nominations such as TQA or multicriteria assessment tools (MCAT).

As there are many sustainability rating tools, each one differs in its structural characteristics, which are the assessment attributes, the weighting schemes, the implemented assessment model, and the assessment ranking based on its country of origin (Ali and Al Nsairat, 2009; Dixon et al., 2008). Several studies were conducted to distinguish the differences between many of the well-known sustainability rating tools such as BREEAM, LEED, Green star, CASBEE, and HK BEAM. Some of these studies highlighted the variations in the assessment criteria of these tools and their weighting schemes, or the ranking that changes from a regional context to another (Banini et al., 2013; Berardi, 2012; Bunz et al., 2006; Crawley and Aho, 1999; Dimitrijevic and Langford, 2007; Fenner and Ryce, 2008; Forsberg and Malmborg, 2004; Reed et al., 2011). Also, other studies compared the efficiency of these tools utilizing various evaluating criteria such as popularity, availability, methodology, applicability, accuracy, user-friendliness, development, and result presentations (Abd'razack and Ludin, 2013; Al-Waer and Sibley, 2005; Nguyen and Altan, 2011). Moreover, another study compared LEED, BREEAM, and CASBEE concerning the applicable building phases the tools can cover, who can use the tool, and the types of buildings that can be assessed (Haapio and Viitaniemi, 2008; Xiaoping et al., 2009). Lee and Burnett (2008) illustrated the difference between LEED, BREEAM, HK BEAM concerning the energy assessment, its credits, baseline, simulation tools requirements, and scope of the assessment.

The following discussion will spotlight on the most prevailing sustainability rating tools and their assessment models (credit calculating methods). The assessment models that are implemented can be categorized into three groups: 1) direct aggregation of the achieved credits that is applied in LEED, Green Globes, Green Building Index, Green Mark, HK BEAM (BCA, 2012b; Green Building Initiative, 2014; GBI, 2011; HK GBC, 2012; USGBC, 2009); 2) weight-based credits model, which is used in BREEAM (BRE, 2015); and 3) ratio between building performance and environmental loading that is adopted by CASBEE (JaGBC, 2008). The direct aggregation of credits model is based on the achieved credits in each assessment attribute. Subsequently, a simple summation of these credits is performed, and then the grade is determined either based on the total achieved points or based on the percentage of the achieved points to the total available points. The weight-based credits model is dependent on a predetermined weight of each attribute through a multilevel weighting scheme or using weights for the main attributes (criteria or categories) through a single level weighting scheme, which is the case of BREEAM. So, in each category, the score is calculated for each attribute, then the percentage of the achieved score to the maximum total score is determined and multiplied by the corresponding weight of the category. The product of the previous process is aggregated in all the categories to get the total assessment and determine the final grade. The third model divides the assessment attributes into two groups: the attributes that assess the building performance and others that assess the building burden on the environment. The score of the first group is called building performance or quality (Q) while the other is called environmental loading (EL). The ratio between the two scores is determined, so the higher the Q than EL, the building will be considered more sustainable. Hence, this study will be concerned with the weight-based models and will propose a multilevel weighting model.

Moreover, many studies were performed to establish sustainability rating tools for specific regional contexts (Ali and Al Nsairat, 2009; Alyami and Rezgui, 2012; Bragança et al., 2010; Chandratilake and Dias, 2013; Gething and Bordass, 2006; Malmqvist et al., 2011; Nguyen and Altan, 2011); however, few of them illustrated the assessment models that were utilized to determine the final sustainability grade of a building.

Among these studies, Ali and Al-Nsairat (2009) proposed a rating tool for residential buildings in Jordan. Many factors encouraged the development of a sustainability rating tool that was based on Jordanian context, which were: poverty in energy resources, inefficient use of energy resources, limitation in water resources, trends towards modern buildings, and variety in the topography of the land. Further, the developed rating tool was called SABA. It comprises seven categories: *site*, *water efficiency*, *energy efficiency*, *material*, *indoor environmental quality*, *waste and pollution*, and *cost and Economy*. The analytic hierarchy process (AHP) was implemented to determine the weight of each attribute according to the Jordanian context. Moreover, the assessment structure hierarchy was divided into three levels: parameters, indicators, and categories. Nguyen and Altan (2011) developed a tool that is called Tall Building Sustainability Indicators (TBSI), which comprises eight categories and another additional bonus, which is innovation. These categories were classified into two sets: building performance, and environmental performance. Building performance comprises *project management*, *IEQ*, *building services*, and *design features*; wheras environmental performance comprises *resources consumption*, *material aspects*, *environmental loading*, *social and economic aspects*, and *innovations*. The TBSI's factor is calculated to stand for the balance between the building performance (B) and the environmental loading (E), where EL is the environmental loading. Moreover, Alyami and Rezgui (2012) proposed an approach for developing a sustainability rating tool for Saudi Arabian context, which adopted several well-known and widely spread rating tools such as BREEAM, LEED, CASBEE, SB Tool to consolidate the proposed assessment criteria. This rating tool includes ten criteria, which are *management, IEQ, sustainable sites, energy, water and waste, materials, economic aspects, pollution and risk*, *quality of services,* and *innovations*. The score determination was not illustrated in this research, and the AHP method was utilized to determine the weight of each criterion. Also, Bragança et al (2010) suggested a sustainability rating tool for residential buildings for Portugal. The study divided the assessment attributes into dimensions, indicators, and parameters. The dimensions are the three pillars of sustainability, which are *environmental performance*, *social performance*, and *economic performance*. The environmental indicators are *climate change*, *emissions*, *water efficiency*, and *resource depletion*. The social indicators are *hydrothermal comfort*, *indoor air quality*, *acoustic comfort*, *visual comfort*. Finally, the only economic indicator is the *life-cycle cost*.

Based on the previous studies, there are some limitations that can be addressed briefly as follows: 1) these studies developed their own systems based on their regional contexts (own countries) and did not express the importance of each assessment criteria according to the different regional context that always encountered when apply these systems globally; 2) most of the studies considered a single level weighting scheme, which only expresses the main assessment categories and overlooked the subsequent ones (factors and sub-factors) ; and 3) the majority of the studies utilized AHP in weight determination process, however it was proved to have some drawbacks in its results as will be illustrated in section 3.2.

3 METHODOLOGY AND MODEL DEVELOPMENT

Developing the assessment model of the proposed sustainability tool undergoes six steps as shown in Figure 1 and as follows: 1) identify the sustainability assessment attributes such as criteria, factors, and indicators, 2) determine the weights of the criteria and the global weights (W_g) of factors applying fuzzy multi-atribute decision making technique, 3) evaluate the scores of indicators (SC_{ind}) and factors (SC), 4) determine the sustainability index (SI) of each factor, 5) determine the building sustainability index (BSI) and the building sustainability assessment ratio (BSAR), and 6) establish the ranking scheme for the sustainability assessment tool.

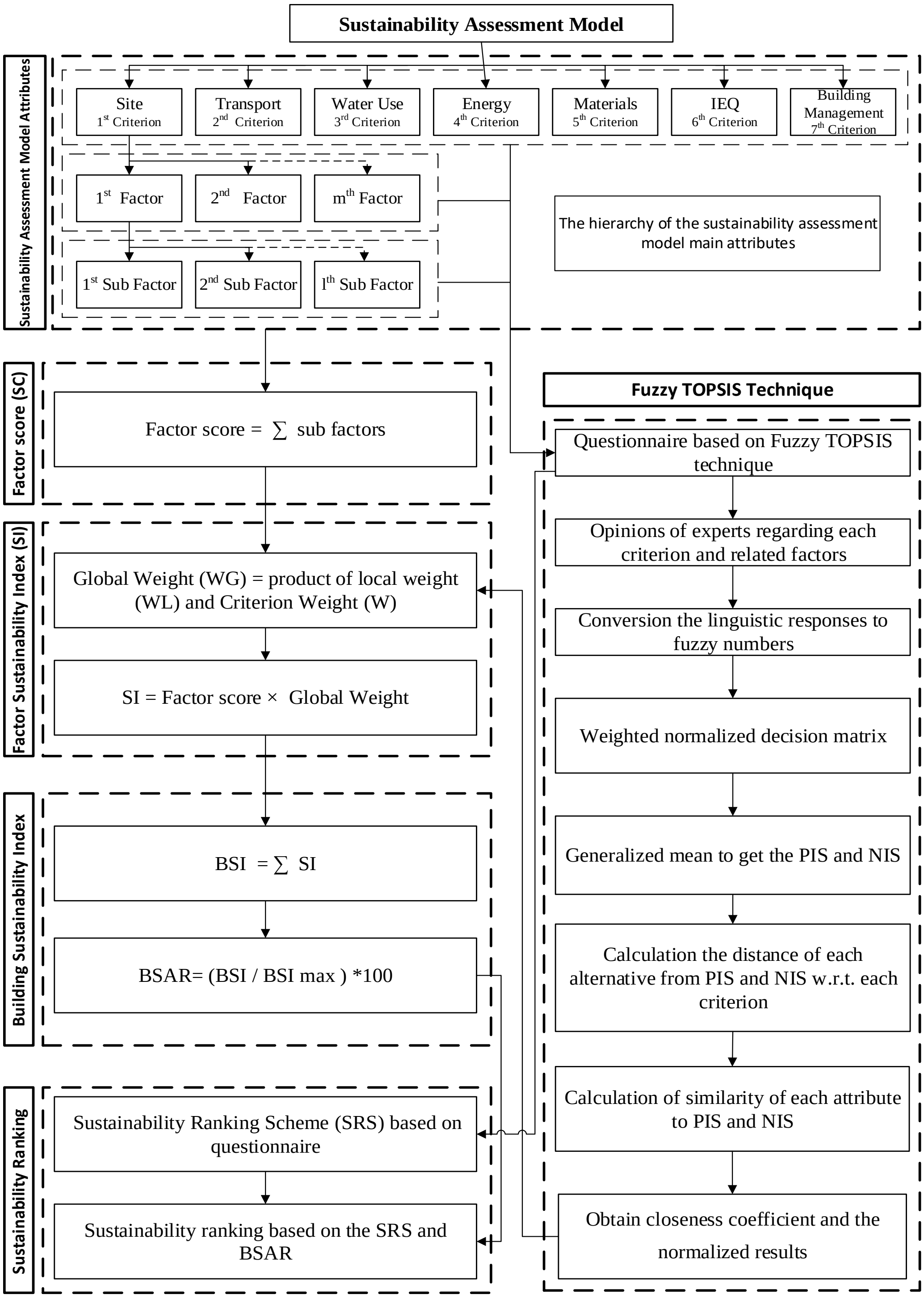


Figure 1: Sustainability Assessment Model Development Methodology

3.1 Identification of the Sustainability Assessment Attributes

Selecting the sustainability assessment attributes was performed according to comparisons and integrations based on reviewing the following: 1) previous studies that were concerned with developing of sustainability rating tools (Ali and Al Nsairat, 2009; Alyami and

Rezgui, 2012; Bragança et al., 2010; Chandratilake and Dias, 2013; Gething and Bordass, 2006; Malmqvist et al., 2011; Nguyen and Altan, 2011); 2) widely-used and well-known rating tools such LEED, BREEAM, CASBEE, HK-BEAM, Green Mark, Green Building Index, and Greenhip (BRE, 2015; BCA, 2012b; GBC Indonesia, 2012; GBI, 2011; HK GBC, 2012; JaGBC, 2008; USGBC, 2009); 3) studies that dealt with the comparative analysis between the existing rating tools (Abd'razack and Ludin, 2013; Al-Waer and Sibley, 2005; Banini et al., 2013; Berardi, 2012; Bunz et al., 2006; Crawley and Aho, 1999; Dimitrijevic and Langford, 2007; Fenner and Ryce, 2008; Forsberg and Malmborg, 2004; Haapio and Viitaniemi, 2008; Nguyen and Altan, 2011; Reed et al., 2011; Xiaoping et al., 2009); and 4) the unstructured (informal meetings) and structured interviews (questionnaires) with some buildings' stakeholders such as engineers, architects, facility managers, and sustainability experts to gather information, which is related to their perception on the attributes that affect the sustainability of existing buildings. The outcome of these reviews was the identification of the sustainability assessment attributes, which were considered to have a significant influence on the sustainability of existing buildings as will be shown in the following sections.

