CRITICAL SUCCESS FACTORS FOR SUSTAINABLE RETROFITTING OF UNIVERSITY CAMPUS BUILDINGS

A thesis submitted in partial fulfillment of the
requirements for the degree of

Masters of Science
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by

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thesis titled

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has been accepted towards the partial fulfillment
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THESIS ACCEPTANCE CERTIFICATE

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This thesis is dedicated to my parents and my respected teachers!

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ABSTRACT

Energy retrofitting along with environmental protection and social benefits is critical for campus sustainability. Most of the universities fail to fully appreciate the significance of sustainable retrofitting mainly due to lack of realization. This research is aimed at identifying the critical success factors (CSFs) that contribute towards successfully achieving sustainable retrofitting of university campus buildings. A multi-disciplinary literature review and thorough interviews with sustainability coordinators, academic researchers, professors and industry experts were conducted to distil the success factors contributing towards campus sustainability retrofitting implementation. Such an identification and description of CSFs has not been subject of comprehensive study as such, as evident from a thorough review of existing literature. Factors were grouped into six categories based upon their interconnectedness. For research purpose and to fully investigate the significance of specific success factors, Vensim PLE and @Risk5.5 software were used to check the interdependency of CSFs and to run sensitivity analysis. Sensitivity analysis analyzed the impact of CSFs on sustainable retrofitting and provided 0.679 and 0.38 as the upper and lower limits for the model to check any project to be sustainably retrofitted or not. Such factors for sustainable retrofitting of university campus will be helpful for policy makers, planners and practitioners in integrating the dimensions of sustainability, including environmental, economic and social, more effectively towards the reification of sustainable campus.

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LIST OF ABBREVIATIONS

CSF	=	Critical Success Factor
IEQ	=	Indoor Environmental Quality
IEA	=	International Energy Agency
ECBCS	=	Energy Conservation in Buildings and Community System
SOTM	=	Support Of Top Management
SR	=	Sufficient Resources
SSQPT	=	Skilled And Suitably Qualified Project Team
I & F	=	Investment/Finance
BSFR	=	Building Suitability For Retrofit
SL	=	Strong Leadership
TAS	=	Trust Among Stakeholders
EP&IC	=	Energy Policies And Its Compliance
C&C	=	Communication And Cooperation
BH	=	Building History
STATU	=	Sustainability Targets And Their Understanding
BRASC	=	Building Regulations And Standard Codes
EE	=	Economic Environment
FA	=	Funding Allocation
GOBV	=	Growth Of Building Value
OB	=	Occupant Behavior
US	=	User Satisfaction
CC	=	Climate Conditions
PC	=	Project/Building Characteristics

ERM	=	Effective Risk Management
CDF	=	Cumulative Density Function
TS	=	Total Literature Score
RII	=	Relative Importance Index

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

It is widely agreed that the built environment accounts for half of all climate damage, pollution and energy (Assefa et al., 2007). Climate damage is broadly related to the amount of things made and power used which becomes a consumption issue. Technology on its own does not deliver reduced energy consumption, it is how we use it that does (Walker, 2013). Building construction and operation constitutes significant proportion of total energy end-use (Asadi et al., 2012). Also, major portion of such energy consumption in building sector owes to existing buildings operations while replacement rate of such buildings by new ones is only around 1.0–3.0% per annum (Becchio, 2013); such an energy amounts to 40% of the total final energy and 24% of CO2 emissions (Peng Xu et al., 2012).

Large building facilities, build up areas, and activities as to facilitating large number of users make university campuses fairly big consumers of energy (Lauder et al., 2015; Najihah et al., 2013; Saleh et al., 2015; Sesana et al., 2016). Energy-efficient buildings are needed to promote sustainable environment and to save energy. Energy-efficiency can be significantly improved through proper retrofitting or refurbishment described as addition of new technology or features to older systems. Through sustainable retrofitting or refurbishment, a considerable reduction occurs in energy consumed by buildings and emission of greenhouse gases which directly impact climate (ürge-Vorsatz et al., 2007). A few notable case studies of such retrofitting have been reported for hotel buildings in China (Peng Xu et al., 2012), office buildings in Southern Europe

(Kyritsis et al., 2016), residential buildings in Qatar (Kharseh and Al-Khawaja, 2016), Denmark (Thomsen et al., 2016) and Turkey (Cetiner and Edis, 2014), and hospital buildings in Italy (Buonomano et al., 2014).

1.2 SUSTAINABILITY

Defined as "*meeting the needs of the present generation without compromising the ability of future generations to meet their own need*" (Bansal and DesJardine, 2014), the concept of sustainability is not new; it has a rather long history and it has evolved over time. It is a policy concept and can be traced back to Brundtland Report of 1987 (Drexhage and Murphy, 2010). Following the report, global public policy was given a new direction when predictions were made of exhaustion of vital natural resources (Kuhlman and Farrington, 2010). Though Brundtland Report offered a new rhetoric to sustainability argument, it is marred with criticism for being vague, hypocritical and delusional (Robinson, 2004).

Although born out of environmental concerns, the concept is now broadly acknowledged to be multidimensional. Studies have demonstrated that the benefits of sustainability are not just confined to economic, environmental and social but also enhance the value of organizations (Fiksel et al., 1999). As sustainability is a rather basic characteristic of a dynamically developed system, it can be viewed as a permanent adaptation to varying conditions. Such adaptability is natural for all ecosystems. It is for education to include adaptive procedures to public administration decision-making on human socio-ecologic-technical systems (Procházková, 2005).

Studies of various dimensions of sustainability have brought to light different discourses over time and have often been treated separately (Giovannoni and Fabietti, 2013). In Figure 1-1, interaction of various dimensions of sustainability is shown. In true sense, sustainability as a concept includes seeking economic prosperity, social equity, as well as environmental quality. Such goals may be secured if accurate interaction of the three constituent elements is identified in *'the triple bottom line'* (Gibson, 2006; Meler and Magaš, 2014).

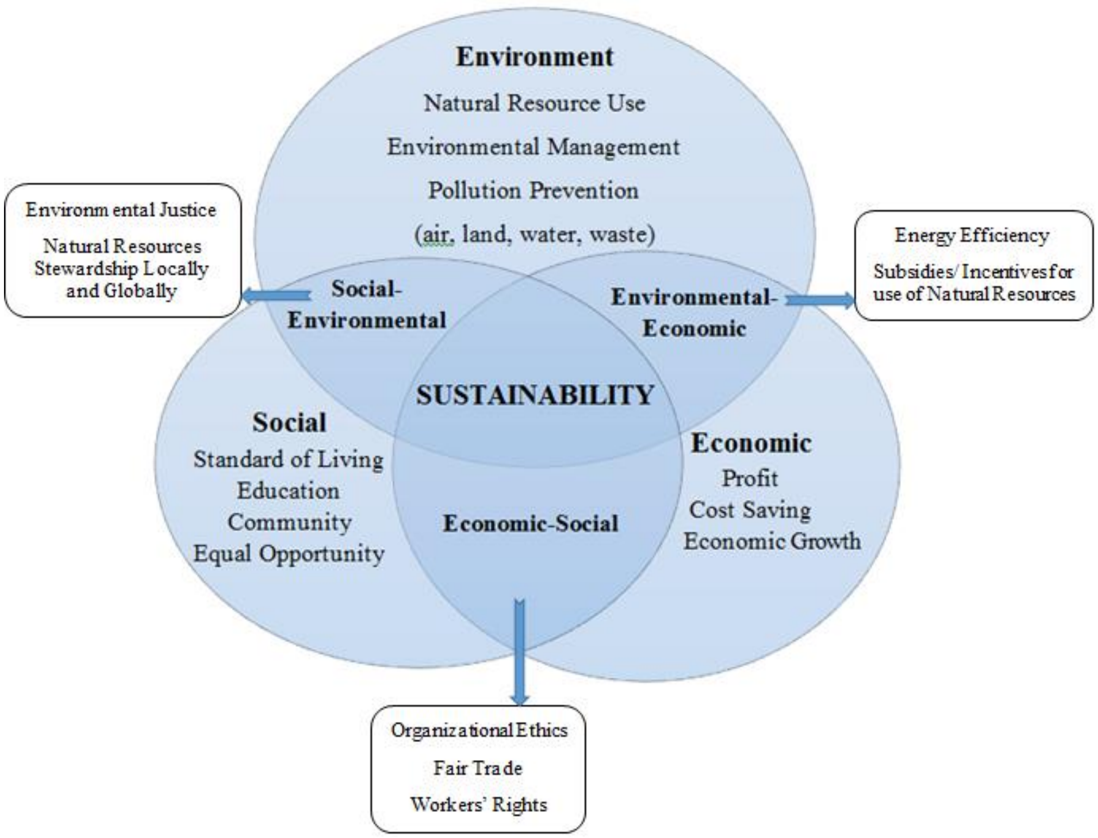

Figure 1-1 The Three spheres of sustainability (Adams, 2006; Rodriguez, 2002)

As regards to universities, the term '*sustainability*', is applied to mean establishing such a management system refers as to help develop a vibrant campus economy and to achieve high quality of life; this must coincide with the aim to safeguard environment and to sustain natural resources (Kirsche, 2008). Programs emanating from such institutions' commitment to environment, social and economic health, or *'triple bottom line'* are regarded sustainable programs. Applicable at both individual as well as institutional level, sustainability is a balancing act.

1.3 SUSTAINABLE DEVELOPMENT

Sustainable development is defined as *"the preservation of environment along with the critical development-related issues like stable economic growth, continual social progress, the efficient resource usage, and the eradication of poverty in order to meet the present day needs for infrastructure and the working environments without compromising the ability of future generations to meet their own needs in times to come"* (Hopwood et al., 2005; Mebratu, 1998; Sharma and Ruud, 2003).

For all human systems sustainability is necessary; also, all human system assets need to incorporate in themselves the principles of sustainable development. Sustainable development therefore resists to undermine the very systems on which it rests including social, political, and ecological systems (Rusko and Procházková, 2011). According to World Commission on Environment and Development (1987), such development makes compromise neither to the present needs nor to the ability of future generations to fulfill their needs (Imperatives, 1987).

Activities in accord with sustainable development need to reflect an urge to mend social inequities and to repair environmental damage; it must maintain strong economic footing (Harris, 2003). It is through realization of socio-economic-environmental concerns integration throughout the process of decision making that goals of sustainable development, including long term economic and environmental stability, can be achieved (Emas, 2015).

Specially, in context of developing countries, sustainable development constitutes overriding national policy objective which must be reflected in all other policy making. This also explains stance of such countries in climate change negotiations where they resist any attempts which might cause foreclosure of sustainable development for them (Hammond, 1995).

Sustainable economic development is such development strategy which offers ample economic prospects and better quality of living without undermining of principles of equity and concerns for environment protection. Such development framework is much needed not least due to the fact that people of developing countries simply cannot afford constraints such as of climate change restricting their growth and development (Drexhage and Murphy, 2010). It may be said that such developing countries would be much more capable of contributing towards worldwide efforts to address climate change if their basic economic problems are solved. It is for this reason that Sustainable development as the prime priority of developing countries must be given its due share of consideration and also reflected in global climate change discourse (Portney, 2013).

1.4 UNIVERSITY CAMPUS SUSTAINABILITY

In higher education the discussion of sustainability can be traced back to 1970s with emphasis on environmental education. It was not until 1993 when Kyoto Declaration stimulated campus sustainability interest and practice. This was primarily achieved by pushing higher education institutions to encourage sustainability by reevaluating their operations to incorporate sustainable development principles and practices (Faghihi et al., 2015).

Campus sustainability may be realized in multitude of ways from actual infrastructure changes in buildings to incorporating features such as green roofs; creating awareness and educating users of campuses to bring about changes in their behavior in use of such facilities that would reduce energy consumption can also be helpful (Faghihi et al., 2015). UK Carbon Trust noted in their study that considerable and enduring energy savings can be achieved by active engagement of actual users of buildings coupled with technological changes. Such methods if properly applied can achieve as much as 23% energy savings (Saleh et al., 2015).

