Project Lifecycle Optimization and Feasibility Study: The Way to Implementation of Sustainable Construction Management Practice

Nariman Ghodrati

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Prof. Dr. Elvan Yılmaz
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Civil Engineering.

Asst. Prof. Dr. Mürüde Çelikağ
Chair, Department of Civil Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Civil Engineering.

Asst. Prof. Dr. Alireza Rezaei
Supervisor

Examining Committee

1. Prof. Dr. Tahir Çelik
2. Assoc. Prof. Dr. Özgür Eren
3. Asst. Prof. Dr. Alireza Rezaei

ABSTRACT

Sustainable construction is a method which helps engineers to take into account social, environmental and economical aspects of their work equally. With increasing awareness among engineers for reducing the impact of construction industry on environment, sustainable construction is gaining momentum. The purpose of this study is to illustrate the practical solutions for sustainable construction strategies and energy efficient buildings to prevent more unnecessary burden on environment.

For accomplishing this goal, a research study comprising of a comprehensive literature review, software modeling and a single case study was undertaken. Literature review consisted of citation of previous research works regarding sustainability and building lifecycle strategies. Also, for showing, analyzing and evaluating sustainable methods and practices, several software and techniques including building information modeling and building adaptive reuse were considered. The results of this research indicate that designers can contribute to reducing energy consumption by using suitable building materials and construction managers can eliminate any hasty decision for immature demolition by taking advantage of building adaptive reuse method.

Keywords: Sustainable Construction, Building Adaptive Reuse, Lifecycle Energy Analysis

ÖZ

Sürdürebilir inşaat metodu mühendislere sosyal, çevresel ve ekonomik konulara eşit ağırlık vermelerini sağlamaktadır. Mühendisler arasında inşaat endüstrisinin çevre üzerinde olan etkilerinin farkındalığı artıkça, sürdürülebilir inşaat metodları ivme kazanmıştır. Bu çalışmanın amacı sürdürülebilir inşaat stratejilerinin ve enerji tasarruflu binaların çevre üzerine nasıl daha az yük verdiklerini göstermektir.

Bu amaca ulaşmak için, bütünlüklü literatür araştırması yapılmış, bilgisayar programı gelitirilmiş ve bir de vaka çalışması yapılmıştır. Literatür araştırması sürdürülebilir inşaat ve yaşam boyu bina stratejilerini içeren önceki araştırmaları içermiştir. Aynı zamanda, sürdürülebilir inşaat metodları ve uygulamaları, ve Bina Enformasyon Modellleri ve binalarda uygulanabilen yeniden kullanımı içeren bazı bilgisayar programları ve teknikleri gösterilmiş ve analiz edilmiştir. Bu araştırmanın neticeleri, bina tasarımcılarının enerji tüketiminde tasarrufa gidebilecek yapım malzemelerini kullanarak ve inşaat yöneticilerinin alelacele yıkım metodları yerine çıkan malzemeleri yeniden kullanılabilecek metodlarla yıkım işlerini tamamlamalarının enerji tüketimini azaltabileceğini göstermiştir.

Anahtar kelimeler: Sürdürülebilir İnşaat, Bina Yeniden Kullanım Uygulamaları, Yaşamboyu Enerji Analizi

To my beloved Family

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INTRODUCTION

1.1 Introduction to Sustainable Construction

Generally, sustainability is defined as an approach to eliminating our needs and manufacturing products by retaining the balance and concurrent equilibrium of social, economic and environment as well as protecting the earth by proportional extracting of raw materials. For accomplishing this goal, we have to be vigilant and watchful to protection of the environment. Particularly, sustainable construction describes construction as conscientious supervision and execution of project in a safe place according to environmental protection standards and procedures. Meanwhile, it is commonly applied for explanation of the function of sustainable development (Struble and Godfrey, 2012).

The research question in this thesis is based on current trend of developers in construction industry which their first priority is to increase profit of projects without enough attention in long term impact. To sum up, it can be proposed that how builders can take into account long term impact of their constructions in advance? Is there any strategy to eliminate negative influence of construction industry?

To investigate practical method of sustainable construction and to examine some aspects of sustainability, this study aims to consider sustainability criteria in a case study and analyze influence of sustainable policies and strategies. Therefore, the methodology in this thesis comprises of lifecycle assessment based on primary concepts of value management and engineering economy which are collected in a software namely Sindex. The methods in this thesis are based on a though literature review in order to find a practical solution for sustainable construction and optimization of lifecycle. Then, computerized modeling and analysis of a case study were undertaken to demonstrate and confirm the facts and values related to sustainable construction. Furthermore, some software and programs including Autodesk Revit Architecture, Green Building Studio, Building Adaptive Reuse Model and Sustainability Index were applied to analyze and assess some criteria such as comparison of lifecycle energy consumption of the building and potential for reuse of historical building. The results and outcomes of this study proposed a practical method which would lead builders toward more reasonable behaviors such as less energy consumption and more wisely decision making process during the lifecycle.

1.2 Problem Statement

It is to a certain extent obvious for everyone that early demolition of building before reaching the end of lifecycle causes financial loss and leads to more material and energy consumption. Likewise, there is no doubt that lifecycle optimization of buildings contribute to less expenditures on assets and is more profitable for the owners. On the other hand, by recent population growth, engineers, owners and developers are more conscious about environmental issues than before.

Therefore, finding, and analyzing appropriate method for implementation of sustainable policies and strategies in construction helps specialists to shift the traditional unsustainable construction methods towards decreasing their unnecessary burden on earth and environment by using more sustainable techniques and reducing energy consumption.

Thus, in spite of having massive amount of methods, techniques, and procedures that are invented and recommended by engineers with each method having different specifications and requirements for particular location, this study aims to examine, assess and choose three appropriate practical methods of sustainability related to optimization of building lifecycle and by applying them to the case study find the results. According to the sustainability technique which is compiled in this thesis, engineers will be able to properly decide on demolition of buildings or buildings adaptive reuse and lifecycle analysis of buildings for fulfillment of a project as accurate as possible. Lack of these procedures in construction industry causes huge amount of solid waste as a result of early demolition, massive quantity of energy and cost expenditure along with environmental troubles due to the wrong decision making process.

1.3 Aims and Intention of the Research

The aims of this study are investigation and examination of methods, strategies and procedures to find practical solutions of sustainable construction and to suggest some ways to reduce the negative impacts of construction industry on environment to equally increase the social, economical and environmental aspects of projects.

As a result, for accomplishment of this study there are some purposes that need to be met. These aims include:

i. Assessing the effect of three different building components and materials on lifecycle of the projects.

ii. Demonstrating a sustainable technique for decision making process to whether demolish a building or extending its lifecycle by applying building adaptive reuse method.
iii. Using Sindex as a sustainability assessment software to show to what extent a project is sustainable.

1.4 Works Done

Findings and results of this thesis was possible by doing comprehensive research and literature review to find some practical methods and solutions among different possible approaches to take advantage of them and through using each of them in a case study considering all aspects of these tools in a real case.

i. Regarding to the first aim of this thesis which wants to show influence and impact of three different building components, by modeling the case study in Autodesk Revit and Green Building studio, the outcomes show that each components which was based on one specific type of materials for wall and roof of the building has different outcome related to the lifecycle of building, so based on these outcome I was able to decide which one is better from energy consumption and cost expenditure point of view.
ii. Second aim of this thesis was related to show a sustainable technique for changing the function of an old building for a new purpose instead of early demolition by assessment of its adaptive reuse potential. This technique helps engineers to wisely decide between demolition or adaptive reuse. Therefore, by applying the model of building adaptive reuse on a case study according to physical life of the building and assessment of seven obsolescence factors, the potential for changing the function of the building was ranked.

iii. For satisfying the last aim related to the sustainability assessment based on Sindex, social, economical and environmental information of the case study was collected and modeled in the software and based on weighted evaluation technique the building was ranked as a sustainable projects.

1.5 Achievements

Based on the aim and question of this thesis which wants to show a sustainable method and practice for construction sector in Iran to manage life cycle of projects more social, economical and based on environmental factors, the achievements are:

i. Through a comprehensive literature review based on previous research works and methods, I was able to found three sustainable methods related to lifecycle of buildings and applied them step by step to the case studies.

ii. Existing methods for lifecycle assessment in projects alone, are usually taking into account some aspect of lifecycle and ignore the other parts. However, by applying the methods and findings of this thesis to a project as a framework, builders and designers can consider whole of the life cycle from beginning to the end.

iii. In conclusion, the findings of this study proposed a solid framework based on three strategies, which in each stage and phase of construction are applicable. In design stage by using building information modeling designers can assess the influence and effect of their design on lifecycle, during the feasibility study stage engineers by using Sindex can rank a project to weather is sustainable or not and at the end of lifecycle they can apply building adaptive reuse technique to the building to decide whether demolish a building of not.

1.6 Thesis Outline

This thesis comprises of seven chapters. In chapter two which is literature review, the previous and current researches related to implementation of building information modeling in sustainable construction, sustainability measurement for building adaptive reuse and lifecycle energy analysis are studied and explained.

In the third chapter, research methodology and the process of data analysis and data collection is described. This chapter includes data collection, energy evaluation in building, sustainability measurement for building adaptive reuse and sustainability index as an environmental benchmarking tool.

Chapter four is dedicated to the case study which is the main part of this thesis. Case study includes two different buildings. First of all, the historic building analyzed to find building adaptive reuse potential and after that the next case evaluated for its sustainability index and finding influence of building components on energy analysis.

In chapter five, the results and findings that acquired from the case study are analyzed which include lifecycle energy and cost analysis for different alternatives, building adaptive reuse potential.

Chapter six comprises of implementation of sustainable construction management based on sindex. For the aim of sustainable construction, a lifecycle assessment method was used which based on four different criteria related to the monetary value and non monetary value the case study was ranked.

Finally, chapter seven which is the last part of this research is devoted to the results, outcomes and recommendations according to the aim and scope of this thesis. At this chapter, according to different methods, tools and software a new way towards sustainable, energy efficient and green building constructions is suggested.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The objective of sustainability is to protect the environment for future generations and doing some preventive measures to keep it healthy. Sustainability means considering environmental, social and economical part of actions when taking advantage of environment. Otherwise, the earth cannot sustain the burden of such actions and will encounter many problems in long run.

In this chapter, the critical points of current and previous publication of other researches related to performance of building information modeling in sustainable construction, sustainability measurement for building adaptive reuse and lifecycle energy analysis are studied and explained.

2.2 Overview

During the last few decades, the traditional model of construction, without enough attention to social and environmental issues has been the root cause of serious global and ecological problems. As a matter of fact, people instinctively move towards making more profit and unintentionally have more attention to economical aspect of sustainability that leads to more resource consumption and damage to environment. Therefore, it is the responsibility of governments and authorities to ensure that in each single project, besides thinking to have a more profitable investment, make certain that social and environmental strategies and policies are considered. Only by taking into account these important topics and having balance between social, environment and economic we can reduce the impact of construction and eliminate unnecessary burden on earth (Dobbelsteen, 2009).

Obviously, managing to have a satisfactory balance to attain sustainability necessitates several efficient methods to be used in every stage of construction from beginning of lifecycle to the end. Especially in construction projects, design stage is important because at this stage, designers should examine most environmentally friendly building systems that reduce the operational and recurrent energy and as a result, cost of buildings during its life.

Regardless of construction stage, in general, there are some indications by which engineers are able to judge whether the project is sustainable or not. For example, consider a project is planned to have enormous contribution to society such as construction of a museum or sport stadium. We can definitely say that these kinds of projects are in line with sustainability criteria. As another sustainable example, take into account projects with intention to improve arid environments such as irrigation channels or projects for protecting soil from erosion such as a forestation project. Additionally, it is important to point out that there are some exceptions in projects that engineers should be vigilant and avoid them. For instance, an irrigation project that in first glimpse seems as an acceptable plan, however, with scrutiny we can find that the decision making process and feasibility study of this project is under pressure of politicians or is just for absorption of financial resources for political gestures.

Generally, extra people's consumptions, huge amount of burning fossil fuels, and unsustainable deforestation are some examples of actions that cause global warming and are the main reasons for increasing the earth temperature. Now, we can decide to save our habitat for ourselves alone or keep it alive for next generations.

There are many different agendas for the aim of sustainability that each should follow some rules and regulations regarding to environment, social, and economy. These are three fundamental pillars of sustainability that can be seen in Figure 1. Negligent to each aspect of this triangle will take years of effort for compensation (Yudelson, 2009).

Figure 1: The main parts of sustainable development (Yudelson, 2009)

The basic description and definition of sustainability emphasizes on the issue that any development without considering the viability of earth is not acceptable.

Therefore, if a construction project causes problem to environment and leads to loss of habitat and destruction, even with large amount of income and benefits cannot be sustainable.

In other word, Sobotka and Wyatt (1988) describe the content of sustainable development as activities that should emphasize on consuming less natural resources, decreasing environmental damage and causing hazard, achieving profitable growth by protecting the development of economic principles currently and for next generations and moving toward reasonable use of the environment.

From the researcher's perspective, each building should be seen as a single product, with awareness fits entire lifecycle from extracting of raw materials until destruction. In this framework, another method sets major principles for the sustainable building evaluation (Anink et al., 1996):

i. Damage to the environment because of careless using of recourses,
ii. Lack of raw materials because of careless using of recourses,
iii. Energy utilization at all levels of construction,
iv. Water consumption,
v. Sound and smell contamination,
vi. Dangerous emissions,
vii. Increasing global temperature, and
viii. Hazard of growing construction waste.

The factors of sustainable improvement are creating consideration to the construction industry, which is an internationally important and extremely dynamic sector in both industrial and non-industrial countries (The building and construction sector, 2012). From the sustainability point of view, according to statistical data of European Union, the largest part of employment is related to construction industry with nearly 12 million workers being responsible for 8% of total employments. From the environmental point of view, construction industry is highly accountable in power usage, water contamination, ecological deterioration and supply depletion (Zimmermann et al., 2005).

The production, preservation and utilization of buildings cause trouble to our environment and presently are responsible for dramatically changes in the world's atmosphere and ecology. Therefore, this has important implications for land and home developers, homeowners and tenants to act carefully and take into account all essential factors before making any decision. On the other hand, Asia will be responsible for approximately 49% of the supplementary international power usages of next decade (Atkinson, 2007)

According to United Nations Environment Program (Cheng et al., 2008) construction sector is accountable for 30% of environmental problems worldwide. Majority of this energy utilization is for building activities, and about 10-20% is for construction and demolition. International Panel of Climate Change (IPCC, 2007) and Levine et al. (2007) explained that from 1971 to 2004, construction related carbon emission has grown by 2% yearly worldwide.

According to above mentioned reasons, the construction sector needs to be under the specific examination by management team and engineers. Therefore, from starting phase of construction in feasibility stage until commissioning stage, we are responsible to assessment and control of environmental impacts.

2.3 Construction Industry versus Sustainable Development

Construction industry is one of the most important industries contributing to air Pollution in the world and as a result put vast pressure on environment. Construction industry is accountable for more than 30% of entire global energy consumption by nearly more than 70% of power consumption in whole lifecycle for providing its tenants with the need for cooking, washing, cooling and other requirements (Cheng et al., 2008). The 10-20 percent residual is embodied energy consumed throughout the extraction of materials, processing and using in building, however can enhance to more consumption if building useful age is not long enough(UNEP, 2007).

The reuse of historic buildings, called adaptive reuse, was introduced to construction industry for the period of 1960s and 1970s in United State as a result of increasing level of environmental awareness (Cantell, 2005). Building adaptive reuse can be evaluated as the most powerful solution in construction management sector to eliminate impact of new projects (Langston, 2008). Adaptive reuse is used in many forms of historical and old buildings such as airports, public buildings, manufacturing buildings, and for most of designers adaptive reuse of old structures is observed as a primary aim to attract government attention to more sustainable construction in countries (Langston et al., 2008).

Sustainable construction is a broad term that characterizes environmentally awareness design methods as well as considering economic and political issues in the construction industry. The preliminary responsibility for those who are involved in construction sector and want to move toward sustainability is to bear in mind the following issues whether they work in residential, nonresidential or industrial construction works:

i. Power source: searching, finding and using new types of power sources such as solar and wind powers other than fossil fuels with huge amount of damage for environment and people.
ii. Resources: selecting, reprocessing and recycling supplies during construction, operation and preservation of building to decrease supply requirements.
iii. Waste: generating fewer wastes and recycling more.
iv. Pollution: generating less toxicity materials and solid contamination.

The performance of those achievements could develop earnings and savings, and will lead us in the direction of a sustainable future (CIOB, 2004).

The aim of sustainable plan is to reduce harmful ecological effects entirely from starting point of construction. It requires no fossil fuel resources and less impact to the world (Kibert, 2008). Thus, green design will help to give confidence and a bright future for our planet by two main goals (Sassi, 2006). First, reducing the environmental influences created by construction, operation in use and end of lifecycle. Second, finding people’s realistic needs and eliminating them to decrease their environmental impact.