The selection of the aforementioned rating tools that were analyzed in the study was based on three criteria: 1) the World Green Building Council list of existing building rating systems; 2) the broad range of implementations of these rating tools around the globe, and 3) the availability of their related data and technical guidelines. Furthermore, the selected rating tools were pioneers in establishing sustainability rating tools and some of the selected rating system were prototypes for other countries to develop their rating tools such as BREEAM that was adopted by other countries like Canada, Australia, Hong Kong (Berardi, 2012; Ding, 2008; Fenner and Ryce, 2008; Haapio and Viitaniemi, 2008; McArthur et al., 2014).

Seven criteria were concluded to have a significant impact on the sustainability of buildings which are: site, transportation, energy efficiency, water use, material and waste, indoor environmental quality, and building management (Mahmoud and Zayed, 2017). Each criterion comprises factors and indicators that are utilized to address the performance of different areas, which affect the sustainability of existing buildings as shown in Figure 2.

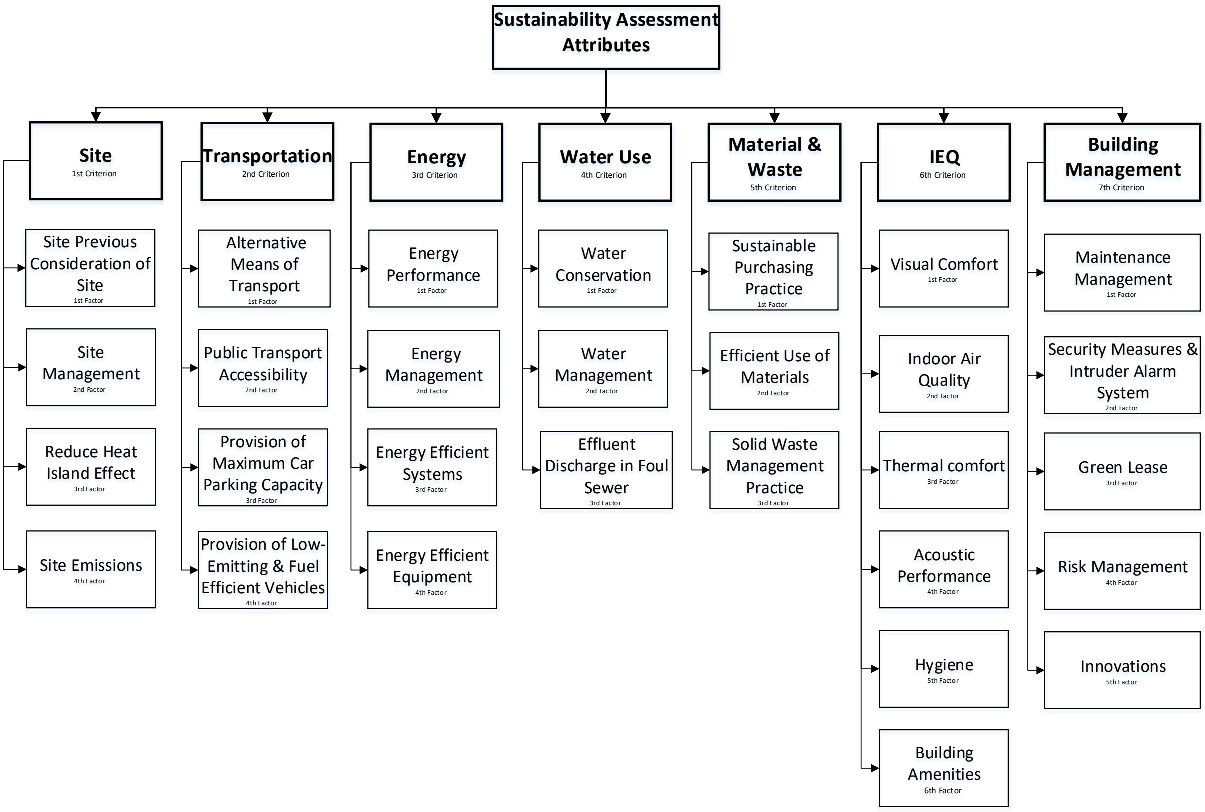


Figure 2: Sustainability Assessment Attributes (Criteria and Factors)

There are two types of indicators, which were used in the developed rating tool: quantitative indicators, and qualitative indicators. The qualitative indicators deal with long-term plans, policies, and procedure-based aspects, in which a building will be scored according to the degree of its fulfillment to these requirements. Whereas, the quantitative indicators are design-based and deal with the fulfilment of the design requirements and the thresholds that are based on equations and quantity constraints. Hence, each indicator has maximum available credits (points) to be achieved; if the building fulfills the requirements of particular indicators, it will gain the maximum points, if it doesn't, the building will score some or no credits according to the degree of fulfillment. The following sub-sections will illustrate briefly the description and the score determination of the factors and indicators.

3.1.1 Site and Ecology Criterion

The *site and ecology* criterion comprises four factors and thirteen indicators. The indicators of *previous consideration of site* and *site management* factors are qualitative, while the indicators of *reduce heat island effect* and *site emission* factors are quantitative. Also, the indicator *light pollution reduction* under the *site emissions* factor is qualitative. The indicator *heat island reduction in non-roof area* is utilized to mitigate the effect of heat that arises from the solar emissivity of the materials of the non-roofed landscape of the project. The points will be awarded if the qualified non-roof area (Q) is more or equal to 50% of the total non-roofed area (USGBC, 2009). The indicator *heat island reduction in roof area* is utilized to drop off the effect of the dark materials that are used in roof finishing, as these materials absorb the sun heat and emit it back to the surrounding, resulting in increasing the cooling loads, electricity consumption, and greenhouse gas (GHG) emissions. The summation of the weighted average solar reflectance index (SRI) of the roof area that is greater than 75% of roof area and the planted area, which is more than 50% of the roof area must be greater than or equal to the net roof area (USGBC, 2009). Moreover, the *exterior walls finishing and planting* indicator is applied to increase the efficiency of the building envelope materials to decrease its solar gain, by utilizing materials with high solar reflectance index (SRI) or benefit from the planting surfaces by applying the efficient material ratio. The efficient material ratio is the ratio between the summation of the planted area and the high SRI material installed on the building envelope to the total exterior wall area (BCA, 2012b; JaGBC, 2008). Also, the *consideration of wind movement and building exterior design* indicator encourages the efficient design of the exterior building shape to allow the prevailing wind flow within the site, which can be achieved either in the building extension or retrofitting (JaGBC, 2008). Finally, the *greenery provision and* *ecological features* indicator is calculated to mitigate the heat island effect by encouraging to increase the green area spot in the project (BCA, 2012b).

3.1.2 Transportation Criterion

The *transportation* criterion comprises four factors and five indicators. The *cyclist facilities* and *carpooling* are qualitative indicators. The factors *public transport accessibility and community accessibility*, *provision of maximum car parking capacity*, and *provision of low-emitting and fuel-efficient vehicles* are all qualitative. The *reduction in the conventional commuting trips* indicator is quantitative as it depends on numerical calculations to get the reduction percentage in the conventional commuting. A random sample of regular occupants of the buildings are selected to examine their commuting methods through questionnaires. The ratio between the ones who use alternative means of transportation for commuting to the whole sample size represents the reduction in conventional commuting, then the points can be achieved according to the reduction percentage (USGBC, 2009).

3.1.3 Energy Criterion

The *energy* criterion is composed of four factors and fourteen indicators. The factor *provision of energy management* and all its related indicators, the *energy efficient circulation systems* indicator, and the *high-efficiency boilers and hot water systems* indicator are all qualitative. Contrastingly, the *minimum energy performance* indicator is quantitative. It requires historical data or simulation data for the energy consumption of the building. It includes three steps as proposed to get the final score as follow: 1) conduct data entry for the energy (electricity and natural gas consumption) in the energy star portfolio manager, 2) identify the energy use intensity from portfolio manager, 3) calculate the percentage less than national average consumption to select the corresponding points (USGBC, 2009). Furthermore, the evaluation of *thermal performance reduction of building envelope* indicator is used to enhance the overall performance of the building envelope to minimize solar heat gain and in turn, decrease the cooling load for the building (BCA, 1986; BCA, 2012b). Moreover, the *lighting efficiency and interior zoning control* indicator is applied to encourage the use of efficient lighting while maintaining the same lighting quality (BCA, 2012b). Furthermore, the following indicators are dependent on the degree of improvement to achieve points such as *renewable energy systems*, *energy efficient appliances, and cloth drying facilities*, and *energy-efficient AC equipment*.

3.1.4 Water Use Criterion

The *water use* criterion includes three factors and eleven indicators. All the indicators of the *water management* factor are qualitative. In contrast, the other indicators are quantitative. The *minimum indoor plumbing fixtures*, *additional indoor plumbing fixtures* indicators calculate the percentage of water reduction over the baseline by entering the required data such as the number of occupants, type of fixtures used, and their water consumption rates (flush rate or flow rate) (USGBC, 2009). Moreover, the *water recycling and rainwater harvesting* indicator is implemented to encourage the reduction in the use of potable water and use either grey water or other harvested from rain (BRE, 2015; GBC Indonesia, 2012; GBI, 2011; HK GBC, 2012; JaGBC, 2008).

3.1.5 Material and Waste Reduction Criterion

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

3.1.6 Indoor Environment Quality Criterion:

This criterion is composed of six factors and twenty-five indicators. All the indicators are qualitative except the following: 1) *natural lighting and external views*, 2) *minimum IAQ performance*, 3) *increased ventilation performance*, 4) *localized ventilation & ventilation in common areas*. The *natural lighting and external views* indicator possesses two methods of calculation: 1) using simulation to prove that 50% of the regularly occupied areas have illumination of minimum 270 lumen/m^2 and maximum 5300 lumen/m^2, and 2) using calculation of the product of visible light transmittance and wall floor area ratio (USGBC, 2009). Moreover, *Minimum IAQ Performance* and *Increased Ventilation Performance* indicators are applied to enhance the air quality in buildings, consequently, preserve health and well-being of the occupants. The points of these indicators are awarded according to the ratio between the calculated required outdoor airflow and the required by the standard (ASHRAE, 2007).

3.1.7 Building Management Criterion

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

3.2 Weight Determination for Criteria and Factors

The weight of each criterion and factor was evaluated by applying a fuzzy multi-attribute decision-making technique that is called *Technique for Order of Preference by Similarity to Ideal Solution* (TOPSIS). Fuzzy TOPSIS is used to select the best alternative or to rank a group of alternatives, which have different criteria and attributes. This technique had been proved through several studies that it is capable to overcome the uncertainties arise when considering opinions of individuals in the weight determination processes, and its ability to transform linguistic data into crisp numerical values (Chu and LIN, 2003; Hwang and Yoon, 1981; Kahraman et al., 2008; Triantaphyllou and Lin, 1996). Also, this research seeks to introduce another approach rather than AHP, which was used in most of the previous studies that dealt with weight determination. In addition, AHP was proved to possess some limitations as follows: 1) the process is unable to deal with all the assessment attributes at the same time and it focuses only in two attributes (Chandratilake and Dias, 2013), 2) the anomalies that may arise through the weight determination process cannot be tracked and rectified, 3) the result of the same problem may differ when using different problem structures, and 4) some ambiguities inherited when defining the conversion scale from linguistic scale (linguistic variables) to numerical scale that express the verbal priorities (Chandratilake and Dias, 2013; Ishizaka and Labib, 2009).

Furthermore, the input data for this method is dependent on the responses of experts to a proposed questionnaire to evaluate the weight of each criterion and factor. Fuzzy TOPSIS undergoes eight steps to reach the final weight of the criteria and factors as will be illustrated in following sub-sections:

3.2.1 Questionnaire Based on Fuzzy TOPSIS Technique

Data was collected through two groups of questionnaires, which were distributed among engineers and sustainability experts in two different countries, Canada and Egypt. These two countries were selected due to their obvious variations in their regional contexts such as climate, cultural and social considerations, and economic aspects to illustrate the significant influence of these regional variations on both the weights of the sustainability attributes and the total sustainability assessment. More countries could have been utilized in this research to develop a worldwide rating tool, but these two countries have been used as a proof of concept. Moreover, the number of responses that were collected from Egypt and Canada were 40 and 20 respectively. Although this number of responses was not quite enough, it can represent a guide for the weight of the proposed criteria and factors in the two countries. Also, the answer bias may impact the results, therefore, the reliability check was crucial to assure the consistency of the collected answers to be used for further implementation and analysis. The coefficient of variance was utilized as one of the methods to check the consistency of the data (Chandratilake and Dias, 2013). The second method was the Chronbach's alpha that was developed in 1951 by Lee Chronbach to measure the consistency or reliability of data that measure single and unidimensional aspect (Cronbach, 1951; Cronbach, 2004). This method reflects the consistency in a scale ranges from zero to one; many studies agreed that alpha value of 0.7 represents an acceptable reliability (Kline, 2000; Pison and Van Aelst, 2004; Vaske et al., 2017). Almost all the values of the Cronbach's alpha for the collected data are over 0.7. Moreover, another proof for the consistency of the data is the coefficient of variance, in which most of the collected data has low values of the coefficient of variance that ranged from 5% to 43%. Consequently, the data that had been collected was proved to be robust, consistent, and reliable and can be used for the weight determination of each of the criteria and factors for both Canadian and Egyptian context, and to be implemented in the development of the sustainability assessment model. Although the collected data was reliable and consistent according to the performed statistical analysis, but the sample size is needed to be increased to represent the near actual weights that can be utilized in the formal scheme of the developed model. The sample size is dependent on the level of precision (margin error), confidence level, and degree of variability. Several formulae can be applied to determine the required sample size, one of the commonly used formula is shown in equation (1) (Israel, 1992; Rose and Canhoto, 2015).

$$n = \frac{Z^2 pq}{e^2} \tag{1}$$

Where:

n: Required sample size;

Z: z-score dependant on the confidence level;

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

q: 1-p; and

e: margin of error.

