DEVELOPMENT OF A RISK ASSESSMENT METHOD FOR SUSTAINABLE CONSTRUCTION OF MEGAPROJECTS

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ABSTRACT

DEVELOPMENT OF A RISK ASSESSMENT METHOD FOR SUSTAINABLE CONSTRUCTION OF MEGAPROJECTS

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Mega projects are large-scaled and long-term investments. Therefore, they have significant impacts on national economy in micro and macro scale, environment and society in comparison to the small and medium-sized construction projects. Time, cost and quality are the most common criteria that are utilized to evaluate the performance of the construction projects, yet those criteria become insufficient to evaluate the mega construction projects' success. These projects have a long life-cycle from the planning stage to the demolition phase of the project and significant impacts on environmental and social consequences. For this reason, three pillars of sustainable construction objectives which are economic, environmental and social sustainability should be integrated into the mega construction projects, and it should be aimed to obtained a sustainable outcome for the whole life-cycle of the mega construction projects with the integration of those objectives. On the other hand, there are various risk factors that threaten the achievement of the sustainable construction objectives. The present study proposes a risk assessment method for sustainable construction of megaprojects (RAMSCOM). For this purpose, sustainable construction objectives and risk factors are identified through the literature review. Then, the relationships among sustainable construction objectives and risk factors are presented in a conceptual framework.

Subsequently, relationships among objectives and risk factors are quantified in order to analyze the threats for the sustainable construction objectives and enhance decision making process in advance. Finally, the usability of the proposed model is tested on a real construction megaproject and findings regarding the megaproject are discussed.

Keywords: Decision-Support System, Megaprojects, Performance, Project Management, Sustainable Construction

ÖZ

MEGA İNŞAAT PROJELERİNİN SÜRDÜRÜLEBİLİR İNŞAATI İÇİN RİSK DEĞERLENDİRME YÖNTEMİ GELİŞTİRİLMESİ

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Mega projeler büyük ölçekli ve uzun vadeli yatırımlardır. Bu nedenle, küçük ve orta ölçekli inşaat projelerine kıyasla, mikro ve makro ölçekte, çevre ve toplumda ulusal ekonomi üzerinde daha önemli etkileri vardır. Zaman, maliyet ve kalite; inşaat projelerinin performansını değerlendirmek için kullanılan en yaygın ölçütlerdir; ancak bu ölçütler mega inşaat projelerinin başarısını değerlendirmek için yetersiz kalmaktadır. Bu projeler projenin planlama aşamasından yıkım aşamasına kadar uzun yaşam döngüsüne sahiptir ve aynı zamanda çevresel ve sosyal sonuçlar üzerinde önemli etkileri vardır. Bu nedenle; ekonomik, çevresel ve sosyal sürdürülebilirlik olan sürdürülebilir inşaat hedeflerinin üç sütunu mega inşaat projelerine entegre edilmelidir ve mega inşaat projelerinin tüm yaşam döngüsü boyunca bu hedeflerin entegrasyonu ile sürdürülebilir bir sonuç elde edilmesi amaçlanmalıdır. Diğer taraftan, sürdürülebilir inşaat hedeflerine ulaşılmasını tehdit eden çeşitli risk faktörleri vardır. Bu çalışma, mega projelerin sürdürülebilir inşası için bir risk değerlendirme yöntemi önermektedir (RAMSCOM). Bu amaçla, sürdürülebilir inşaat hedefleri ve risk faktörleri literatür taraması ile tanımlanmaktadır. Daha sonra, sürdürülebilir inşaat hedefleri ve risk faktörleri arasındaki ilişkiler kavramsal bir çerçevede sunulmaktadır. Ardından, sürdürülebilir inşaat hedeflerini etkileyen tehditleri önceden analiz etmek ve karar verme süreçlerini iyileştirmek için sürdürülebilir inşaat hedefleri ile risk faktörleri arasındaki ilişkiler nicelleştirilmiştir. Son olarak, önerilen modelin kullanılabilirliği gerçek bir mega proje üzerinde test edilmiştir ve mega projeye ilişkin bulgulara yer verilmiştir.

Anahtar Kelimeler: Karar Destek Sistemi, Mega Projeler, Performans, Proje Yönetimi, Sürdürülebilir İnşaat

To my beloved family

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BBN	Bayesian Belief Networks
CI	Consistency Index
CIA	Cross Impact Analysis
COS	Cost of Safety
CR	Consistency Ratio
FMEA	Failure Mode and Effect Analysis
GDP	Gross Domestic Product
ICRAM	International Construction Risk Assessment Model
IPKB	Istanbul Project Coordination Unit
MCDM	Multi Criteria Decision Making
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
RAMSCOM	Risk Assessment Method for Sustainable Construction of Megaproject
RI	Random Consistency Index
RPN	Risk Priority Number
SC	Sustainable Construction
SMART	Simple Multi-Attribute Rating Technique

SMARTER Simple Multi-Attribute Rating Technique Exploiting Ranking

LIST OF SYMBOLS

λ_{max}	Maximum Eigenvalue

CHAPTER 1

INTRODUCTION

This chapter provides an overview of the research. First of all, the background of the study and statement of the research problem are addressed. Subsequently, aim, objectives and research questions regarding the study are presented. This chapter concludes with an explain for the structure of the thesis.

1.1. Problem Statement

Construction sector has become a critical sector considering its contribution to the world economy. The Gross Domestic Product (GDP) share of construction sector has been increasing especially for the developing countries. In Turkey, the direct contribution of GDP share in construction sector has been 8%, and its indirect contribution has been around 30% in recent years (Türkiye İnşaat Sanayicileri İşveren Sendikası, 2018). According to Hosseini et al. (2018), approximately $57 trillion will be reserved to the megaprojects in the world and two-third of this amount will come from the developing countries. A construction activity also has some effects on the society. Celik and Budayan (2016) emphasize that construction sector does have a vital position to satisfy the human needs because the adverse impacts of the construction projects may interfere with the local people to carry out their daily routine. The potential adverse effects of construction projects are categorized into four main topics. Damage to nature and built environment includes loss in serviceability of playfield and parks, loss of habitats and parts, loss of landscape. Pollution is caused by cleanliness of the cars, house, neighborhood, backyard, loss of peace of the neighborhood, degradation of ambient conditions, preventions of usage of the outdoor areas of the house. Traffic has some adverse consequences due to prolonged closure of road space, detours and utility cuts. Moreover, local people may be affected because of the road safety problems, human health hazard problems, living quality decline, safety hazards in the construction area and loss of parking lots. Besides the economic and social aspects, construction sector has a significant impact on environment as well. For instance, Pamuk and Kuruoğlu (2016) state that a vast quantity of non-renewable resources is consumed and environment is polluted due to wastes generated. Yılmaz and Bakış (2015) list negative consequences of construction activities as decrease in bio-diversity, destruction of forest areas, loss of agricultural areas, destruction of natural green areas and global warming. The level of global resource consumption and global pollution of construction industry are provided in Table 1.1.