Regarding sustainable development, many publications have been distributed. One of the valuable references was prepared by Sturge (2008) which explained the method, considerations and strategies of sustainable development in accordance with protecting natural resources for next years. Thus, it is obvious that sustainability is very important nowadays with improved global consciousness which has found more priority than before. However, managing to achieve a satisfactory balance for sustainability necessitates several efficient methods to be used in all stages of construction.

So far, several studies have been carried out to classify the root causes of poor performance in sustainable construction and address key factors that contribute to the aim of sustainable development. For example, Yung and Chan (2012) and Holden et al. (2008) have proposed a number of sustainability factors which emphasized on a framework for achieving sustainable development and examined its challenges and barriers. Šaparauskas and Turskis (2006) analyzed different problems of sustainable construction and they developed an indicator system for construction sustainability and found that construction industry in Lithuania moves towards sustainability.

Chew, (2010) by focusing on strategies to achieve resource efficiency, promoted the adoption of sustainable construction materials and practices. He also presented some recent initiatives of sustainable construction, such as the development of demolition protocol and sustainable construction capability development fund. To investigate the level of knowledge and achievement of sustainable practices based on the perceptions of the project developers, Zainul Abidin (2010) has investigated the application of sustainable construction concept and he suggests that to improve the momentum of sustainable practice in the industry, actions should be directed towards improving this knowledge at all levels. Shen et al. (2011) by examination of 9 different practices grouped an international urban sustainability indicators list and they showed that the list can be used to guide the selection of indicators of sustainable urbanization plans and improve the effective communication of the status of practices. For the aim of improving current situation of urban land use in China, Zhang et al. (2011) based on 13 indicators presented an evaluation system and the findings lead to further suggestions for government.

Despite the contribution of all above mentioned studies to sustainable development, they provide few insights into practical way of sustainable construction and just some of them have addressed more tangible method and technique for sustainable construction in all levels. The objective of this research is to present three different sustainable methods which could cover all stages of construction projects form cradle to grave.

Bullen and Love (2010) examined owner's and practitioner's views and experiences associated with adaptive reuse. They presented a building viability process model that can be used by owners, occupiers and planners to determine the strategy needed to meet changing commercial and regulatory demands being required of buildings. Likewise, a more comprehensive assessment provided by Ai Lin Teo and Lin (2011). They suggest a model for assessing adaptation potential of public housing in Singapore and discuss its validation process. Moreover, numerous research studies performed in many countries to acknowledge adaptive reuse method as a viable alternative and affordable housing strategies (Cantell, 2005; Velthuis and Spennemann, 2007; Watson, 2009).

The study of Yıldırım and Turan (2012) demonstrated that design criteria can highlight the significance of cultural heritage through adaptive reuse and they emphasized the challenges of reuse in terms of development involving historical buildings to provide guidelines for future projects. Shipley et al. (2006) examined the business of heritage development include renovation or adaptive reuse of buildings and determined that involved parties should support the developers to find new uses for historic buildings and bring their development skills. Wang and Zeng (2010) presented a method for the reuse selection of historic buildings which enables decision-makers to understand the relationships of attributes in reuse selection problems.

Obviously, most of the researches have paid attention to fulfill two objectives include categorizing the indicators of sustainability to improve current policies in achieving sustainable development and developing a framework for assessment of building adaptive reuse potential, which neither of these methods alone, can be used as a comprehensive solution for builders. To fill in this gap, this study wants to demonstrate three methods, which if engineers apply them simultaneously, not only perform a consistent process of sustainable construction but also contribute to reduce the impact of new construction on energy consumption.

2.4 Lifecycle Energy Analysis - Material Alternatives

Global Energy consumption will increase to more than 70% by the next decades (Energy Information Administration, 2006). In order to meet these huge amounts of energy requirements, engineers have to construct a lot of dams, power plants and burn enormous resources of natural raw materials (Langston and Ding, 2001). But for a permanent solution, it is the responsibility of designers and scientists to change the traditional way of using energy to green methods such as take advantage of solar panel, see waves, etc.

Several researchers have found that more than 70% of energy requirements of high rise buildings are consumed for internal weather comfort of people and occupants of buildings during lifecycle and approximately less than 30% of energy requirements are consumed for extracting and production of raw materials for construction stage. In addition, the amount of energy that is needed for construction and destruction of the buildings at the end of their lives is less than 2% of total (Ramesh et al., 2010).

The amount of embodied energy of materials such as the energy that is needed for extracting soil and processing it in factory to ultimately creating bricks has direct impact and influence on lifecycle energy analysis. Utama and Gheewala (2009) estimated lifecycle energy of a building with different types of materials and structural systems. They found that some types of materials can reduce the amount of energy consumption more than 35%.For instance, if a designer decides to construct a building with aluminum and glazing for exterior facade instead of concrete, this decision can increase the embodied energy of this building much higher. This is due to the fact that, producing of aluminum is a difficult process and needs huge amounts of time and effort in factory in comparison with concrete. However, aluminum has an advantage over concrete in sustainability point of view which is capability of many times recycling that it increases its salvage value (Medgar and Martha,2006). As another example, Xing et al. (2008) found that using non-ferrous and more natural materials such as clay or even concrete have less environmental impact and energy usage during the lifecycle of the buildings than ferrous materials such as steel.

Consequently, operation energy consumption during the lifecycle of a building with steel structure is more because of the superior thermal conductivity of steel. Therefore, lifecycle energy usage and environmental impacts of steel structure buildings is to some extent more. As a result, it is obvious that construction elements and components have major impact on energy consumption of structure.

In recent years construction industry has many breakthroughs in the field of lifecycle energy analysis, calculating energy consumption, modeling of the buildings before real construction, and visualization of design before reality for analyzing all aspects of construction. Nowadays, designers and architects can use some sophisticated methods after drawing basic sketches such as building information modeling to analyze future buildings from numerous aspects such as orientation of building, potential for erecting solar panels to absorbing most lighting and sun, clash detection for analyzing any possibility of defect in mechanical elements and etc. (Krygiel and Nies, 2008). Therefore, comparison for performance of different building systems and materials is now an easy task for engineers by using these software and tools towards reducing energy consumption and environmental impacts (Crosbie et al., 2010).

Based on examination of variety of building components and materials, researchers found that building materials have major impacts on energy consumption. The amount of embodied energy for different construction materials can be seen in Table 1. Energy analysis of different building materials was performed by Cole and Kernan (1996) to find out which type of materials have less energy requirement for production and are the best choice for performance of a green building. On the other hand, Cole (1999) analyzed variety of building elements that were constructed from single element such as concrete or have different elements such as wood, steel, glazing, stone and so forth. Based on his finding, concrete materials had best results than others due to being produced from local resources with minimum expenditure for transportations. Adalberth (2000) spent years of her studies for doing examination on building components from different aspects such as durability, flexibility and energy considerations. Eventually, she found that for total lifecycle of building with a same usage in long run, operational energy of concrete is less than wood.

Table 1: Embodied energy in building materials (Lawson Buildings, 1996)

Building Materials	Embodied Energy MJ/KG
Kiln dried sawn softwood	3.4
Kiln dried sawn hardwood	2.0
Air dried sawn hardwood	0.5
Hardboard	24.2
Particleboard	8.0
MDF	11.3
Plywood	10.4
Glue-laminated timber	11.0
Laminated veneer lumber	11.0
Plastics – general	90
PVC	80.0
Synthetic rubber	110.0
Acrylic paint	61.5
Stabilized earth	0.7
Imported dimension granite	13.9
Local dimension granite	5.9
Gypsum plaster	2.9
Plasterboard	4.4
Fiber cement	4.8
Cement	5.6
In site Concrete	1.9
Precast steam-cured concrete	2.0
Precast tilt-up concrete	1.9
Clay bricks	2.5
Concrete blocks	1.5
AAC	3.6
Glass	12.7
Aluminum	170
Copper	100
Galvanized steel	38

From previous researcher’s works, it can be seen that several investigations have analyzed the influences of heat conduction on the energy consumption of the structures in different weather conditions. Kalema et al. (2008) assessed the impact of building envelope with different types of materials for lightweight and heavyweight building and found different results for energy consumption of the building for heating and cooling in different locations. The results were about 4-16% energy saving of thermal mass.

Marceau and Van Geem (2002a, 2002b, 2002c) offered their findings of lifecycle analysis for building materials from the beginning of the construction until the end of its life. One of their findings was that in a same function, the negative influence of wood materials is more than concrete based on thermal mass point of view of the building.

According to above mentioned findings, many of previous researches concentrated upon operational energy consumption of the buildings for cooling and heating during its lifecycle, instead of doing embodied energy analysis for finding their results according to different building materials.

Buildings are used for various of functions such as university, hospital, office, recreational place, etc. But, to achieve our goals for contributing to sustainability issues including economical, environmental and social aspects, we need to use different sources of materials. “Worldwide, 30–40% of all primary energy is used for buildings and they are held responsible for 40–50% of green house gas emissions” (Asif et al., 2007). As a result, accomplishing sustainable construction goals in society is necessary for construction sector. To attain the objectives of sustainability, it is essential to define a method that includes important parts of green development topics in building construction. In other words, lifecycle assessment can be defined as analysis of total characteristics, features and influences of producing and operating a facility for the sake of environment and earth (Scheuer et al., 2003). These evaluations take into account the whole energy that is related to the building. The systems restriction of these methods can be seen in Figure 2 which includes the energy consumption of different levels including manufacturing, use, and demolition. Manufacturing phase consists of production of building components and parts including fabrication erection and installation and renewal of the buildings. Operation phase includes all actions that are associated with the operation and usage of the buildings during their physical life. These actions consist of preservation of living situation of the buildings as well as maintaining and servicing of mechanical equipments plus water and electricity tools. For the third part, demolition phase encompasses demolition of the building and moving solid debris and materials to dumping sites or recycling factory.

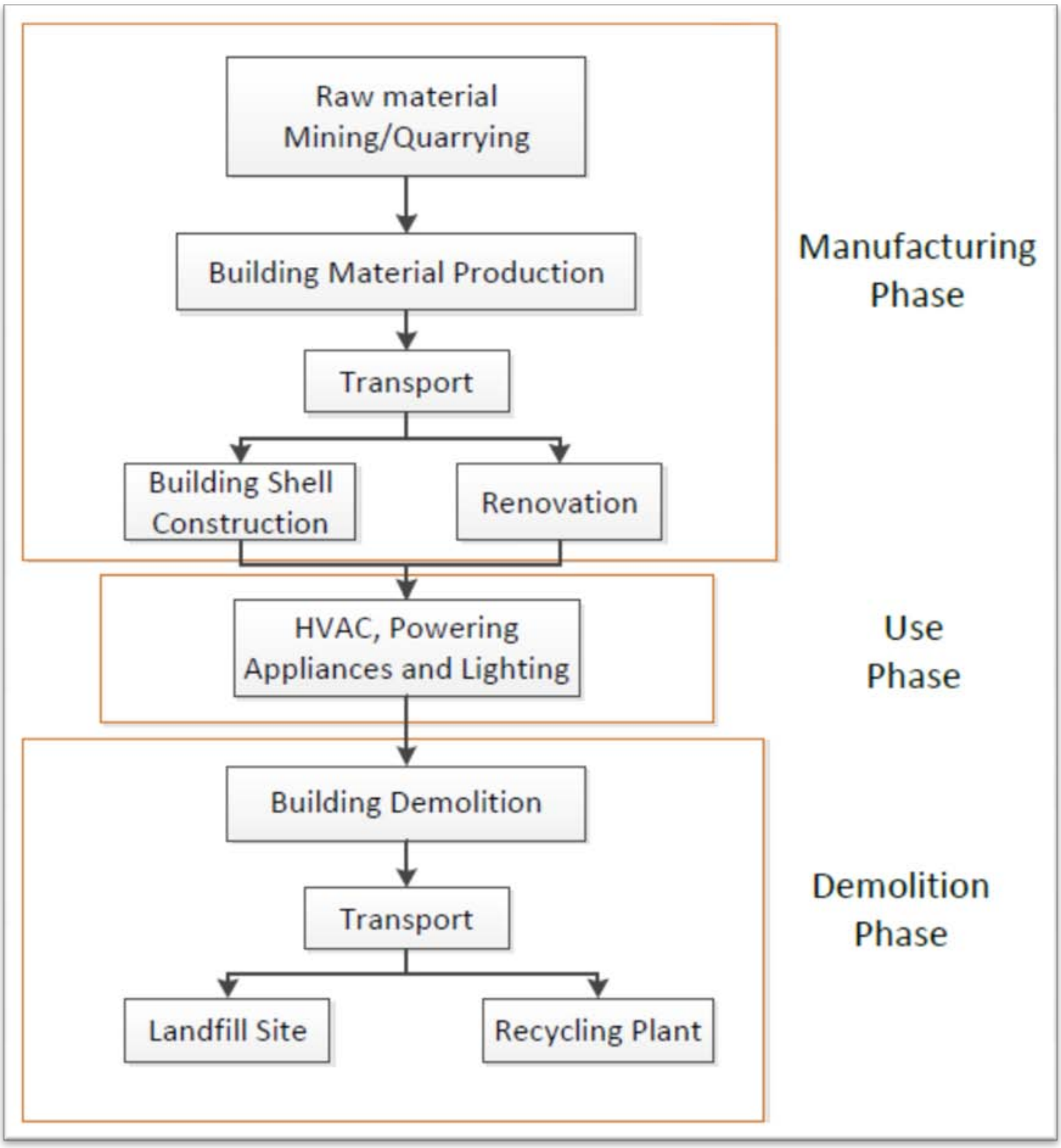

Figure 2: System restrictions for lifecycle energy analysis (Ramesh et al., 2010)

2.5 Implementation of Building Information Modeling

Nowadays, the construction industry has experienced some innovative breakthrough in method of management and construction such as sustainability and building information modeling. Building information modeling is described as some computerized actions which result in visualization of real construction for less expensive, more reliable, more accurate and less time consuming design process. Some consequences of building information modeling developed into a shared information supply to facilitate decision making process for a building from beginning conceptual levels of lifecycle until end (NIST, 2004). Building information modeling has many advantages for construction industry through reducing the time of construction, decreasing the potential of any design difficulty and help to producing more energy efficient projects. Therefore, building information modeling contributes to enhance project worth with a minimum construction price. From other point of view, Sustainable construction becomes an important topic as the environmental impacts and global warming issues gain momentum.

Currently, with the help of building information modeling technique we can analyze various aspects of building by assessing different features that combine with physical model to give reasonable and reliable outcomes for investigations. Additionally, the results are appropriate for using to define the shape of building design, recognizing design shortages, and establishing preliminary building specifications. The engineers can take advantage of building information modeling as an important device for more sustainable design and to specify the best building materials with appropriate building orientation. Without using building information modeling technique, it would be much time consuming and cost prohibitive to calculate and analyze the influence of each single design possibilities (Ruben et al., 2009).

Chapter 3

RESEARCH METHODOLOGY

3.1 Introduction

For satisfying the aim of this thesis and according to the nature of the study, different research method alternatives analyzed and finally case study was chosen. The case studies are including two residential building which are located in southern part of Iran.

In this chapter, research methodology and the method of data analysis and data collection is described. This chapter comprises of data collection for lifecycle assessment, energy evaluation in buildings and sustainability measurement which are according to adaptive reuse model and building information modeling.

3.2 Overview

The aim of this thesis is to illustrate some practical ways and solutions for executing construction projects according to sustainable criteria. Therefore, author proposes some methods which are collected based on needs of projects in Iran. So, according to findings of the author from many sources including books, research papers, dissertations, conferences, and web pages, the following topics are considered to be suggested to engineers to take into account before and after the construction including energy analysis for the lifecycle of the facilities, assessment of possibility for building adaptive reuse, ranking the project base on Sindex and building information modeling. For the sake of sustainability evaluation and analysis, a building visualization technique is also required to assess the modeled case study in Autodesk Revit Structure and/or Architecture which makes lifecycle energy examination feasible. As a result, the theoretical method which was used for this thesis comprises a combination of approaches. The literature review in this thesis comprises of comprehensive assessment of presented, previous and current researches for the aim of sustainability, energy analysis and building adaptive reuse. Additionally, two case studies were analyzed for the sake of in depth analysis in the scope of this thesis.

For use of case study method, there are two choices; multiple case studies or a single case study. Each technique has pros and cons. Many case studies examination suggests diversified range of evaluation however there could be a possibility for the author to unintentionally interrelate them for more desirable results in spite of some results that are out of target of investigation. On the other hand, Single case studies are capable of giving us very detailed data, although the framework is very narrow and unique to give us a general rule for other cases.

So, based on the discretion of supervisor and the nature of the study, the suggestion of Groat and Wang (2002) seems more acceptable who proposed that “the preference of multiple versus single case studies is better to be according to the type and nature of the research questions”. Consequently, according to the gaps in this study which were regarding the impact and influence of different construction materials on sustainability, extending the physical life of the building and lifecycle energy, the single case study was chosen.

3.3 Data Collection

For the aim of lifecycle assessment of the case study, a two-storey residential building which is located in southern part of Iran was selected. Therefore, the building, which is shown in Figure 3, was modeled to test the application of sustainable policies, to show the extent of sustainability in new design and comparison three different building components.