The questionnaire is divided into two main sections: 1) the respondent self-information, and 2) criteria and factors degree of importance. In the respondent self-information section, the respondents were required to enter a general information that expresses their professions and years of experience. Hence, the years of experience for each respondent will be expressed as weight, which will be given to address the reliability of the responses in the calculations. The criteria and factors degree of importance section aims to identify the weight of each criterion and factor that will affect the final sustainability assessment. The weight will differ according to the regional location of the building. Two hundred experts in buildings, construction, and sustainability fields were contacted through a period of one year by emails and interviews to fill out the questionnaire. There is a diversity of respondents' professions in the Canadian and the Egyptian samples. The Canadian respondents include civil engineers, mechanical/electrical engineers, sustainability experts, facility managers, and architects, whereas the Egyptian samples embrace architects, civil engineers, and sustainability experts as shown in Figure 3.

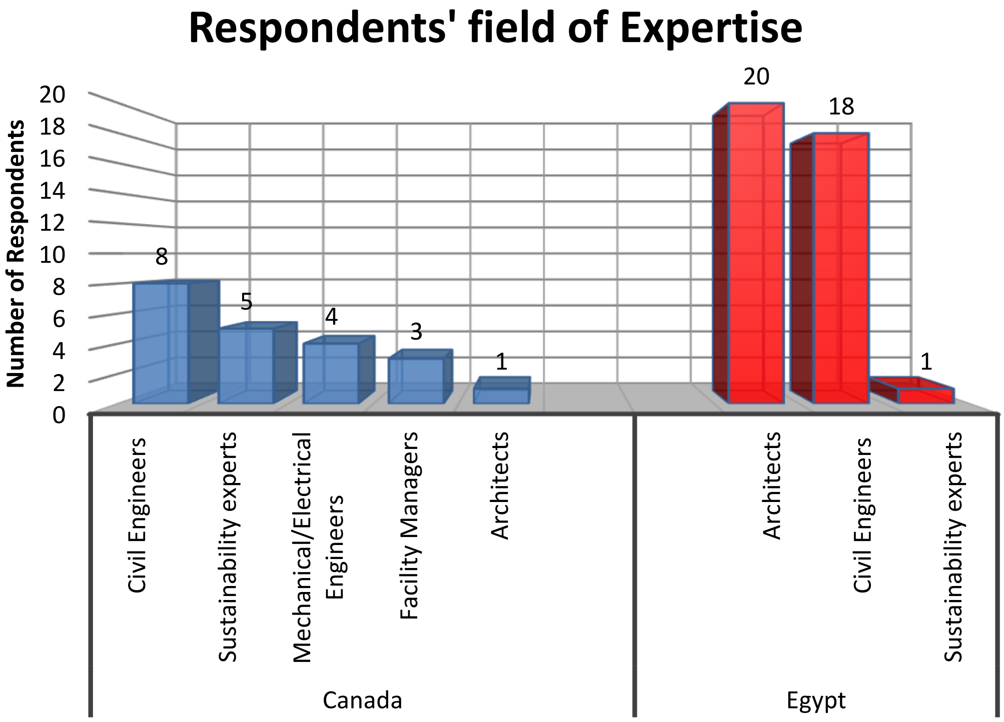


Figure 3: Respondent Fields of Expertise

3.2.2 Opinions of Experts Concerning the Importance the Criteria and Factors

This part of the questionnaire aims to identify the importance of each criterion and factor that will affect the total sustainability assessment based on different regional contexts. The respondents are requested to enter five sets of three numbers to express five-linguistic variables (degrees of importance): very high, high, medium, low, and very low. This procedure will be utilized in a fuzzy method to fuzzify (change to one crisp number rather than three fuzzy numbers) these linguistic variables for further calculations as illustrated in Figure 4. Each set of the linguistic variables corresponds to three numbers, which represents a triangular fuzzy number (TFN) that comprises of minimum boundary (lowest number in a set), middle boundary (intermediate number), and the maximum boundary (highest number in a set). Moreover, the first set starts with zero as a minimum boundary and the fifth set ends with the one as a maximum boundary. As shown in Figure 3, as an example of a respondent data entry, the first TFN is (0, 0, 0.2) represents the minimum degree of importance (very low), the third TFN is (0.3, 0.5, 0.7) represents Medium, and the fifth TFN (0.8, 1, 1) represents the highest one (very high).

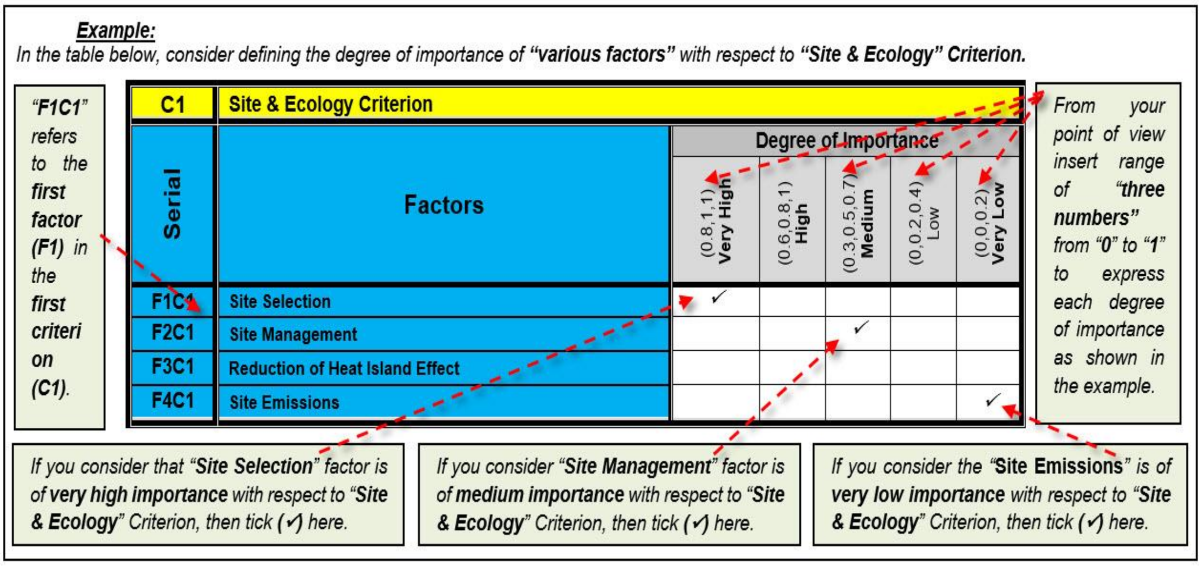


Figure 4: Expressing Linguistic Scale into Triangular Fuzzy Numbers

3.2.3 Conversion of the Linguistic Responses to Fuzzy Numbers

The fuzzification (conversion from linguistic variables to fuzzy numbers) was identified through the responses of respondents concerning entering a range of three numbers that express each of the five linguistic variables. Twenty-Two out of 60 respondents answered the part of the numerical representation of the linguistic variables, in which the final triangular fuzzy numbers were determined as the mean of all the responses in each column as shown in Table 1 and as represented in Figure 5. The five linguistic variables are very low, low, medium, high, and very high which corresponds to five triangular fuzzy numbers ranging from (0.01, 0.09, 0.23) for very low and (0.82, 0.94, 1.00) for very high.

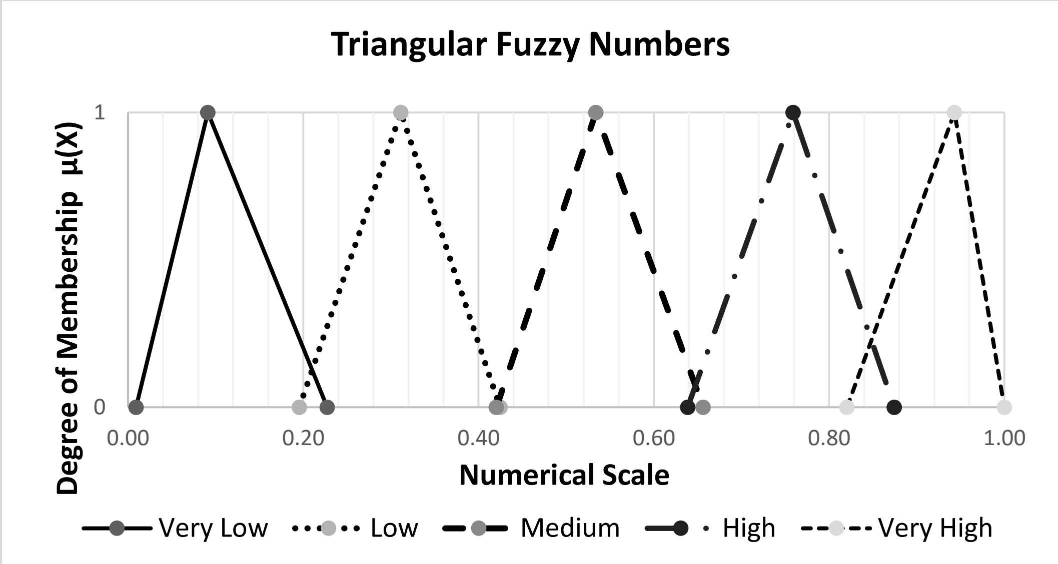


Figure 5: Triangular Fuzzy Numbers Representation

Table 1: Determination of the Triangular Fuzzy Numbers

No.	Very Low			Low			medium			High			Very High		
1	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
2	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
3	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
4	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
5	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
6	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.6	0.7	0.8	0.8	0.9	1
7	0	0.2	0.5	0.5	0.6	0.64	0.65	0.7	0.74	0.75	0.8	0.84	0.85	0.9	1
8	0	0.1	0.2	0.3	0.3	0.3	0.4	0.5	0.6	0.7	0.7	0.7	0.8	0.9	1
9	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
10	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
11	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
12	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
13	0	0	0.2	0	0.2	0.4	0.3	0.5	0.7	0.6	0.8	1	0.8	1	1
14	0	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.5	0.7	0.8	0.8	0.9	1	1
15	0	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1
16	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
17	0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.8	0.8	0.8	1	1
18	0	0.2	0.4	0.4	0.5	0.6	0.6	0.65	0.7	0.7	0.8	0.9	0.9	0.95	1
19	0.1	0.1	0.2	0.4	0.4	0.5	0.6	0.7	0.8	0.8	0.9	1	0.9	0.9	1
20	0	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.8	0.7	0.8	1	0.8	1	1
21	0	0.1	0.2	0.1	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
22	0	0	0.1	0.2	0.25	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1
	0.01	**0.09**	**0.23**	**0.20**	**0.31**	**0.42**	**0.42**	**0.53**	**0.66**	**0.64**	**0.76**	**0.87**	**0.82**	**0.94**	**1.00**

3.2.4 Weighted Normalized Decision Matrix

As a part of the weight determination procedures, Table 2 to Table 4 demonstrate the detailed stages for the weight determination procedures of each criterion based on the Egyptian context. The weighted normalized decision matrix comprises three stages 1) decision matrix, 2) normalized decision matrix, and 3) weighted normalized decision matrix. The decision matrix represents gathering the linguistic variable from each respondent according to their perception about the weight of each criterion with respect to the entire sustainability assessment.