Table 1.1 *The level of global resource consumption and global pollution (Dixon, 2010)*

Global Resource	**%**
Energy	45-50
Water	50
Materials for buildings and roads (by bulk)	60
Agricultural land loss to buildings	80
Timber production for construction	60 (90% of hardwoods)
Coral reef destruction	50 (indirect)
Rainforest destruction	25 (indirect)
Global Pollution	**%**
Air quality (cities)	23
Climate change gases	50
Drinking water pollution	40
Landfill waste	50
Ozone depletion	50

Nevertheless, construction projects vary in size and megaprojects have significant impacts on the aforementioned aspects above because megaprojects are large-scaled and long-term investments in comparison to the small and medium-sized construction projects. Number of megaprojects have been increased in recent decades due to the rapid urbanization, globalization and population growth especially for the emerging economies. According to Atkinson (1999), time, cost, quality are the most common criteria to determine the construction projects as successful or not. Atombo et al. (2015) state that time, cost, quality criteria are not sufficient enough to determine the construction megaprojects as successful or not because the success of them can be ensured by the integration of sustainability principles that are economic, environmental and social sustainability. However, sustainable construction is a new concept for the construction sector. The term sustainable construction was first introduced by Kibert in 1994 and he defines sustainable construction as creating a healthy living space by using efficient and ecologically based principles. Sabini et al. (2019) state that there is a rise of interest between sustainability and project management concepts from 1993 to 2017. On the contrary, Dikmen and Birgonul (2017) mention that there are limited studies which integrate the concepts of risks and sustainability in the project management field. In this sense, a risk assessment method is proposed to analyze the risks that may interfere the achievement of a sustainable outcome from the megaprojects.

1.2. Aim and Objectives of the Research

Achievement of the sustainability is the most important goal for the megaprojects considering the life-cycle from the planning stage to the demolition phase. Thus, the current research aims to enhance decision making processes regarding the sustainable construction of megaprojects. For this purpose, a risk assessment method is proposed for the sustainable construction of megaprojects (RAMSCOM). Thereafter, usability of the proposed method is demonstrated on a hypothetical project, and then tested on a real megaproject.

1.3. Research Questions

The research questions are listed as follows.

- Which are the most important sustainable construction objectives considering the characteristics of the megaproject?

- Which risk factors are relevant for mega construction projects and how shall they be assessed?
- What are the possible threats for sustainable construction objectives and how can the threats be eliminated considering the project and country conditions?

1.4. The Structure of the Thesis

This thesis includes seven chapters:

Chapter 1 begins with a brief introduction, presents the problem definition, aim and objectives of the study, and poses the research questions.

Chapter 2 presents the literature review findings. The literature review begins with the research about mega construction projects regarding the historical origins of mega construction projects. Then, definition of megaprojects and characteristics of mega construction projects are analyzed in detail. The literature review continues with the sustainability concept and sustainable construction. This part starts with seeking the answer of how sustainability and sustainable development concept have emerged throughout the history. Then, sustainability, sustainable development and sustainable construction objectives are explained. This chapter concludes with the literature review on risk management. Definition of risk and risk management are mentioned. Finally, risk management processes including risk identification, risk assessment, risk response and, risk monitoring and control are presented profoundly.

Chapter 3 summarizes the research steps for the proposed Risk Assessment Method for Sustainable Construction of Megaprojects (RAMSCOM). In this chapter, research steps including preliminary conceptual model, establishment of RAMSCOM, implementation of RAMSCOM and discussion of findings are explained briefly.

Chapter 4 presents the preliminary conceptual model. For the preliminary conceptual model, sustainable construction objectives and risk factors are identified. Then, the relationships between sustainable construction objectives and risk factors are demonstrated on a preliminary conceptual model.

Chapter 5 introduces the RAMSCOM. This chapter begins with the development process of the RAMSCOM. Fundamentally, the framework for the proposed model is outlined by explaining how the relationships between sustainable construction objectives and risk factors are quantified. This chapter concludes with the implementation of the RAMSCOM on a hypothetical construction megaproject with the explanations for each step.

Chapter 6 continues with the implementation of RAMSCOM on a real construction megaproject.

Chapter 7 presents and summarizes the conclusions regarding proposed model. Major findings from the proposed risk assessment method, benefits and limitations of the model are discussed. This chapter ends with some recommendations for the future studies.

CHAPTER 2

LITERATURE REVIEW

This chapter covers the literature review about mega construction projects, sustainable construction and risk management.

2.1. Literature Review on Construction Megaprojects

A detailed literature review on mega construction projects was presented below. Firstly, a brief history about mega construction projects was mentioned to demonstrate how construction megaproject was emerged in the history and to investigate the current situation of megaprojects by explaining the reasons why megaprojects are increased in the recent century. Then, definition and characteristics of the megaproject were mentioned from the point of view of various authors considering the current status of the megaprojects.

2.1.1. A Brief History about Construction Megaprojects

First settlements in the human history existed in the Neolithic age. In this age, the Earth entered a warming trend, the climate change allows people to be engaged in agricultural activities which corresponds to the transition phase from the consumer to the producer society. A nomadic life was started to be abandoned progressively and humankind began to settle in agricultural fields (Svizzero, 2014). Human started to construct places in order to protect themselves from external factors. Most of the first settlements like Göbeklitepe, Çatalhöyük, Hacılar, Çayönü were built in Anatolian district (Harmankaya, 1997). All in all, the main purposes of the first settlements were sheltering and defense.