Of critical importance for sustainable campuses are such factors as waste, including food waste, recycling, energy consumption, and transportation; all these add to total carbon emission of campus. Proper implementation framework, developed for foregoing aspects, is required so as to sustain whole process (Sesana et al., 2016).

1.5 PROBLEM STATEMENT

This research aims to identify Critical Success Factors (CSFs) facilitating to achieve sustainable retrofitting of university campus buildings. There is not much work that synthesizes the CSFs needed for sustainable retrofitting. Thus it is hoped that the findings of this research will be of great help for policy makers, planners and practitioners to integrate the dimensions of sustainability (environment, economic and social) more effectively towards the reification of sustainable campus.

1.6 OBJECTIVES OF THE RESEARCH

Following are the objectives which are expected to be attained after successfully completing this research work:

- To identify CSFs for sustainable retrofitting of campus buildings.
- To prioritize the selected CSFs based upon their significance.
- To develop a decision model based on Sensitivity analysis for identified CSFs.

1.7 RESEARCH SIGNIFICANCE

Universities have been conceptualized as “small cities” because of their large size, population and also because of their impact on society and environment. It consequently constitutes a worldwide concern for planners and policymakers of such facilities (Lauder et al., 2015; Sesana et al., 2016). There is an urgent need to preserve natural resources for developing low carbon economies. This research will help in conducting the university campus buildings' retrofit most effectively by creating CSFs to promote energy conservation and sustainability.

Keeping in mind the CSFs, policy makers and practitioners will take pragmatic decisions and choose best practices for the sustainable retrofitting of university campus buildings. Sustainable university helps reduce negative environmental, societal, economic and health effects produced by their use of resources; such campuses employ efficient use of resources in their pursuance to fulfill their purposes of scholarship, outreach, research and partnership to aid society make the transition to sustainable lifestyles.

Chapter 2

LITERATURE REVIEW

2.1 SUSTAINABLE RETROFITTING

One of the main purposes of sustainable retrofitting is to effectively reduce energy consumption for usual operational needs of buildings; other goals include improved indoor environment and helping building owners and occupants to make most of their buildings. For such purposes sustainable retrofitting employs combination of techno-economic measures.

2.1.1 Concept of Retrofitting

It is generally the case that building structure and fabric life outperforms that of other installed services and it is for this reason that the term ‘retrofitting’ is often associated with building services. For Douglas (2006) and Wilkinson (2011), retrofit is *"any work or effort to a building over and above its maintenance to modify or change its function, capacity or performance*"; viewed in this sense, retrofitting includes any proper attempt to upgrade, adjust, or to reuse a building as to suit new requirements. According to Khodeir et al. (2016), retrofitting can be defined *as "introduction of new and more modern systems into an already existing building"*, whereas, Ma et al. (2012), stated retrofitting as “the *work required to up-grade an aged, old or deteriorated building*”.

2.1.2 Concept of Sustainable Retrofitting

Sustainable retrofitting not only incorporates new technology or features into the old buildings but also enhance its capacity to withstand environmental and human factors. The primary objective of sustainable retrofitting, it must be emphasized, is to check the buildings’ energy consumption; other goals include improvement in indoor thermal comfort, reduction in heating costs. Whereas, in doing so it must include and consider interests of residents, heating enterprises, and energy service corporations to ensure social steadiness and harmony (Zhao et al., 2009).

There exists a fairly wide range of retrofitting measures, easily in implementable retrofitting measures such as making use of more efficient light sources as well as more comprehensive and combined measures such as upgrading the building services and envelope (Nik et al., 2016). Retrofits offer an opportunity for upgrading and improving many of the components of space heating/cooling systems during a building's lifetime. While, element of cost cannot be ignored and in many cases achieving highest levels of performance might be too costly to be undertaken, there is an overall opportunity. At times reduction in costs of retrofitting may be possible where retrofitting is effectively combined with other elements of renovation. Thus, policy can affect both whether a retrofit is made and the level of the retrofit (Buchner et al., 2013). An example of such retrofitting action might be the replacement of single glazed window units with sealed double glazed window units such a replacement constitutes an upgrade which would help prevent heat loss through the fabric; also, considerable improvement would also be noted in levels of indoor environmental quality (IEQ). Such an improvement as an added advantage is realized by retrofitting upgrade for building users by effectively reducing draughts, improving noise insulation and aesthetics of the building (Jaggs and Palmer, 2000).

Globally, almost one third of final energy consumption and a fair share in Greenhouse Gases' (GHG) emission owe to buildings and structures. Building sector therefore might be regarded as "the largest untapped source of cost effective energy saving and CO_2 reduction potential" (Bruce et al., 2015; Russell-Smith et al., 2015; Thomsen et al., 2016). Table 2-1 is showing the percentage consumption of national energy by the building sector in different countries.

Table 2-1 Percentages of National Energy Consumption by Building Sector in Different Countries (Masoso and Grobler, 2010)

Countries	**Energy Consumption**	**Reference**
Spain	23%	Lombard et al., 2008
Japan	25%	Yoon et al., 2005
China	28%	C. Lam et al., 2006
European Union	37%	Lombard et al., 2008
Switzerland	47%	Zimmermann et al., 2005
United Kingdom	39%	Lombard et al., 2008
Brazil	42%	Debin & Silva, 2005

Existing buildings consume most of the energy and their replacement rate with new buildings is not more than 1.0–3.0% per annum (Becchio, 2013; Ma et al., 2012). Therefore, any attempt aimed at reducing worldwide energy use as well as forwarding environmental sustainability must, in order to succeed, focus on improving energy efficiency in existing buildings (Ma et al., 2012). In such a critical scenario, sustainable retrofitting of the existing buildings is the best option to opt as it increases energy efficiency, optimize building performance, increases tenants' satisfaction and enhances economic return without sacrificing their values (Khodeir et al., 2016).

2.1.3 Application of Sustainable Retrofitting in Buildings

Retrofit projects in addition to making buildings energy efficient, enhance structural conditions of such buildings; it also achieves better living conditions for occupants of such buildings (Jaggs and Palmer, 2000). Sustainable retrofitting as applied to existing buildings is not limited to only physical and functional elements of such buildings; it also includes such concepts as reduction of energy consumption, control on emission of pollutants, air quality and spatial comfort improvement, and operational waste reduction. Back in 1960s and also in 1970s when energy efficiency not of much consideration, most of the buildings were constructed in haste and relied on insufficient insulation of the building envelope and inefficient heat production systems; such buildings still operational accounts for significant energy consumption. At the same time it also offers an opportunity to achieve efficient energy balance and indoor environment using modern rehabilitation strategies. For example, Genre et al. (2000) stated that: by efficiently controlling building heating and cooling loads coupled with the use of efficient building envelope would enhance efficiency, indoor environment quality and satisfaction level of building users.

Importance of inclusive consideration of all necessary factors at planning stage, to achieve most out of retrofitting, must be emphasized. Such consideration must include factors as to function and purpose of the building as well as nature of occupation. Also, pre-execution stage must decide on cost effectiveness of such projects. Such financial cost effectiveness decisions must be based on considerations such as rent of the building prior to retrofitting. Actual degree of degradation of building and its services must be found; environment quality must also be known (Genre et al., 2000).

2.1.4 Key Phases for the Implementation of Sustainable Retrofitting

Sustainable retrofitting of existing buildings has many positive impacts on their economic sustainability, social sustainability and the environmental performance. Key idea is efficient use of energy. Such an efficient energy utilization results in reduced operational and maintenance costs which along with return on investment are two key factors essential for realization of economic sustainability. Social sustainability can be achieved by improving user experience and comfort level of tenants; means to this end include clever utilization of natural light, efforts to ensure good air quality and healthy environment. Similarly, environmental sustainability is only possible through efforts to check carbon dioxide emissions and other pollutants; finding ways to improve service life also helps achieve environmental sustainability (Wilkinson, 2011).

The process of sustainable retrofitting can be structured into five major phases. The retrofit process starts with setting up a retrofit scope and leading the way for designing phase. Next phase involves those decisions as to finalize mechanism of retrofit. After that, decisions on strategy of the retrofit are settled. Once such strategies have been finalized a number of possible models or mockups are developed. Below is the detailed explanation of these phases: (Khodeir et al., 2016; Ma et al., 2012; Sesana et al., 2016)

2.1.4.1 Assessment of Existing Structure

In the first stage of sustainable retrofitting, the aim is to initially outline the purview of retrofitting and then allocate the objectives of project. This can be done by amassing data and facts & figures. The project team dictates which elements of a building require retrofitting by scrutinizing the existing condition. At this stage a pre-retrofit analysis may be carried out for better cognizance of operational complications. Furthermore, condition appraisal can also be used to evaluate the anticipated residual life of building components.

2.1.4.2 Concept of Energy Review and Capacity Assessment

In this stage, data collected during previous phase is utilized to understand the concept of energy audit and assess the capacity or performance of the existing structure. The performance assessment of the second phase aims, with the collected data, understanding the building energy use and individuates the inefficient and unacceptable thermal comfort conditions.

2.1.4.3 Identification of the Retrofit Options

Recognizing retrofit options is the main goal of the third phase by using energy models, risk assessment method and economic analysis tools. The reliable estimation as of energy benefits and economic feasibility are essential to prioritize and choose the most suitable and cost effective retrofit options.

2.1.4.4 Site Implementation and Commissioning

Successful execution and commissioning forms the fourth phase whereby finalized retrofit activities are executed followed by necessary testing to ensure such activities produce the results as desired. It should be accepted that in certain circumstances some retrofit measures might hinder performance of certain operations of tenants and of buildings.

2.1.4.5 Validation and Verification

Last phase to the foregoing process involves measuring and verifying the results. It must be ensured that whole undertaken process of retrofitting produces desired outputs. For example such measurements must reflect the energy savings. It also needs to be found that how actual users of such retrofitted buildings feel about such and upgrade; a post occupancy survey may, for example, serve the purpose.

2.1.5 Effectiveness of Building Retrofits

Having said that as much as 30 to 40 percent reduction in energy consumption can actually be achieved, it needs to be underlined that some retrofitting technologies actually perform better than others for certain regions depending on climate conditions (P Xu et al., 2012). It is among the top priorities to reduce energy consumption in existing buildings and promote sustainable retrofit practices. After all most efficient utilization of resources is only possible through energy efficient technologies.

Factors specific to a structure such as geometry, size, building envelope, HVAC systems, electrical systems, and climate among others determine how successful a retrofitting activity would be for a particular structure. It is therefore not surprising that same retrofitting measure, when applied on two different buildings, may produce different results. Further, a particular retrofitting measure, when applied as part of set or combination, would produces different results than it would when applied individually. Two retrofit measures, for example, each reducing the consumption by 15 percent individually, might just reduce consumption much less that 30 percent when applied simultaneously (Chidiac et al., 2011a).

Unfortunately, there is no simple and straightforward way and more often than not policymakers as well as engineers fail to generalize as to most efficient energy utilization methods (P Xu et al., 2012). From the policy making perspective, and to achieve long-term sustainability targets, clear indication of cost-effective measures along with better understanding of factors responsible for suitability of one retrofitting measure over others, is of prime importance (Becchio, 2013).

2.2 IMPORTANCE OF SUSTAINABLE RETROFITTING IN UNIVERSITY CAMPUS BUILDINGS

Retrofitting techniques applied in university campus are more beneficial with respect to others because campus supply great number of end users who influence the society with their behavior; such unique capacity of universities is universally recognized (Alshuwaikhat and Abubakar, 2008). Taking a lead in moving towards sustainability would serve well such institution's purpose of improving socio-economic conditions of such society which has conveyed a special charter on institutions of higher education (Shriberg, 2002). Universities inherently serve and accommodate a large number of users which explains size and infrastructure facilities of such institutions; but it also means that environment would be fairly affected. Such affects may be in the form of pollution, environmental deterioration and carbon dioxide emissions. Much of such affects can be deterred effectively by a combination of measures at technical as well as organizational level. Noting a few exceptions most of university campuses are without systematic approach towards reducing impact of foregoing negative effects (Richardson and Lynes, 2007).