Additionally, the fuzzification process of these linguistic variables were dependent on the scale that was determined in the previous section forming the decision matrix for each of the seven criteria as shown in Table 2. The first column in Table 2 represents the number of respondents; each row demonstrates the decision of each respondent for the seven criteria. Each of the seven columns, which represents the criteria, consists of the linguistic decision of each respondent and its corresponding TFN, in which all the TFNs are called the decision matrix. Furthermore, the normalized decision matrix was developed to normalize the ranking of alternatives (decision of respondents) to be unit free, such that all the values of the TFNs for all the criteria in a row (single respondent), in Table 2, was divided by third value of the largest TFN in the same row by utilizing equation (2) (Ertuğrul and Karakaşoğlu, 2008; Pramanik et al., 2016; Yong, 2006). Furthermore, the weighted normalized decision matrix was obtained by multiplying the reliability weight of each respondent by all the corresponding values (the same row) for all the criteria as shown in equation (3) and Table 3. The reliability weight is a value from zero to one, however, this weight remains constant among all respondents to prevent subjectivity in the determination of this weight and to make the calculations procedures easier. The reliability weight that was used in the case of the Egyptian context is 0.025, which represents the value of one divided by 40 respondents from the Egyptian context.

$$\tilde{r}_{ij} = \begin{cases} \frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} (for\ benefit\ attribute) \\ \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{c_{ij}} (for\ cost\ attribute) \end{cases} \quad (2)$$

$$\tilde{v}_{ij} = \tilde{r}_{ij}.\tilde{w}_j \quad (3)$$

Where:

a_j^*, b_j^*, c_j: three values of a TFN with the highest ranking;

a_j^-, b_j^-, c_j^-: three values of a TFN with the minimum ranking.

$\tilde{V}$: weighted normalized decision matrix;

$\tilde{w}_j$: weight of each attribute; and

$\tilde{r}_{ij}$: ranking each alternative with respect to one attribute (j).

Table 2: Fuzzification of Criteria Responses of the Egyptian Respondents

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

Table 3: Normalized and Weighted Matrices of Criteria (Egyptian Sample)

Respondent	Site and Ecology Criterion			Transportation Criterion			Energy Criterion			Water Use Criterion			Material and WasteReduction Criterion			Indoor Environmental Quality Criterion			Building Management		
	Weighted Matrix			**Weighted Matrix**			**Weighted Matrix**			**Weighted Matrix**			**Weighted Matrix**			**Weighted Matrix**			**Weighted Matrix**		
1	0.011	0.013	0.017	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.013	0.017	0.016	0.019	0.022
2	0.016	0.019	0.022	0.011	0.013	0.017	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.005	0.008	0.011
3	0.021	0.024	0.025	0.011	0.013	0.017	0.016	0.019	0.022	0.005	0.008	0.011	0.005	0.008	0.011	0.021	0.024	0.025	0.016	0.019	0.022
4	0.016	0.019	0.022	0.011	0.013	0.017	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022
5	0.000	0.002	0.006	0.011	0.013	0.017	0.021	0.024	0.025	0.011	0.013	0.017	0.000	0.002	0.006	0.016	0.019	0.022	0.000	0.002	0.006
6	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.013	0.017	0.016	0.019	0.022	0.011	0.013	0.017
7	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
8	0.021	0.024	0.025	0.011	0.013	0.017	0.016	0.019	0.022	0.000	0.002	0.006	0.011	0.013	0.017	0.011	0.013	0.017	0.021	0.024	0.025
9	0.016	0.019	0.022	0.000	0.002	0.006	0.021	0.024	0.025	0.005	0.008	0.011	0.011	0.013	0.017	0.021	0.024	0.025	0.016	0.019	0.022
10	0.011	0.013	0.017	0.005	0.008	0.011	0.011	0.013	0.017	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.013	0.017	0.021	0.024	0.025
11	0.011	0.013	0.017	0.011	0.013	0.017	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.013	0.017	0.005	0.008	0.011	0.016	0.019	0.022
12	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.013	0.017	0.016	0.019	0.022
13	0.016	0.019	0.022	0.005	0.008	0.011	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022
14	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
15	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022
16	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022
17	0.021	0.024	0.025	0.011	0.013	0.017	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.013	0.017	0.021	0.024	0.025
18	0.021	0.024	0.025	0.011	0.013	0.017	0.011	0.013	0.017	0.016	0.019	0.022	0.005	0.008	0.011	0.000	0.002	0.006	0.011	0.013	0.017
19	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.013	0.017	0.000	0.002	0.006	0.021	0.024	0.025	0.021	0.024	0.025
20	0.016	0.019	0.022	0.011	0.013	0.017	0.021	0.024	0.025	0.016	0.019	0.022	0.005	0.008	0.011	0.021	0.024	0.025	0.005	0.008	0.011
21	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022
22	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025	0.021	0.024	0.025
23	0.021	0.024	0.025	0.011	0.013	0.017	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.013	0.017	0.016	0.019	0.022	0.016	0.019	0.022
24	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.011	0.013	0.017	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022
25	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025
26	0.021	0.024	0.025	0.011	0.013	0.017	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.013	0.017	0.016	0.019	0.022	0.011	0.013	0.017
27	0.021	0.024	0.025	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.013	0.017	0.011	0.013	0.017	0.011	0.013	0.017
28	0.016	0.019	0.022	0.011	0.013	0.017	0.021	0.024	0.025	0.021	0.024	0.025	0.011	0.013	0.017	0.016	0.019	0.022	0.016	0.019	0.022
29	0.016	0.019	0.022	0.011	0.013	0.017	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022	0.011	0.013	0.017	0.016	0.019	0.022
30	0.021	0.024	0.025	0.011	0.013	0.017	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.013	0.017	0.011	0.013	0.017	0.016	0.019	0.022
31	0.021	0.024	0.025	0.011	0.013	0.017	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.013	0.017	0.011	0.013	0.017	0.011	0.013	0.017
32	0.018	0.022	0.025	0.012	0.015	0.019	0.006	0.009	0.012	0.012	0.015	0.019	0.006	0.009	0.012	0.000	0.003	0.007	0.006	0.009	0.012
33	0.021	0.024	0.025	0.005	0.008	0.011	0.005	0.008	0.011	0.011	0.013	0.017	0.005	0.008	0.011	0.016	0.019	0.022	0.011	0.013	0.017
34	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.013	0.017	0.011	0.013	0.017	0.016	0.019	0.022
35	0.018	0.022	0.025	0.012	0.015	0.019	0.018	0.022	0.025	0.018	0.022	0.025	0.012	0.015	0.019	0.018	0.022	0.025	0.018	0.022	0.025
36	0.021	0.024	0.025	0.005	0.008	0.011	0.011	0.013	0.017	0.016	0.019	0.022	0.005	0.008	0.011	0.016	0.019	0.022	0.016	0.019	0.022
37	0.021	0.024	0.025	0.011	0.013	0.017	0.016	0.019	0.022	0.016	0.019	0.022	0.016	0.019	0.022	0.011	0.013	0.017	0.021	0.024	0.025
38	0.018	0.022	0.025	0.012	0.015	0.019	0.018	0.022	0.025	0.018	0.022	0.025	0.012	0.015	0.019	0.012	0.015	0.019	0.018	0.022	0.025
39	0.018	0.022	0.025	0.012	0.015	0.019	0.018	0.022	0.025	0.012	0.015	0.019	0.012	0.015	0.019	0.012	0.015	0.019	0.018	0.022	0.025
40	0.016	0.019	0.022	0.021	0.024	0.025	0.021	0.024	0.025	0.016	0.019	0.022	0.016	0.019	0.022	0.021	0.024	0.025	0.016	0.019	0.022

3.2.5 Determination of the Generalized

The defuzzification process is converting each of the triangular fuzzy numbers to a crisp value. This process was performed by utilizing equation (4) to get the generalized mean (Kahraman et al., 2008). The generalized mean was used to distinguish the positive ideal solution (PIS) that had the (highest generalized mean) and the negative solution (NIS), which had the lowest generalized mean among all the criteria for each respondent.

$$M(v_{ij}) = \frac{-a_{ij}{}^2 + c_{ij}{}^2 - a_{ij}b_{ij} + a_{ij}b_{ij}}{[3(-a_{ij} + c_{ij})]} \tag{4}$$

Where:

v_j^*: positive ideal solution concerning particular attribute;

v_j^-: negative ideal solution concerning particular attribute;

$M(v_{ij})$: generalized mean for each solution; and

a, b, c: three values of the triangular fuzzy numbers.

3.2.6 Computation of the Distances from the PIS and the NIS

The distance between two TFNs was determined by implementing the Euclidean distance method shown in equation (5) (Byun and Lee, 2005; Ertuğrul and Karakaşoğlu, 2008; Pramanik et al., 2016; Yong, 2006). As shown in Table 4, each criterion consists of three columns, the first one represents the generalized mean, the second and the third columns show the distance from PIS (D^+) and the distance from NIS (D^-). Also, as illustrated in the first row in Table 4, the D^+ value in the *energy* and *water use* criteria is zero value that means the first respondent gave these two criteria the highest weight among all the seven criteria and in turn, they represent the PIS, therefore, their distances from the PIS is zero. Contrariwise, for the *site* and *indoor environmental quality* criteria, they represent the NIS, so their distances from NIS (D^-) is zero.

$$d(\widetilde{M}_1, \widetilde{M}_2) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \tag{5}$$

Where:

$d(\widetilde{M}_1, \widetilde{M}_2)$: distance between two triangular fuzzy numbers;

a_1, b_1, c_1: three values of the first triangular fuzzy numbers; and

a_2, b_2, c_2: three values of the second triangular fuzzy numbers.

3.2.7 Determination of the Positive and Negative Similarity (S)

The positive similarity (S^+) is the summation of all distances from PIS (D^+) for each criterion regarding all the respondents. Conversely, the negative similarity (S^-) is the summation of all distances from NIS for each criterion regarding all the respondents (Byun and Lee, 2005; Ertuğrul and Karakaşoğlu, 2008; Kahraman et al., 2008; Pramanik et al., 2016).

3.2.8 Evaluation of the Closeness Coefficient (CC) and Normalized Weight

The closeness coefficient (CC) is the ratio between the negative similarity and the summation of both positive and negative similarity as illustrated in equation (6). Additionally, normalization of all the CC was performed to get the final weight of each criterion (Byun and Lee, 2005; Ertuğrul and Karakaşoğlu, 2008; Kahraman et al., 2008; Pramanik et al., 2016). As shown in Table 4, the *energy* criterion has the highest CC of value 0.738 and weight of value 0.2, whereas the *transportation* criterion has the lowest weight, then, the same procedures were followed to determine the rest of weights for each factor of the seven criteria.

$$CC_i = \frac{S_i^-}{S_i^- + S_i^*} \tag{6}$$

Table 4: Defuzzification of Criteria (Egyptian Sample)