Agricultural revolution leads to some social consequences as well. For instance, it allows to improve trading and cooperation between people. Moreover, people started to concentrate on other activities. Different types of occupations were emerged and technology was developed. Trade between different societies was increased and the economy of some societies was developed more in comparison to the other societies (Sadowski, 2017). Empires were founded in Mesopotamia and South America district. Besides the sheltering and defense purposes, the aim of the structures was changed into another concept. The size of the structures was changed in a larger scale and giant structures were built in order to manifest prestige, economic situation, technological developments and political power. Egyptian Pyramids can be given as an example of the first mega structures in the Ancient World around Mesopotamia district. Temple of Kukulkan is another example for the ancient megastructures from Mayan Empire. Besides the reasons aforementioned, megaprojects can be seen as a defense purpose in Ancient World as well. The Great Wall of China was built in order to protect China from external attacks. In summary, the first mega structures were built for prestige, economic, political, technological and defense purposes (Olson, 2009).

Developments in agriculture, increase in the population, increase in labor force due to the mitigation to the cities and demand to the consumer goods make a good environment to take place the first industrial revolution in late 1800s. In the first industrial revolution, manufacturing was started done by machines. Second industrial revolution took place after 80 years and electrical power was utilized for manufacturing. After 120 years from second industrial revolution, third industrial revolution happened. Manufacturing was started to be done by automation. Fourth industrial revolution takes place in the 21th century and it allows to do manufacturing process by high technologies with computers (Eğilmez, 2018).

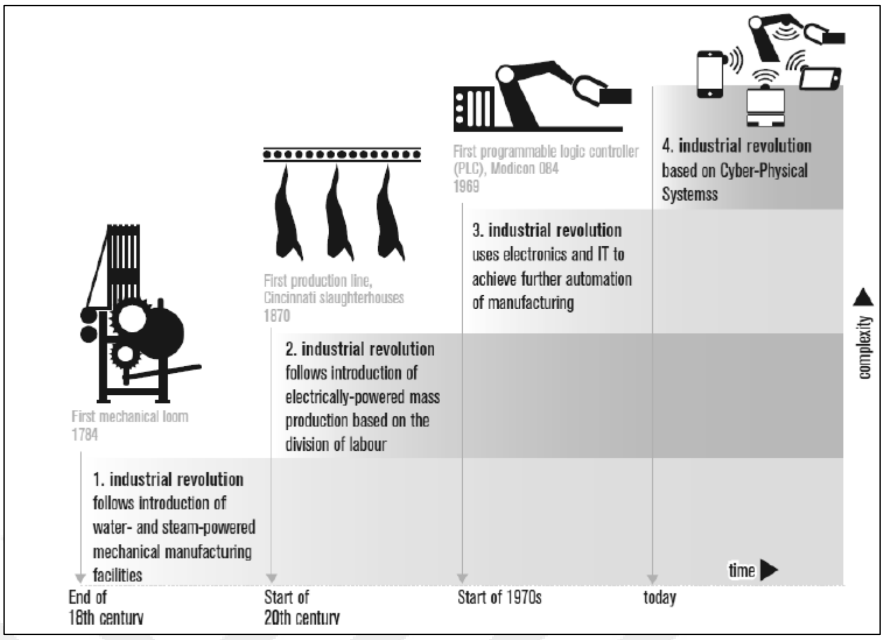

Figure 2.1. The four stages of industrial revolution (Alaloul et al., 2018)

Industrial revolutions have some direct effects on construction sector. More diversified and more stable construction materials in terms of shape and size are started to be produced in a faster way. Moreover, technology is integrated into the construction sector more by utilization of information technologies (Leal and Salgado, 2018). Rapid urbanization, globalization and increase in population, mitigation to the metropolitan cities have increased tremendously in the recent years. As a consequence, the idea of the construction of megaprojects including superstructures and infrastructures was raised in order to address the needs of community (Türkiye İnşaat Sanayicileri İşveren Sendikası, 2018).

2.1.2. Definition of Construction Megaproject

A megaproject is defined as *a major project or undertaking in business or construction* in Merriam-Webster Dictionary. Collins Dictionary defines megaproject as a *very large, expensive, or ambitious business project.* In the sense of non-academic perspective, size and cost are the two key elements to define a megaproject. However, the megaproject terminology defined in a non-academic way is not clear enough because there is not any specific threshold value or a range for cost and scale to distinguish whether the selected project is a megaproject or not. Academic perspective deals with the definition of megaproject in a more detailed way. However, there is not a common and agreed definition for a megaproject (Erol et al., 2018). Fiori and Kovaka (2005) mention construction megaproject as a single construction project or combined construction projects formed by magnified cost, extreme complexity, high level of risk, great impact to the society and including many challenges to the stakeholders. According to Flyvbjerg (2014), megaprojects are large-scaled and complex ventures. They cost a billion dollars or more, take many years to develop and construct, include multiple public and private stakeholders and impact on people. Zidane et al. (2012) put emphasize on giant scale, average capital cost of US$ 985 million, long duration, technological demand and organization of different disciplines for the megaprojects. Mega construction projects are characterized by contracts sums over $1 billion, huge number of stakeholders with a high level of impact on society and environment due to their large size (Mok et al., 2014). On the other hand, Gallert and Lynel (2003) approach megaprojects in a more sociological aspect. Megaprojects were described as a transformation of the built environment in a visible way by Gallert and Lynel (2003).

Construction megaprojects are defined considering the following aspects. It can be concluded from previous studies that the most remarkable element to define a megaproject is in terms of their size. Construction megaprojects are large-scaled projects. Due to size of the megaproject, factors used to define construction megaprojects are affected more specifically. The duration of megaprojects has become longer. Large scale and long duration have direct effects on the total cost of the megaproject. Total cost spent for the megaprojects increases and they become high-cost invested projects with a minimum investment cost of 1 million dollars. Different disciplines are needed to be able to construct a megaproject. Number of participants, duration and cost of project have cause to emergence of complexities and risks in the megaproject. In summary, the megaprojects are large-scaled, long-term and costly investments of at least $ 1 billion with the participation of different disciplines that include complexity and risk factors throughout the entire life-cycle of the construction project.

2.1.3. Characteristics of the Construction Megaprojects

Construction projects varies in small, medium and mega projects. There are some characteristics that enable to distinguish megaprojects from small and medium-sized construction projects. These characteristics can be categorized into size, resource usage, duration, complexity, uniqueness (design, function) in terms of amount used. Besides the quantified characteristics, there are some qualitative characteristics like high impact and sublime factors as well.