Also, in this study a decision making process has been performed on an old building which is shown in Figure 4, to show the trend of decision making process between demolition or adaptive reuse, which according to the results, building was demolished and replaced with a new building.

Figure 3: Residential house in southern part of Iran which was chosen for lifecycle assessment

Figure 4: Historic building which after evaluation did not achieve enough score for adaptive reuse and so demolished

The residential two-storey building which is shown in Figure 3 was modeled for the aims of this thesis which include building lifecycle analysis and demonstration of sustainability index. Outcomes were also according to modeling of the case study in the Autodesk Revit Architecture, Autodesk Green Building Studio and Sustainability Index. Moreover to find building adaptive reuse potential in historic building which is presented in Figure 4, the adaptive reuse potential model was used.

Therefore, outcomes, results and findings were attained according to the case study approach and assessing three building's component alternatives to be capable for identifying excellent arrangement in relation to lifecycle. Extending useful life of the buildings plays a major role in reducing environmental impacts of new construction and is always more sustainable than demolition. So, some information related to the case study such as building age and type of construction components were collected.

Succeeding that, a decision making tool was used to decide on whether to save the building or demolish it.

Moreover, for the aim of this thesis, data was collected from some sources as follows:

i. Interviews with engineer, architect and owner of the two-storey residential building which is presented in Figure 3 was conducted which most of whom reside in Iran and to somehow they have direct contact with sustainable housing programs to find the desired data and case study.

ii. The essential information of the two-storey residential building prepared by the architect in AutoCAD files and then for the purpose of lifecycle analysis transferred to Revit and saved as a gbXML file. “There are various exchange formats that assist building information modeling software interoperability. The gbXML web-based schema can be used, for example, to communicate essential heating, cooling, volume, and envelope”.

iii. After selecting appropriate case and preparation of drawings in details, for lifecycle analysis with Green Building Studio, the building was uploaded to the software as a gbXML file. Then, type of the building such as office, school, hospital, residential and the exact location of the building were defined. For finding nearest weather station, many locations were chosen and the best one was considered. After that, the software automatically acquired the essential information for price of energy, ecological information of the place, environmental data and climate situation.

iv. For calculating the sustainability index, economic information of the project such as costs, benefits and percentage of discount rate were collected to calculate the cash flow and net benefit. Then, the case was defined for its functional performance including “non-monetary benefits such as functionality, aesthetics, thermal performance, indoor air quality, adaptive reuse potential, flexibility, storage potential and plan efficiency”.

3.4 Energy Evaluation in Building

The Green Building Studio is one of the most sophisticated tools for designers and owners to calculate the lifecycle energy and cost of the building according to different material alternatives, building location and weather conditions. The Autodesk Green Building Studio is a software that can help us to analyze various features of building regarding to construction, use and operation during its life. Some of the results of the software include: “annual and lifecycle energy cost, energy consumption, peak electric energy demand (kW), lifecycle energy consumption, potential for energy, water use, natural ventilation potential and carbon emission calculations” (Autodesk, 2008).

By using the software, it is possible to model the envelope of the building, analyze building energy and replace the desired alternative based on comparative analysis as well as helping to estimate the energy cost related to decisions. As a result of above mentioned facts, Autodesk has a newcomer powerful tool for the most sustainable designs. So, by these tools the only thing that engineers and architects need is to be more conscious about the green building rules and enthusiasm to save earth for the next generations (Autodesk, 2008).

For beginning a construction project with Autodesk, exact location of construction site must be defined. Because, energy analysis cannot be possible without taking into account real information about weather and climate conditions such as wind speed, sunlight hours, rain volume and temperature.

As mentioned earlier, Autodesk Green Building Studio helps designers from the first stage of the project to analyze every aspect of the designs according to Revit based drawing to find best results. This enables engineers to get more reliable and accurate information for their projects and lets them to try a lot of green, affordable, less cost prohibitive and sustainable design alternatives. The main view of Revit is shown in Figure 5 which helps to upload gbXML for energy analysis.

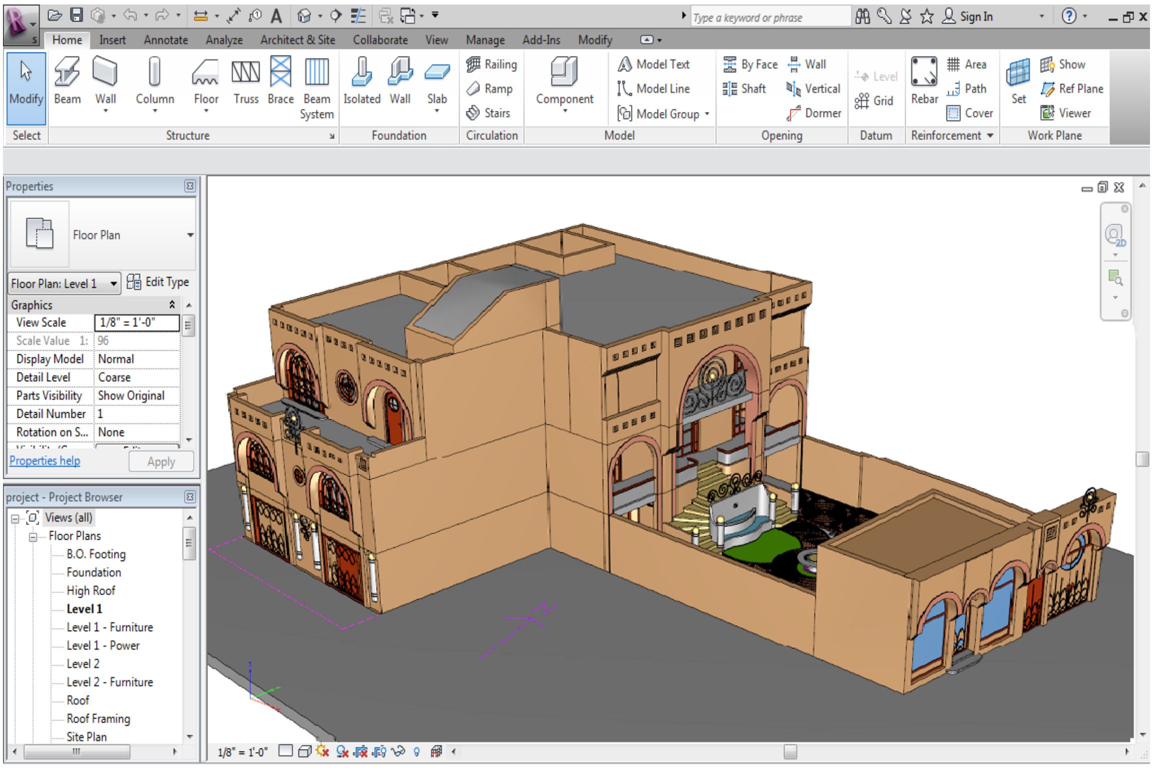

Figure 5: Preliminary construction design for lifecycle energy analysis

According to project's information such as location, shape, dimension and requirements, the software gives suitable materials, building orientation, style and amount of facade, windows overhangs and glazing by considering total aspect of municipality and local regulations and laws for more reasonable results. Therefore, with the help of Green Building Studio, it is possible to determine whole aspect of the design like a lower U-value window glazing, or HVAC system.

For the sake of building energy analysis, some requirements should be specified to the software to get best results. Because of the nature of the building's envelope which is directly responsible for heat conduction and energy transfer, the main concern of the energy analysis software is to require enough data for building's exterior walls, doors and windows, roof, etc. Revit has variety of data for each alternative and allows the user to define them. Meanwhile, software has some requirements which need to be pursued for getting best outcomes (Autodesk, 2008):

i. Do not employ Revit like solid CAD software: This mistake usually happens when users are searching for a collection of building's information. As a result, walls, ceilings, roofs, and other elements may possibly not be modeled because of enough building information, data and specifications.
ii. Model exterior building's skin and shell: Defining elements as main components of building's envelope such as exterior walls are essential for energy analysis.
iii. Creating Revit model in first stage of design is extremely significant: A basic model is sufficient to evaluate types and net size of windows, direction, and shading. Green Building Studio just needs special data and information of the building to find results.
iv. Defining the windows and openings: Opening parts of the building influence HVAC consumption. As the software can easily define the size, direction and

type of the opening in each part of the design, it is not important to specify them at the beginning.

v. Model main components of the building: Due to the fact that the small parts of the building such as closet do not have important impact on energy consumption of the facility, so designing very complex models is difficult to analyze, and as a result they can be eliminated.

vi. Connect all elements of building's envelope: In Revit model if every part of the envelope is not connected correctly, that part of design could take into account as an opening or leakage area having negative impact on energy consumption.

3.5 Sustainability Measurement for Building Adaptive Reuse

Buildings can make contribution to the environment and society by extending their lives in a new function instead of early demolition. Thus, finding a new solution for assessment of this potential is significant. With the help of multi criteria assessment tools like Sindex, engineers are able to calculate the impacts of buildings during their lifecycle instead of just time of possession or function. Nowadays, these valuable methods will guarantee that buildings with considerable residual capability to serve our civilization will be protected and found a new opportunity to help people. Therefore, by using this technique, we can take into account lifecycle of buildings from beginning to the end. Consequently, this thesis helps to increase builder's capability for more sustainable construction by using techniques which increase awareness to the environmental influences of construction.

Even though buildings are used for many years, they need persistent preservation and refurbishment. In some cases, buildings can be considered as an inappropriate asset for their main function because of obsolescence, or can be redundant and unneeded because of variation in building requirements. So, as an engineer, we are responsible to decide whether to demolish a building to build a new construction, or instead, renovate or reuse it.

"Each man made structure such as building can become obsolete as time passes. So, a building's life that interprets its structural safety is effectively reduced by obsolescence, results in a useful life somewhat less than its expected physical life" (Langston and Lauge-Kristensen, 2002).

The valuable (effective) age of a building or other product has been mostly complicated previously to estimate due to untimely obsolescence (Seeley, 1983). Buildings that are currently in use, after a while as getting older and obsolete are a main source of raw materials for other projects and new constructions. Meanwhile, there is better solution for an old building instead of demolition or using as a mine of materials which is to use the building in a new form by doing a little refurbishment and renovation. This method is called adaptive reuse that a new opportunity of life can be given to a historic building that can help us to reduce environmental impact of new construction and contribute to saving our national heritage. If as an owner, someone just thinks of economical aspect of construction, demolition might be the only way, however, if we bear in mind social and environmental issues as other factors, we can see that extending useful life of a building is more beneficial.

Adaptive reuse has enormous function to preserve resources by additional sustainable measures. This kind of performances helps to reduce greenhouse gas emissions and consequently as an excellent solution for sustainability offered to the builders for contributing to less environmental impact. Nowadays, a raise in amount of investment and expenditure can be observed towards renovation works, and this trend is now more important than expenses for new construction (Douglas, 2006). Adaptive reuse is a type of renovation that causes relatively complicated challenges for engineers. These days, it can be seen that many disused non-residential buildings have been used as excellent residential buildings and give a new opportunity to people for living in cities (Langston,2011).

“The adaptive reuse potential model (ARP) used by Langston et al. (2008) categorizes and classifies adaptive reuse potential in buildings, and can be explained as a sustainable method to guarantee that in spite of increasing population, engineers have solutions to find enough habitant”. The model has broad function to every building with different purpose. For using this method, we have just to evaluate the “expected physical life and the current age of the building, both reported in years. It also requires an assessment of physical, economic, functional, technological, social, legal and political obsolescence” (Langston et al., 2008). The main window of software and the physical life calculator are shown in Figures 6 and 7 which include adaptive reuse potential, obsolescence and physical life worksheet.

Adaptive reuse potential			adaptive reuse potential (ARP%) =	45.7
The building was not well maintained over its life, but was well designed and located in a strategic position. It relies on retail for its existence. In 1990 it was made a Declared Monument and is therefore preserved against				
physical life (L_p) =	150	years	index =	160
building age (L_b) =	105	years	override =	
original construction date	1906		today's date =	2011
last refurbishment date =	1906	(enter only if refurbishment was major)		
physical (O_1)	0.15			
economic (O_2)				
functional (O_3)	0.05			
technological (O_4)	0.05			
social (O_5)	0.20			
legal (O_6)				
political (O_7)	0.20			
total =	0.65		obsolescence rate pa	0.43
useful life (L_u) =	78.4	years	adaptive reuse potential is moderate and decreasing	
years to useful life =	-26.6	years		
maximum arp score (%) =	72.7		(assuming $L_u = L_b$)	
ARP difference (%) =	59.1	%		
Risk Management:				nil
best case obsolescence	0.50	(low)		
useful life (L_u) =	91.1			
ARP% =	48.2		adaptive reuse potential is modera and decreasing	(no change)
worst case obsolescence	0.75	(high)		
useful life (L_u) =	71.0			
ARP% =	44.2		adaptive reuse potential is modera and decreasing	(no change)
ARP difference (%) =	8.3			

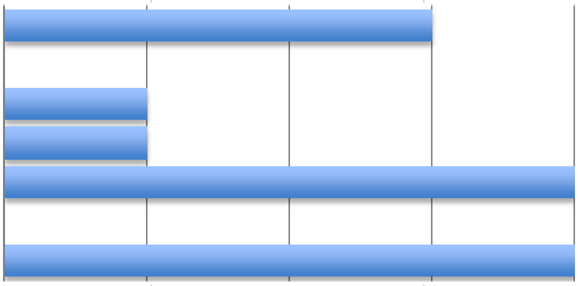

Figure 6: The adaptive reuse potential technique which produced by Langston et al. (2008)

	Physical life worksheet	suggested forecast (years) =	150
	Western Market, 323 Des Voeux Road, Sheung Wan		
	The Western Market was built originally as a two-storey market in an Edwardian style. It is the oldest surviving example of a market building in Hong Kong. It is constructed from masonry and		y/n ?
environmental context	Is the building located within 1 kilometre of the coast?		y
	Is the building site characterised by stable soil conditions?	#	y
	Does the building site have low rainfall (<500mm annual average)?		n
	Is the building constructed on a 'greenfield' site?		y
	Is the building exposed to potential flood or wash-away conditions?		y
	Is the building exposed to severe storm activity?		y
	Is the building exposed to earthquake damage?		n
	Is the building located in a bushfire zone?		n
	Is the building located in an area of civil unrest?	#	n
	Are animals or insects present that can damage the building fabric?	#	y
occupational profile	Is the building used mainly during normal working hours?		y
	Are industrial type activities undertaken within the building?	#	n
	Is the building open to the general public?		y
	Does the building comprise tenant occupancy?		n
	Is a building manager or caretaker usually present?	#	n
	Is the building intended as a long-term asset?	#	y
	Does the building support hazardous material storage or handling?		n
	Is the building occupation density greater than 1 person per 10 m^2?		n
	Is the building protected by security surveillance?		n
	Is the building fully insured?		y
structural integrity	Is the building design typified by elements of massive construction?		y
	Is the main structure of the building significantly over designed?		n
	Is the building structure complex or unconventional?		y
	Are building components intended to be highly durable?	#	y
	Are there other structures immediately adjacent to the building?		n
	Does the building have a stable footing system?	#	y
	Was the workmanship standard for the project high?		y
	Is the roof design susceptible to leaking in bad weather conditions?	#	n
	Is the building protected against accidental fire events?		n
	Is the building designed as a public monument or landmark?		y

Figure 7: The adaptive reuse potential technique for calculating the physical of historical building produced by Langston et al. (2008)

Using obsolescence factors is a good way for calculating the anticipated useful age of a structure by reducing its anticipated physical age. By calculating obsolescence factors according to the opinions of architect and engineer for the historical building, it can be expected from the monument to have less potential for its future useful life; however this amount can be considered to be valuable for the sake of building adaptive reuse. “An algorithm based on a standard decay (negative exponential) curve produces an index of reuse potential (known as the ARP score) and is expressed as a percentage” (Langston, 2011). So, current buildings can be rated based on their location, contemporary age, amount of remaining useful life and possibility they have for adaptive reuse. There are some exceptions for calculating the rate of building to find its potential for adaptive reuse, for example if the building undergone a major refurbishment or renovation in its lifecycle and owner spends a large amount of money for its maintenance, as a result the useful age of the building can be increased. In other words, “the decay curve can be reset by strategic capital investment during a renewal process by the current owner, or a future developer, at key intervals during a building’s lifecycle” (Langston, 2011).

Chapter 4

CASE STUDY

4.1 Introduction

The case study required detailed examination of initial construction cost, building lifecycle costs, environmental analysis, and power consumption. Therefore, sufficient details of the project were required for the study.

This chapter is consisted of two case studies and includes two different buildings which were constructed in Iran. Initially, an old building evaluated to rank the building for adaptive reuse potential and succeeding that a two-storey residential building assessed for its sustainability index and lifecycle assessment.

4.2 Case Study of Old Building for Finding Adaptive Reuse Potential

For the aim of finding building adaptive reuse, mainly two types of data were required. The first one was related to the questionnaire which is presented in Figure 7 for finding the physical life of the case study based on 30 questions and will be explained in next chapter and the second one is related to finding seven obsolescence factors which was determined based on detailed examination of the old building.