Retrofitting design is not a static idea but involves a whole range of activities and choices. Having a care for energy and environment questions in retrofitting does not necessarily translates into purchase and installation of latest and costly equipment. Rather, it is design approach centered around choices that would result in efficient utilization of available resources (Cantin et al., 2002).

Institutions are a miniature of the real world. These should be the place of innovation for carrying out experimentations with sustainable retrofitting. Velazquez et al. (2006), defined a sustainable university as "a higher educational institution, wholly or partially, that involves, the minimization of negative *environmental, economic, societal, and health effects generated in the use of their resources, at any level, in order to fulfill any of its functions in order to help society in making the transition towards sustainable lifestyles."* Sustainable retrofitting gains becomes even more important when applied towards university campuses because of unique capacity of such institutions to influence and educate public opinion (Beaudoin and Tremblay, 2002), as university is the place where knowledge and practice, both can meet (Sesana et al., 2016).

2.3 RETROFITTING TECHNIQUES

Roberts (2008) classified the retrofitting techniques into two major categories; active and passive. Activities aimed at improving existing systems with minor but clever modifications such as installing double glazed windows, modifying existing windows so as to ensure airtightness, or retrofitted insulation all constitute passive measures. As the name suggests, active measures on other hand focus on more active approach ranging from upgrade or replacement of existing systems, such as modifying/replacing boilers, to inclusion of energy from renewable sources.

There are numerous retrofitting techniques which are used previously like Balaras (1996) worked on thermal mass so as to use particular materials with high values of specific heat capacity; such a use would delay peak indoor loads because such materials are better in storing heat and releasing it slowly at later time. Chan and Chow (1998) studied building envelop and saved upto 47% cooling energy by providing effective and properly design envelop insulation, Mili (2001) recommended use of insulation to cutoff demand of mechanical means for heating and cooling, and also emphasized use of moveable blinds and curtains for better and desired air flow. Christian and Kosny (2006) studied thermal behavior of walls and noted that walls have a vital role to play in providing towards acoustical and thermal wellbeing indoors. Fluhrer et al. (2010) worked on retrofitting of Empire state building by upgrading windows to improve natural ventilation and energy reduction by using Demand Control Ventilation technique by installing CO_2 sensors for control of outside air to the air handling units, Murthy et al. (2011) gave economical, conventional solution to control CO_2 emissions by providing concrete slab solar water heating, Chidiac et al. (2011b) applied simulation program and Energy Plus on a Canadian office building and concluded that when changes were made to the building envelope properties in combination with the boiler up-gradation, improvements in the HVAC system, economizer addition and heat recovery system with lighting load retrofit; a great reduction in energy consumption and natural gas usage was observed.

According to Busato (2003), while difference in pressure across the building envelope is responsible for stimulating natural ventilation, there are techniques which can be employed to modify air patterns. These include proper use of horizontal projections (canopies, overhangs, varandas). Further, building elements providing solar shading should be designed and incorporated so as to let through solar radiations in winter while reflecting them in summers.

Similarly, Tingqiao and Xiufang (2011) researched on passive evaporating cooling by spraying running water on top of cavity wall and saved 62-90% energy demands, Sadineni et al. (2011) used the ventilated walls for typical summer cooling energy savings, Sharaf and Al-Salaymeh (2012) used doubly glazed ‘low-energy’ windows to reduce thermal bridges; such windows are coated and filled with gas of some low U-value. Jayswal (2012) researched on energy conservation through Downdraught Evaporating cooling in Ahmadabad, India. For the study, four Scenarios were developed for the performance analysis, variable components were building envelop insulation and Shading devices HVAC system. Simulations were run through eQUEST by using energy efficient techniques in buildings, results indicated that cost only increases 12-13% of conventional building cost but energy can be saved up to 76%.

2.4 IEA ECBCS ANNEX 36

To promote the energy efficiency of existing buildings, a series of Annex projects has been launched by the International Energy Agency (IEA). Annex 36 is one of its projects that deal with the energy retrofitting of existing buildings (Kluttig et al., 2002). It regards education as means at hands for any nation to excel and grow in community of nations. In this context universities assume an even important role and all attempts that aid knowledge transfer at such facilities must be appreciated. It has been observed that such transfer process can be aided by proper indoor environment and acoustics. IEA has developed Energy Conservation in Buildings and Community System (ECBCS) with purpose of forwarding research and providing focus on building energy efficiency. Annex 36 deals with such energy efficiency improving measures for existing campuses. Knowledge so created in the field would be utilized to undertake model retrofitting projects in participating countries. The main objectives of this Annex are listed as to:

- Develop such procedures and instruments as to guide stakeholders in undertaking sustainable retrofitting projects
- Help promote efficiency considerations and evaluations at policy and decision making level
- Make efforts to promote and forward suggestions to encourage use of retrofitted buildings
- Encourage efforts aimed at improving energy efficiency and cost effectiveness

2.4.1 An Example of Sustainable Retrofitting in an Educational Building

Retrofitting educational buildings must resolve the problems like poor thermal, lighting and acoustic quality, allowing the teachers and students to excel their abilities to work in the best possible conditions. If the sustainable concepts are integrated in the retrofitting of educational building, comfort has to be the higher and the better for the lifecycle of building. So, time and dynamic parameters must be integrated in the comfort target. Best comfort level is achieved by controlling various parameters of the indoor environment. A high level comfort is not necessarily the sustainable one as the sustainable comfort needs to consider users or inhabitants and lifespan of building. In this way, a reduction of comfort cannot be synonym of a reduction of greenhouse gas emission. Thus, a sustainable comfort could deal with relevant aims of energy consumption management during all the lifecycle of building.

An educational institute as shown in Figure 2-1, located in the Region Rhône-Alpes was analyzed by Cantin et al. (2002). The retrofitting project aimed to enlarge the built area and to retrofit spaces. Other purpose was to offer improved indoor experience of the building for the users along with refurbishment of its general features. In this institute, the oil furnace was replaced by a heat exchanger and temperature of hot water circulated through rooms relied on specific use. Ducts were insulated with 3 cm glass wool. As for the ventilation, a suitable threshold level was maintained by mechanical ventilation while provision was made inside rooms and halls to increase if desired so to suit specific needs.

A Building Energy Management System was put in place with purpose of controlling heating/cooling, ventilations, and issuing proper alarms. Natural lighting was provided through glazed facade with high ratio of glazing. To control excessive light, windows were fitted with roller blinds on ground floor, and outdoor screens at first floor while on eastern, western and southern frontages, aluminum fins were provided. A zenithal lighting was provided in the classrooms of first floor by light-shelves. Energy conservation was achieved by improved building envelope insulation and fully utilizing daylight.

Some of issues, mainly related to heating control system, were highlighted in subsequent student feed-back. While 30% respondents felt good about temperature, it was just acceptable for another 40%. Most people reported overheating especially in the afternoon and in morning, 80% and 50% respectively. Lighting was, overall, reported to be satisfactory with less than 30% cited having difficulty due to glare and insufficient lighting of black board. Equipment performance was observed to be satisfactory, except some noise problems due mainly owing to ineffective noise insulation. Some ventilation problems were also reported with 80% feeling dusty, occasional strong smell for 50%, and 70% having a feel of enclosed space.

Louise Labé secondary school is located near Lyon, built in the 1953 and retrofitted in 2000.

Figure 2-1 Left view (before retrofit); Right view (after retrofit)

2.5 CONTRIBUTION OF HUMAN FACTORS

Human factors have a large contribution towards the conservation of energy and saving the environment. Masoso and Grobler (2010) performed energy audits on randomly selected six commercial buildings in Botswana and South Africa. They found that the largest energy consumers were air conditioning systems along with the equipment that are unnecessarily left ON and then lighting. They concluded that occupancy behavior is very important towards energy consumption and there must be energy awareness campaigns, energy audits, technological and punitive actions, and incentives etc. to spread the energy conservation awareness. Menzies et al.

(1997) investigated the effects of individually operated ventilation system on workers' productivity and concluded that 11% higher productivity was achieved by introducing individually controlled ventilation system rather than the control group whose productivity was reduced by 4 % as they don't have the control on the indoor air quality at their workstation according to their demands.

Likewise, Agent based approach was used by Azar and Menassa (2012) to investigate the impacts of occupants' behavior on energy use in a commercial building. One of the conclusions was that occupants' behavior has a great impact on energy use so they should be well aware about the usage and control of their energy sources in a more efficient manner in order to save energy.

The building energy retrofits not only improve greenhouse gas effect and energy demand but also occupants' comfort and environment in which that building is in contact with. Ascione et al. (2015), in their case study of an educational building (University of Sannio, Italy) investigated energy diagnosis methodologies and selection of suitable retrofits. They stated that proper selection of best retrofit technology depends on the building type, its characteristics, the environment and the availability of funds. This case study reported that the occupants' behavioral changes, changes in their comfort ranges and the indoor environment control considerably affected energy efficiency.

2.6 CHALLENGES AND OPPORTUNITIES

Sustainable retrofitting offers many challenges. Choosing from among various potential sustainable measures is not a simple task; this is so not least due to the fact that it involves taking into consideration inclusively all impacts of such measures on environment as well as on the performance of the building itself (Asadi et al., 2012; Chow et al., 2013; Noris et al., 2013). In choosing as to most suitable retrofitting measure, challenge is apparent mainly because any change in climate, services, human behavior, or policy of government would directly affect such choices (Ma et al., 2012).

Like challenges, sustainable retrofitting has many opportunities to offer too. Serious research efforts have been made to explore such opportunities (Golić et al., 2011; Hestnes and Kofoed, 2002; Ma and Wang, 2009) and it has been conclusively shown that energy efficiency of existing buildings can be fairly improved by taking proper retrofitting measures (Chidiac et al., 2011a; Mahlia et al., 2011; Xing et al., 2011).

In so far as university campuses are concerned, the implementation of sustainable retrofitted buildings has to face financial and organizational challenges (Richardson and Lynes, 2007).

2.6.1 Financial Challenges and Opportunities

Financial challenges may include high initial capital costs but, later on, the benefits will outweigh the initial retrofitting cost (Bruce et al., 2015). Every retrofit project needs large upfront investment but people are reluctant to pay as they are unaware of the long term benefits of such retrofit measures (Dahle and Neumayer, 2001). Direct benefits include money and energy savings in the form of low electricity bills and lesser operational and maintenance costs; whereas, it also forwards progressive image of institution, reflects institution’s commitment towards society and environment called indirect benefits. Such indirect benefits also bring associated financial gains. Incentives and Government policies can play a vital role in sorting out financial problems (Roseland, 2012) and in implementing the sustainable retrofitting strategies within existing buildings to make it low energy consumer and environment friendly (Amecke et al., 2013).

In view of ever increasing energy demand and price, environmental concerns, and looming risks of financial crisis it is wise to invest in energy efficiency measures; there is a need for constituting such financial frameworks so as to encourage such investments (Becchio, 2013).

2.6.2 Organizational Challenges and Opportunities

Universities are most suited candidates to take a lead in sustainability for obvious reasons inter alia research resources and capacity to lead. Universities have universally agreed capacity to influence, educate and guide society towards a better and promising future. "*Universities bear profound responsibilities to increase the knowledge, awareness, tools and technology to create an environmentally sustainable future*" (Shriberg, 2002).

Universities are considered as the model for their students and country so sustainability should be demonstrated in their functions. But a coordinated approach is missing to assess the campus initiatives and providing rational strategies for the successful implementation of sustainable measures. University's traditional organizational structure, lack of communication and collaboration among the stakeholders, need and space for awareness among institution's community and lack of strong leadership represents potential challenges which must be met (Velazquez et al., 2005).

To overcome organizational challenges, the top management should state sustainable objectives, goals and targets (Collins and Clark, 2003). If effective communication and collaboration exist among all the stakeholders then there are obvious gains for faculty in practical application of their research, and for campus in terms of sustainability (Velazquez et al., 2005). In other words, it can be said that it not only develops trustworthiness for campus building researchers but also help in improving the economic and environmental performance of campus buildings.