2.1.3.1. Size

Large scale and giant size are the terminologies used in order to clarify the size of the megaprojects (Flybjerg, 2014; Zidane et al., 2012; Mok et al., 2014). There is not a common way to specify the size of the megaprojects because the function of the megaprojects differs from each other. As an illustration, height and floor area can be used as criteria for the skyscrapers. For the transportation projects, size can be measured in terms of length. For the facilities like hospitals or airports, total capacity of the building can be used in order to make a comparison among construction projects under the same category.

2.1.3.2. Resource Usage

A vast quantity of resources in terms of money, direct and indirect labor are utilized in megaprojects. First of all, megaprojects are high-cost investments. In general, cost threshold value for construction megaprojects is specified as $1 million (Mok et al., 2015, Flyvbjerg, 2014). On the other hand, Erol et al. (2018) mention that cost threshold value may depend on the country conditions. The economic situation in the emerging countries and developed countries are different. In some cases, cost threshold value is represented in terms of local currency or a ratio that shows the relationship between total project cost and Gross Domestic Product (GDP) of the country as demonstrated in Table 2.1.

Table 2.1. *Cost threshold values for MCPs (Erol et al., 2018)*

Cost Threshold	**Reference Study**
1 billion US Dollar	Kumaraswamy (1997)
	Capka (2004)
	Han et al. (2009)
	Jergeas and Ruwanpura (2010)
	Flyvbjerg (2014)
	Rolstadås et al. (2014)
5 billion Chinese Yuan ~ 734 million US Dollar (National Development and Reform Commission in China)	Hu et al. (2015a)
0.5-1 billion US Dollar	Hu et al. (2015a)
	Biesenthal et al. (2018)
0.3-20 billion US Dollar	Eweje et al. (2012)
250-300 million Euro (for small and medium sized European countries)	Mišić and Radujković (2015)
100 million Euro (International Project Management Association-European Union)	Hu et al. (2015a)
1 billion HK Dollar ~ 127 million US Dollar (Development Bureau in Hong Kong)	Mok et al. (2015)
100 million US Dollar	Brookes and Locatelli (2015)
United States: 0.01% of GDP	Hu et al. (2015a)
EU Countries: 0.02% of GDP	
China: 0.01% of GDP	
Hong Kong: 0.01% of GDP	
South Korea: 0.05% of GDP	

Besides the cost aspect, megaprojects are comprised of numerous stakeholders in different disciplines (Eyiah-Botwe et al., 2016). Different actors are involved in megaprojects such as project owner, government, sponsor, contractor, sub-contractors, consultants, suppliers (Erol et al., 2018).

2.1.3.3. Duration

Construction megaprojects are long-term investments considering the life-cycle of them. As presented in Figure 2.2, life-cycle of the construction project includes planning, design, construction, commissioning, utilization, maintenance and decommissioning (Guo et al., 2009).

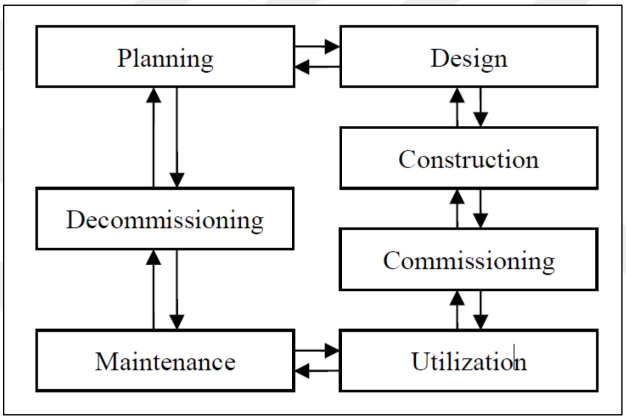

Figure 2.2. Life-cycle of a construction project (Guo et al., 2009)

Brockman and Girmscheid (2007) state that construction period of megaprojects is four years. Some construction megaprojects constructed around late 20th century and early 21th century are listed in Table 2.2. Megaprojects are selected according to the total project cost of more than $ 1 billion and the total duration of the megaprojects are listed with construction start and finish dates in Table 2.2.

Table 2.2. *Duration of the MCPs*

Name of the Construction Megaproject	Construction Start Date	Construction Finish Date	Construction Period	Total Project Cost
Akashi Kaikyō Bridge	1988	1998	10	US $ 3.6 billion
Burj Al Arab	1994	1999	5	US $ 1 billion
Three Gorges Dam	1994	2003	9	US $ 31.765 billion
European Organization for Nuclear Research (CERN)	1998	2008	10	US $ 13.25 billion
Beijing National Stadium	2003	2007	4	C.N. ¥ 2.3 billion
Burj Khalifa	2004	2009	5	$ 1.5 billion
Trans-Anatolian Gas Pipeline	2015	2018	3	US $ 8 billion
İstanbul Airport	2015	2019	4	€ 7 billion

2.1.3.4. Complexity

Megaprojects are complex projects in comparison to the other construction projects. For example, lack of cooperation among participants, changes affecting the duration of the projects or vagueness in laws and regulations make megaprojects complex investments (Boeteng, 2014). In addition, Kardes et al. (2013) state that megaprojects require cutting-edge engineering and construction techniques as well. Frick (2008) puts emphases on the risk and uncertainty in terms of design, funding and construction while defining the complexity as a characteristic of megaprojects. Brockmann and Girmsheid (2007) represent the complexity as a result of the possible relations among different elements.

Brujin and Leijten (2008) analyze complexity under two main categories which are technical complexity and social complexity in the perspective of management. According to Brujin and Leiten (2008), technical complexity refers to the project's technical system and social complexity refers to the constellation of players involved. Technical and social complexity characteristic in terms of manageability are listed in Table 2.3 and Table 2.4 below.