So, the old building which is shown in Figures 8 and 9 was modeled to identify and rank for adaptive reuse potential. The building was designed and built in Dezful, Iran, as a residential building in 1968. Construction materials were masonry brick, steel and concrete. Most of the unique interior decorations in the building were misplaced or missing, prior to recent renovations. The building comprises of three major parts including: the aboveground floor, underground floor, and foundation. The ground floor has a commercial space including an office. As can be seen in next chapter, after analyzing the old building for adaptive reuse, the results show that there is no possibility for adaptive reuse and building must be demolished. So, the second alternative which is a two-storey residential building was chosen and other method of sustainability as will be explained considered for them.

Results of building adaptive reuse were attained based on modeling of the old building in the software for finding building adaptive reuse potential. Then, based on outcomes which were zero possibility for adaptive reuse, the best solution was considered to demolish the building.

Figure 8: Main entrance of old building which was chosen for demolition

Figure 9: Front view of old building from inside

4.3 Case Study of Two-Storey Residential Building for Sustainability Analysis

For the aim of sustainability analysis and lifecycle assessment the two-storey residential building was modeled in Sindex which uses multiple criteria to calculate a sustainability index and then the construction design transferred to Autodesk Revit Architecture and Autodesk Green Building Studio which helped for lifecycle analysis. Figures 10 and 11 give a general overview for this building.

Figure 10: Front view of building from inside

Figure 11: Main entrance and commercial part of building

Some essential facts related to the building are as follow:

- Address: Taleqhani Street No. 45 Dezful / Iran
- Architect: S. A. Shahrokni
- Lot Area: 392 m^2
- Building Gross Area: 677 m^2
- Building cost exclusive lot = 2,700,000,000 Rls.
- Yard Area: 120 m^2
- Built: 2010-12

The building includes steel structure frame and load bearing masonry brick walls. The building is roughly rectangular in two directions and has two floors, with a partial basement. The roof was firstly designed as a sloped roof but during the bidding process it was replaced with a flat roof. Various sustainable technologies were experimented during the project, including rainwater collection, energy efficient hot water heater as well as consumption of salvaged wood, metal and brick for interior doors and walls. Finally, insulation was installed to save energy and reduce resource consumption for sustainable aims. The location of the building in Iran is illustrated in Figure 12.

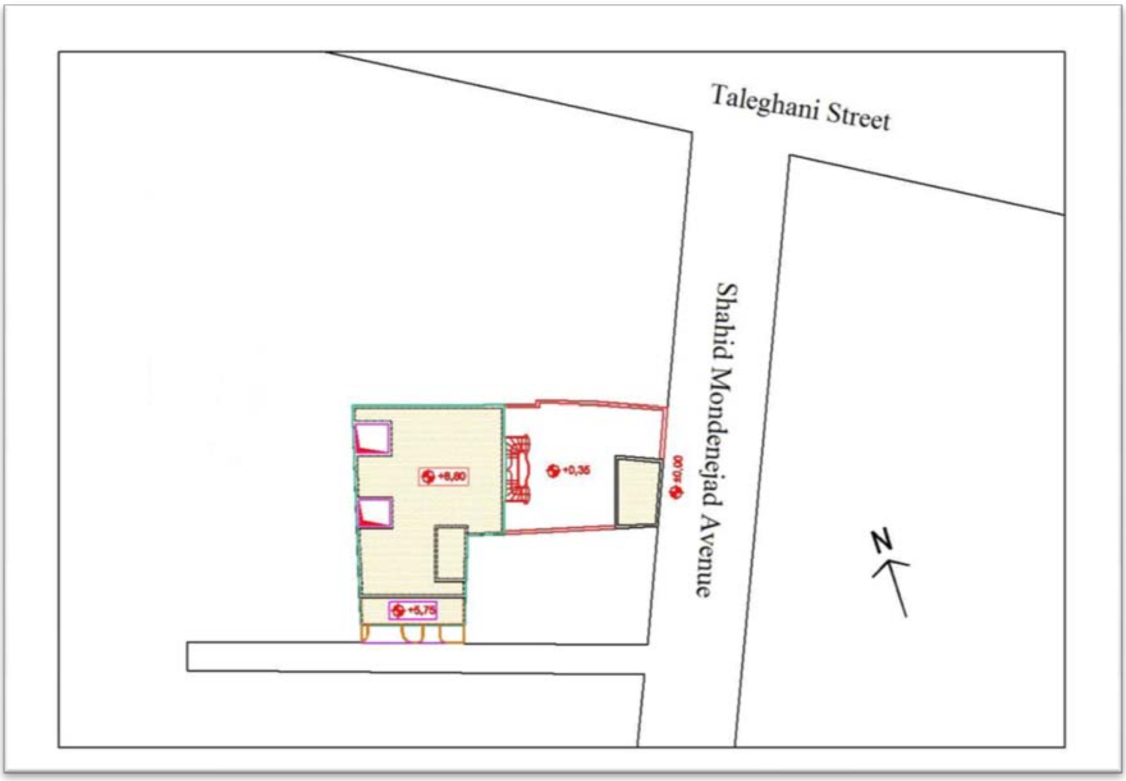

Figure 12: Location of the building, Dezful, Iran

Based on the scope and aims of thesis which requires detailed examination of building for assessment of lifecycle, drawings are presented in Figures 13 to 18.