2.7 CRITICAL SUCCESS FACTORS

Critical success factors are such factors, usually few in number, which are essentially important for overall performance of certain organization, department, or individual in the pursuit of their targeted objectives and goals. In other words, such factors represent those critical areas where "things must go right" for any hope of success in achieving the set targets (Fortune and White, 2006; Leidecker and Bruno, 1984). To put it more precisely such critical success factors reflect where the focus ought to be for any successful manager. It therefore needs to be underlined that in order to make optimum utilization of resources, clear identification of such factors at an early stage is essential. Once the CSFs are explicit, managerial priorities' can be set more knowledgeably and improved allocation of the manager's resources, especially time, can be made (Bullen and Rockart, 1981).

Importance of such factors in optimum utilization of resources demands serious consideration from perspective of management and resource allocation. For this reason, the term "critical success factors" is aptly chosen. Ability to identify and appreciate such factors can really be the difference between success and failure for a manager (Bullen and Rockart, 1981).

Universities make great contribution towards the growth of the society and they have a part to play by shaping public opinion and educating people about sustainability (Najihah et al., 2013). There is an urgent need to preserve natural resources for developing low carbon economies. Identification of CSFs will help in conducting the university campus buildings' retrofit most effectively and will also promote energy conservation and sustainability concepts.

Keeping in mind the CSFs, policy makers and practitioners will take pragmatic decisions and choose best practices for campus sustainability retrofitting, for only a sustainable university ensures safety of its environment while its functions, purposes, and its commitment towards society are fulfilled in true sense; such is possible by making use of sustainability approaches of which sustainable retrofitting is a part.

After an intensive study of literature related to sustainability, sustainable practices towards retrofitting of existing building structure and retrofitting options for university campus buildings, 20 papers were selected from which 41 factors were identified which appear as contributing greatly towards the reification of making sustainable retrofitted university campus buildings. These factors are shown in Table 2-2 along with their quantitative and qualitative appearance in the literature and also overall criticality towards achieving the expected targets is given.

Table 2-2: CSFs from Literature Review for Sustainable retrofitting of Campus Buildings

CSF Categories	Sr. No.	Papers / CSFs	(Cantin et al., 2002)	(Velazquez et al., 2005)	(Fortune and White, 2006)	(Richardson and Lynes, 2007)	(Miller and Buys, 2008)	(Masoso and Grobler, 2010)	(Pengpeng Xu et al., 2011)	(Ma et al., 2012)	(Amecke et al., 2013)	(Yang, 2013)	(Ihuah et al., 2014)	(Nord and Sjøthun, 2014)	(Bruce et al., 2015)	(Disterheft et al., 2015)	(Saleh et al., 2015)	(Schlör et al., 2015)	(Sesana et al., 2016)	(Kharseh and Al-Khawaja, 2016)	(Thomsen et al., 2016)	(Zhou et al., 2016)	Quantitative Appearance	Qualitative Appearance	Criticality
Management Responsibilities	1	**Support of top management**		H	H	H	H		H				H			H	M						0.4	0.949	**0.380**
	2	**Sustainability targets and their understanding**			H	H				H	M		M			H	H		H				0.4	0.908	**0.363**
	3	**Energy Audits**					M	H		H	H			H			H		H	M			0.4	0.908	**0.363**
	4	**Govt. Policies and regulations**		H						H	M	H	H	H								H	0.35	0.943	**0.330**
	5	**Building regulations and standard codes**									H	H								M	H		0.2	0.908	**0.182**
	6	**Strong leadership**			M	H							H				M						0.2	0.825	**0.165**
	7	**Energy Policies and its compliance**		H							H	H					M		M				0.25	0.858	**0.215**
	8	**Compliance with current government building regulations and codes**													H						H		0.1	0.990	**0.099**
	9	**Energy performance contract**									M											H	0.1	0.825	**0.083**
Stakeholders Contribution	10	**Investment/finance**	M			H	H			H	H	H		H	H			M			H		0.5	0.924	**0.462**
	11	**Stakeholder involvement**		M	H		H		H				H		H	H	M		M				0.45	0.843	**0.380**
	12	**Financial incentives**				H	M	M	L	H	H	H			M		H						0.45	0.807	**0.363**
	13	**Economic environment**							H	H				H					M	H		H	0.3	0.935	**0.281**
	14	**Payback period**				M	M			H										H			0.2	0.825	**0.165**
	15	**Funding allocation**		H					H												H		0.15	0.880	**0.132**
	16	**Sufficient resources**			M					M							M						0.15	0.660	**0.099**
	17	**Trust among stakeholders**															H						0.05	0.990	**0.050**
	18	**Profit mentality**		M																			0.05	0.660	**0.033**
	19	**Growth of building value**													M								0.05	0.660	**0.033**
Human Factors	20	**Energy awareness**		H			H	H			H	H	M	M	M		H		M				0.5	0.858	**0.429**
	21	**Communication and cooperation**		H	H	H	M		M		M	M	M			H	M				M		0.55	0.780	**0.429**
	22	**Education and outreach**		M	L		H	M			M	H		M	M		M		M				0.5	0.693	**0.347**
	23	**Occupant behavior**	M					H		H				H	H							H	0.3	0.935	**0.281**
	24	**Community engagement and partnership**					M										H						0.1	0.825	**0.083**
	25	**User satisfaction**	M							M													0.1	0.660	**0.066**
	26	**Interdisciplinary research**		H																			0.05	0.990	**0.050**
Building and Climate Factors	30	**Climate conditions**	M					H		H	H	H	L	H	L			H	M	M			0.55	0.780	**0.429**
	28	**Project/building characteristics**	M		L				H	H	M			H	H				M	H			0.45	0.807	**0.363**
	29	**Geographical constraints**	M							M					H								0.15	0.770	**0.116**
	27	**Building history**	M							M									M				0.15	0.660	**0.099**
	31	**Energy saving potential**								M	M											M	0.15	0.660	**0.099**
Retrofit Technologies	32	**Skilled and suitably qualified project team**			M				H			M	H	H			H						0.3	0.880	**0.264**
	33	**Chosen sustainable strategy**	M												M	H		H	H			M	0.3	0.825	**0.248**
	34	**Operation and maintenance**								M	M			H			H						0.2	0.825	**0.165**
	35	**Choice of energy system**								M								M	H				0.15	0.770	**0.116**
	36	**Proven/familiar technology**			L														H				0.1	0.660	**0.066**
	37	**Complete diagnosis before**	H																				0.05	0.990	**0.050**

		retrofitting																						
	38	**Building suitability for retrofit**												M								0.05	0.660	**0.033**
	39	**Equipment and occupants**	M																			0.05	0.660	**0.033**
	40	**Problem solving abilities**										L										0.05	0.330	**0.017**
Risk Management	41	**Effective risk management**			M				L	H			L				H		M				0.3	0.660	**0.198**

Chapter 3

RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

Methodology for this research work is elaborately explained in this chapter. Research strategy indicates that how and in what sequence a researcher will carry out and demonstrate his work to accomplish the desired objectives and goals (Herr and Anderson, 2014).

The study mainly focuses on identification and shortlisting of CSFs based upon their significance towards the sustainable retrofitting of university campus buildings. Thus, it was deemed suitable to focus the methodology towards a combined analysis of literature and, academic and industry trends. As depicted in research framework shown in Figure 3-1, selection of methodology is based on the scope and depth needed for the proposed research topic (Zou et al., 2014). To achieve the objectives of this research, in-depth face-to-face interviewing approach (Mitra and Wee Kwan Tan, 2012) was adopted as a data collection tool.

The research process involved a preliminary literature review of relevant contemporary data and material from journal articles, research reports, conference papers and internet to gain background knowledge about the research topic. This initial phase was followed by a systematic in-depth review in order to develop an overall research framework for the study and for the identification of CSFs for sustainable retrofitting of campus buildings.

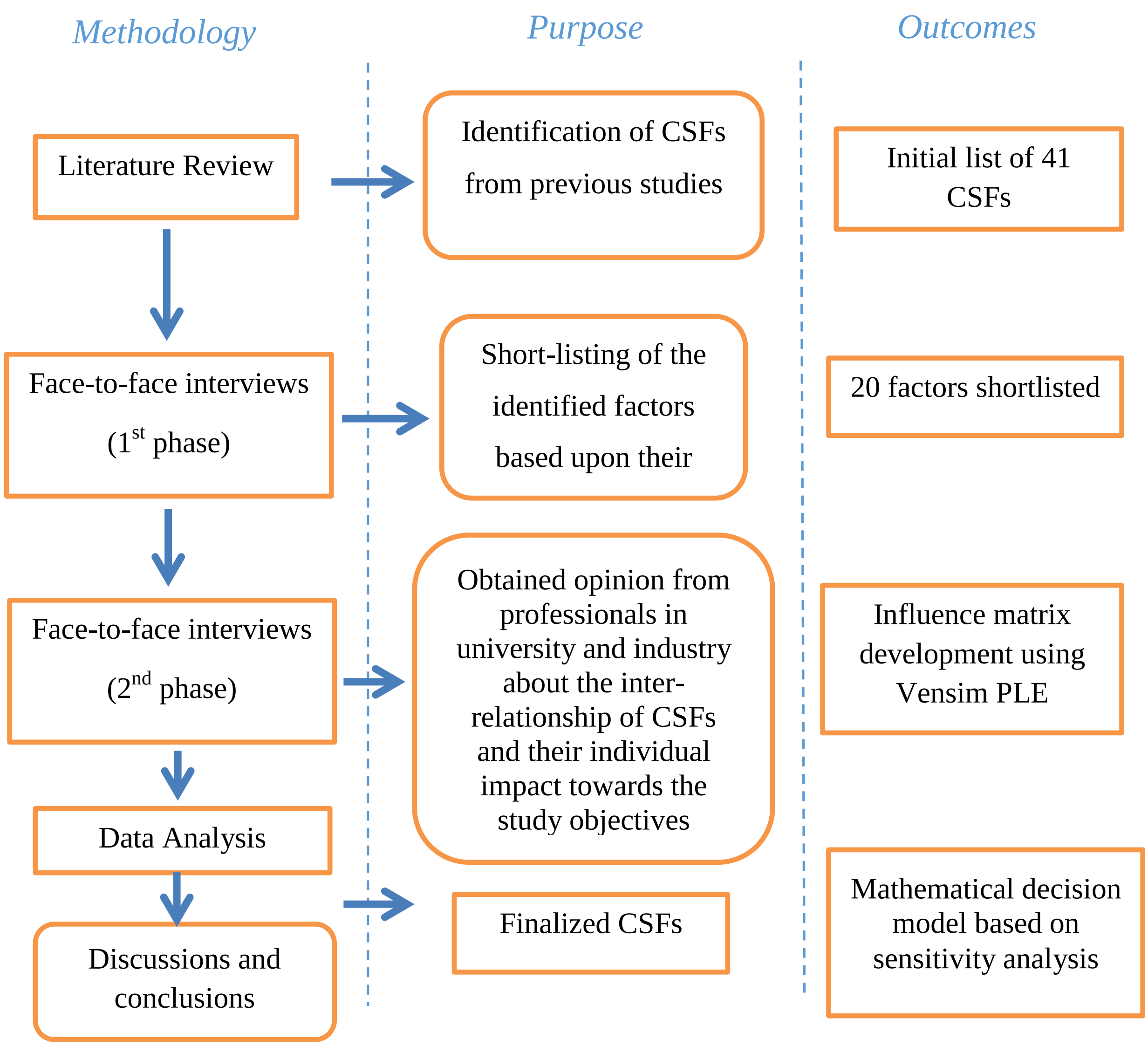

Figure 3-1: Research framework

3.2 CONTENT ANALYSIS

A detailed content analysis technique suggested by Hsieh and Shannon (2005) was employed to perform quantitative and qualitative assessment of the identified factors. The quantitative assessment was based on the frequency of appearance (λ) of identified factors in the selected material. Further, the selected papers were thoroughly reviewed to ascertain the criticality of identified factors on a High-Medium-Low scale. The qualitative scale was later converted into 5-3-1 semi-quantitative form for calculation purpose and qualitative score (β) for each factor was established. The total literature score (TS), as given in Equation 3.1, is the product of quantitative and qualitative scores.

$$TS = \lambda \times \beta \qquad \text{Equation 3.1}$$

Based on the content analysis scoring, a comprehensive list of 41 success factors was developed for which the percentage criticality was determined to assess the contribution of each factor towards the successful achievement of sustainable retrofitting. Furthermore, these 41 factors were used as an input for ranking of identified factors through expert opinion (structured interviews).