Table 2.3. *Manageability and unmanageability of projects in the context of technical (Buijin and Leiten, 2008)*

Manageable if...	**Less well manageable if…**
Robust (overdesign)	Less robust (under design)
Proven technology (tame technology)	Innovative technology (unproven technology, unruly technology)
Divisible	Indivisible
Loose coupling	Tight coupling
Fallback option	No fallback option
Monofunctional	Multifunctional
Incremental implementation	Radical implementation

Table 2.4. *Manageability and unmanageability of projects in the context of social* (*Buijin and Leiten, 2008)*

Manageable if...	**Less well manageable if…**
Limited dependence on user preferences	Major dependence on user preferences
Uniformity between preferences and aims of commissioning party/users	Variety between preferences and aims of commissioning party/users
Stability of preferences and aims of commissioning party/users	Dynamic of preferences and aims of commissioning party/users
Little blockage power held by third parties	Great deal blockage power held by third parties
Short transformation time	Long transformation time
Limited influence of project on social environment	Major influence of project on social environment

2.1.3.5. Uniqueness

Function of the megaproject can be similar yet this does not make megaprojects alike. Even though, it is decided to construct a duplicate of a megaproject constructed before, uniqueness of the megaproject cannot be changed because conditions like country and project related factors cannot be same as the conditions of that day. Boateng (2014) examines the uniqueness of the megaproject in terms of technological aspect. It is stated that existence of technological challenges makes megaprojects unique. For this reason, megaprojects can be considered as engineering craft business according to

Boateng (2014). Zidane et al. (2012) explain the uniqueness of the megaprojects by emphasizing that none of the megaproject looks like each other.

2.1.3.6. Impact

Megaprojects are large-scaled, costly and long-term investments. Therefore, megaprojects draw attention to public and political interest because they have some direct and indirect impacts on state budgets, environment and community (Mišić and Radujković, 2015). Zidane et al. (2013) emphasize the impact of the megaprojects by giving a magnitude as huge impact. It is mentioned that megaprojects confront many challenges during the life-cycle of the project as well. According to Zidane et al. (2012), it is important to manage the challenges and make megaproject successful to obtain positive impacts in the future. On the other hand, Flyvbjerg (2014) points out the importance of selecting the most appropriate project in the beginning in order to get the best economic, social and environmental outcomes for the future.

2.1.3.7. Symbol/Sublime

Megaprojects have been constructed in order to address the needs of the area in a long-term. Megaprojects take attention from the community and media and their giant scale appeals to sense of the people (Söderlund et al., 2017). Even it is denied or not, some iconic meanings are attributed to megaprojects. Flyvbjerg (2014) explains the reasons of why megaprojects are so attractive. According to Flyvbjerg (2014), megaprojects are comprised of four sublimes which are technological, political, economic and aesthetic sublimes. First of all, technological sublime is about crossing the borders for what technology can do. The main aim is to build the first of anything like the tallest building, the longest bridge, the largest airport and the largest wind turbine. Political sublime is a way to manifest political power of the politicians. In this sense, megaprojects become monumental in terms of visibility to attract people and press. The third sublime is economic sublime. Economic sublime is a personal satisfaction of business people and trade unions by making money from the megaproject. The last sublime is the aesthetic sublime which is related with the design of the megaproject.

Designers' main aim is to design iconically beautiful buildings. As a result, designers expect to get good reactions and to be mentioned about their achievement of the iconic results.

Table 2.5 *The four sublimes (Flyvbjerg, 2014)*

Type of Sublime	Characteristic
Political	The rapture politicians get from building monuments to themselves and their causes, and from the visibility this generates with the public and media
Technological	The excitement engineers and technologists get in pushing the envelope for what is possible in "longest-tallest-fastest" type of projects
Economic	The delight business people and trade unions get from making lots of money and jobs off megaprojects, including for contractors, workers in construction and transportation, consultants, bankers, investors, landowners, lawyers, and developers
Aesthetic	The pleasure designers and people who love good design get from building and using something very large that is also iconic and beautiful, like the Golden Gate bridge

All in all; the characteristics of megaprojects are specified as size, resources usage, duration, complexity, uniqueness, impact and sublime. It cannot be denied that those characteristics do have direct and indirect impacts on society, environment and economy both in the short term and in the long term. All in all, megaprojects are long-term investments in contrast to small size and medium sized construction projects and the impacts of them should be considered in advance in order to achieve sustainable outcomes from the megaproject without disregarding the future generations.

2.2. Literature Review on Sustainability Concept and Sustainable Construction

In this part, literature review on sustainable development and sustainable construction is gone through. First of all, it is mentioned about how the idea of sustainability concept is emerged by referring to the historical events. Then, the sustainable development and three pillars of sustainability is explained in a general context. Last but not least, sustainable construction and its objectives are stated in detail.

2.2.1. Historical Origins of the Sustainability and Sustainable Development Concept

The idea of sustainability and sustainable development as a modern understanding has emerged gradually since the 1950s. After the World War II, some countries have become developed and some countries cannot be able to reach the developed level. Economic growth has become the most important indicator to demonstrate how much the country was developed from 1950s to 1960s. It is realized that economic growth cannot be the only indicator to show the development of the country because spread of the capitalism have led the increase in poverty and decrease in welfare of the citizens. As a result, the way of more equitable welfare distribution was started to seek among countries by early 1970s (Waas et al., 2011). The dependence on the natural resources for the energy production have caused crisis related to the natural resources in 1970s. Du Pisani (2006) states that different types of natural resources such as wood, coal, oil, natural gas were used in order to address the needs of the humanity throughout the history. However, the rate of the consumption of the natural resources has started to increase a lot in the last century due to the consumption of natural resources in a thoughtless way. For instance, wood was used for fuel and construction sector, and it became an indispensable raw material up to at least the 18th century. In the 19th century, coal became a prominent source of energy. Then, the oil became the primary source of energy in the 20th century. Population growth and increase in consumption after the Industrial Revolutions have led to demand on the natural resources more. According to Appanagari (2017), the adverse effects of the Industrial Revolutions on natural resources resulted in exploitation of them and increased industrial output. The demand on raw materials has caused into deforestation, excavation of land for mining, reduction in agricultural fields due to industrial expansion, decrease in ground water level due to the large amount of withdrawal of groundwater and collapsing of ground surface. Besides the adverse effects mentioned above, industrial wastes, toxic gases, chemical precipitates, smokes were released and those outputs have caused the pollution of the natural resources.

It is realized that natural resources are not infinite so natural resources should be preserved, optimized and sustained considering the future generations. Otherwise, future generations will not be able to meet their own needs with limited capacity of the natural resources (Mensah and Castro, 2004). Benyus (1997) states the danger of the natural resources and future generations in the following quotation.

> When we objectively view the recent past – and 200 years is recent even in terms of human evolution – one fact becomes clear: the industrial revolution as we now know it is not sustainable. We cannot keep using materials and resources the way we do now.
>
> (Benyus, 1997)

All in all, the idea of sustainability has grown out among different ideas including environmental protection, economic growth and social situation of the citizens in the recent century (Waas et al., 2011).