Respondent	Site and Ecology Criterion			Transportation Criterion			Energy Criterion			Water Use Criterion			Material and Waste Reduction Criterion			Indoor Environmental Quality Criterion			Building Management Criterion		
	Mean	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mea**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**	**Mean**	**D^+**	**D^-**
1	0.013	0.010	0	0.019	0.004	0.006	0.023	0	0.010	0.023	0	0.010	0.019	0.004	0.006	0.013	0.010	0	0.019	0.004	0.006
2	0.019	0.004	0.011	0.013	0.010	0.006	0.023	0	0.015	0.023	0	0.015	0.019	0.004	0.011	0.023	0	0.015	0.008	0.015	0
3	0.023	0	0.015	0.013	0.010	0.006	0.019	0.004	0.011	0.008	0.015	0	0.008	0.015	0	0.023	0	0.015	0.019	0.004	0.011
4	0.019	0.004	0.006	0.013	0.010	0	0.023	0	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0	0.010	0.019	0.004	0.006
5	0.003	0.020	0.000	0.013	0.010	0.011	0.023	0	0.020	0.013	0.010	0.011	0.003	0.020	0	0.019	0.004	0.016	0.003	0.020	0
6	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0	0.010	0.019	0.004	0.006	0.013	0.010	0	0.019	0.004	0.006	0.013	0.010	0
7	0.019	0.004	0	0.019	0.004	0	0.023	0	0.004	0.023	0	0.004	0.023	0	0.004	0.019	0.004	0	0.019	0.004	0
8	0.023	0	0.020	0.013	0.010	0.011	0.019	0.004	0.016	0.003	0.020	0	0.013	0.010	0.011	0.013	0.010	0.011	0.023	0	0.020
9	0.019	0.004	0.016	0.003	0.020	0	0.023	0	0.020	0.008	0.015	0.005	0.013	0.010	0.011	0.023	0	0.020	0.019	0.004	0.016
10	0.013	0.010	0.006	0.008	0.015	0	0.013	0.010	0.006	0.023	0	0.015	0.023	0	0.015	0.013	0.010	0.006	0.023	0	0.015
11	0.013	0.010	0.006	0.013	0.010	0.006	0.023	0	0.015	0.023	0	0.015	0.013	0.010	0.006	0.008	0.015	0	0.019	0.004	0.011
12	0.023	0	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.023	0	0.010	0.019	0.004	0.006	0.013	0.010	0	0.019	0.004	0.006
13	0.019	0.004	0.011	0.008	0.015	0	0.019	0.004	0.011	0.019	0.004	0.011	0.023	0	0.015	0.023	0	0.015	0.019	0.004	0.011
14	0.023	0.000	0.004	0.019	0.004	0	0.019	0.004	0	0.023	0	0.004	0.019	0.004	0	0.023	0	0.004	0.023	0	0.004
15	0.019	0.004	0	0.019	0.004	0	0.023	0	0.004	0.023	0	0.004	0.019	0.004	0	0.019	0.004	0	0.019	0.004	0
16	0.019	0.004	0	0.023	0	0.004	0.023	0	0.004	0.019	0.004	0	0.019	0.004	0	0.019	0.004	0	0.019	0.004	0
17	0.023	0	0.010	0.013	0.010	0	0.023	0	0.010	0.023	0	0.010	0.019	0.004	0.006	0.013	0.010	0	0.023	0	0.010
18	0.023	0	0.020	0.013	0.010	0.011	0.013	0.010	0.011	0.019	0.004	0.016	0.008	0.015	0.005	0.003	0.020	0	0.013	0.010	0.011
19	0.023	0	0.020	0.019	0.004	0.016	0.019	0.004	0.016	0.013	0.010	0.011	0.003	0.020	0	0.023	0	0.020	0.023	0	0.020
20	0.019	0.004	0.011	0.013	0.010	0.006	0.023	0	0.015	0.019	0.004	0.011	0.008	0.015	0	0.023	0	0.015	0.008	0.015	0
21	0.023	0	0.004	0.019	0.004	0	0.023	0	0.004	0.023	0	0.004	0.019	0.004	0	0.023	0	0.004	0.019	0.004	0
22	0.023	0	0.004	0.019	0.004	0	0.019	0.004	0.000	0.023	0	0.004	0.023	0	0.004	0.023	0	0.004	0.023	0	0.004
23	0.023	0	0.010	0.013	0.010	0	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0	0.019	0.004	0.006	0.019	0.004	0.006
24	0.023	0	0.010	0.019	0.004	0.006	0.023	0	0.010	0.013	0.010	0	0.023	0	0.010	0.019	0.004	0.006	0.019	0.004	0.006
25	0.019	0.004	0	0.019	0.004	0	0.023	0	0.004	0.023	0	0.004	0.019	0.004	0	0.023	0	0.004	0.023	0	0.004
26	0.023	0	0.010	0.013	0.010	0	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0	0.019	0.004	0.006	0.013	0.010	0
27	0.023	0	0.010	0.019	0.004	0.006	0.023	0	0.010	0.019	0.004	0.006	0.013	0.010	0	0.013	0.010	0	0.013	0.010	0
28	0.019	0.004	0.006	0.013	0.010	0	0.023	0	0.010	0.023	0	0.010	0.013	0.010	0	0.019	0.004	0.006	0.019	0.004	0.006
29	0.019	0.004	0.006	0.013	0.010	0	0.019	0.004	0.006	0.023	0	0.010	0.019	0.004	0.006	0.013	0.010	0	0.019	0.004	0.006
30	0.023	0	0.010	0.013	0.010	0	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0	0.013	0.010	0	0.019	0.004	0.006
31	0.023	0	0.010	0.013	0.010	0	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0	0.013	0.010	0	0.013	0.010	0
32	0.022	0	0.019	0.015	0.006	0.012	0.009	0.013	0.006	0.015	0.006	0.012	0.009	0.013	0.006	0.003	0.019	0	0.009	0.013	0.006
33	0.023	0	0.015	0.008	0.015	0	0.008	0.015	0	0.013	0.010	0.006	0.008	0.015	0	0.019	0.004	0.011	0.013	0.010	0.006
34	0.023	0	0.010	0.019	0.004	0.006	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0	0.013	0.010	0	0.019	0.004	0.006
35	0.022	0	0.006	0.015	0.006	0	0.022	0	0.006	0.022	0	0.006	0.015	0.006	0	0.022	0	0.006	0.022	0	0.006
36	0.023	0	0.015	0.008	0.015	0	0.013	0.010	0.006	0.019	0.004	0.011	0.008	0.015	0	0.019	0.004	0.011	0.019	0.004	0.011
37	0.023	0	0.010	0.013	0.010	0	0.019	0.004	0.006	0.019	0.004	0.006	0.019	0.004	0.006	0.013	0.010	0	0.023	0	0.010
38	0.022	0	0.006	0.015	0.006	0	0.022	0	0.006	0.022	0	0.006	0.015	0.006	0	0.015	0.006	0	0.022	0	0.006
39	0.022	0	0.006	0.015	0.006	0	0.022	0	0.006	0.015	0.006	0	0.015	0.006	0	0.015	0.006	0	0.022	0	0.006
40	0.019	0.004	0	0.023	0	0.004	0.023	0	0.004	0.019	0.004	0	0.019	0.004	0	0.023	0	0.004	0.019	0.004	0
S^+, S^-		**0.099**	**0.239**		**0.314**	**0.124**		**0.115**	**0.324**		**0.164**	**0.275**		**0.308**	**0.130**		**0.218**	**0.221**		**0.200**	**0.239**
CC	**0.708**			**0.284**			**0.738**			**0.627**			**0.297**			**0.503**			**0.545**		
Weight	**0.191**			**0.077**			**0.200**			**0.169**			**0.080**			**0.136**			**0.147**		

3.3 Score Determination of Factors and Indicators

Each of the proposed criteria comprises number of factor and indicators, each of which has certain available points to be achieved. Consequently, the score of each factor was determined by a proposed formula by aggregating the points of its related indicators as shown in equation (7). The score of each indicator was determined by utilizing the equations that will be illustrated in the following section:

$$SC_j = \sum_{i=1}^{l} SC_{ind_i} \tag{7}$$

Where:

$SC\ f_j$: score of the j^{th} factor in each criterion; and

ind_i : score of the i^{th} indicator in each factor.

3.4 Determination of the Factor Sustainability Index (SI)

The procedures of the weight determination were described in detail in section 3.2. The result of this process was the determination of the weight of each criterion (W_k) and factor weight that is called local weight (WL); WL is the weight of each factor with respect to its related criterion. Moreover, the global weight (WG) that was utilized in the assessment process is the product of the WL of the factor and the W_k of the related criterion as illustrated in equation (8); WG is the weight of each factor with respect to the over all sustainability tool and the summation of all the WGs is equal to one. Furthermore, the sustainability index of each factor (SI) is the product of the factor score (SC) and its corresponding global weight (WG) as shown in equation (9).

$$WG_j = W_k \times WL_j \tag{8}$$

$$SI_j = SC_j \times WG_j \tag{9}$$

Where:

WG_j : corresponding global weight of the j^{th} factor;

W_k : corresponding weight of the k^{th} criterion;

WL_j : corresponding local weight of the j^{th} factor; and

SI_j : sustainability index of j^{th} factor.

3.5 Determination of Building Sustainability Index (BSI)

Further, the building sustainability index (BSI) is the summation of all the sustainability indices of all the factors and was calculated based on the proposed equation (10). The building sustainability assessment ratio (BSAR) is the percentage between the BSI and the maximum BSI. The maximum BSI is determined, utilizing the previous steps in the factor score determination, by substituting the achieved score by the maximum available score, which is the maximum available points dedicated for each indicator. The BSAR can be expressed either by equation (11) and or in the general form as in equation (12).

$$BSI = \sum_{j=1}^{m} SCf_j \times W_{g_j} = \sum_{j=1}^{m} SI_j \tag{10}$$

$$BSAR = \frac{BSI}{\mathrm{BSI}_{max}} \times 100 \tag{11}$$

$$BSAR = \frac{\sum_{j=1}^{m} SC_j \times WG_j}{\sum_{j=1}^{m} (\mathrm{SC}_j)_{max} \times WG_j} \times 100 \tag{12}$$

Where:

BSI : building sustainability index; and

BSAR : building Sustainability Assessment Ratio.

3.6 Sustainability Scale Determination

The final step in the methodology is the ranking scheme development, which was dependent on two procedures: the responses of experts and the review of the widely used tools. The responses of experts was collected through questionnaires that investigated their opinion about the suitable scale to represent each level of sustainability of buildings (i.e. outstanding, excellent, very good, good, pass, and fail), as well as the threshold for each criterion that represents the minimum requirement for each criterion to achieve a particular rating as shown in Figure 6. The proposed sustainability ranking is a scale from (0) to (100), which represents seven sustainability ranks (failure, pass, good, very good, excellent, outstanding). All the BSAR that are less than 50% represents failure, and above 50% with an increment of 10% accounts for each of the above mentioned seven ranks.

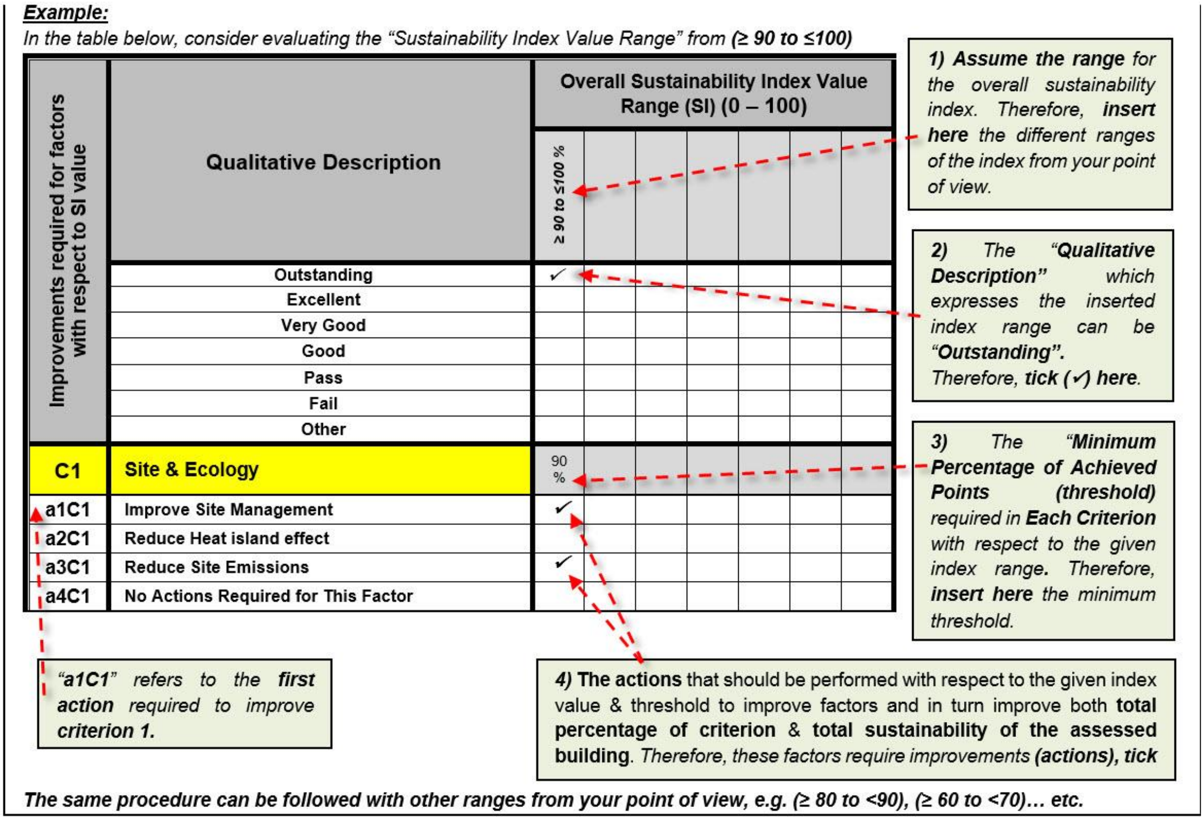


Figure 6: Sustainability Scale and Minimum Threshold Data Entry

4 MODEL IMPLEMENTATION

The developed sustainability assessment model was implemented by utilizing two case studies through a proposed framework as shown in Figure 7. The framework included four steps 1) case study data, 2) building information model (BIM), 3) energy simulation model, and 4) sustainability assessment and ranking.