3.3 CRITERIA FOR SELECTION OF PARTICIPANTS

The experts involved in this stage included facility managers, industry experts and academic researchers and factors were shortlisted on the basis of their contribution and significance level upon a 5-point Likert scale (Allen and Seaman, 2007). The experts were selected on the basis of snow-ball sampling technique (Noy, 2008). Thus, a total of 24 professionals, much interested and keen to participate and express their opinions regarding the research topic, were engaged in this study whose details are shown in Table 3-1.

Table 3-1: Details of experts

Sr. #	Professionals	Experience
1	Facility Managers (n = 8)	6 with experience more than 20 years and 2 with more than 5 year experience in facility management of university buildings
2	Academic Researchers (n = 9)	Professors and lecturers with more than 10 year experience in research related to sustainability practices
3	Industry Experts (n = 7)	3 Project directors with experience more than 30 years, 2 engineers with more than 5 years and 2 project managers with more than 10 year experience in different university buildings renovation projects related to sustainability

Number of interviewees was well justified by Mason (2013) as the sample size becomes irrelevant in qualitative studies due to the fact that the value of the research is based on quality of data.

3.4 CRONBACH'S COEFFICIENT ALPHA TEST

Cronbach's coefficient alpha test was performed to check the reliability of the 5-point Likert. The particular test is used to measure the internal consistency among factors. According to Gliem and Gliem (2003), if Cronbach's coefficient alpha value is greater than 0.7, then the results are reliable and if the value is greater than 0.9, then data is highly consistent.

3.5 RANKING OF SUCCESS FACTORS

Relative importance index (RII) of all identified CSFs was carried out to rank them as suggested by Babar et al. (2016) based on interviews score using Equation 3.2, where *W* is the score given to each factor by the interviewee, *A* is the highest possible weighting of each factor, i.e., 5 in this case; and *N* is total number of interviewees.

$$RII = \frac{\sum W}{\mathrm{AxN}} \qquad (0 \leq \mathrm{RII} \leq 1) \qquad \text{Equation 3.2}$$

After the ranking of CSFs, interviewees were again approached for a 2nd round of semi-structured interview for the development of systems thinking model based on influence matrix. Each interview lasted for approximately 2 hours during which experts helped identify inter-relationships between shortlisted CSFs and the corresponding level of impact on sustainable retrofitting. Conclusive remarks were taken by the experts in the light of developed influence matrix regarding possible strategies which can be incorporated into the overall decision-making process achieving desired sustainability goals for retrofitting in university campus buildings.

After data collection, a systems thinking framework was developed using Vensim PLE to gain better understanding of the system of CSFs under study. In the end, data was mathematically modeled using MS Excel and this model was used as an input for sensitivity analysis. According to Pannell (1997), sensitivity analysis is a highly suitable and widely used technique for understanding the impact of a set of variables on a given outcome. It also helps in decision making by providing information about alternative strategies. So, sensitivity analysis was performed using @Risk®5.5 Excel addon and results are discussed in later section.

Chapter 4

RESULTS AND DISCUSSION

This chapter represents the results and analysis on the data collected. Discussion is also done in this chapter over various findings. For the data set particular to this research, value for alpha came out to be 0.95 which means that the results are reliable for analysis and highly consistent.

4.1 RANKING OF CSFS

The results of content analysis using quantitative and qualitative methods are presented in Table 2 in chapter 2. Resultantly, ranking of the CSFs was developed through calculation of RII in the form of percentage (%) criticality for comparison with the industry results and conducting a gap analysis between literature and industry trends. A total of 41 CSFs were identified after a systematic review of literature and categorized into six functional groups.

Comparative trends of RII values of CSFs calculated from literature and interviewee scores are presented in Figure 4-1 where it can be seen that some factors that are ranked highly important in literature have not acquired the same rank in interview based RII trend. For example, the factor, *energy audits* is given much importance in literature but it is ranked low in interviews. As far as literature is concerned, many studies highlight the importance of energy audits in sustainable retrofitting of buildings (Alajmi, 2012; Ascione et al., 2011; Ma et al., 2012; Pengpeng Xu et al., 2011). For example, Ma et al. (2012) stated that investigation of energy use within a building plays an important role in executing a retrofit project as they identify the areas having energy saving potential and also provide the necessary information required for assessment of building performance. Further, highlighting the importance, Pengpeng Xu et al. (2011) reported that energy audits provide the information that helps in identifying the potential retrofit measures or opportunities.

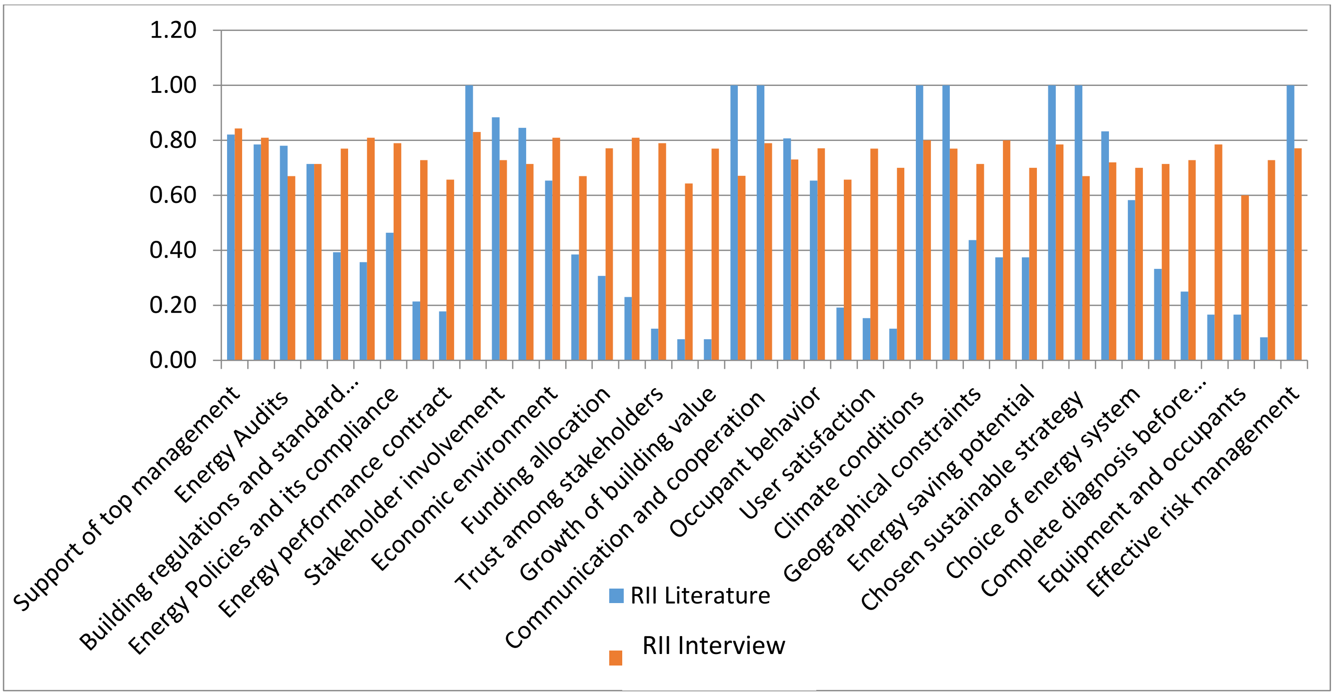

Figure 4-1: Graph showing trends of RII score obtained from literature and interviews

On the other hand, some authors show their concern regarding the reliability of the information provided by energy audits. For example, Clément (2012) analyzed that forecasted energy savings investigated as a result of energy audit cannot be considered accurate. This point was further supported by Eisenberg et al. (2012) that energy audit results are not trustworthy as auditors are often not trained and much qualified to provide an accurate assessment of pricing for the broad spectrum of measures being proposed. Similar response was received from most of the interviewees that since there is no established system of auditing that could be relied upon and also management shows lack of concern about the implementation of such audits on regular basis so this factor is the lowest implemented factor.

Likewise, many other factors which were ranked high in literature found a lower value from interviewees such as *government policies and regulations, energy awareness*, etc. Figure 4-1 also represents that some factors like *building suitability for retrofit* and *growth of building value* that ranked low on the basis of literature score are reported highly important by the interviewees for the sustainable retrofitting of educational buildings. On the contrary, factors like *investment/finance* and *climate conditions* find their place high both in literature and in interview score.

Based on the interview based RII values, the most critical CSFs are shown in Figure 4-2 along with their grouping. This shortlisting was based upon experts' experience in related field and ongoing trends and practices of the construction retrofit processes.

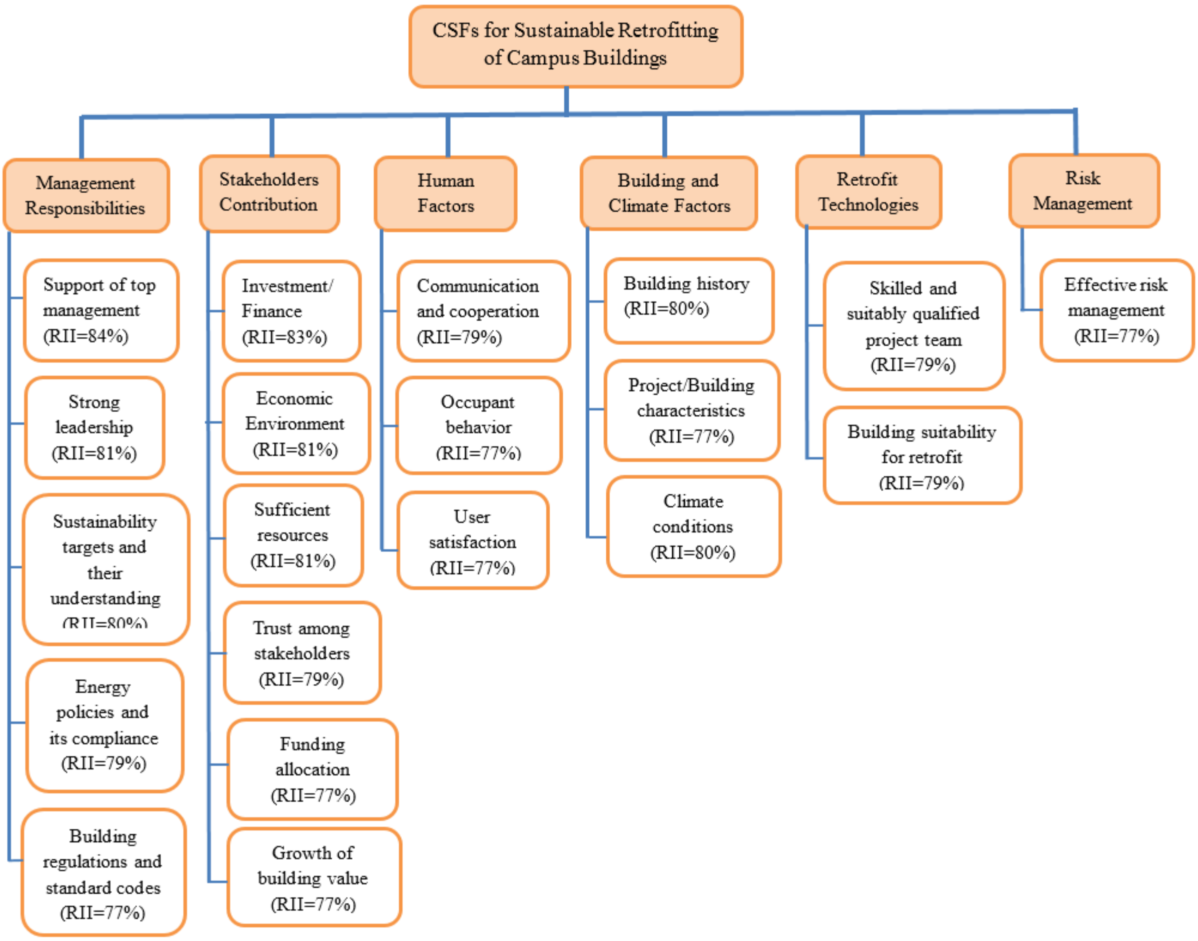

Figure 4-2: Framework of short listed CSFs

4.2 DISTRIBUTION OF CSFS INTO CATEGORIES

CSFs were grouped into six categories namely as:

1. Management responsibilities
2. Stakeholder contribution
3. Human factors
4. Building and climate factors
5. Retrofit technologies
6. Risk management

Discussion on all of these six categories is stated below.