2.2.2. Sustainability and Sustainable Development

It is the fact that humanity has led to increasingly unfavorable climate changes and natural disaster, wars, political and socio-economic instability (Klarin, 2018). Throughout the history, the environmental problems have become globalized, the socio-economic problems have become globalized as well. In terms of the environmental aspect, United Nations (2012) put emphasize on the fact that it is getting closer to global ecological limits. If it is continued like the way it is done up to know, possible environmental outcomes are presented below by Diesendorf (1999).

- changes, possibly irreversible, to the composition of the atmosphere and therefore to Earth’s climate
- destruction of stratospheric ozone and therefore increased damage to living organisms from ultraviolet light in sunshine
- degradation of topsoil and increases in desertification

- loss of biological diversity
- damage to photosynthesis and nutrient cycles
- widespread pollution of air, rivers and oceans
- depletion of artesian water storages

However, the world is not only facing the irreversible environmental problems. According to Cobb (1998), sustainability cannot be achieved by disregarding the socio-economic problems all around the world. In terms of the socio-economic aspect, Diesendorf (1999) mentions as the gap between rich and poor people, human violations, working conditions, world population children poverty, diseases, refugee problems, the status of women, inequities due to the dominant economic system.

As a result, sustainability and sustainable development ideas are presented in order to address issues related to environment, economy and society.

2.2.2.1. Sustainability

> Sustainability is the condition or state which would allow the continued existence of homo sapiens, and provide a safe, healthy and productive life in harmony with nature and local cultural and spiritual values. It is the goal we would like to achieve.
>
> (Du Plessis, 2002)

Du Plessis (2002) emphasizes that it is important to balance the needs of humanity and to consider the carrying capacity of the planet, and capacity of the planet should be protected in order to meet the future generations need. The main goal of sustainability is stated as to provide a safe, healthy and productive life in harmony with nature, culture and spiritual values. Diesendorf (1999) mentions the sustainability and sustainable futures as the goals for the process of the sustainable development.

2.2.2.2. Sustainable Development

> Sustainable development is the kind of development we need to pursue in order to achieve the state of sustainability. It is a continuous process of maintaining

> a dynamic balance between the demands of people for equity, prosperity and quality of life, and what is ecologically possible. It is what we need to do.
>
> (Du Plessis, 2002)

Klarin (2018) states that three key events set the principles of sustainable development. The first period mainly focuses on the negative consequences of the economic development, and certain economic theorists such as Smith, Marx, Malthus, Ricordo, Mill shaped the notions of that period. Mebratu (1998) mentions about the problems including limits to growth caused by resource scarcity, unemployment, poverty, diseases, unchecked population increases for this period as well. The first period ended in 1972 with the First United Nations Conference on the Human Environment held in Stockholm, and that conference became as a starting point of the second period. The terms like development and environment, development without destruction in development in accordance with environment was emphasized in this period. Brundtland Report known as Our Common Future was published in 1987 and the boundaries, definition and concept of sustainable development were introduced for the first time in the literature. In this report, sustainable development is defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The definition of sustainable development according to this report puts emphasize on the renewable and long-term usage, protection and conservation of nature, raising ecological awareness, stricter national regulation and international co-operation, stopping population growth, using industry and technology in line with environmental requirement, developing technological innovations in order to reduce impact on environment. Third period covers the period from the declaration of Brundtland Report up to today. The main focus of the third period is to define a global framework to solve issues related with environmental degradation with the integration of economic issues. Rio Declaration on Environment and Development, and Agenda 21 have become key documents for the sustainable development.

Environmental, social and economic aspects of the sustainable development are known as three pillars of sustainability. The concept of ‘three pillars’ has been attributed in Brundtland Report, Agenda 21 and the 2002 World Summit on Sustainable Development, and the three pillars constitute the sustainable development goals in three main categories (Purvis et al., 2019). Slocum (2015) defines sustainable development as placing equal emphasis on the economic, social and environmental components. He states that without any of three components, the sustainability idea cannot be achieved. For instance, viability is the existence of strong economy and strong environmental, but it neglects issues related to the society. The equity demonstrates good performance in economic and social aspects, yet environmental as a third aspect is not considered. If economic aspect is not considered and only the environmental and social pillars are integrated, this scenario is called bearable. All in all, Purvis et al. (2019) state that the main aim of the sustainability is to achieve balancing of trade-offs among three pillars. A schematic representation of three dimensions of sustainable development can be found in Figure 2.3.

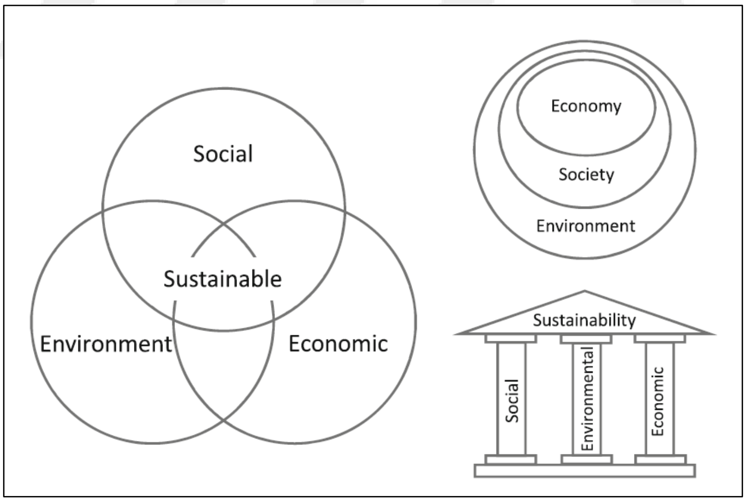

Figure 2.3. Three dimensions of sustainable development with alternative representations (Purvis et al., 2019)

Basiago (1998) mentions the criteria for economic, environmental and social sustainability criteria for economic sustainability are growth, development, productivity and trickle down, criteria for social sustainability are equity, empowerment, accessibility, participation, sharing, cultural identity, institutional stability; criteria for environmental sustainability are mentioned as eco-system integrity, carrying capacity and biodiversity. The criteria for three pillars of sustainability are listed in Table 2.6.