4.1 Case Study Data

The two case studies are the EV Building and John Molson Building (MB) which are two buildings of Concordia University that are located at Sir George William (SGW) Campus downtown Montreal, Canada. The EV Building was opened in September 2005, it comprises seventeen stories with a gross area of 54,335m^2 that accommodates research and graduate teaching labs, three hundred specialized labs, conference rooms, meeting rooms, and administrative offices. The MB building was opened in September 2009, which comprises fifteen stories with a gross area of 37,000 m^2. This building includes one auditorium, six amphitheaters, twenty-two conference rooms, and 289 offices, 44 private study rooms, three designated open study areas, eight open relaxation/study areas, and seven waiting areas. The MB building adopts some eco-friendly features such as low-flow plumbing fixtures that reduce the consumption of potable water by 45%, no indoor parking facilities, green roof, and integrated photovoltaic solar panels.

4.2 BIM Models

The BIM models for the EV and MB buildings had been executed using Revit software and utilizing the CAD drawings that was provided by the facility management team at Concordia SGW campus as shown in Figure 7. The models illustrated 1) the properties of the exterior façades, and 2) the properties of the interior spaces. These models were used for two purposes: 1) gathering data for the sustainability assessment model; and 2) prerequisite model for the energy simulation model. Various information were extracted from the models and were used in the assessment process such as: 1) the gross floor area that was utilized in the energy consumption calculations, in the determination of the *greenery provision* value, and in the determination of the *reduction of theheat island effect of the non-roofed areas*indicator; 2) the wall areas that were used in the assessment of the *exterior wall planting and the installed SRI material* indicator in the *reduce heat island effect* factor; 3) the number of plumbing fixtures, which was used in the calculations of *water use* criterion; 4) the roof area data that was utilized in the assessment of the indicator *heat island reduction in the roofed areas* in the factor *reduce heat island effect*; 4) the building envelope area in the prevailing wind direction, which was used to calculate the sub-factor *consideration of wind movement in buildings*; and 5) the number of interior spaces that was utilized in the determination of the score of some indicators in *energy*, *water use*, and *indoor environmental quality* criteria.

4.3 Energy Simulation Models

The energy simulation models were developed by using the integrated environmental solution software (IES), that were used to perform energy simulations to stand for the energy consumption of the buildings in yearly, monthly or daily basis. These data were required for the assessment of the *energy* criterion. Seven simulations for the EV Building were performed, using different weather data files, to compare between the energy consumptions according to the different regional contexts as shown in Figure 8. Hence, the score of the *energy* criterion will vary from region to another even the same building was subjected to the assessment (i.e. assuming the same building was built in different countries). The accuracy of the output of the simulation model was compared to the actual data of energy consumption of the EV building. The actual total energy consumption of the building is 23,000 MWh, whereas it is 23,656 MWh, according to simulation, which increased the confidence in the output of the simulation. As illustrated in Figure 8, the energy consumption (in MWh) in the cold weathered cities, i.e. Montreal and New York, is much higher than other warm weathered countries due to the high demand for space heating and hot water provision. Furthermore, even the case study buildings (i.e. EV and MB Buildings) with the same physical and thermal properties of materials were used in simulations the EV and MB in Montreal, Canada performs differently than when they were simulated in Cairo, Egypt, which shows the impact of the regional context of each country on the energy performance of the building.

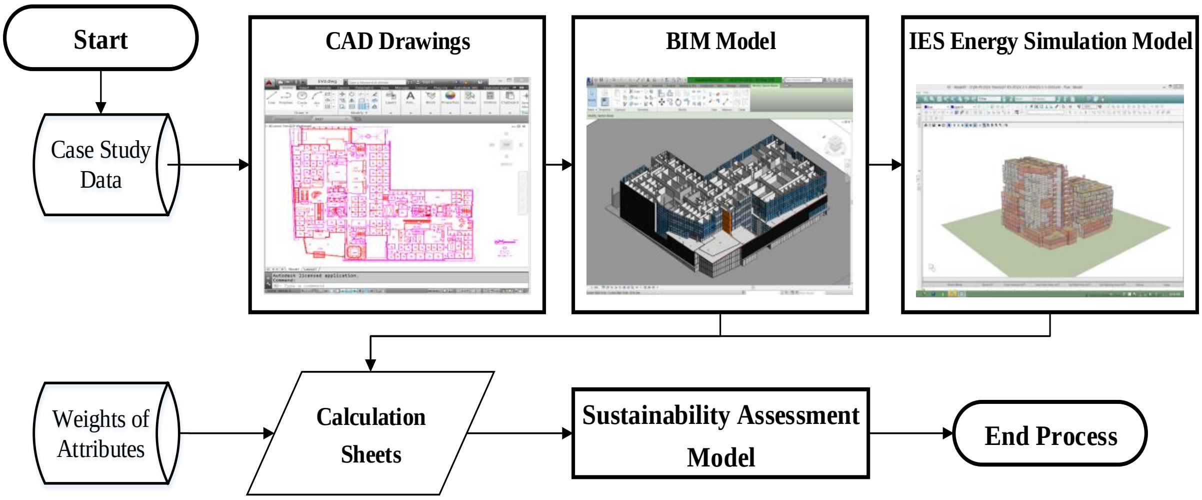


Figure 7: Sustainability Assessment Framework

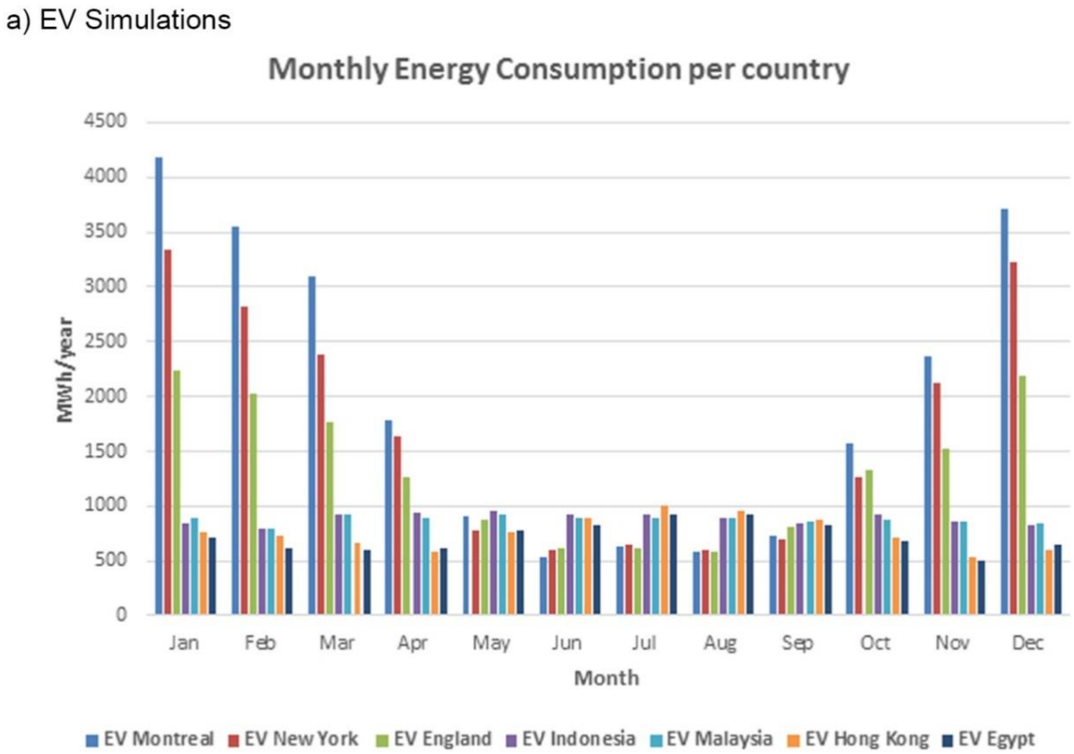


Figure 8:Case studies energy simulations output

4.4 Sustainability Assessment

The score of each indicator was determined based on 1) the collected data of the two case studies; 2) the output of the BIM model and the energy simulations; and 3) utilizing the assessment model equations from equation (8) to equation (13). The whole assessment process and the scores for each factor and its sustainability index are illustrated in Table 7 and Table 8.

These tables represent the BSAR determination for the EV and the MB based on the Canadian and the Egyptian weights respectively. Each table comprises six sections, which are 1) the sustainability assessment attribute description, 2) the local and the global weight determination, 3) the score determination for each factor for the EV and the MB buildings assessment, 4) the sustainability index of each factor, 5) the BSI of the two case studies, and 6) the BSAR of the two case studies.In each case study, the score and the sustainability index of each factor are subdivided into achieved and maximum sections; the achieved scores and indices are the current assessment of the building, whereas the maximum ones represent 100% of points that can be awarded in each factor.

5 RESULTS AND ANALYSIS

This section will discuss three results: 1) the values of the determined weight based on the Canadian and the Egyptian contexts; 2) the BSAR of the two case studies according to the two selected regional contexts, and 3) the model validation.

5.1 Weight Values

Based on the questionnaires and the fuzzy TOPSIS technique, the weight values are illustrated in Table 5. The reason behind the differential weighting undoubtedly reflects significant local variations. The rationale of some of these values can be interpreted based on the questionnaire and the responses of the respondents, whereas others cannot be specified based on the data at hand due to the small sample size. Therefore, all the obtained values are based on the sample size which of both the Canadian and the Egyptian cases as discussed previously.

The Egyptian sample shows higher weight for the criteria of *site and ecology*, and *water use,* with values 0.191 and 0.196 respectively, than those in Canadian sample of values 0.099 and 0.117 respectively. The high weight value of the *water use* criterion, according to the questionnaires, are attributed to hot weather, scarcity of rain, and the potential for the occurrence of water crises. Further, both countries nearly have the same weight for *energy* and *building management* criteria. Alternatively, the Canadian sample experiences higher weight values of 0.123, 0.118, and 0.118in *transportation*, *IEQ*, and *material* than that in Egyptian sample with values 0.077, 0.080, and 0.136 respectively.

In the site criterion, the Egyptian sample demonstrates highest weight in *site selection* and *site management* factors than Canadian one with values 0.390 and 0.281 respectively. On the other hand, the *reduce heat island effect* and *site emissions factors* are the highest in Canadian sample of values 0.362 and 0.218 respectively. In *transportation* criterion, the Canadian sample takes the lead in *alternative means of transportation* and *fuel-efficient vehicle* factors, their weights are 0.301 and 0.318 respectively. Contrariwise, the Egyptian sample has highest weights of *public transport accessibility* and *car parking capacity* factors of values 0.255 and 0.290.

In the Energy criterion, *energy performance* factor has the highest weight in both countries, whereas the *energy management*, *energy efficient systems*, and *energy efficient equipment* factors take higher priority in the Egyptian sample than the Canadian one with weights 0.195, 0.264, and 0.202 correspondingly. In addition, the Canadian sample has the highest values of the *efficient use of material* and the *solid waste management* factors which are 0.508 and 0.363 respectively, whereas in the Egyptian one these values are 0.427 and 0.281.

In the *IEQ* criterion, the Egyptian sample possesses a higher interest in the *visual comfort* and *building amenities* factors with values 0.140 and 0.117 respectively, whereas the corresponding values in the Canadian case are 0.119 and 0.069 respectively. The a*coustic performance* and *thermal performance* factors acquire the highest weight in the Canadian sample of values 0.125 and 0.236 respectively. Both samples have nearly the same weight values for the *hygiene* and *indoor air quality*, in which poor air qualities and lack of hygienic practices have the direct impact on buildings' users that can cause illnesses and absenteeism that affect one of the sustainability pillars, which is the social aspect.

Finally, in the uilding management criterion, the weight values of the *maintenance management* and *green lease* factors are high in Canadian of values 0.320 and 0.180 respectively. Contrariwise, the weight of *security measures* factor has a higher interest in the Egyptian than Canadian of values 0.139 and 0.130 respectively.