4.2.1 Management Responsibilities

Management plays an important role in decision-making regarding energy saving strategies that are easy to implement and need low investment (Najihah et al., 2013). Top management leads in terms of providing resources for any project to be initiated and without their support no project, neither a retrofit nor any other infrastructure project, can embrace success. It provides assistance in setting and clarifying strategic objectives and stakeholder expectations in a way that the project can be executed and delivered in an efficient manner in accordance with the set objectives to achieve the expected results (Menassa and Baer, 2014). Though in literature the factor, *support of top management*, did not find its place at top but in this study, it is characterized as the most important factor towards the reification of sustainable retrofitting. The main reason behind such difference is the fact that literature is not confined to campus buildings but covers other fields too. But the academic and industry related experts, having experience in campus building retrofit projects, rank it as the top most important factor considering it the backbone of any project without the assistance of which, the project will fail.

Other factors that are placed in this category after short listing include *strong leadership*, *sustainability targets and their understanding*, *energy policies and its compliance*, and *building regulations and standard codes*. These factors were ranked highly important within this category based upon their relative significance in the application of sustainable retrofit process. For instance, energy policies, and building regulations and codes set the minimum criteria for energy efficiency requirements in retrofit process (Ma et al., 2012). Experts were putting emphasis that upper management should have knowledge regarding sustainability and its implementation in retrofit projects. On the basis of their experience, most of the interviewees revealed that the lack of energy standards and building codes results into an increased energy consumption as verified by Kharseh and Al-Khawaja (2016) in their study that in Qatar, lack of such standards resulted into significant increase in energy consumption in the last decade. So, energy policies and building codes must be considered as a prerequisite in developing any policy for retrofit process of educational buildings.

4.2.2 Stakeholders Contribution

Stakeholders' positive contribution in any sustainable retrofit project increases the sustainability and energy saving potential of the existing buildings with respect to economical, technical, environmental and social perspectives (Menassa and Baer, 2014). Stakeholders here are those who invest their interest in the ongoing building retrofit project, its operations and future retrofit outcome. Their requirements of improved comfort, productivity and health must be aligned and properly addressed if the energy saving target is to be achieved from the retrofit project (Peng Xu et al., 2012). According to Menassa and Baer (2014), the importance of stakeholders' involvement in determining the type and extent of any retrofit measure cannot be denied. Therefore, economic incentives play an important role in attracting the stakeholders to invest in the retrofit projects as upfront cost of any energy retrofit project is high and many stakeholders are reluctant to invest (Amecke et al., 2013). This investment and arranging finance is one of the main challenges that are being faced in policy making decisions. Stakeholders need to understand that in the long run, advantages of the sustainable retrofitting overweigh the cost in the form of energy savings and also results into healthy environment (Ma et al., 2012). Thus the factor *investment/finance* demands special attention in decision making process.

Likewise, *economic environment* is another factor that is essential to be considered during sustainable building retrofit decision making process so that the best suited retrofit options could be prioritized and opted (Sesana et al., 2016; Zhou et al., 2016). It varies from one region to another as different retrofit measures have varying economic viability and could cause different energy rates in different climate conditions and building types (Kharseh and Al-Khawaja, 2016). Along with economic stability of the project, *resource allocation* and their efficient management should also be given prime importance during decision making (Saleh et al., 2015). Resources like manpower, finance, space, materials and machinery need special attention as they contribute towards the timely completion of project as well as success of the project and its profitability.

Other factors that are included in this category are *trust among stakeholders*, *funding allocation* and *growth of building value*. Majority of the participants emphasized that to get the maximum benefit from the retrofit project, these factors are worth considering during decision making process because without their consideration, retrofit project may fail.

4.2.3 Human Factors

Energy use of any building is directly affected by the human factors like occupant behavior, user satisfaction and, communication and cooperation. Decision makers have to make complex choices keeping in mind the occupants' behavior and cognizance (Cantin et al., 2002). To achieve best results from the retrofit project of educational building, occupants have to be considered as a primacy unit in decision making as per interviews. Furthermore, a survey in Nordic countries showed that 10-20% energy use can be reduced only by controlling human factors especially occupant behavior (Ma et al., 2012). Likewise, Santin et al. (2009) also emphasized the importance of occupants' behavior and characteristics on building energy use. He concluded after a survey in Netherlands that energy use can be reduced significantly through occupants' behavior and positive attitude towards energy savings.

Disterheft et al. (2015) in his research also focused on the fact that in decision making strategy, factor *communication and cooperation* should also be given special attention as it will allow to identify clear goals and tangible objectives. All interviewees were agreed that good communication and collaboration among the facilities management, faculty staff, designers and building experts benefits the university in terms of sustainability and also in the practical implementation of research.

4.2.4 Building and Climate Factors

The effectiveness of the selected retrofitting options and scenarios depends largely upon certain building characteristics (like age, size, type, occupancy characteristics) and climate conditions. In the interviews conducted, all participants were strongly agreed that building and climate factors play an integral role in any retrofit project. For instance, a research conducted by Kharseh and Al-Khawaja (2016) showed that insulation of building envelop results in 30% annual energy savings in cold climate and 23% in hot and humid climate. Implementing same retrofit measures in different buildings and in different climates results into different energy saving rates. So all the interviewees were focused and emphasized the importance of these factors during decision making about the retrofit measures and technology to be used in the project as large benefits could be achieved through their proper consideration.

4.2.5 Retrofit Technologies

Many factors were included initially in this category but the factors that were ranked highly important by the interviewees came out to be *skilled and suitably qualified project team* and *building suitability for retrofit.* There are many retrofit technologies that are readily available in the market but the choice of best retrofit measure depends on various factors like building characteristics and its potential for the retrofit, climate change and behavior change. However, if the project team is not properly trained, skilled and qualified then best chosen retrofit measure may not be functional properly as it has to be installed by that unskilled project team. Thus, the selection for the *skilled and qualified project team* should be given prime importance if to achieve required objectives and goals, said by many interviewees. They were also focused on the fact that before going to retrofit any building, there must be some screening tools to assess that either it is suitable for the retrofit or not. *Suitability for the retrofit* is very important factor that should not be ignored to save the large investment on pre-retrofit visits and energy audits. According to all the interviewees, if these two factors were ignored then project will be at stake. So their consideration is essential in any retrofit project.

4.2.6 Risk Management

Effective risk management identifies the strengths, weaknesses, threats and opportunities of the project. To ensure the project success, said by the interviewees, potential risks must be identified and assessed proactively and a contingency budget must be there to deal with those risks. *Effective risk management* results into best retrofit solutions and also benefit in terms of cost savings as uncertain project events can be dealt proactively. But interviewees showed their concern about the selection of the project manager as he plays a vital role in implementing *effective risk management* throughout the project. They also suggested that risk management should be a part of day to day operations, project meetings and workers trainings to maximize the benefits (for example, timely completion, cost savings and quality results) from the project.

4.3 GRAPHICAL MODEL

The polarity of each factor over other factors was determined by generating influence matrix as shown in Table 4-1. Delphi technique was used to get the polarities of each relation of selected factors.

Table 4-1: Influence matrix for short listed CSFs

		Management responsibilities					Stakeholders contribution						Human factors			Building and Climate Factors			Retrofit Technologies		isk Managemen
	CSFs	Support of top management	Strong leadership	Sustainability targets and their understanding	Building regulations and standard codes	Energy Policies and its compliance	Investment/finance	Economic environment	Funding allocation	Sufficient resources	Trust among stakeholders	Growth of building value	Communication and cooperation	Occupant behavior	User satisfaction	Climate conditions	Project/building characteristics	Building history	Skilled and suitably qualified project team	Building suitability for retrofit	Effective risk management
Management responsibilities	Support of top management		1	1		1	1		1	1	1		1		1				1		1
	Strong leadership	1		1	1	1	1	1	1	1	1		1		1				1		1
	Sustainability targets and their understanding	1	1		1	1	1	0	1	1	1	1	1	1	1				1		1
	Building regulations and standard codes			0		0	-1	0	0												
	Energy Policies and its compliance	0		1			1	0	1			1			1						1
Stakeholders contribution	Investment/finance					1		1	1	1									1		1
	Economic environment	1					1		1	1	1								1		1
	Funding allocation	1				1	1	1		1	1	1							1		1
	Sufficient resources						1		1		1		1		1				1		1
	Trust among stakeholders	1	1	1		1		1					1	1	1						1
	Growth of building value	1					1		1							1					
Human factors	Communication and cooperation	1	1	1		1		1			1			1	1						1
	Occupant behavior						1											0			1
	User satisfaction													1							
Building and Climate Factors	Climate conditions				0	0	1		0					0			0	0			
	Project/building characteristics						0								0			0		0	0
	Building history						0		0											0	1
Retrofit Technologies	Skilled and suitably qualified project team	1		1		1		1	1		1		1		1						1
	Building suitability for retrofit																				
Risk Management	Effective risk management			1			1	1	1	1	1	1	1		1						

Using the influence matrix, a graphical model was generated using Vensim PLE software that represents the inter relationships of shortlisted factors as presented in Figure 4-3. This model also indicates the behavior of factors over each other and also their impact on sustainable retrofitting process of educational buildings.

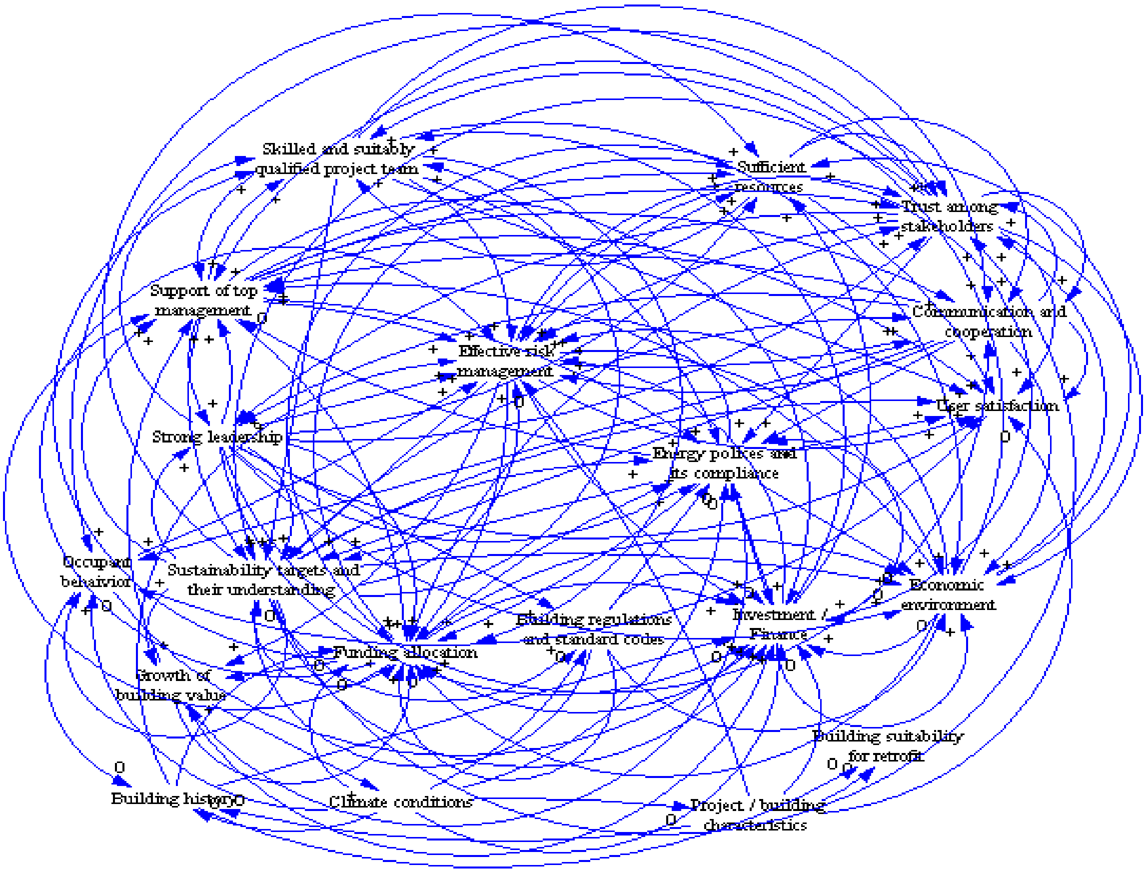

Figure 4-3: Graphical representation of CSFs' inter dependency

4.4 SENSITIVITY ANALYSIS

In order to transform the graphical model into decision making tool for the excellent effectiveness of sustainable retrofitting of buildings, the inter-dependent factors' relationships have to be quantified. For this purpose, a mathematical model was prepared so that sensitivity analysis could be run that would be helpful in checking to what extent an educational building project is sustainably retrofitted. Mathematical model is shown in Table 4-2.