Table 2.6. *The paradigm of sustainable development (Basiago, 1998)*

Element	Criteria
Economic Sustainability	Growth
	Development
	Productivity
	Trickle Down
Social Sustainability	Equity
	Empowerment
	Accessibility
	Participation
	Sharing
	Cultural Identity
	Institutional Stability
Environmental Sustainability	Eco-System Integrity
	Carrying Capacity
	Biodiversity

Sustainable Construction

> Sustainable construction means that the principles of sustainable development are applied to the comprehensive construction cycle from the extraction and beneficiation of raw materials, through the planning, design and construction of buildings and infrastructure, until their final deconstruction and management of the resultant waste. It is a holistic process aiming to restore and maintain harmony between the natural and built environments, while creating settlements that affirm human dignity and encourage economic equity.
>
> (Du Plessis, 2002)

Global issues including climate change, exponential population growth, finite natural resources have led humanity to pay more attention to sustainability and sustainable development and those global issues have become concerns on construction industry as well (Goh and Rowlinson, 2015). As construction sector does not only suffer from the completion projects on time, within budget and on the agreed quality; Simanjuntak and Betailia (2017) put emphasis on the importance of implementation of sustainability principles in the construction sector. It is expected to address economic environment and community needs as well.

Environmental problems caused by construction activities throughout the whole life -cycle of the construction project are stated by various authors. Vyas et al. (2014) state that buildings consume a large amount of resources and energy. Moreover, buildings have influence on quality of urban air, water and climate change. 45% of world energy and 50% of water are used in construction industry. 23% air pollution, 50% green gas production, 40% of water pollution, 40% of solid waste in cities are the environmental problems caused by construction industry as mentioned by Yılmaz and Bakış (2015). In addtion, Yılmaz and Bakış (2015) also specify some negative environmental consequences of the buildings like consumption of non-renewable resources, decrease in biological diversity, destruction of forest areas, loss of agricultural areas, destruction of natural green areas and global warming. According to Gunatilake (2013), construction industry is a key sector for achievement of sustainable development goals. For instance, reduction of Green House Gas (GHG) can be increased to 80% by the year 2050.

Sustainable construction can be considered as an application of the principles of sustainable development into the construction industry (Sourani and Sohail, 2005). Simanjuntak and Betalia (2017) state that sustainable construction is a form of sustainable development in construction industry as well. A schematic representation of the integration of sustainable development and construction industry is shown in Figure 2.4.

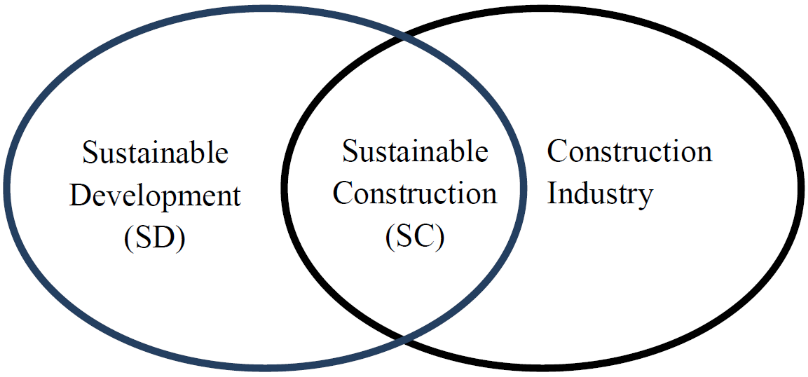

Figure 2.4. Sustainable construction (Gunatilake, 2013)

In 1994, a new concept was introduced to construction sector with the integration of sustainable development principles. Sustainable construction was mentioned for the first time in literature by Kibert in 1994. Kibert (1994) defines sustainable construction based on two sustainable environmental criteria which are minimizing resource depletion and preventing environmental degradation with the contribution of the third criteria of providing a healthy built environment. Sustainable construction has been defined by various authors and the definitions can be found in Table 2.7 below.

Table 2.7. *Definitions for sustainable construction (Gunatilake, 2013)*

Reference Study	Definition
Kibert (1994 cited Hill and Bowen, 1997)	Creating a healthy built environment using resource-efficient, ecologically-based principles
Huovila and Richter (1997)	SC, in its own processes and products during their service life, aims at minimizing the use of energy and emissions that are harmful for environment and health, and produces relevant information to customers for their decision making
Augenbroe et al. (1998)	A possible strategy to better meet the needs of clients and owners while ensuring success in an increasingly competitive and constrained operational environment
Habitat II (1996 cited Ofori, 1998)	SC will make use of resources within the carrying capacity of ecosystems and take into consideration the precautionary principle approach and by providing the people... with equal opportunities for a healthy, safe and productive life in harmony with nature and their cultural heritage and spiritual and cultural values and which ensures economic and social development and environmental protection

Table 2.7. *(Cont'd)*

Reference Study	Definition
Lanting (1998)	A way of building which aims at reducing (negative) health and environmental impacts caused by the construction processes or by building or by the built environment
Raynsford (2000)	The set of processes by which a profitable and competitive industry delivers built assets (buildings, structures, supporting infrastructure and their immediate surroundings) which, enhance quality of life, offer flexibility and the potential to cater for user changes in the future, provide and support desirable natural and social environments, maximize the efficient use of resources
Hendriks (2001)	A way of designing and constructing buildings that support health (physical, psychological, and social) and which is in harmony with nature, both animate and inanimate
The Agenda 21: SC for Developing Countries (Du Plessis, 2002)	The principles of sustainable development are applied to the comprehensive construction cycle, from the extraction and beneficiation of raw materials, through the planning, design and construction of buildings and infrastructure, until their final deconstruction and management of the resultant waste. It is a holistic process aiming to restore and maintain harmony between the natural and the built environments, and create settlements that affirm human dignity and encourage economic equity
van Bueren and Priemus (2002)	The design, development, construction, and management of real estate such that the negative environmental effects of the construction, restructuring, and management of the built environment are reduced as far as possible
UNEP (2003)	The use and/or promotion of a) environmentally friendly materials b) energy efficiency in buildings and c) management of construction and demolition waste
Kibert (2008)	SC may best be defined as how the construction industry together with its product the built environment, among many sectors of the economy and human activity, can contribute to the sustainability of the earth including its human and non-human inhabitants
Shen et al. (2010)	SC practice refers to various methods in the process of implementing construction projects that involve less harm to the environment (i.e. prevention of waste production), increased reuse of waste in the production of construction material (i.e. waste management) and beneficial to the society, and profitable to the company

Table 2.7. *(Cont'd)*

Reference Study	Definition
Robichaud and Anantatmula (2011)	a philosophy and associated project and construction management practices that seek to: (1) minimize or eliminate impacts on the environment, natural resources and non-renewable energy sources to promote the sustainability of the built environment; (2) enhance the health, wellbeing and productivity of occupants and whole communities; (3) cultivate economic development and financial returns for developers and whole communities; and (4) apply life cycle approaches to community planning and development

2.2.2.3. Sustainable Construction Objectives

Sustainable construction objectives are essential to achieve a sustainable outcome from the construction projects. Sourani and Sohail (2005) state that sustainability should integrate at least three dimensions which are social, economic and environmental dimensions. Social, economic and environmental dimensions are mentioned as triple bottom line which are known as more common dimensions in sustainability. Technical, managerial, cultural and community are mentioned as fewer common dimensions considering the sustainability perspective. Categorization of sustainability dimensions can be seen below in Figure 2.5.