Table 5: Comparison between the Weights of Criteria and Factors in Two Countries

Criteria	**Site & Ecology**	**Transportation**	**Energy**	**Water Use**	**Material & Waste Reduction**	**IEQ**	**Building Management**
Canada	**0.099**	**0.123**	**0.220**	**0.117**	**0.118**	**0.167**	**0.156**
Egypt	**0.191**	**0.077**	**0.200**	**0.169**	**0.080**	**0.136**	**0.147**

Factors of 1st Criterion	Site Selection	Site Management	Reduce Heat Island Effect	Site Emissions
Canada	0.191	0.228	0.362	0.218
Egypt	0.390	0.281	0.180	0.149

Factors of 2nd Criterion	Alternative Means of Transportation	Public Transport Accessibility	Car Parking Capacity	Fuel Efficient Vehicle
Canada	0.301	0.282	0.098	0.318
Egypt	0.174	0.255	0.290	0.280

Factors of 3rd Criterion	Energy Performance	Provision of Energy Management	Energy Efficient Systems	Energy Efficient Equipment
Canada	0.413	0.146	0.252	0.189
Egypt	0.339	0.195	0.264	0.202

Factors of 4th Criterion	Water Conservation	Water Management	Effluent Discharge in foul Sewer
Canada	0.406	0.467	0.127
Egypt	0.472	0.406	0.123

Factors of 5th Criterion	Sustainable Purchasing	Efficient Use of Materials	Solid Waste Management
Canada	0.129	0.508	0.363
Egypt	0.291	0.427	0.281

Factors of 6th Criterion	Visual Comfort	Indoor Air Quality	Thermal Comfort	Acoustic Performance	Hygiene	Building Amenities
Canada	0.119	0.271	0.236	0.125	0.181	0.069
Egypt	0.140	0.278	0.205	0.085	0.174	0.117

Factors of 7th Criterion	Maintenance Management	Security Measures	Green Lease	Risk Management	Innovations
Canada	0.320	0.130	0.180	0.219	0.152
Egypt	0.281	0.139	0.154	0.239	0.187

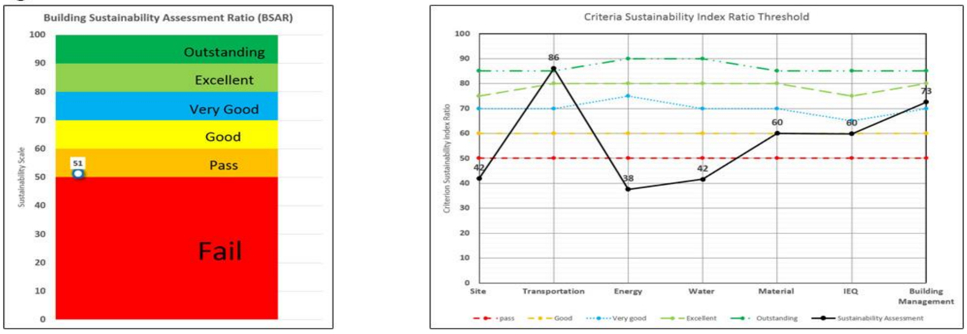
5.2 Sustainability Assessment Results

The results of the sustainability assessment of buildings can be classified into four parts. The first part is the factor score (SC) that has been illustrated in Table 6 and Table 7 under the column of the achieved score, which showes the score that has been achieved in each factor based on its related qualitative and quantitative indicators. The second part is the sustainability index of each factor (SI), as an example, the achieved and the maximum sustainability index $(SI)_{max}$ of the site management factor in the canadian case is 0.113 and 0.135 respectively, as shown in Table 6. Moreover, the third part is the values of the BSI and the BSI_{max}, these values for the EV building for the Canadian case are 5.762 and 11.227 respectively and for the same building in the Egyptian case are 6.423 and 10.412 respectively. Finally, the fourth part is the BSAR, which is the percentage of the BSI to the BSI_{max} as illustrated in equation (5). The BSAR for the EV and the MB buildings for the Canadian case are 51.23% and 59.73% respectively as shown in Table 6, whereas these values in the Egyptian case are 61.69% and 68.50% respectively as shown in Table 7. Accordingly, the EV building, in the Canadian scenario and the Egyptian Scenario, achieved the sustainability ranking pass and good respectively as shown in Figure 9. All the assessment attributes in both scenarios, except for energy criterion, have the same achieved scores, but they have different indices, which are dependent only on the weight variations. The same achieved score has been used in both scenarios to make the results only dependent on the weight to illustrate the impact of the weight, which expresses the local variation, on the overall sustainability assessment. Consequently, as shown in Figure 9, the criterion sustainability ratio (the percentage between the summation of SI in single criterion to the summation of the SI_{max}), for *site and ecology, transportation*, *water*, *material*, *IEQ*, and *building management* criterion excluding *energy* criterion, in the EV Canadian scenario are 42%, 86%, 42%, 60%, 60% and 73%, whereas for the EV Egyptian scenario are 54%, 89%, 43%, 55%, 59%, and 73%. The sustainability indices of the criteria of

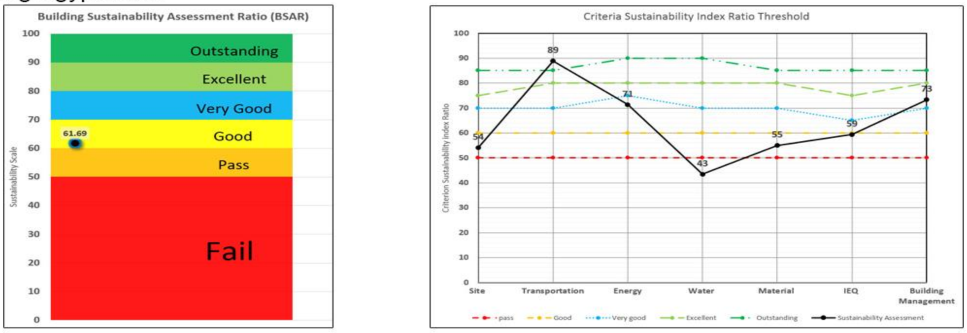
MB Canadian scenario are 60%, 86%, 50%, 67%, 60%, and 88% respectively, but the corresponding values for the MB Egyptian cases are 72%, 89%, 53%, 61%, 59%, and 88% as illustrated in Figure 9. The criteria sustainability ratios of the *site*, *transportation*, *water* in the EV and MB case studies in the Egyptian scenario is higher than that in the Canadian one because of the weight in the former scenario is higher than the latest one. Contrarily, the criteria sustainability ratios of the material, *IEQ* in the EV and MB case studies in the Canadian scenario is higher than that in the Egyptian due to the high weight values in the Canadian scenarios in the aforementioned criteria. In addition, the energy data of two case studies in both the Canadian and the Egyptian scenarios differs according to the variation in energy performance of the building due to the environmental difference between the two countries. The environmental variations affect the energy demand, the energy consumption, and the base line bench marks of energy consumption. Hence, the energy scores are achieved according to the percentage of consumption conservation more than the baseline bench mark.

The high percentage of the final sustainability BSAR is attributed only to the high value of weights in case of the Egyptian scenario, as all the achieved scores were kept the same in both scenarios, Egyptian and Canadian scenarios. The rationale of this procedure is to empathize the impact of weight on the overall sustainability assessment.

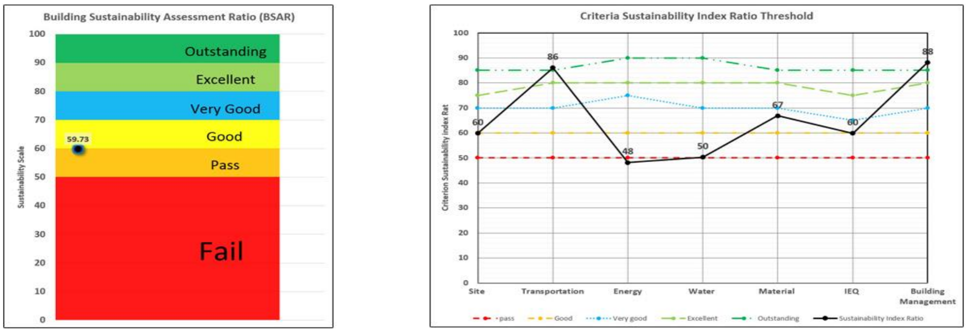
a) EV Building Canada Case



b) EV Building Egypt Case



c) MB Building Canada Case



d) MB Building Egypt Case

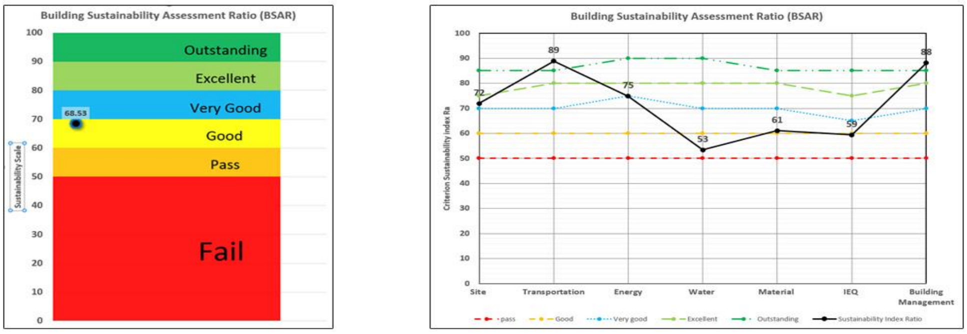


Figure 9: Criteria Sustainability Index Ratio and The Sustainability Ranking for EV and MB Buildings-Case of Canada and Egypt Contexts

Table 6: Sustainability Index Determination - Canada Case Studies

Criterion Name	Criterion Weight (W)	Factors	Weight local (WL)	Weight global (WG)	EV Building				MB Building			
					Achieved score (SC)	Maximum Score $(SC)_{max}$	Factor Index (SI)	Maximum Factor Index $(SI)_{max}$	Achieved score (SC)	Maximum Score $(SC)_{max}$	Factor Index (SI)	Maximum Factor Index $(SI)_{max}$
Site and Ecology	**0.099**	Site Selection	0.191	0.019	1	2	0.019	0.038	2	2	0.038	0.038
		Site Management	0.228	0.023	5	6	0.113	0.135	5	6	0.113	0.135
		Reduce Heat island effect	0.362	0.036	1	8	0.036	0.287	3	8	0.108	0.287
		Site Emissions	0.218	0.022	2	2	0.043	0.043	2	2	0.043	0.043
		Total	**-**	**0.099**	**9**	**18**	**0.211**	**0.503**	**12**	**18**	**0.301**	**0.503**
Transport	**0.123**	alternative methods of transport	0.301	0.037	14	18	0.518	0.666	14	18	0.518	0.666
		Public transport accessibility	0.282	0.035	10	10	0.347	0.347	10	10	0.347	0.347
		maximum car parking capacity	0.098	0.012	1	1	0.012	0.012	1	1	0.012	0.012
		Provision of Fuel efficient vehicles	0.318	0.039	1	1	0.039	0.039	1	1	0.039	0.039
		Total	**-**	**0.123**	**26**	**30**	**0.916**	**1.064**	**26**	**30**	**0.916**	**1.064**
Energy	**0.220**	Energy Performance	0.413	0.091	7	28	0.636	2.544	9	28	0.818	2.544
		Provision of energy management	0.146	0.032	8	12	0.257	0.385	8	12	0.257	0.385
		Energy efficient systems	0.252	0.055	5	17	0.277	0.942	10	17	0.554	0.942
		Energy efficient equipment	0.189	0.042	11	11	0.457	0.457	11	11	0.457	0.457
		Total	**-**	**0.220**	**31**	**68**	**1.628**	**4.329**	**38**	**68**	**2.086**	**4.329**
Water	**0.117**	Water Use	0.406	0.048	10	18	0.475	0.855	13	18	0.618	0.855
		Water Management	0.467	0.055	5	17	0.273	0.929	5	17	0.273	0.929
		Effluent discharge in foul sewer	0.127	0.015	0	1	0.000	0.015	1	1	0.015	0.015
		Total	**-**	**0.117**	**15**	**46**	**0.748**	**1.799**	**19**	**46**	**0.906**	**1.799**
Material	**0.118**	Sustainable Purchasing Policy	0.406	0.048	1	5	0.015	0.076	1	5	0.015	0.076
		Efficient Use of Materials	0.467	0.055	5	7	0.300	0.420	6	7	0.360	0.420
		Solid Waste Management Practice	0.127	0.015	5	9	0.214	0.386	5	9	0.214	0.386
		Total	**-**	**0.118**	**11**	**21**	**0.529**	**0.881**	**12**	**21**	**0.589**	**0.881**
Indoor Environmental Quality	**0.167**	Visual Comfort	0.119	0.020	6	9	0.119	0.179	6	9	0.119	0.179
		Indoor Air Quality	0.271	0.045	10	17	0.453	0.769	10	17	0.453	0.769
		Thermal comfort	0.236	0.039	4	5	0.158	0.197	4	5	0.158	0.197
		Acoustic Performance	0.125	0.021	3	3	0.063	0.063	3	3	0.063	0.063
		Hygiene	0.181	0.030	3	9	0.091	0.272	3	9	0.091	0.272
		Building amenities	0.069	0.012	2	3	0.023	0.035	2	3	0.023	0.035
		Total	**-**	**0.167**	**28**	**46**	**0.906**	**1.515**	**28**	**46**	**0.906**	**1.515**
Building Management	**0.156**	Operation & maintenance	0.320	0.050	12	17	0.599	0.849	15	17	0.749	0.849
		Security Measures	0.130	0.020	4	4	0.081	0.081	4	4	0.081	0.081
		Green Lease	0.180	0.028	1	2	0.028	0.056	2	2	0.056	0.056
		Risk Management	0.180	0.028	2	3	0.068	0.102	2	3	0.068	0.102
		Innovations	0.152	0.024	2	2	0.047	0.047	2	2	0.047	0.047
		Total	**-**	**0.156**	**21**	**28**	**0.824**	**1.136**	**25**	**28**	**1.002**	**1.136**
		Total Sustainability Index (TSI)					**5.762**	**11.227**			**6.706**	**11.227**
		Building Sustainability Assessment Ratio (BSAR)					**51.32**				**59.73**	