Table 4-2: Mathematical model of CSFs

CSFs	Initial Value	Influential Factors	Polarity	Effect Score	Mean Weight	Normalized Weight	Factor Influence	Influenced Value	Normalized Influenced Value
Support of top management (SOTM)	1	Strong leadership	+	5	1	0.13	0.75	1.75	0.88
		Energy Policies and its compliance	-	5	1	0.13			
		Trust among stakeholders	+	5	1	0.13			
		Communication and cooperation	+	4	0.8	0.10			
		Skilled and suitably qualified project team	+	5	1	0.13			
		Sustainability targets and their understanding	+	4	0.8	0.10			
		Economic environment	+	3	0.6	0.08			
		Funding allocation	+	5	1	0.13			
		Growth of building value	+	4	0.8	0.10			
Sufficient resources (SR)	1	Support of top management	+	4	0.8	0.14	1	2	1
		Strong leadership	+	4	0.8	0.14			
		Investment/finance	+	4	0.8	0.14			
		Sustainability targets and their understanding	+	5	1	0.17			
		Economic environment	+	4	0.8	0.14			
		Funding allocation	+	4	0.8	0.14			
		Effective risk management	+	4	0.8	0.14			
Skilled and suitably qualified project team (SSQPT)	1	Support of top management	+	5	1	0.17	1	2	1
		Strong leadership	+	5	1	0.17			
		Investment/finance	+	4	0.8	0.14			
		Sufficient resources	+	4	0.8	0.14			
		Sustainability targets and their understanding	+	3	0.6	0.10			

		Economic environment	+	4	0.8	0.14			
		Funding allocation	+	4	0.8	0.14			
Investment/finance (I&F)	1	Support of top management	+	5	1	0.09	0.579	1.58	0.79
		Strong leadership	+	4	0.8	0.07			
		Energy Policies and its compliance	+	3	0.6	0.05			
		Sufficient resources	+	4	0.8	0.07			
		Building history	-	3	0.6	0.05			
		Sustainability targets and their understanding	+	5	1	0.09			
		Building regulations and standard codes	-	5	1	0.09			
		Economic environment	+	4	0.8	0.07			
		Funding allocation	+	5	1	0.09			
		Growth of building value	+	4	0.8	0.07			
		Occupant behavior	+	4	0.8	0.07			
		Climate conditions	+	3	0.6	0.05			
		Project/building characteristics	-	4	0.8	0.07			
		Effective risk management	+	4	0.8	0.07			
Building suitability for retrofit (BSFR)	1	Building history	-	4	0.8	0.50	-1	0	0
		Project/building characteristics	-	4	0.8	0.50			
Strong leadership (Rusko and Procházková)	1	Support of top management	+	4	0.8	0.25	1	2	1
		Trust among stakeholders	+	4	0.8	0.25			
		Communication and cooperation	+	4	0.8	0.25			
		Sustainability targets and their understanding	+	4	0.8	0.25			
Trust among stakeholders (TAS)	1	Support of top management	+	4	0.8	0.11	1.33	2.33	1.17
		Strong leadership	+	3	0.6	0.08			
		Sufficient resources	+	4	0.8	0.11			
		Communication and cooperation	+	5	1	0.14			
		Skilled and suitably qualified project team	+	5	1	0.14			

		Sustainability targets and their understanding	+	3	0.6	0.08			
		Economic environment	+	4	0.8	0.11			
		Funding allocation	+	4	0.8	0.11			
		Effective risk management	+	4	0.8	0.11			
Energy Policies and its compliance (EP&IC)	1	Support of top management	+	5	1	0.13	0.79	1.79	0.9
		Strong leadership	+	4	0.8	0.11			
		Investment/finance	+	4	0.8	0.11			
		Trust among stakeholders	+	3	0.6	0.08			
		Communication and cooperation	+	3	0.6	0.08			
		Skilled and suitably qualified project team	+	3	0.6	0.08			
		Sustainability targets and their understanding	+	4	0.8	0.11			
		Building regulations and standard codes	+	4	0.8	0.11			
		Funding allocation	+	4	0.8	0.11			
		Climate conditions	-	4	0.8	0.11			
Communication and cooperation (C&C)	1	Support of top management	+	5	1	0.16	1	2	1
		Strong leadership	+	5	1	0.16			
		Sufficient resources	+	5	1	0.16			
		Trust among stakeholders	+	5	1	0.16			
		Skilled and suitably qualified project team	+	4	0.8	0.13			
		Sustainability targets and their understanding	+	4	0.8	0.13			
		Effective risk management	+	4	0.8	0.13			
Building history (Anderson et al.)	1	Occupant behavior	-	4	0.8	0.31	-0.231	0.77	0.38
		Climate conditions	-	4	0.8	0.31			
		Project/building characteristics	+	5	1	0.38			
Sustainabilit	1	Support of top management	+	4	0.8	0.13	0.81	1.81	0.90

y targets and their understanding (STATU)		Strong leadership	+	4	0.8	0.13			
		Building regulations and standard codes	-	3	0.6	0.10			
		Energy Policies and its compliance	+	4	0.8	0.13			
		Trust among stakeholders	+	4	0.8	0.13			
		Communication and cooperation	+	4	0.8	0.13			
		Skilled and suitably qualified project team	+	5	1	0.16			
		Effective risk management	+	3	0.6	0.10			
Building regulations and standard codes (BRASC)	1	Strong leadership	+	3	0.6	0.27	1	2	1
		Sustainability targets and their understanding	+	4	0.8	0.36			
		Climate conditions	+	4	0.8	0.36			
Economic environment (EE)	1	Strong leadership	+	5	1	0.13	1	2	1
		Sustainability targets and their understanding	+	4	0.8	0.10			
		Building regulations and standard codes	+	3	0.6	0.08			
		Energy Policies and its compliance	+	4	0.8	0.10			
		Investment/finance	+	4	0.8	0.10			
		Funding allocation	+	4	0.8	0.10			
		Trust among stakeholders	+	4	0.8	0.10			
		Communication and cooperation	+	3	0.6	0.08			
		Skilled and suitably qualified project team	+	4	0.8	0.10			
		Effective risk management	+	4	0.8	0.10			
Funding allocation (FA)	1	Support of top management	+	5	1	0.10	1	2	1
		Strong leadership	+	4	0.8	0.08			
		Sustainability targets and their understanding	+	4	0.8	0.08			
		Building regulations and standard codes	+	3	0.6	0.06			
		Energy Policies and its compliance	+	3	0.6	0.06			
		Investment/finance	+	4	0.8	0.08			

		Economic environment	+	4	0.8	0.08			
		Sufficient resources	+	4	0.8	0.08			
		Growth of building value	+	4	0.8	0.08			
		Climate conditions	+	3	0.6	0.06			
		Building history	+	3	0.6	0.06			
		Skilled and suitably qualified project team	+	4	0.8	0.08			
		Effective risk management	+	4	0.8	0.08			
Growth of building value (GOBV)	1	Sustainability targets and their understanding	+	4	0.8	0.27	1	2	1
		Energy Policies and its compliance	+	4	0.8	0.27			
		Funding allocation	+	4	0.8	0.27			
		Effective risk management	+	3	0.6	0.20			
Occupant behavior (OB)	1	Sustainability targets and their understanding	+	4	0.8	0.19	0.62	1.62	0.81
		Trust among stakeholders	+	4	0.8	0.19			
		Communication and cooperation	+	4	0.8	0.19			
		User satisfaction	+	5	1	0.24			
		Climate conditions	-	4	0.8	0.19			
User satisfaction (US)	1	Support of top management	+	5	1	0.11	1	2	1
		Strong leadership	+	5	1	0.11			
		Sustainability targets and their understanding	+	5	1	0.11			
		Energy Policies and its compliance	+	5	1	0.11			
		Sufficient resources	+	5	1	0.11			
		Trust among stakeholders	+	5	1	0.11			
		Communication and cooperation	+	4	0.8	0.09			
		Project/building characteristics	+	5	1	0.11			
		Skilled and suitably qualified project team	+	4	0.8	0.09			
		Effective risk management	+	4	0.8	0.09			

Climate conditions (CC)	1	Growth of building value	+	4	0.8	1.00	1	2	1
Project/building characteristics (PC)	1	Climate conditions	-	4	0.8	1.00	-1	0	0
Effective risk management (ERM)	1	Support of top management	+	5	1	0.09	0.86	1.86	0.93
		Strong leadership	+	4	0.8	0.07			
		Sustainability targets and their understanding	+	4	0.8	0.07			
		Energy Policies and its compliance	+	4	0.8	0.07			
		Investment/finance	+	4	0.8	0.07			
		Economic environment	+	4	0.8	0.07			
		Funding allocation	+	4	0.8	0.07			
		Sufficient resources	+	4	0.8	0.07			
		Trust among stakeholders	+	4	0.8	0.07			
		Communication and cooperation	+	4	0.8	0.07			
		Occupant behavior	+	4	0.8	0.07			
		Project/building characteristics	-	4	0.8	0.07			
		Building history	+	3	0.6	0.05			
		Skilled and suitably qualified project team	+	4	0.8	0.07			
								33.5	16.75

Mathematical model was prepared using MS Excel where inputs to the model were given based upon the result of the conducted interviews from the industry experts, facility managers and academic researchers. Normalized influence value for each factor was obtained through this model that tells the contribution of each factor towards the targeted objective after being influenced by other factors. Normalized influence value (α) was calculated using equation 4.1 as:

$$\alpha = (\kappa_i + \gamma_i) / 2 \qquad (0 \leq \alpha \geq 1) \qquad \text{Equation 4.1}$$

In equation 3, κ_i is the initial value of each factor assigned to it as an input that ranges from 0 to 1 when running the sensitivity analysis whereas γ_i is the factor interaction influence that quantifies the effect of influential factors. The factor influence is calculated using equation 4.2.

$$\gamma_j = \sum_{j=1}^{n} \kappa_j * \beta_j \qquad \text{Equation 4.2}$$

Substituting equation 4.2 in equation 4.1, we get:

$$\alpha = (\kappa_i + \sum_{j=1}^{n} \kappa_j * \beta_j \;) / 2 \qquad (0 \leq \alpha \geq 1)$$

Where, β_j is the influencing factor effect on other corresponding factors.

Equations from the model were used as input for running sensitivity analysis using software @Risk5.5 to analyze the impact of CSFs to the overall result. Using this software, 5000 iterations were performed that means 5000 different initial values between the range 0 and 1 were used to get the more precise result. The cumulative density function (CDF) is presented in Figure 4-4.