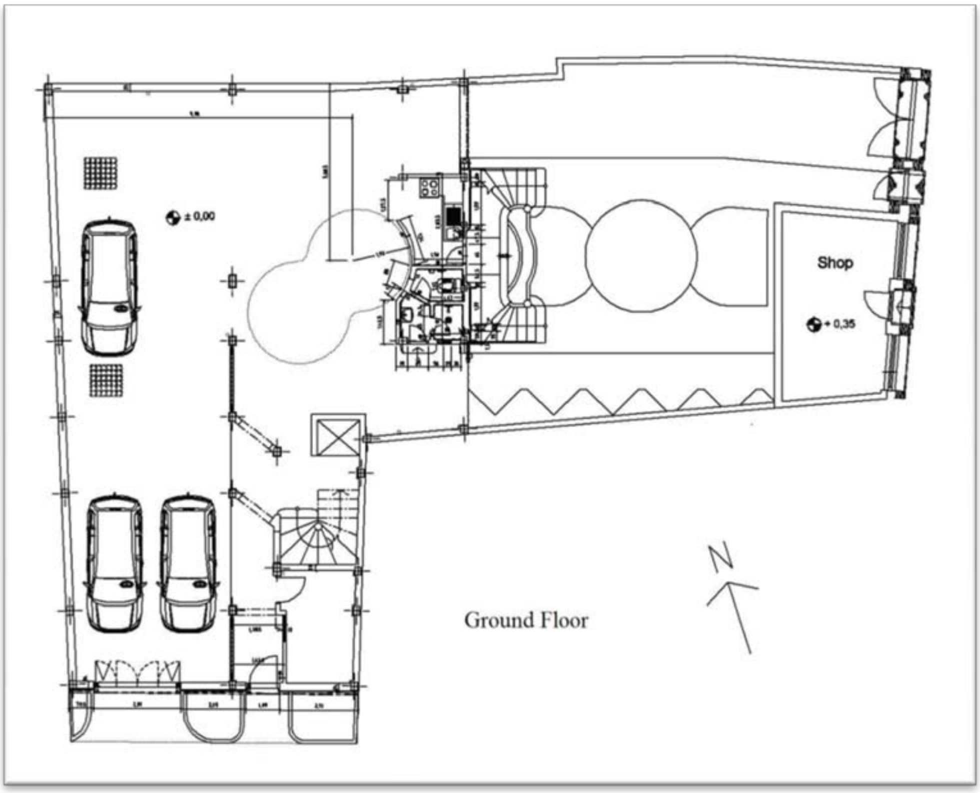

Figure 13: Plan of the building for Ground Floor

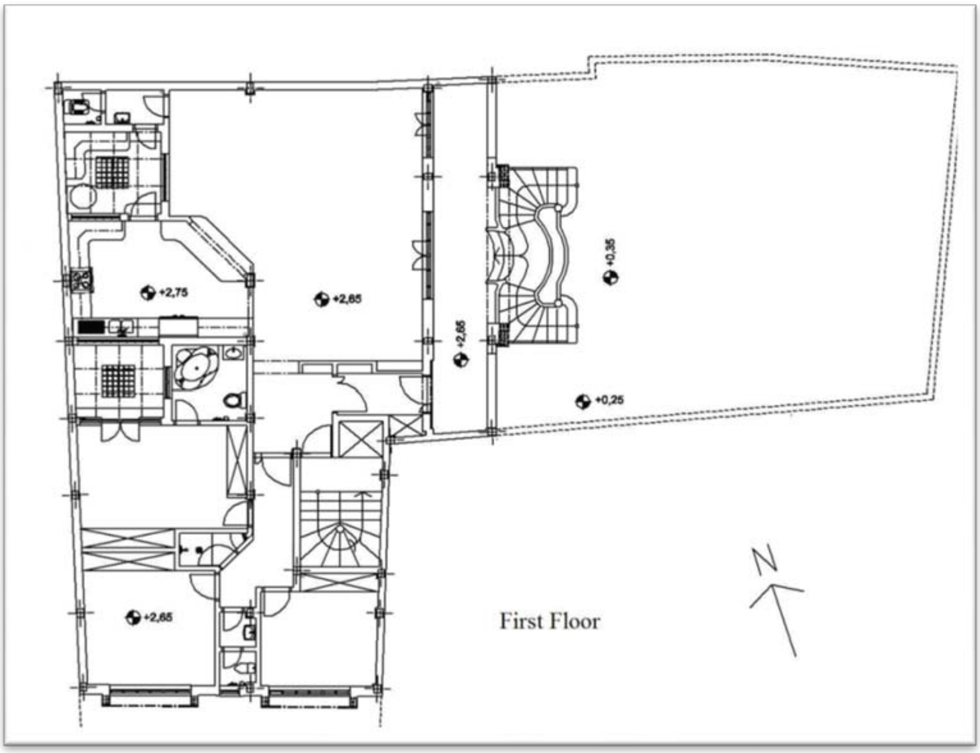

Figure 14: Plan of the building for First Floor

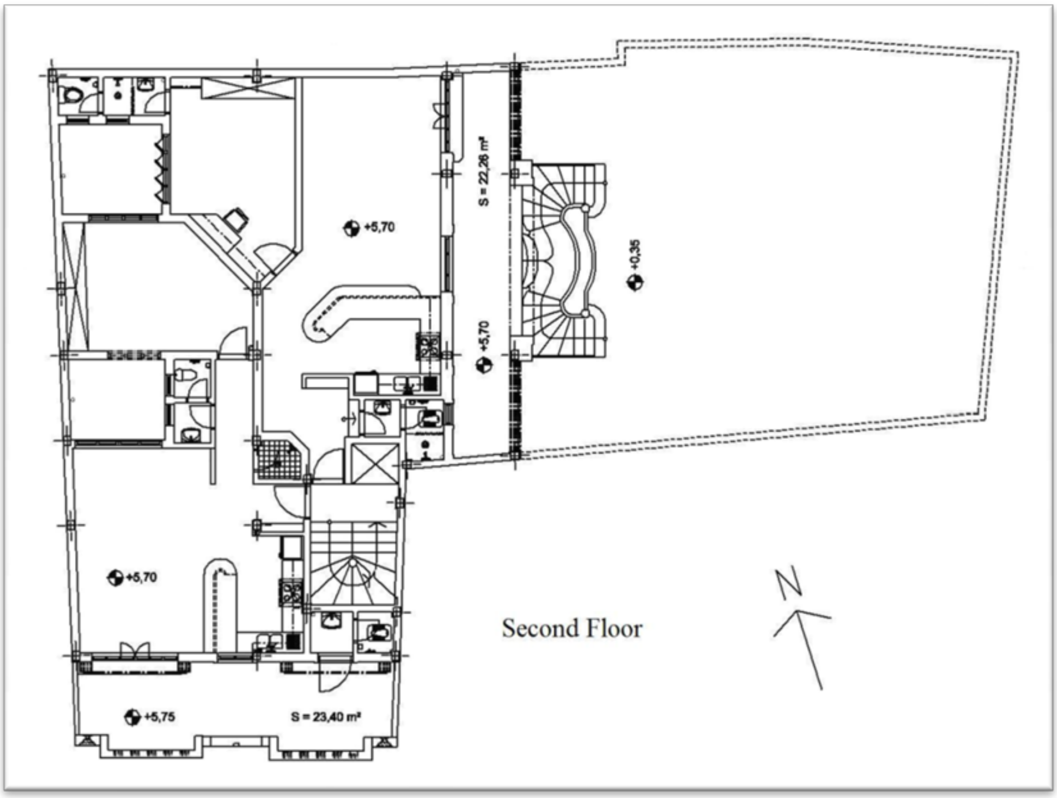

Figure 15: Plan of the building for Second Floor

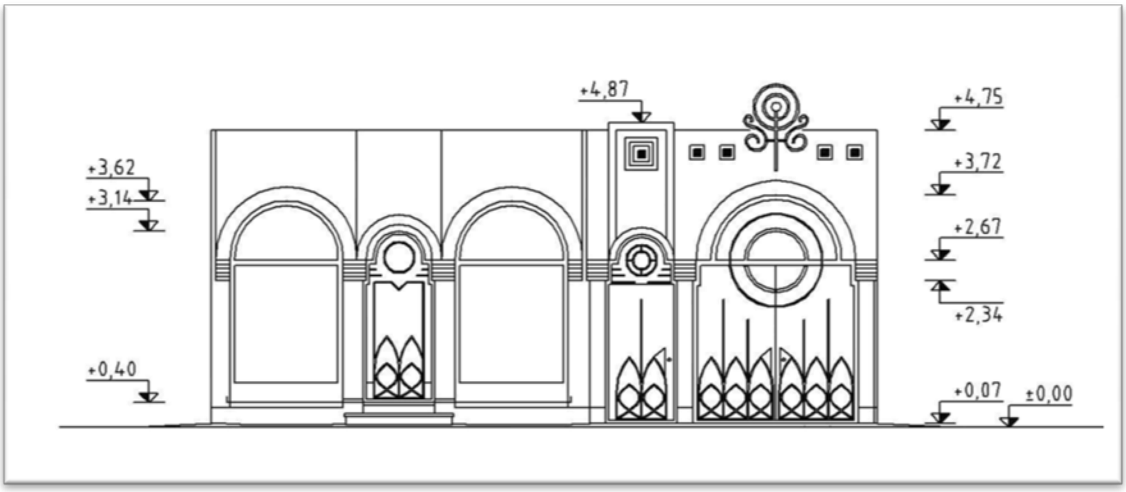

Figure 16: Eastern view of the building from outside

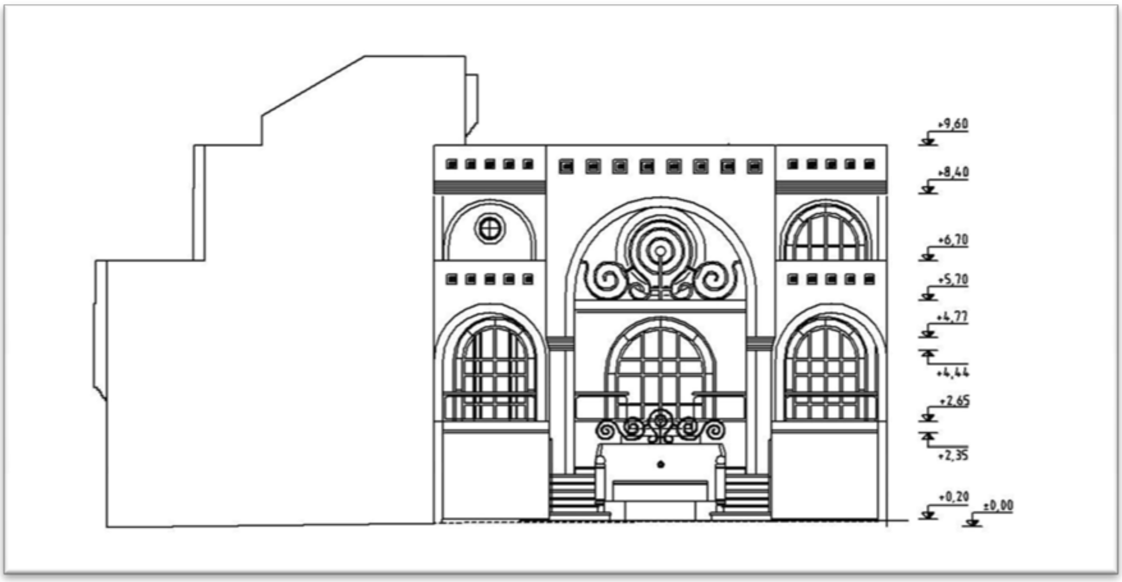

Figure 17: Eastern view of the building from inside

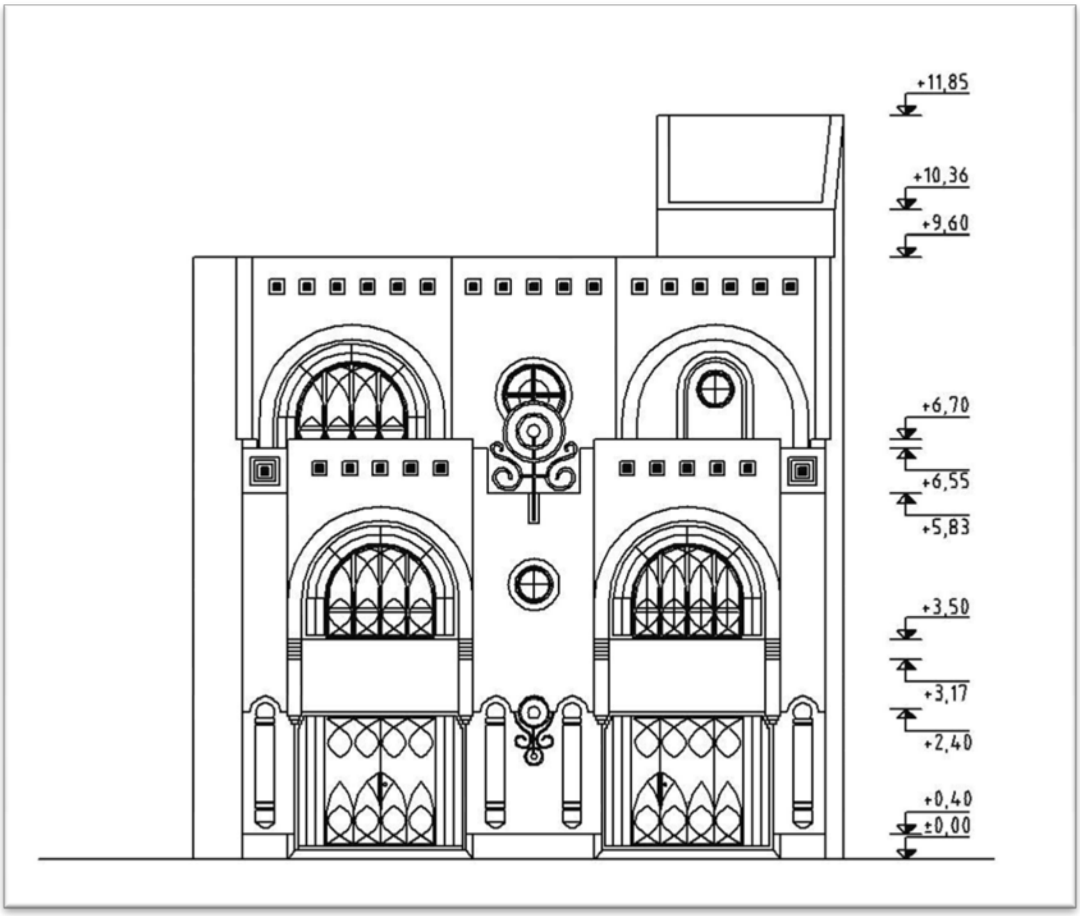

Figure 18: Southern view of the building

Chapter 5

DATA ANALYSIS

5.1 Introduction

For the aim of sustainability analysis, with the help of Green Building Studio and building information modeling the lifecycle of case study which is two-storey residential building is evaluated.

In this chapter, the outcomes obtained from the case study which include lifecycle energy and cost analysis of building for three components alternatives and building adaptive reuse potential before demolition of building to show two practical ways for builders and designers that if take into account before any decision can help to reduce negative influences on lifecycle consumption .

5.2 Lifecycle Analysis

So far, many tools and methods have been used for analysis of the pros and cons of different building components on energy consumption. One of the most powerful tools is Green Building Studio which by the help of building information modeling can contribute to analyze lifecycle in buildings. For using building information modeling tools in favor of assessing influence of materials on energy consumption, many approaches are considered. These approaches can be classified as whether related to building's form or building's components. However, the most important technique engages to utilization of green construction materials. For the implementation of sustainability, the engineers should establish their purposes towards using sustainable materials and techniques in their designs. To achieve this intention, a great amount of information and knowledge about the nature and character of building materials is required. It is the responsibility of materials experts to introduce sustainable materials with lowest quantity of embodied energy to design team from the first stage of projects. Meanwhile, building information modeling tools can help material engineers to define new materials with their characteristics and specifications to be used for further designs.

To meet the project requirements, one of the best ways is to use building information modeling to reduce the time of design, increase project efficiency, and provide engineer, designers and architects more fully developed project alternatives. However, for obtaining outcomes, it is important to bear in mind that most of the software would give us best results if we used them from the beginning of project and iteratively. It means that as soon as designers prepared basic designs, building information modeling will help us to create single adjustment and continue piece by piece examination for each building's components.

5.2.1 Annual Cost of Energy

Amount of energy consumption during the lifecycle of buildings is related to weather conditions, nature of social and culture of community, and most important rate of energy efficiency of the building. Cost of annual energy consumption is calculated based on unit price of electricity and gas which is different in each country and when we define the location of the building in Green Building Studio will be determined.

5.2.2 Lifecycle Energy and Cost Analysis for Three Alternatives

For analyzing lifecycle energy which has direct impact on lifecycle cost, many different factors can be evaluated. Therefore, after several interviews that held with native architects, there was a consensus that main parts of the envelope of the buildings have maximum influences on lifecycle. Because, heating and cooling, lighting, internal comfort of residents and ventilation which are principal responsible for energy consumption are directly under influence of envelope of the building. For example, windows to wall ratio, thermal mass or heat conductivity of the wall and orientation of building are some factors that if not designed correctly, can double or more the energy consumption. Hence, in spite of a lot of materials and building systems, it was decided to analyze walls and roof of the building. So, based on climate conditions of southern part of Iran which is hot and humid, three types of most popular walls and roof systems were selected. General information of the selected walls and roofs are listed in Table 2.

Table 2: Feature of different walls and roof systems (Autodesk, 2012)

Alternative 1	**Metal Frame Wall without Insulation and Metal Frame Roof without Insulation**					
Alternative 2	**Wood Frame Wall with super high Insulation and Wood Frame Roof with super high Insulation**					
Alternative 3	**Wall with Structural Insulated Panels and roof with Structural Insulated Panels**					
Criterion	**Heat conductivity**	**Salvage value**	**Assembly insulation**	**Moisture resistance**	**Load bearing**	**Thermal mass**
Alternative 1	**Excellent**	**Excellent**	**Bad**	**Bad**	**Good**	**Bad**
Alternative 2	**Good**	**Bad**	**Good**	**Good**	**Bad**	**Excellent**
Alternative 3	**Bad**	**Good**	**Excellent**	**Excellent**	**Excellent**	**Good**

As mentioned earlier, three alternatives were selected and based on the criterion of each alternative, project lifecycle energy and cost were evaluated. The assessment was based on the nature of each alternative which was according to heat conductivity, salvage value, assembly insulation, moisture resistance, load bearing, and thermal mass that can be seen in Table 2. Green Building Studio calculates different amount of energy consumption which is directly related to project lifecycle cost. Lifecycle cost was calculated based on annual unit price of energy that can be defined separately for each location. Therefore, three models for roof and wall structure were analyzed and as a result, most excellent model according to lifecycle energy and cost was ranked. The interpretation of each feature for building lifecycle can be seen in Table 3.

Table 3: Interpretation of building lifecycle features (Autodesk, 2008)

Terminology	Interpretation
Annual energy cost	The estimated total annual utility cost for all electricity and fuel used by the project.
Lifecycle energy costs	The estimated total cost for all electricity and fuel used by project over a 30 year period.
Annual energy consumption	The estimated measure of how much electricity and fuel project may use during a typical one-year-period
Lifecycle energy consumption	The estimated measure of how much electricity and fuel project may use during a 30-year-period.
Total Annual Energy Cost	The estimated total annual utility cost for all electricity and fuel used by the project.
Total Annual Electric Cost	The estimated total annual cost for all electricity consumed by the project.
Annual Peak Electric Demand	The estimated highest electricity usage during any one hour for the year.
Annual Electric Use (kWh)	The estimated annual electricity usage for the project, measured in kilowatt-hours (kWh).
Energy Use Intensity (EUI)	A measure of the combined electricity and fuel used by the project, per area (square meter in SI units) per year. For this metric system the electricity usage is converted from kWh units to kBtu units in the imperial system.
1 kWh = 3.412 kBtu. In the international system of units electricity is converted to MJ. 1kWh = 3.6 MJ	

Lifecycle results and outcomes for three different alternatives are illustrated in Tables 4, 5 and 6.

Table 4: Lifecycle results of Autodesk Green Building Studio for Alternative 1

1. Metal Frame Wall without Insulation and Metal Frame Roof without Insulation Estimated Energy & Cost Summary		
Annual Energy Cost	$7,658	
Lifecycle Cost	$104,302	
Annual Energy		
Electric	54,939	kWh
Fuel	79,556	MJ
Annual Peak Electric Demand	33.8	kW
Lifecycle Energy		
Electric	1,648,176	kWh
Fuel	2,386,670	MJ

Table 5: Lifecycle results of Autodesk Green Building Studio for Alternative 2

2. Wood Frame Wall with super high Insulation and Wood Frame Roof with super high Insulation Estimated Energy & Cost Summary		
Annual Energy Cost	$ 4,948	
Lifecycle Cost	$ 67,395	
Annual Energy		
Electric	35,713	kWh
Fuel	29,977	MJ
Annual Peak Electric Demand	20.7	kW
Lifecycle Energy		
Electric	1,071,404	kWh
Fuel	1,818,146	MJ

Table 6: Lifecycle results of Autodesk Green Building Studio for Alternative 3

3. Wall with Structural Insulated Panels and roof with Structural Insulated Panels Estimated Energy & Cost Summary		
Annual Energy Cost	$ 4,165	
Lifecycle Cost	$ 56,731	
Annual Energy		
Electric	30,020	kWh
Fuel	29,450	MJ
Annual Peak Electric Demand	16.6	kW
Lifecycle Energy		
Electric	900,613	kWh
Fuel	883,486	MJ

As depicted in Tables 4, 5 and 6,the most economic lifecycle energy consumption acquired based on Alternative 3 as opposed to Alternative 1 which spoiled energy because lack of thermal mass, insulation and etc. Figures 19, 20 and 21 are shown Monthly electricity usage for Alternative 1, 2 and 3.

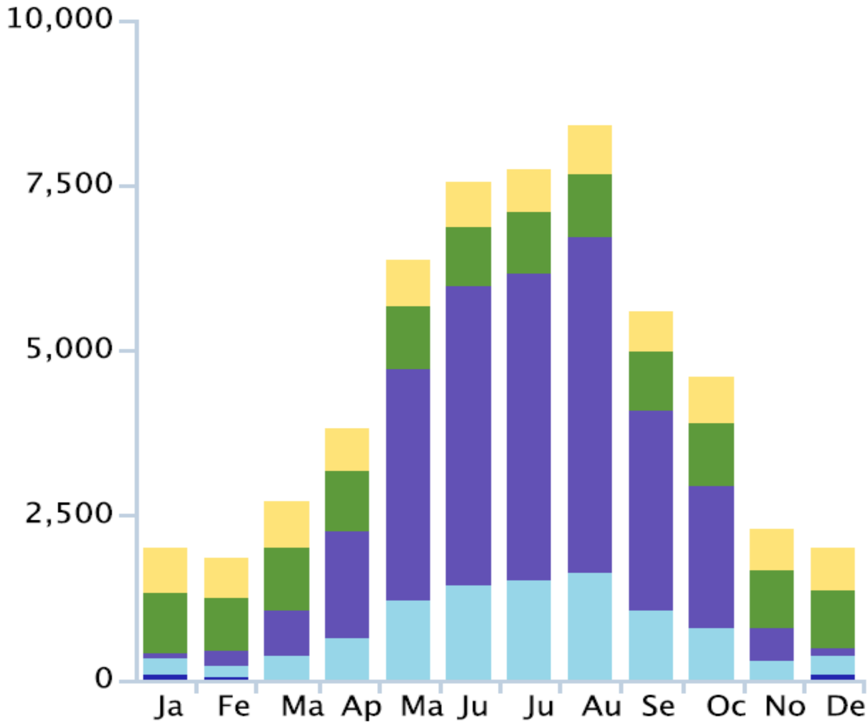

Figure 19: Monthly electricity usage for Alternative 1

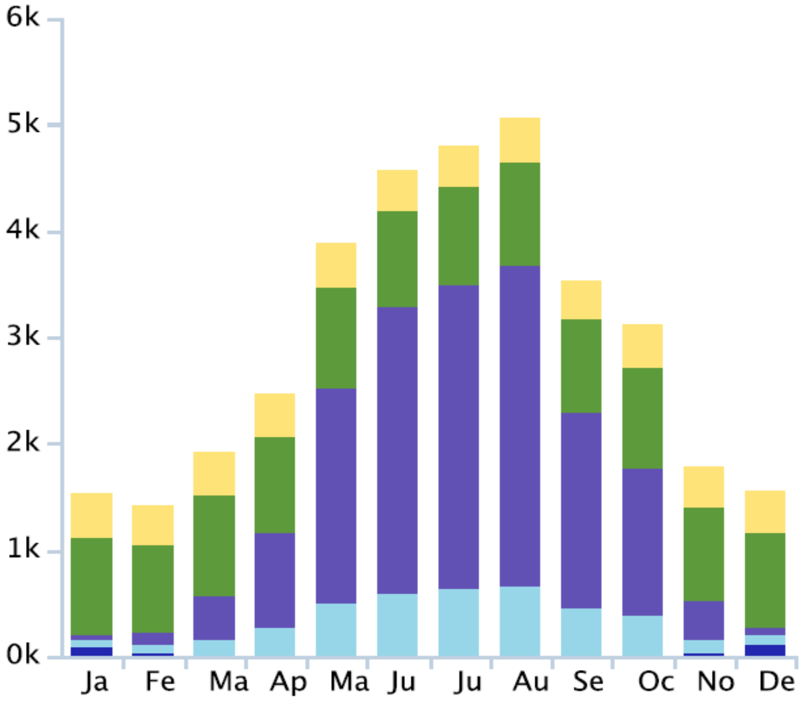

Figure 20: Monthly electricity usage for Alternative 2

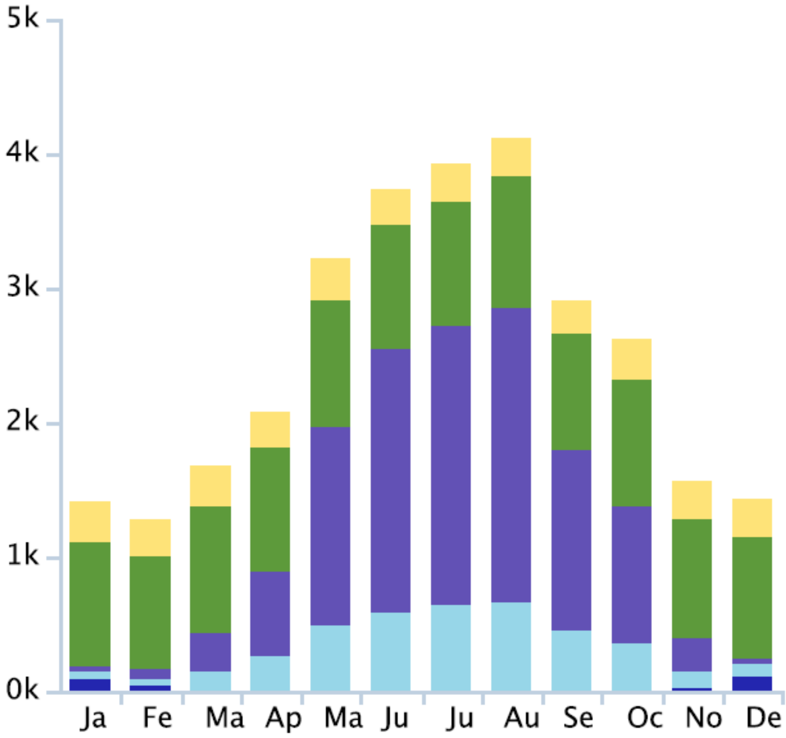

Figure 21: Monthly electricity usage for Alternative 3

5.3 Building Adaptive Reuse Potential

Adaptive reuse can be defined as a method of adjusting an old building by a specific usage with a new responsibility by extending its physical life when its main duty is not necessitate anymore.

Demolition of building has many negative effects for human and environment. It raises the quantity of construction rubbish as well as needs to use huge volume of fossil fuel for hauling it to appropriate location or suburb of city to be dump. On the other hand, demolition of a project makes terrible noises and distribution of dust particles that is harmful for people and urban aesthetic. As opposed to demolition, renovation and restoration of a historical building can contribute to beauty and culture of metropolitan as well as decreasing the usage of raw materials and air pollution. As a result, the amount of energy consumption and unnecessary expenditure will be eliminated. So, just avoiding the time consuming and cost prohibitive process of demolition solely is a good reason for building adaptive reuse (Adaptive reuse, 2004). The significant benefits for adaptive reuse include "sustainability, reduced embodied energy, and decreased liability exposure. Therefore, the benefits of adaptive reuse against demolition of assets can be tremendous" (Frey, 2008).