Table 7: Sustainability Index Determination – Egypt Case Studies

Criterion Name	Criterion Weight (W)	Factors	Weight local (WL)	Weight global (WG)	EV Building- Egypt Environment				MB Building- Egypt Environment			
					Achieved score (SC)	Maximum Score $(SC)_{max}$	Factor Index (SI)	Maximum Factor Index $(SI)_{max}$	Achieved score (SC)	Maximum Score $(SC)_{max}$	Factor Index (SI)	Maximum Factor Index $(SI)_{max}$
Site and Ecology	**0.191**	Site Selection	0.390	0.074	1	2	0.074	0.149	2	2	0.149	0.149
		Site Management	0.281	0.054	5	6	0.268	0.322	5	6	0.054	0.268
		Reduce Heat island effect	0.180	0.034	1	8	0.103	0.275	3	8	0.103	0.275
		Site Emissions	0.149	0.028	2	2	0.057	0.057	2	2	0.057	0.057
		Total	-	**0.191**	**9**	**18**	**0.434**	**0.803**	**12**	**18**	**0.577**	**0.803**
Transport	**0.077**	alternative methods of transport	0.174	0.013	14	18	0.188	0.241	14	18	0.188	0.241
		Public transport accessibility	0.255	0.020	10	10	0.196	0.196	10	10	0.196	0.196
		maximum car parking capacity	0.290	0.022	1	1	0.022	0.022	1	1	0.022	0.022
		Provision of Fuel efficient vehicles	0.280	0.022	1	1	0.022	0.022	1	1	0.022	0.022
		Total	-	**0.077**	**26**	**30**	**0.428**	**0.481**	**26**	**30**	**0.428**	**0.481**
Energy	**0.200**	Energy Performance	0.339	0.068	24	28	1.627	1.898	22	28	1.492	1.898
		Provision of energy management	0.195	0.039	8	12	0.312	0.468	8	12	0.312	0.468
		Energy efficient systems	0.264	0.053	5	17	0.264	0.898	10	17	0.528	0.898
		Energy efficient equipment	0.202	0.040	11	11	0.444	0.444	11	11	0.444	0.444
		Total	-	**0.200**	**48**	**68**	**2.648**	**3.708**	**51**	**68**	**2.776**	**3.708**
Water	**0.169**	Water Use	0.472	0.080	10	18	0.798	1.436	13	18	1.037	1.436
		Water Management	0.406	0.069	5	17	0.343	1.166	5	17	0.343	1.166
		Effluent discharge in foul sewer	0.123	0.021	0	1	0.000	0.021	1	1	0.021	0.021
		Total	-	**0.169**	**15**	**46**	**1.141**	**2.623**	**19**	**46**	**1.401**	**2.623**
Material	**0.080**	Sustainable Purchasing Policy	0.291	0.023	1	5	0.023	0.116	1	5	0.023	0.116
		Efficient Use of Materials	0.427	0.034	5	7	0.171	0.239	6	7	0.205	0.239
		Solid Waste Management Practice	0.281	0.022	5	9	0.112	0.202	5	9	0.112	0.202
		Total	-	**0.080**	**11**	**21**	**0.306**	**0.558**	**12**	**21**	**0.341**	**0.558**
Indoor Environmental Quality	**0.136**	Visual Comfort	0.14	0.019	6	9	0.114	0.171	6	9	0.114	0.171
		Indoor Air Quality	0.278	0.038	10	17	0.378	0.643	10	17	0.378	0.643
		Thermal comfort	0.205	0.028	4	5	0.112	0.139	4	5	0.112	0.139
		Acoustic Performance	0.085	0.012	3	3	0.035	0.035	3	3	0.035	0.035
		Hygiene	0.174	0.024	3	9	0.071	0.213	3	9	0.071	0.213
		Building amenities	0.117	0.016	2	3	0.032	0.048	2	3	0.032	0.048
		Total	-	**0.136**	**28**	**46**	**0.741**	**1.249**	**28**	**46**	**0.741**	**1.249**
Building Management	**0.147**	Operation & maintenance	0.281	0.041	12	17	0.496	0.702	15	17	0.620	0.702
		Security Measures	0.139	0.020	4	4	0.082	0.082	4	4	0.082	0.082
		Green Lease	0.154	0.023	1	2	0.023	0.045	2	2	0.045	0.045
		Risk Management	0.239	0.035	2	3	0.070	0.105	2	3	0.070	0.105
		Innovations	0.187	0.027	2	2	0.055	0.055	2	2	0.055	0.055
		Total	-	**0.147**	**21**	**28**	**0.725**	**0.990**	**25**	**28**	**0.872**	**0.990**
		Total Sustainability Index (TSI)					**6.423**	**10.412**			**7.136**	**10.412**
		Building Sustainability Assessment Ratio (BSAR)					**61.69**				**68.5**	

5.3 Sensitivity Analysis

A sensitivity analysis has been conducted by utilizing the same achieved points for each of the four energy factors, which were shown in the model implementation section, while applying seven whole changing scenarios for the weight values of each factor, considering that the sum of the four values in each changing case is constrained to one. As shown in Figure 10, the values of the criteria sustainability index ratio, (the ratio between the available sustainability indices of related factors to the maximum sustainability indices of the same factors), changes dramatically from 37.8% to 72.4% which are represented on the upper horizontal axis. These differences emphasize the importance of introducing multi-level weighting scheme in the sustainability assessment that reflects the impact of the regional variations on the sustainability assessment process to obtain a reliable sustainability evaluation.

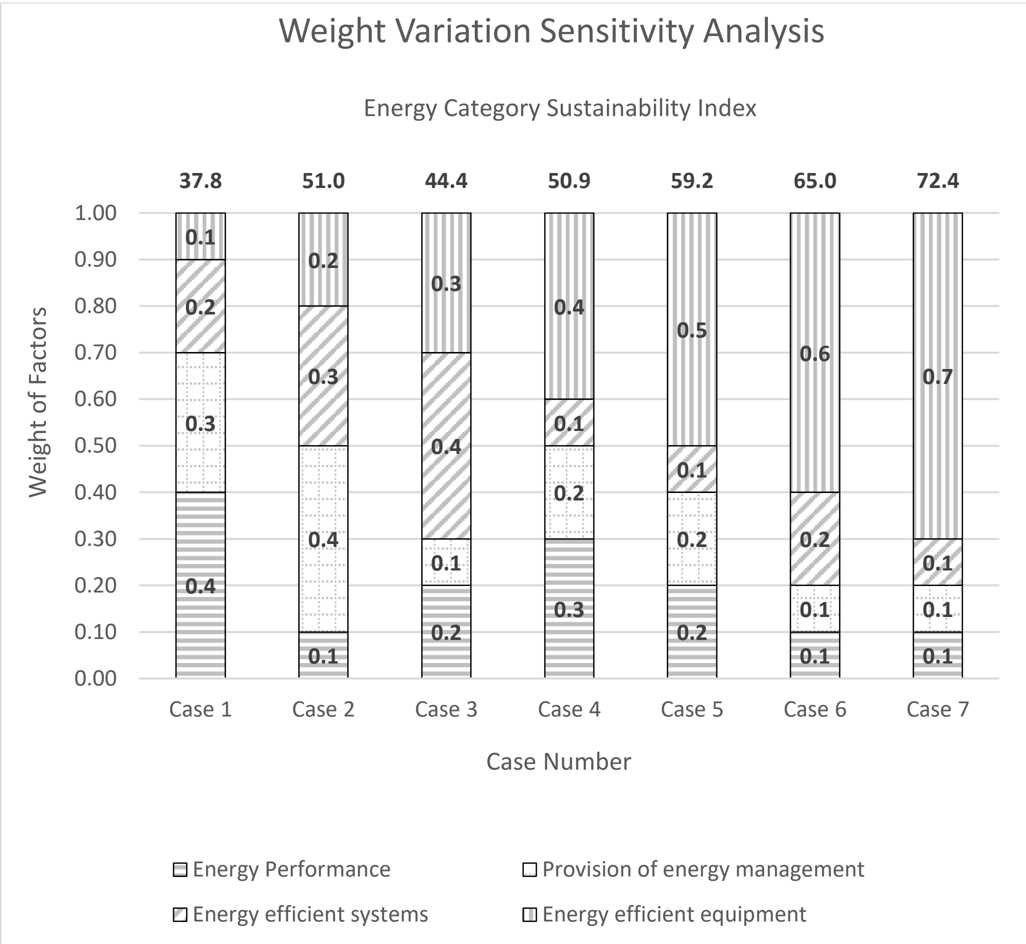


Figure 10: The Effect of Weight Differences on the Value of Energy Category

6 CONCLUSIONS

This research demonstrated a methodology for developing a globally working rating tool using a multilevel weighting scheme. Also, this research showed the hierarchical structure of the proposed sustainability assessment tool which is divided into criteria, factors, and indicators. The factors and indicators were divided into qualitative and quantitative attributes which were consolidated from different rating tools, and some of them were introduced based on the opinions of experts. These attributes tackled different aspects that assess the whole building sustainability. These attributes such as the seven criteria and their factors and indicators are considered consistent and will not subjected to variation when assessing different buildings in different regions, but the regional variations will affect only their values of weight. Furthermore, the research illustrated the weight determination procedures by applying fuzzy TOPSIS multi attribute decision making technique. The weight was determined through the collected data from the Egyptian and Canadian experts using questionnaires. The reliability of data was examined, and the results showed the effect of the different regional contexts on the weights of the proposed assessment attributes. As a further enhancement, increasing the number of respondents will help in determining precisely the weights for the proposed attributes.

Moreover, the study introduced a proposed assessment model with various formulae to assess the sustainability of buildings using a multilevel weighting. These weights were introduced in the assessment model for each criterion and factor. Furthermore, new expressions were added which were the sustainability index (SI), the building sustainability index (BSI), and the building sustainability assessment ratio (BSAR). The introduced BSAR helps in reflecting the relativity of the sustainability perception from country or region to another, as the BSAR is a ratio between the achieved BSI and the maximum BSI depending on the determined weight. Whereas, the assessment attributes and the maximum available credits for each attribute were kept constant for every assessment to preserve consistency, to set a unified basis of the sustainability assessment, and to make it easier for the facility managers and property investors to compare between the sustainability of their buildings in different countries using a unified or consistent language. Consequently, the study addressed a shortcoming in the rating systems that are utilizing only the aggregation of points in which they aren't capable of expressing the regional variations when applied worldwide using the same evaluation procedures. Moreover, the proposed model was validated by utilizing a sensitivity analysis to show the impact of changing the weight values on the assessment process.

As a limitation of the developed rating model, it is still dependent on an extensive (and potentially expensive) survey process to obtain the local weight of each country. Also, the collected responses that were used to develop the weight of both countries, Canada and Egypt, is considered insufficient to obtain the near actual weights, as stated previously and according to the previous discussion on the sub section 3.2.1 the required sample size can be between 150 to 250 for each country to obtain reliable formal weight value rather than a proof of concept that was illustrated in this research.

Finally, the main contribution of the research to the industry is providing the decision makers with a generic tool that can: 1) determine the current sustainability of buildings; 2) can compare between the sustainability assessment among different regions using consistent assessment attributes and assessment model; and 3) can highlight the weak areas in the sustainability which require more attention, based on the assessment. Also, the research contributes to the body of knowledge by developing an integrated sustainability assessment framework as a step towards establishing a comprehensive globally working sustainability assessment tool.

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