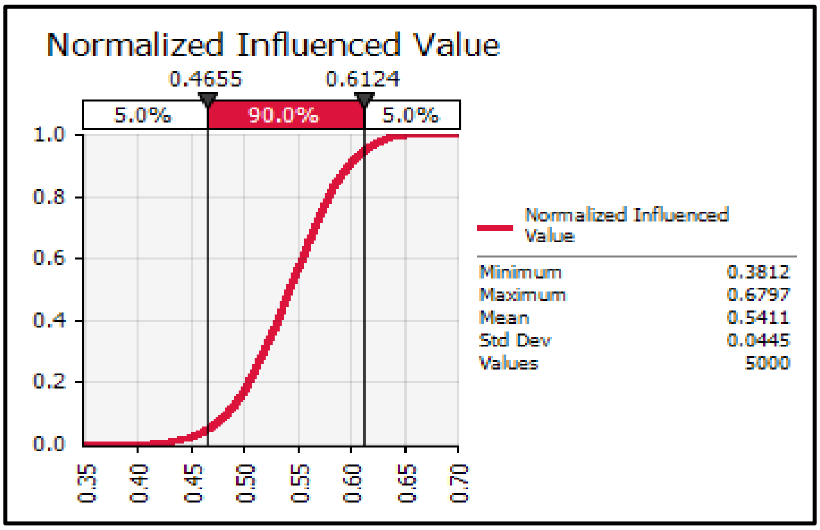

Figure 4-4: CDF for the normalized influenced value of CSFs

The CDF graph shows that sustainable retrofitted project will have a minimum value of 0.38 and maximum value of 0.68. These values represent the limitations of the model that a project will be least sustainable if the value comes closer to 0.38 and, likewise, if value approaches 0.68 then that project is highly sustainable or the priority project. When initial values from some project that need to be retrofitted will be entered to this model, it will give a certain value that will fall within the limits of the model and will indicate the extent of sustainability that would be achieved through that project. Through this model, a range can also be defined that means if a project gets a value above 0.6 then it will be consider highly sustainable and similarly if below 0.45 then needs special attention and should be reconsidered. And, likewise, in between 0.45 and 0.6, project can be preceded considering as a medium level project.

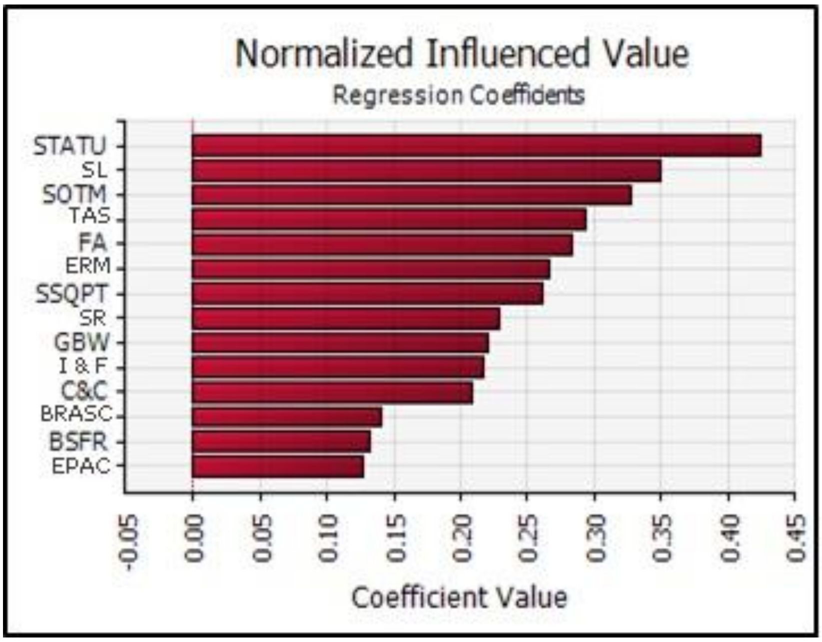

Figure 4-5: Regression coefficients for CSFs

Sensitivity analysis also provides regression coefficients showing individual impact of the CSFs towards the outcome. Figure 4-5 shows that the factor '*sustainability targets and their understanding'* has the highest impact towards sustainable retrofitting or in other words this factor should be given prime importance in decision making process. Likewise, *strong leadership* is the second most important factor to be considered while taking any decision regarding retrofitting of educational buildings.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Sustainable retrofit projects contribute largely towards energy and cost savings, and environmental protection. Therefore, retrofitting techniques when applied in campus buildings become more useful and beneficial as compared to the others as campus supply large number of end users who influence the society with their behavior. In other words, university related persons will take this idea of retrofitting the buildings sustainably to their hometowns and this new aspect of energy saving and environment friendly construction will be introduced to the different regions in no time.

This research identified and ranked the CSFs needed for the sustainable retrofitting of university campus buildings according to their significance based upon intensive literature review and experts opinion in relevant field. Keeping in view the inter relationships, CSFs were grouped into six categories namely management responsibilities, stakeholder contribution, human factors, building and climate factors, retrofit technologies, and risk management. Based upon the interviews result, 41 factors were short listed to 20 CSFs as shown in Figure 4-2. If the university management is capable of having a good record of implementing retrofit process sustainably using these identified CSFs then they are likely to get success in saving the energy and environment. Owing to the complexity and connectedness of these CSFs, their interrelationships were also identified and quantified in this study. Systems dynamics was used for the graphical modeling of the inter dependency of CSFs after preparing an influence matrix. This would be helpful in understanding the way one factor affects the other. Sensitivity analysis was run to get the impact of CSFs to the overall retrofit process. When CSFs related inputs from any project that needs to be retrofitted will be entered to this software, it will indicate whether it is a priority project or certain changings have to be made to make it more sustainably retrofitted. In other words, if sensitivity analysis provides the value near 0.38 then the project will be poorly retrofitted and as the value goes towards 0.679 then the project is expected to achieve the required sustainable targets.

The research findings will help the policy makers and practitioners to integrate the dimensions of sustainability in better way towards the reification of sustainably retrofitted campuses, and promote energy and resource conservation as a result. CSFs identification will also help the decision makers in choosing the best retrofit alternative presenting the maximum sustainable performance. In future, results from this research could be utilized for detailed estimation of economic benefit of energy efficient measures and their associated uncertainty. Also, result from this study may not be relevant directly to other building types so their CSFs can also be identified and prioritized.

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APPENDIX 1

Department of Construction Engineering and Management
School of Civil and Environmental Engineering
National University of Sciences and Technology
H-12,Islamabad,Pakistan
Contact : +92-(0)51-90854164

Dear Sir / Madam,

Subject: ***Request for facilitating data collection***

We are conducting a study at the Dept. of Construction Engineering & Management (NIT-SCEE) of National University of Sciences & Technology (NUST), Islamabad regarding the sustainability retrofitting of campus buildings.

As you are aware that built environment is responsible for a significant sustainability footprint. Since no more than 2% new buildings get added to the overall built environment, controlling building footprint cannot be successful without tapping into the existing 98% buildings. In this regard, various retrofitting interventions are performed. However, critical factors of such successful intervention are yet to be identified and measured.

This study aims at quantifying the impact of various critical success factors identified through detailed literature review and expert judgment. It is expected that the findings of this study will help facility managers and project directors of academic institutions in sustainability retrofitting decision making. You are very kindly requested to facilitate MS student Maria Zahid, the main researcher of this study, in information gathering.

Your contribution in this regard is highly appreciated. We understand you must be busy with million tasks at hand and other million waiting to materialize. But if you can spare some minutes from your busy schedule, it shall help us greatly.

For additional information, please contact the undersigned.

Dated: 23rd May 2017

With profound regards,

Maria Zahid
(*MS Student in Construction Engineering and Management,NUST***)**

Dr. Muhammad Jamaluddin Thaheem
Assistant Professor and Head of Department

APPENDIX 2

Critical Success Factors (CSFs) For Sustainable Retrofitting of University Campus Buildings

Dear Respondent,

I am a student of National University of Sciences and Technology (NUST), Islamabad, Pakistan, and currently pursuing my MS degree in Construction Engineering and Management. My research topic is "Critical Success Factors For Sustainable Retrofitting of University Campus Buildings" and your feedback will be of great help for my research work.

Energy retrofitting along with environmental protection and social benefits is critical for campus sustainability. Most universities fail to fully appreciate the significance of sustainable retrofitting mainly due to lack of realization. This research is aimed at identifying the CSFs that contribute towards successfully achieving sustainable retrofitting of university campus buildings. Keeping in mind the CSFs, policy makers and practitioners can make pragmatic decisions and choose best practices for the sustainable retrofitting of university campus buildings leading towards sustainable lifestyles.

You are requested to rate the importance of each success factor towards the expected target as per your experience, knowledge and ongoing practices. Your response will be highly appreciated.

Maria Zahid (mariazahid.cem14@nit.nust.edu.pk)
MS Research Student
Construction Engineering and Management
NUST, Islamabad, Pakistan

*Required

Email address *

DEMOGRAPHIC INFORMATION

Your Name *

Country *

Organization/Institute *

Job title/Position in organization *

Total work experience *

- 6-10
- 11-15
- 16-20
- More than 20

Critical success factors identified from intensive literature review are grouped into six categories based on their nature. Kindly rate the importance of each success factor towards the successfully achieving sustainable retrofitting of university campus buildings as per your experience, knowledge and ongoing practices. Your response will be highly appreciated.

Scale:

1. Not at all important   2. Slightly important   3. Neutral

4. Moderately important   5. Extremely important

Management Responsibilities *

(Mark only one oval per row)

	1	2	3	4	5
Support of top management	◯	◯	◯	◯	◯
Strong leadership	◯	◯	◯	◯	◯
Sustainability targets and their understanding	◯	◯	◯	◯	◯
Energy audits	◯	◯	◯	◯	◯
Government policies and regulations	◯	◯	◯	◯	◯
Compliance with current government building regulations and codes	◯	◯	◯	◯	◯
Building regulations and standard codes	◯	◯	◯	◯	◯
Energy policies and its compliance	◯	◯	◯	◯	◯
Energy performance contract	◯	◯	◯	◯	◯

Suggestion or any other factor? (if you think that any of above mentioned factors do not represent its category and should be in some other category then do comment please)

Stakeholders Contribution *

(Mark only one oval per row)

	1	2	3	4	5
Investment/Finance	◯	◯	◯	◯	◯
Stakeholders' involvement	◯	◯	◯	◯	◯
Financial incentives	◯	◯	◯	◯	◯
Economic environment	◯	◯	◯	◯	◯
Payback period	◯	◯	◯	◯	◯
Funding allocation	◯	◯	◯	◯	◯

Sufficient resources	◯	◯	◯	◯	◯
Trust among stakeholders	◯	◯	◯	◯	◯
Profit mentality	◯	◯	◯	◯	◯
Growth of building value	◯	◯	◯	◯	◯

Suggestion or any other factor? (if you think that any of above mentioned factors do not represent its category and should be in some other category then do comment please)

____

____

Human Factors *

(Mark only one oval per row)

	1	2	3	4	5
Energy awareness	◯	◯	◯	◯	◯
Communication and cooperation	◯	◯	◯	◯	◯
Occupant behavior	◯	◯	◯	◯	◯
User satisfaction	◯	◯	◯	◯	◯
Education and outreach	◯	◯	◯	◯	◯
Interdisciplinary research	◯	◯	◯	◯	◯
Community engagement and partnership	◯	◯	◯	◯	◯

Suggestion or any other factor? (if you think that any of above mentioned factors do not represent its category and should be in some other category then do comment please)

____

____

Building and Climate Factors *

(Mark only one oval per row)

	1	2	3	4	5
Climate conditions					
Project/Building characteristics					
Geographical constraints					
Energy saving potential					
Building history					

Suggestion or any other factor? (if you think that any of above mentioned factors do not represent its category and should be in some other category then do comment please)

Retrofit Technologies *

(Mark only one oval per row)

	1	2	3	4	5
Skilled and suitably qualified project team					
Chosen sustainable strategy					
Operation and maintenance					
Choice of energy system					
Proven/familiar technology					
Complete diagnosis before retrofitting					
Building suitability for retrofit					
Equipment and occupants					
Problem solving abilities					

Suggestion or any other factor? (if you think that any of above mentioned factors do not represent its category and should be in some other category then do comment please)

Risk Management *

(Mark only one oval per row)

	1	2	3	4	5
Effective risk management					

Suggestion or any other factor ?.