For having a sustainable design, considering potential for another usage of the building than its main purpose is a fundamental principle (Danatzk, 2010). For example, bear in mind an architect that for the design of a school has enough insight and prospective to give sufficient flexibility to building that after 30 years usage, instead of demolition, the building changes its first purpose to a warehouse and continues its life in a new form. “Under certain conditions, sustainable adaptive reuse is a more viable alternative that can help to improved environmental and social benefits, decreased environmental impact, energy savings and cultural continuity between past and future” (Theodoridou, 2010). However, if after assessing the potential adaptive reuse of a building, we find that demolition is the only possible solution, at this situation the more sustainable way is to recycling leftover materials and use them into a new form (Raut et al., 2011).

“The ARP model developed by Langston et al. (2008) identifies and ranks adaptive reuse potential in existing buildings, and therefore can be described as an intervention strategy to ensure that combined social, environmental and economical values are planned”. This method can be used in different countries and for each type of construction project. For using this model we have to choose our desired building and by using building life calculator software, we can calculate approximately the anticipated age of the building. Meanwhile, based on accurate examination of the building and its surrounding environment in present and past time, we can assess building obsolescence. For example, if our historical building has experienced a major period of lack of maintenance strategy, it is obvious that physical obsolescence will increase.

Obsolescence is a principle factor for decreasing the anticipated natural age of a building to its anticipated useful age. For example a building after twenty years may be safe just for 10 years more because of high rate in obsolescence factors. Therefore, “existing buildings in an organization’s portfolio, or existing buildings across a city or territory can be ranked according to the potential they offer for adaptive reuse at any point in time” (Langston and Shen,2007).

The diagram in Figure 22 is divided into three equal parts with each part representing specified rate for building adaptive reuse that illustrated in Table 7.This model was first used and developed by Langston and Shen (2007) to show the potential of buildings for extending their lives against immature demolition. At this model, potential is defined as susceptibility of a project to being protected, renovated and maintained for a new sustainable life. “Adaptive reuse potential is conceptualized as raising from zero to its maximum score at the point of its useful life, and then falling back to zero as it approaches physical life” (Langston, 2008).The reason is that as time goes by, the curve drops because of obsolescence. It means that at first when the building is new and obsolescence factor is very low, there is a high possibility for each type of usage, however after several decades, when the building is worn out, the probability of new usage is also negligible.

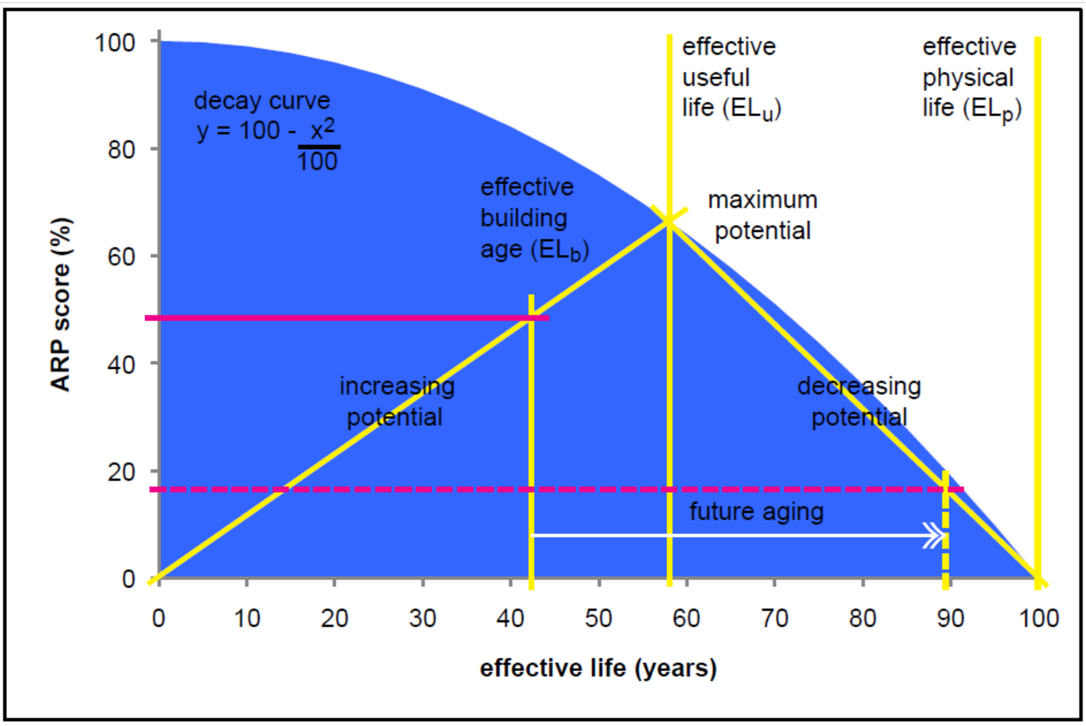

Figure 22: Diagram for estimating adaptive reuse of a project (Langston, 2008)

Table 7: Rate of building adaptive reuse for different building's age

Adaptive reuse scores	**Adaptive reuse potential**
Scores in excess of 50%	High adaptive reuse potential
Scores between 20% and 50%	Moderate potential
Scores below 20%	Low value

The shape of the mountain depicting the rise and fall of adaptive reuse potential that is a function of the obsolescence factors are deemed to apply. "High rates of obsolescence mean lower useful lives and ARP profiles skewed towards the short term, while low rates of obsolescence mean higher useful lives and ARP profiles skewed towards the long term" (Langston, 2008).

5.3.1 Obsolescence of Building

From financial and social views, buildings are one of the most important properties of each person. In the meantime, because preservation of buildings is an ongoing process, it is very essential for the owners of buildings to protect their assets from immature obsolescence and unwilling retirement. However, after several decades, it is inevitable to keep building away from obsolescence. Therefore, this is the best time for an engineer to make a decision to whether renovate a building or demolish it (Langston and Lauge-Kristensen, 2002).

As construction managers, we are familiar with different types of renovation from repairing an imperfection part of a building to a main restoration. In some situations, surface of building is in fine situation, but the structure and major parts of the building are out of service where renovation and repair cannot be undertaken and demolition is required. On the other hand, if the principal parts of the building such as structure are in a good shape but the usage of the building at the current time is not appropriate, adaptive reuse of the case is required. In the mean time, for some cases in the process of demolition versus retrofitting, there is an exception. From social point of view of the sustainability, some buildings and projects cannot be demolished and in every condition engineers require protecting them. For instance, an ancient monument such as the Egyptian Pyramids cannot be demolished at all. At this situation, the obsolescence factors or even building adaptive reuse is no longer relevant. So, "older buildings may have a characteristic that can significantly contribute to the culture of a society and conserve aspects of their history. The preservation of these buildings is important and maintains the community intrinsic heritage and cultural values" (Langston and Lauge-Kristensen, 2002).

Construction managers perpetually encounter with such situations either to hire a house or purchase it, either to get or sell it and either to renovate or demolish it. But this argues are just fiscal aspects of decision making, however, construction managers should think more about environmental and social issues in construction sector. Buildings like other artificial manufactures are imposed to weariness, exhaustion and as a result collapse. Besides, building useful life that is recognized as a structural capacity and competence is gradually decreased because of environmental and physical conditions.

"The useful life of a building or other asset in the past has been particularly difficult to forecast because of premature obsolescence which is described as seven attributes of physical, economic, functional, technological, social, legal, and political" (Seeley, 1983).

5.3.2 Adaptive Reuse Assessment and Physical Life Forecast of the Building

For assessment of physical age of a project, a model was created by Langston (2008). The anticipated physical age of the case study was evaluated to be 50 years as depicted in Figure 23. Based on several questions about the general conditions of the building and its environment, the physical age of the building could be found. “A series of questions give insight into the longevity of a building according to three primary criteria namely environmental context, occupational profile and structural integrity”.

Physical life worksheet

	suggested forecast (years) =		**50**
	Two-storey residential building		
	The building was built originally as a two-storey residential building in Dezful,Iran. It is constructed from masonry and concrete.		**y/n ?**
environmental context	Is the building located within 1 kilometre of the coast?		y
	Is the building site characterised by stable soil conditions?	#	n
	Does the building site have low rainfall (<500mm annual average)?		n
	Is the building constructed on a 'greenfield' site?		y
	Is the building exposed to potential flood or wash-away conditions?		n
	Is the building exposed to severe storm activity?		n
	Is the building exposed to earthquake damage?		n
	Is the building located in a bushfire zone?		n
	Is the building located in an area of civil unrest?	#	y
	Are animals or insects present that can damage the building fabric?	#	y
occupational profile	Is the building used mainly during normal working hours?		y
	Are industrial type activities undertaken within the building?	#	y
	Is the building open to the general public?		n
	Does the building comprise tenant occupancy?		y
	Is a building manager or caretaker usually present?	#	n
	Is the building intended as a long-term asset?	#	n
	Does the building support hazardous material storage or handling?		n
	Is the building occupation density greater than 1 person per 10 m^2?		n
	Is the building protected by security surveillance?		y
	Is the building fully insured?		n
structural integrity	Is the building design typified by elements of massive construction?		n
	Is the main structure of the building significantly over designed?		y
	Is the building structure complex or unconventional?		n
	Are building components intended to be highly durable?	#	n
	Are there other structures immediately adjacent to the building?		y
	Does the building have a stable footing system?	#	y
	Was the workmanship standard for the project high?		n
	Is the roof design susceptible to leaking in bad weather conditions?	#	y
	Is the building protected against accidental fire events?		n
	Is the building designed as a public monument or landmark?		n

Figure 23: Assessment of physical life of the case building

5.3.3 Deduction of Physical Age of the Building by Obsolescence Factor

For calculating obsolescence of the building, seven factors are considered as explained in Tables 8 and 9.

Table 8: Definition of obsolescence (Part1), (Langston and Shen, 2007)

Obsolescence	score
Physical obsolescence Can be measured by an examination of maintenance policy and performance. Useful life is effectively reduced if building elements are not properly maintained.	A scale is developed such that buildings with a high maintenance budget receive a 0% reduction, while buildings with a low maintenance budget receive a 20% reduction. Interim scores are also possible, with normal maintenance intensity receiving a 10% reduction.
Economic obsolescence Can be measured by the location of a building to a city centre or central business district. Useful life is effectively reduced if a building is located in a relatively low populated area.	A scale is developed such that buildings sited in an area of high population density receive a 0% reduction, while buildings sited in an area of low population density receive a 20% reduction. Interim scores are also possible, with average population density receiving a 10% reduction.
Functional obsolescence Can be measured by determining the extent of flexibility imbedded in a building's design. Useful life is effectively reduced if building layouts are inflexible to change.	A scale is developed such that buildings with a low flexibility receive a 0% reduction, while buildings with a high flexibility receive a 20% reduction. Interim scores are also possible, with typical flexibility receiving a 10% reduction.
Technological obsolescence Can be measured by the building's use of operational energy. Useful life is effectively reduced if a building is reliant on high levels of energy in order to provide occupant comfort.	A scale is developed such that buildings with low energy demand receive a 0% reduction, while buildings with intense energy demand receive a 20% reduction. Interim scores are also possible, with conventional operating energy performance receiving a 10% reduction.

Table 9: Definition of obsolescence (Part2), (Langston and Shen, 2007)

Obsolescence	score
Social obsolescence Can be measured by the relationship between building function and the marketplace. Useful life is effectively reduced if building feasibility is based on external income.	A scale is developed such that buildings with fully owned and occupied space receive a 0% reduction, while buildings with fully rented space receive a 20% reduction. Interim scores are also possible, with balanced rent and ownership receiving a 10% reduction.
Legal obsolescence Can be measured by the quality of the original design. The rationale for this is that higher quality leads to higher compliance levels against future (usually increasing) statutory requirements. Useful life is effectively reduced if buildings are designed and constructed to a low standard.	A scale is developed such that buildings of high quality receive a 0% reduction, while buildings of low quality receive a 20% reduction. Interim scores are also possible, with average quality receiving a 10% reduction.
Political obsolescence A less publicized concept can be measured by the level of public or local community interest surrounding a project. Useful life is effectively reduced if there is a high level of (restrictive) political interference expected.	A scale is developed such that buildings with a low level of interest receive a 0% reduction, while buildings with a high level of interest receive a 20% reduction. Interim scores are also possible, with normal public and local community interest receiving a 10% reduction. Where a project can receive a significant benefit from political interference, rather than a constraint, it is feasible to extend the assessment scores into the positive range (-20% to +20%).
Note: In addition to the above, environmental obsolescence is obviously relevant to today's society and arguably deserving of individual assessment. But in this study environmental issues are subsumed within technological obsolescence given the choice of an energy intensity surrogate. As the marketplace continues to become more sustainability conscious, social, legal and political obsolescence will increasingly reflect the environmental agenda.	

Therefore, obsolescence of case building was evaluated and can be seen in Tables 10 and 11 yielding a total obsolescence rate of 75% over 50 years or 1.5% per annum on average.

Table 10: Total obsolescence scores of the building (Part 1)

Obsolescence	Score	Reason
Physical	10%	For the building, maintenance was minimal for some years of its life, and it has been left without enough repairs recently, so a score of 10% has been chosen.
Economic	5%	The building would receive a 5% reduction as it sits is in the densely populated areas of Dezful, Iran.
Functional	10%	Functional obsolescence is moderate and would receive a 10% reduction because the design of structure of building has some flexibility for future changes.
Technological	5%	The building has a plan with appropriate ventilation openings and sealed windows all around. It has little reliance on mechanical systems for occupancy. A value of 5% for technological obsolescence has therefore been selected.

Table 11: Total obsolescence scores of the building (Part 2)

Obsolescence	Score	Reason
Social	10%	The building, although starting its life as a shop front with residence above, has relied to somehow on the income of the tenants. So, A 10% reduction is therefore taken.
Legal	15%	For the building a 15% reduction is applicable because legal precautions were very low at the time of construction.
Political	20%	The building would receive 20% reduction because at that time building underwent war and revolution situations.

5.3.4 Useful Life Estimation

To find the right answer for the useful age of the building, physical age of the project should be firstly calculated which was previously explained. The building was constructed in 1968 and the physical age is calculated at 50 years. “The useful life is determined by discounting the physical life by obsolescence, comprising physical, economic, functional, technological, social and legal criteria. Useful life is then determined through application of Equation 1” (Langston et al., 2008).

$$\text{Useful Life } (L_u) = \frac{L_p}{(1+\sum_{i=1}^{7} O_i)} \qquad \text{(Eq. 1)}$$

Where L_p is the physical life and O_i is the obsolescence type i as listed in Tables 10 and 11. Using these associate values results in a useful life of 23.8.

According to preceding outcomes which give us the answer for physical and useful age as well as the estimation of effective useful life, effective building age, and effective physical life, the outcome for APR is 17.7%. The result is a low potential for reuse and renovation of the building and demolition is accepted for the owner as an alternative. “Values for EL_u (effective useful life) and EL_b (effective building age) are determined by multiplying L_u and L_b by 100 and dividing by L_p respectively” (Langston et al., 2008).

Chapter 6

SINDEX

6.1 Introduction

For the aim of sustainability assessment in this thesis, according to the literature review, one of the appropriate tools and software considered. Sindex, is a tool which based on a weighted evaluation technique and according to four different criteria can rank projects to whether a project is acceptable form sustainable point of view or not. Using this method for Iran’s construction can be beneficial and it can change the fast pace of construction towards more reasonable development. Because, owners and developers can be able to take into account all aspect of sustainability and decide to have a balance approach for construction.

This chapter is consisted of the case study and includes a method for sustainability assessment of building to assess and evaluate the case study based on social, economic and environmental criteria.

Case study approach was considered to find the sustainability of the building based on four different criteria, and to demonstrate the application of sustainability index to rank buildings. Data on the four criteria included in the model were collected in accordance with:

- Financial analysis of project based on building lifecycle cost
- Energy requirements of the building based on lifecycle energy
- Analyze contribution of the building to society based on social criteria, and
- Environmental assessment of project according to risk evaluation questionnaire.

6.2 Sustainability Index as a Benchmarking Tool

In recent years, by taking advantage of sustainability index, engineers have a good method for achieving sustainable aims in construction industry as it employs a multi criteria approach that measures economic, social and environmental aspects for evaluating projects and buildings. Sindex is a software for measuring the degree of sustainability and targeting the building for finding that to what extent building is sustainable. Sindex with the help of computer tools can let to calculate the social, environmental and economic level of a building or project (Ding , 2004).

Environmental issues need an ongoing consideration and need to be taken into account by builders and designers. So, as time goes by, the authorities have to change and update the environmental standards and codes for more preventive measures. For having sustain environment, the pace of growth should be sustainable and being according to sustainability aims. If we want to have less impact on environment and preserve it for next generation, there should be a target for engineers to measure balance approach between economy and environment. The sustainability index is a lifecycle assessment tool that combines economic, social and environmental criteria (Ding, 2004).

Therefore, sustainability assessment of buildings and lifecycle analysis are valuable techniques to support engineers and architects to bear in mind all the sustainability factors as specified by previous authors in projects and building design. For this aim, a rating system according to four factors is considered during the construction phase to allow acceptance or rejection of buildings depending on sustainability rating factors (Langston, 2003).

The factors which are considered in Sindex are main criteria for measuring sustainability of projects and using decision making tool for rating projects. The software was developed by Professor Craig Langston in response to a request from the Australian Institute of Quantity Surveyors to develop a computer-based tool for sustainability modeling to be used by practitioners both in Australia and overseas and it can be easily used for international buildings and projects. Sindex can assess and evaluate a sustainable rate as developed for the purpose of ranking and selecting projects based on their performance. The four criteria in software can be seen in four windows which are elaborated below and includes (Ding, 2004):

6.2.1 Maximize Wealth - A Factor for Viability of Project's Investment

One of the main goals and aspirations for each project is to increase the profit and maximize wealth. For measuring this criterion, our point of reference for evaluation is "benefit-cost ratio (BCR). BCR is calculated as the discounted project income divided by the discounted life-cost measured over the economic life of a development" (Ding, 2004). Therefore, for this criterion, the aim is to increase ratios and as a result increase project's profit. By default in the software, 1:1 is a position at which earns and losses are the same and cost and benefits are calculated in terms of present value. Building expenses consist of primary costs in the beginning of the project and the following costs in operation stage, preservation and substitute of defect components as well as cost per year during the tenancy phase of a building. Project revenues are calculate based on amount of hiring income and other probable financing sources such as administration financial supports and donations which can be granted by governments or other secondary sources.

6.2.2 Minimize Resource - A Factor for Evaluation of Energy Usage

The amount of consumptions in building during its operation is shown in minimize resource window of software which is used for the assessment of energy usage during the lifecycle of the building. Minimizing resources is a different economic factor and can be measured by calculating the amount of embodied energy that is consumed in construction and preservation as well as the operational energy used for occupancy requirements. All energy values are entered as GJ or GJ/m^2.

6.2.3 Maximize Utility - A Factor for Non-Monetary Profits

Utility is a functional capability of a building and comprises of non-monetary profits like functionality, beauties, heat and cooling retention or conduction, tenant comfort, adaptive reuse potential, flexibility, community benefits and tourism potential. The functional performance is described according to the ways that the building is supposed to contribute to its occupants, for example sport facilities or hospital and etc. Functional performance is a social criterion and is an area that designers, developers and users want to maximize.

6.2.4 Minimize Impact - A Factor for Evaluating Environmental Impacts

The minimize impact is a part of the software which evaluates the habitat destruction and impact of project for biodiversity of environment and is an environmental criteria for considering the probability of environmental harm created during the project lifecycle. The factors to minimize impact are rated by a questionnaire in different parts which include: production, design, construction, operation and destruction.

Based on above mentioned criteria, the software can assess whether a building has minimal impact on environment or maximize by answering to different questions such as if hazardous materials such as asbestos are used in building and etc.

Therefore, by defining all requirements of Sindex for four criteria, we can be confident that the project is valuable from sustainability point of view or not. After all requirements of the project are defined as an input, then based on indexing algorithm we can understand that how much our project is contributing to sustainability (Langston and Ding, 2001).

6.3 Data Collection and Sustainability Analysis

For using Sindex in this thesis, the essential information related to the case study was collected to satisfy all criteria. For assessment of economic criteria, detailed information related to lifecycle cost of the building was collected. In addition, several interviews conducted with owner and engineers of the building to gather data for energy consumption and environmental risk assessment of the project and finally by doing accurate interview with owner of the building each question related to the aim and scope of sustainability assessment was responded. There are four steps for finding the best score and results for this analysis which can be seen below in a chronological order.

6.3.1 Firs Criteria-Maximize wealth

For calculating life cycle of building, discount cash flow which is the first economic criteria and is shown in Figure 24, the basic concept of value management was used.

First of all, the initial cost of the building calculated based on the available bill of quantity and unit price of Iran as well as prepared drawing which is $200,000 based on the reference rate of US dollar and Iran currency. The initial cost includes costs associated with construction of the building or costs of labor, materials, equipment and overhead. It is worthwhile to mention that for lifecycle assessment in discounted cash flow technique three formulas were used. The discounted cash flow, DCF, is calculated as:

$$\mathrm{DCF} = \frac{\mathrm{CF\,1}}{(1+\mathrm{r1})^{1}} + \ldots + \frac{\mathrm{CFn}}{(1+\mathrm{r1})^{\mathrm{n}}} \qquad \text{(Eq.2)}$$

Where CF is the cash flow and r is the discount rate.

Net present value, NPV, is calculated as:

$$\mathrm{NPV}=\sum_{1}^{n} \text{Discounted net benefit} \qquad \text{(Eq.3)}$$

Benefit cost ratio, B/C, is calculated as:

$$\frac{\mathrm{B}}{\mathrm{C}} = \sum_{1}^{n} \frac{\text{benefit}}{\text{cost}} \qquad \text{(Eq.4)}$$

Maximize Wealth (Discounted Cash Flow)

	Cost	Benefit	Net Benefit	Discounted Net Benefit
Year 0	200000	0	-200000	-200000
Year 1	3350	20000	16650	16165
Year 2	3350	20000	16650	15694
Year 3	3350	20000	16650	15237
Year 4	3350	20000	16650	14794
Year 5	15350	20000	4650	4011
Year 6	3350	20000	16650	13944
Year 7	3350	20000	16650	13538
Year 8	3350	20000	16650	13143
Year 9	3350	20000	16650	12761
Year 10	15350	20000	4650	3460
Year 11	3350	20000	16650	12028
Year 12	3350	20000	16650	11678
Year 13	3350	20000	16650	11338
Year 14	3350	20000	16650	11007
Year 15	15350	20000	4650	2984
Year 16	3350	20000	16650	10375
Year 17	3350	20000	16650	10073
Year 18	3350	20000	16650	9780
Year 19	3350	20000	16650	9496
Year 20	15350	20000	4650	2575
Year 21	3350	20000	16650	8950
Year 22	3350	20000	16650	8690
Year 23	3350	20000	16650	8437
Year 24	3350	20000	16650	8191
Year 25	15350	20000	4650	2221
Year 26	3350	20000	16650	7721
Year 27	3350	20000	16650	7496
Year 28	3350	20000	16650	7278
Year 29	3350	20000	16650	7065
Year 30	3350	20000	16650	6860
Residual		10000	10000	4120

Discount Rate = 3

Net Present Value = 91110

BCR = 1.298702

Figure 24: Maximize wealth a factor for viability of a project's investment

For calculation of maximize wealth in Sindex, explanation and interpretation of terminology and requirements are explained in Tables 13 and 14. In the meantime, there are some assumptions related to the calculation of lifecycle. Cost of maintenance is for each 5 years and its equal to 30% of initial cost of building, however operational cost is annual. We have salvage value or residual scrape at years

30 as a benefit which for this project considered for the price steel which is the only valuable material at the end of life cycle. For maintenance cost, as depicted in Table 12, during the lifecycle of the building there is different proportion of expenses for different building components. For example, the amount of maintenance and replacement expenditure for glazing windows for lifecycle is totally different with the cost of maintenance for interior wooden doors. “The building life costs are compared with a standard format in accordance with the Australian Cost Management Manual” (Australian Institute of Quantity Surveyors, 2006). In building life cost of the case study, electrical and lighting are major source of expenses responsible for 23.27% of the entire lifecycle expenditures, then floor finishes is responsible for 13.45%, roof 7.85% and windows 4.93%. However, the proportions and percentages are mostly influenced by the quality and type of materials and climate situations such as humidity and temperature. The amount of yearly tax according to Iran regulation is equal to the below formula.

$$\text{Yearly tax} = (\text{1 year rent}) \times 75\% \times 9\% \qquad \text{(Eq.5)}$$

Where 9% and 75% are constant factors for discount of yearly rents based on Iran regulations.

Table 12: Average construction maintenance cost of the building by elements

Elements	Cost $	Proportion of total %
Roof	4,710	7.85
Walls	1,956	3.26
Windows	2,958	4.93
Doors	1,056	1.76
Wall finishes	2,910	4.85
Floor finishes	8,070	13.45
Ceiling finishes	1,926	3.21
Fixtures and fittings	2,586	4.31
Sanitary fixtures	1,758	2.93
Sanitary plumbing	1,032	1.72
Water supply	1,458	2.43
Gas services	1,530	2.55
Electrical & lighting	13,962	23.27
Roads, footpaths	1,638	2.73
Landscaping	1,158	1.93
Miscellaneous	11,292	18.82
Total	60,000	100

Table 13: Explanation of requirements for Maximize Wealth (Part 1)

Maximize wealth terminology and requirements	Interpretation
Life Cycle Cost	A sum of all costs of creation and operation of a facility over a period of time.
Life Cycle Cost Analysis	A technique used to evaluate the economic consequences over a period of time.
Discount Rate	The rate of interest that balances an investor's time value of money which for this analysis is 3%.
Study Period	The time period over which a Life Cycle Cost Analysis is performed.
Present Value	The current value of a past or future sum of money as a function of investor's time value of money.
Currency	All values are expressed in US$ in today's terms (2012) as the adopted discount rate is net of inflation which is 3%.
Initial Investment Cost	Any cost of creation of a facility prior to its occupation (one time start-up costs) which includes construction management, land acquisition, site investigation, design, construction and equipment. It has been estimated at $200,000. Detailed bill of quantity is prepared by designer.
Operating Cost (Future Expenses)	Cost of the function of a facility for electricity, water and gas for one year which was determined through an interview with facility manager and based on average consumption of luxurious residential family building is equal to $1000 per year.

Table 14: Explanation of requirements for Maximize Wealth (Part 2)

Maximize wealth terminology and requirements	Interpretation
Residual Value (Future Expenses)	The value of a building or building system at the end of the study period which was calculated equal to $10,000 as a future expense and calculated based on price of steel structure which is the only important factor in Iran for salvage.
Replacement Cost (Future Expenses)	Cost of scheduled replacement of a building system or component that has reached the end of its design life and considered based on previous recorded of information from similar buildings equal to $1000 per year.
Maintenance Cost	Any cost of scheduled upkeep of building, building system, or building component which is 30% of initial cost and as explained in the text, calculate based on Australian Institute of Quantity Surveyors (2006).
Rent expectation	According to the discretion of facility manager and real estate agents the yearly rent expectation for the building is $20,000 as an average across ground and upper floor net rentable areas assuming full tenancy.
Tax	The amount of yearly tax based on Iran regulations for a luxurious rental building has been estimated at $1,350.
Note: Analyses greater than 30 years do not significantly affect NPV or BCR calculations.	

6.3.2 Second Criteria-Maximize Utility

Maximize utility is a factor for assessment of social aspect of facilities to analyze the amount of contribution of the building to its tenant based on a weighted evaluation matrix. So, by assessment of performance of the building based on 12 different criteria, according to the preference and requirements of the owner of the building each criterion ranked between 1 to 10 and allocated a performance score to each of them between 0 to 5.

Each criterion was determined based on the nature of the building as well as the willing of the owner. Heritage preservation was considered because the building is located in an old city and the building received financial grants to be constructed in accordance with culture and existing custom and tradition of the city. Therefore it received weighting of 10 and score of 5 based on assessment of architect of the building.

Aesthetic was considered, because the owner of the building was in favor of spending more money to improve appearance of the building by utilizing some expensive architectural techniques such as an especial brick facade. As a result it received weighting of 9 and score of 4 based on assessment of architect of the building.

Adaptive reuse potential was considered, because building has enough flexibility to change its function and it has a place appropriate for commercial purposes whenever require. Accordingly, it received weighting of 10 and score of 5 based on assessment of owner and civil engineer.

Community benefit received weighting of 9 and score of 4 because it has some potential to be used for educational purposes for art and architecture students as an example for excellent usage of brick facade texture.

Tourism potential is one of the purposes of the building as it had received grants from Bureau of Cultural Heritage to be accordance with traditional values of the city and instead occasionally be used as a monument for exhibition or art gallery. Consequently, it received weighting of 8 and score of 4 based on assessment of architect.

Flexibility is a performance criteria embedded in structure of the building which will help changing the function of the building more easily. Therefore, based on opinion of engineer it received weighting of 10 and score of 5 which is a good rank among other criteria.

Initial cost, was an important factor for the owner of the building and it was the origin of conflict between owner and architect however, it was finally weighted 9 and received score of 5.

As the architect of the building is a sustainability expert and tried to had a balanced approach for sustainability, based on his discretion it received weighting of 10 and score of 5.

For tenant comfort which is an important performance criterion, there was not a general consensus between owner and architect of the building, but I have decided to use the opinion of the architect of the building as an expert opinion, hence, it received weighting of 6 and score of 3.

As the structure of the building is fabricated from steel, it has a negative influence on thermal mass, therefore, it received weighting of 5 and score of 3.

Disabled access, was considered to be part of the function of the building and for this aim, an especial elevator is erected in the building, so, architect, ranked the building to received weighting of 8 and score of 4.

Finally, the ventilation system of the building assessed and it received weighting of 4 and score of 1 which is not a high score from occupant point of view. Therefore, as depicted in Figure 25, weighted value score is 418 which the more the score is, the merrier the project would be.

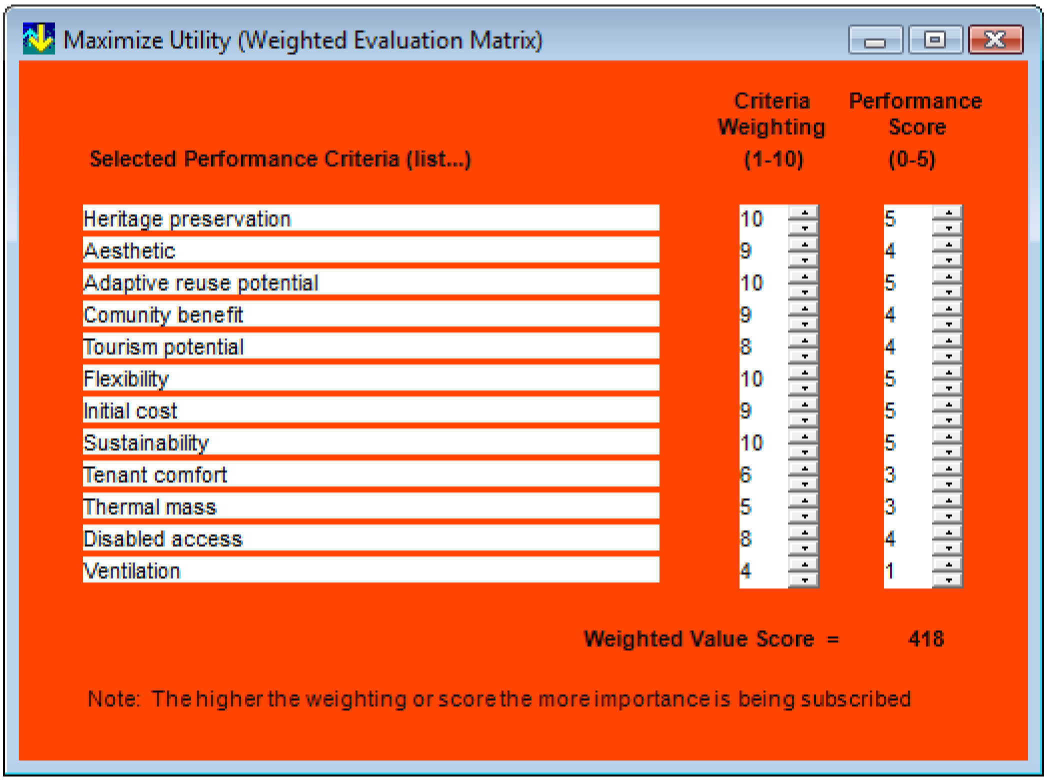

Figure 25: Minimize utility input screen

6.3.3 Third Criteria-Minimize Resources

Minimize resources is a criterion for analyzing the amount of energy consumption in building and it is depicted in Figure 26. If the Actual usage of building is more than target usage, as a result the case requires renewable sources of energy for further consumption. Actual operating energy is based on real consumption of the building for electricity and gas, however, embodied energy (energy already involved in manufacturing and construction) is related to several complex stages for calculation. Boundaries for calculation of embodied energy are from extraction of raw materials in mining process and then process of manufacturing in factory until the final erection in building as a construction material. So, as calculation of embodied energy is a difficult process and is not in the scope of this thesis the embodied energy was determined based on findings of Yohanis and Norton (2002).

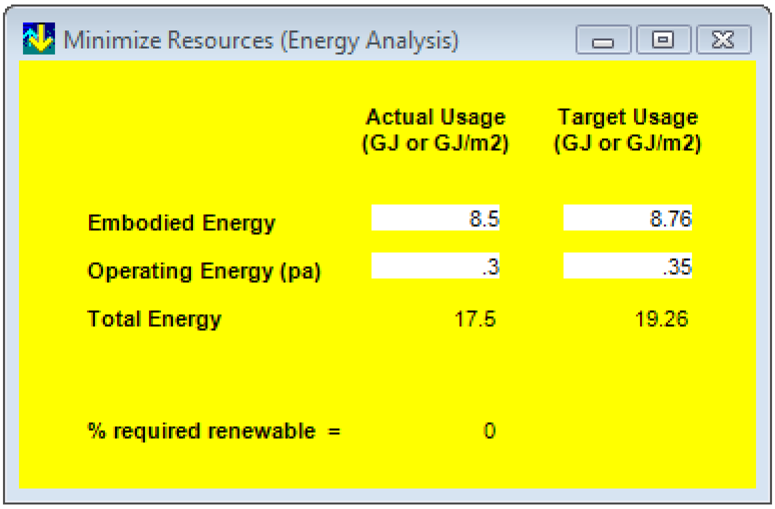

Figure 26: Minimize resource input screen

For calculation of minimize resources in Sindex, explanation and interpretation of terminology and requirements are explained in Table 15.

Table 15: Explanation of requirements for minimize resources

Sindex terminology and requirements for minimize resources	Interpretation
Embodied energy	For residential development, the embodied energy ranged between 3.60 to 8.76 GJ/m2 of gross floor area. A bigger range was found in commercial developments where the initial embodied energy ranged from 3.40 to 19.00 GJ/m2 (Yohanis & Norton, 2002).
Actual operational energy	Actual operational energy calculated based on yearly electricity and gas consumption of building.
Operational energy	Target usage of operational energy is based on a survey of operational energy in Australia which ranging approximately between 0.30 and 1.00 GJ/m2 for yearly consumption (Pullen, 2000).

6.3.4 Fourth Criteria-Minimize Impact

Minimize impact as depicted in Figure 27 is a factor to rank the project according to its influence and impact on environment. There are six different phases for assessment of a project based on a risk assessment questionnaire. Phase one is during the manufacturing of building's materials. There are ten different questions in this phase which were answered through interview with architect and engineer. The questions are:

1. Does the manufacturer have an environmental management plan?
2. Are new raw materials a renewable resource?
3. Does the manufacturing process involve hazardous materials?
4. During manufacture, are greenhouse gas emissions minimal?
5. Does the manufacturing process generate untreated pollution?
6. Are product components manufactured from recycled materials?
7. Are the majority of raw materials imported from overseas?
8. Is manufacturing waste sent to landfill?
9. Are significant amounts of manufacturing waste recycled?
10. Are most products packaged?

By answering to above mentioned questions, to somehow it would be obvious that to what extent the trend of material consumption is accordance with environmental values.

Phase two is related to the design stage of construction and was answered by architect of the building. The questions are:

11. Is environmental performance a specific design objective?
12. Were outcomes evaluated using a life-cost approach?
13. Was embodied energy considered in the decision process?
14. Are there significant heritage implications to be considered?

Therefore, by answering to these four questions, importance of environment can be determined from designer point of view.

Phase three is related to the construction stage and includes the assessment of environmental impact of the project. The answers in this phase are according to the opinion of the architect of the building. The questions are:

15. Will the consumption process generate untreated pollution?
16. Will environmental impacts during construction be monitored?
17. Will construction waste be primarily recycled?

Obviously, the aim of these questions is to rank the level of precautionary measure for construction stage to reduce the impact of building development.

The purpose of phase four is to evaluate the impact of building on environment during the usage phase. So, five different questions were answered by the architect to rank the building. The questions are:

18. Does the intended function use water efficiently?
19. Will pollutants be discharged directly into the environment?
20. Is waste recycled?

21. Are significant energy minimization strategies in place?
22. Is noise transmitted to surrounding spaces?

As a result, by answering to these questions related to usage phase, we can assess to what extent project has negative influence and impact on environment.

Phase five is the last phase for environmental risk assessment which is related to the demolition of building. There are four different questions about demolition stage. The questions are:

23. Are most demolished materials recyclable?
24. Does non-recyclable waste involve hazardous materials?
25. Are all components sent to landfill biodegradable?
26. Has a deconstruction plan been developed?

Obviously, by answering to these question the amount of environmental consideration of the owner and designers can be determined as well as we can rank the risk of project on environment.

The last section in the questionnaire is related to context which is an optional part about general environmental aspects of the building. The questions are:

27. Is the site in a remote location?
28. Is the site environmentally-sensitive or protected?
29. Was an environmental impact statement prepared for the project?
30. Are there rare or endangered species near the site?

31. Will the site’s natural features be significantly disturbed?
32. Is site stability and erosion control a particular objective?
33. Are affected site areas reinstated upon completion of construction?

The above mentioned question are presented to show to what extent designers considered environmental aspect as an important factors besides to economical factors. For example, if designers take into account to put into danger any species near the site they will receive negative score or if they considered protecting natural features significantly the project will rank to have minimal impact.

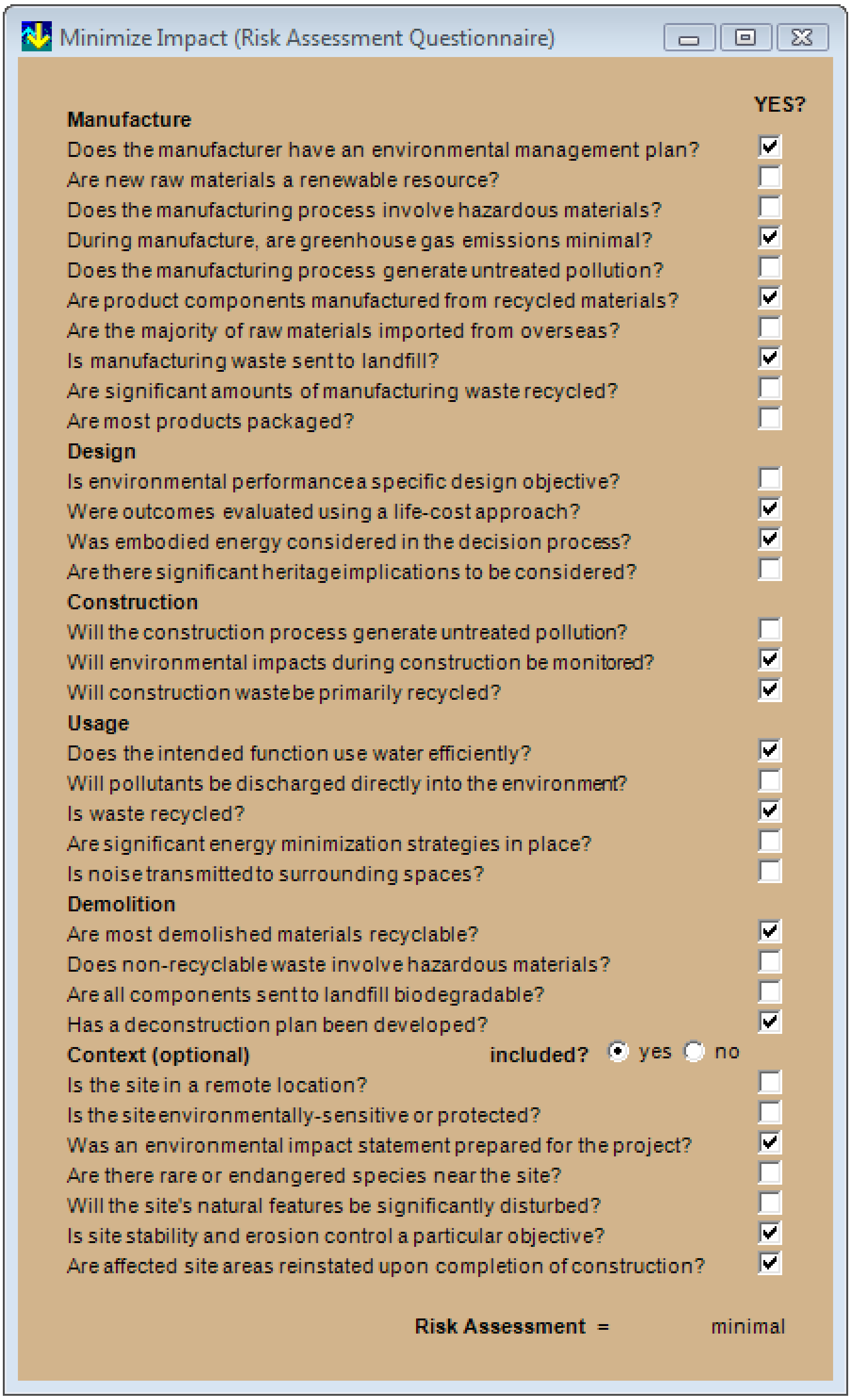

Figure 27: Minimize impact input screen

6.4 Results

As it is illustrated in Figure 28, according to equal preference for all factors, result for the case study building is 3.06 which is somehow an acceptable outcome for a project. Because the results are more than one and the main requirements of the software are satisfied, this building can be accepted as a sustainable design and is profitable from financial, social and environmental perspective. If the criteria for assessment of the project shifts from equal preference to more social, then the result is 4.96 which is a better achievement for the project. However, if designer's requirements are towards more economical aspiration which is not far from desire of developers, the result would be 1.42. Figures 24, 25, 26 and 27 depicted the process of project evaluation from different stages. Meanwhile, it is essential to mention that a good result according to the target of the software is around 3 and more than 5 is nearly out of reach.

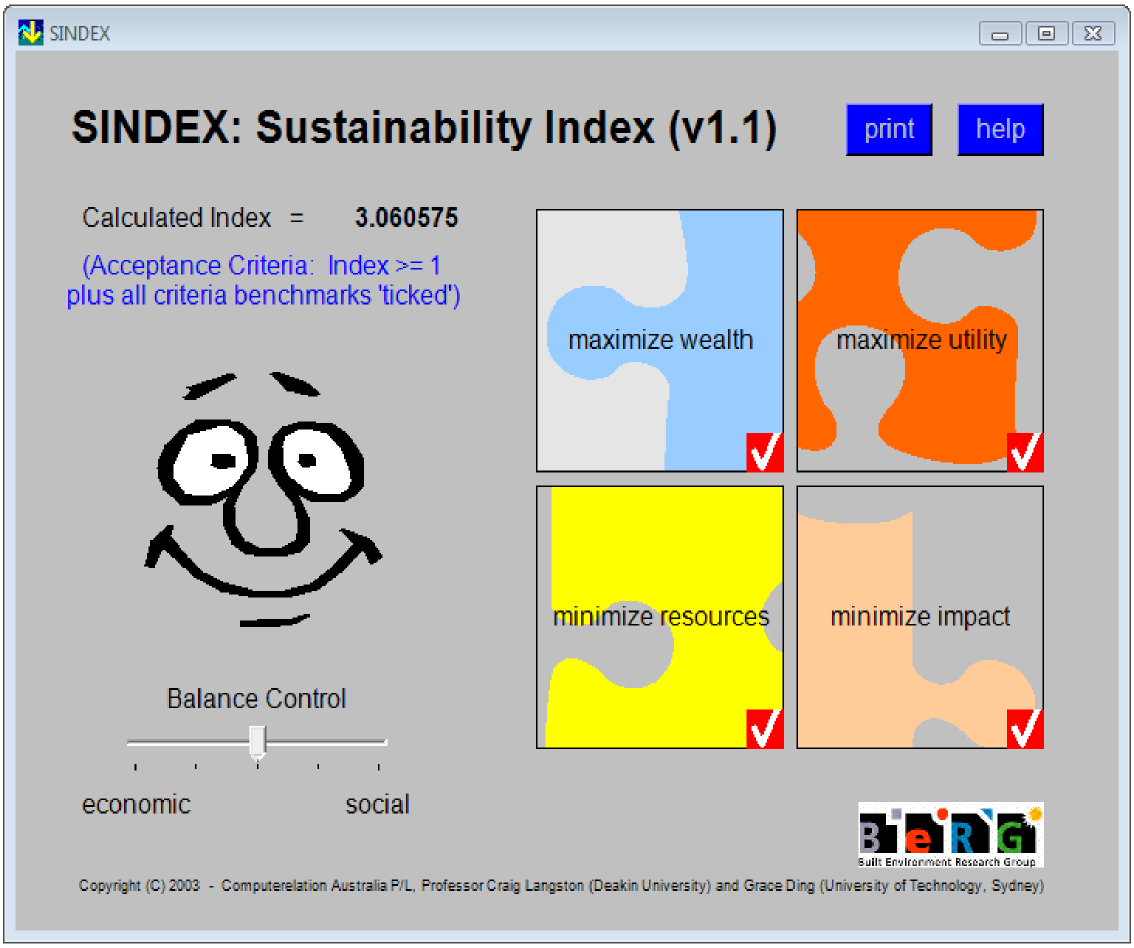

Figure 28: Main view of Sindex along with four criteria

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Construction Sustainability Analysis

For any reason and aim that a building is considered to be built, it needs to be in accordance with the factors and criteria of sustainability. The more sustainable the building, the merrier the project would be. Therefore, it is crucial for designers and engineers to consider more sustainable solutions and practices from early stage of construction. Therefore, as an example for sustainability in this thesis, the influence of three different components was considered to show which alternative has the best results. Besides, decision making process for demolition or renovation of a building is another important stage for the end of lifecycle which needs to be taken into account before any further work.

Therefore, as the purpose of this thesis was established upon sustainability assessments such as energy efficiency of buildings, the results of this thesis point out that to what extent building components normally have influence on energy usage, because the majority of building sustainability indicators are using the energy consumption for analyzing building performance and it is the main factor in building information modeling for the sake of sustainability analysis. On the other hand, in my opinion, early and immature demolition of buildings contributes to huge amount of energy consumption and raw material extractions. Thus, showing the result and finding of sustainability index of case study and analysis of potential for building adaptive reuse was secondary aims of this thesis.

7.2 Conclusions

The results of lifecycle energy analysis for building materials illustrated that to the highest degree, most successful case in energy consumption was alternative 3 which is wall and roof that used structural insulated panels. However it is not far from expectation that using insulation in our building can reduce the amount of energy consumption, but it is important to show which part of building has how much influence on it. Meanwhile, the worst case from energy efficiency point of view referred to alternative 1 which is metal frame wall and roof. It is important to point out that alternative 1 which used metal frame increased the lifecycle energy and cost of the building so was the worst case for the building.

The results of sustainability analysis method which was used during this thesis acknowledge that from sustainability point of view, construction sector needs to concentrate more on renovation and restoration of existing projects for first choice instead of early demolition of building. In addition, this thesis aims to show that building adaptive reuse is required to be taken into account before demolition of existing building. Meanwhile, many tools and methods are available for architects, designers and owners to use before any decision regarding to their new design, construction, renovation and demolition in projects.

Based on the findings of this thesis, building adaptive reuse provides more benefits than ordinary renovation in situation that the previous function and responsibility of buildings is not required. This method gives an opportunity to a historic building to be alive for more years and as a result, it reduces the impact of new construction on environment. For analyzing the process of extending building lifecycle and reuse, engineers ought to have concern for numerous criteria that economical and environmental assessments are part of them. Therefore, according to my point of view, sustainable construction is main concern of construction industry that designers should bear in mind from beginning of construction. Supportive acts for this concern can contribute to alleviate negative influence of fast construction development.

According to outcomes of Sindex explained previously, by having an equal relationship between three sustainable criteria including economic, environment and social, the sustainability index calculated 3.06 that is an acceptable score. The total result of 1 for buildings can be evaluated as the smallest value and the more the index, the merrier the building would be. Therefore, as the total criteria of case study are more than software's acceptable boundary, the building's construction would evaluate as a reasonable, acceptable and sustainable project.

7.3 Recommendations for Future Studies

This thesis shows a method for finding embedded remaining life of buildings which otherwise can be neglected by owners and immature demolition of building will contribute to environmental damage and other consequences. Therefore, by examination of the buildings, this thesis confirms that judgments about whether to renovate a building or demolish it without deep analysis from many aspects cannot be a good judgment, however in some cases demolition can be more sustainable than preservation.

By applying multi criteria evaluation technique such as Sindex, construction managers can analyze entire impact and influence of a project during the whole lifecycle instead of its instant stage of possession, tenure and usage. The purpose of this method is to guarantee that projects are protected to grant more opportunity of existence by considerable residual ability for helping the general public. By using these sustainable methods which are based on several months of research and investigation, we can be confident to attain acceptable level of sustainability in construction industry.

This study helps engineers to strengthen their capability in support of reasonable and proportional resource extraction, consumption and management through noticing important topics including inappropriate and extra material consumption in built environment, as well as facilitate and put into practice suitable executive policies. This thesis findings and results make available improvement on behalf of reducing environmental damages of buildings and mostly kind of damages that are related to the materials previously embodied in properties.

In my opinion, in near future by using more sustainable methods, the embodied energy consumption, material usage and environmental impacts of construction industry will gradually decrease. Moreover, there is a suggestion on behalf of contractors to follow and practice more building adaptive reuse in their careers to reduce the influence of building construction on global warming and climate change.

In conclusion, this thesis with the help of three different methods, tools and software show a practical way towards sustainable, energy efficient and green building constructions. As a construction manager and based on this thesis outcomes, it can be suggested that for decision to whether renovate a building or demolish it, an accurate examination should be performed which as a practical example, adaptive reuse model was used in this study.

Then for lifecycle analysis, by using building information modeling and Green Building Studio the impacts and influences of different construction materials during the lifecycle energy and cost of the building is shown. Finally, after deciding for demolition of an old building, the new building design must be analyzed to show the amount of sustainability and illustrate that to what extent this project is accepted and from which point of view engineers want to build it.

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