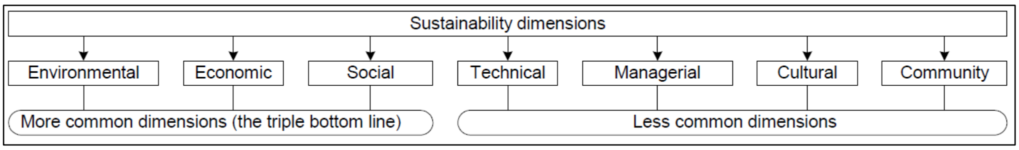

Figure 2.5. Sustainability dimensions (Sourani and Sohail, 2005)

Hill and Bowen (1997) categorize sustainable construction objectives under four pillars. According to Hill and Bowen (1997), social sustainability should improve the quality of human life and provide equity among community. Economic sustainability can be achieved by ensuring financial affordability, employment creation, choosing proper supplies and contractors. Biophysical principles of sustainable construction are mentioned as reducing the use of resources, minimizing pollution and damage to surrounding environment, maintaining biodiversity and creation of a healthy environment. Technical pillars of sustainable construction include the construction of durable, reliable and functional structures, utilization of serviceability, revitalization of existing urban infrastructures.

Sourani and Sohail (2005) state that there are different definitions for the sustainability concept, yet the widely accepted definition of sustainable development can be achieved by the integration of at least three dimensions which are social, economic and environmental. Promoting employment creation, utilization of life-cycle costing, supporting local economics are the economic dimensions of sustainability; preference of renewable resources, maximizing resource reuse/recycling, minimization of pollution considering air, land and water are the environmental dimension of sustainability. Social dimension of sustainable construction stated as intangible dimension is analyzed in a more detailed way in comparison to the economic and environmental dimensions. Social dimension of sustainable construction includes improvement of quality of human life, enhancing cultural diversity, protection of human health, training and development, provision of equal life standards, improvement of the image of construction, participation of stakeholders, provision of employment, respect to other people, improvement of working conditions.

Akadiri et al. (2012) construct a conceptual framework for the integration of sustainability principles in construction based on the triple bottom line of sustainability. Economic sustainability issues are stated as improved productivity, consistent profit growth, stakeholder’s satisfaction, minimized defects, more predictable project completion time, delivering services with the provision of best value. Environmental sustainability issues are analyzed under two main categories. Reduction of net emissions, prevention of nuisance, waste minimization, prevention of pollution, enhancing and protection of the biodiversity are the issues related with the effective protection of the environment. Prudent use of natural resources is the second category under the environmental sustainability, and it contains efficient use of energy by utilization of local supplies and materials, application of lean design principles, utilization of recyclable materials, water and waste management. Social sustainability principles are mentioned as provision of equal conditions, healthy and safety working environment, guaranteeing employee satisfaction, minimization of nuisance and disruption, establishing long-term relationships with the stakeholders, contributing the local economy and provision of the services at the best standards.

Hussin et al. (2013) put emphasize on balancing the basic principles of sustainability aspects together. The basic principles of sustainability are stated as environmental, economic and social aspects. For the environmental aspect, it is important to increase material efficiency, reduce the material quantity, enhance material recyclability, reduce and control the toxic materials, decrease the energy requirement for the procurement, maximize sustainable use, consider the impact of the projects on environment. Economic principles consist of the consideration of life-cycle cost, internalization of external costs, and consideration of alternative financials, promotion of sustainable consumption, consideration of the economic impact on local surroundings. The social dimension of the sustainability includes involvement of stakeholders, encouragement of public participation, consideration of the impact on community, assessment of the impact on health and quality of human life.

The benefits of sustainable construction are specified in terms of economic, environmental, and social aspects by Kim and Park (2013). According to Kim and Park (2013), benefit of economic aspect includes reduced risks and costs, better decision-making on the project, satisfaction and stronger long-term relationships among the stakeholders, more efficient design and construction; environmental aspects are reduction of waste, reduction of demand on natural resources, improvement of the building performance, proposing sustainable and environmental solution; social aspects are increased motivation, productivity and communication.

Atombo et al. (2015) state that there are a number of environmental, social and economic benefits with the implementation of sustainable construction techniques to project management field. Environmental benefits are specified as improvement of air and water quality, reduction of consumption of natural resources, minimization of wastes, addressing global warming by climate stabilization and ozone layer protection, enhancing biodiversity of the site. Economic benefits are reduction of the operation and maintenance cost, increasing revenues, energy-efficient design, conservation of resources sand materials. Social benefits of sustainable construction include enhancement of comfort, provision of a healthy life to the community and reduction of liability.

Enhassi et al. (2016) explain the sustainable development in construction industry as an integration of social, economic and environmental aspects of activity. Social pillar should aim to provide a strong sense of social cohesion, ensure accessibility to the key facilities by everyone, enhance employment opportunities, reduce the impact on the heritage. For the economic pillar, it should be provided employment creation, considered full-cost accounting, enhanced competitiveness, provided sustainable supply chain management, preferred appropriate supplier and construction, considered the long-term economic value of the facility. Waste management, proper use of natural resources, avoidance of pollution, accurate net land disturbance are included under the environmental aspect of sustainability. Like Hill and Bowen (1997), Enhassi et al. (2016) address the technical pillar of sustainable construction as well. Durability, functionality and quality of the structures are mentioned for the technical aspect.

It is agreed that sustainable construction can be achieved by addressing economic, environmental and social aspects. Also, some authors include technical pillar under the sustainable construction objectives. All in all, sustainable construction objectives in terms of economic (Table 2.8), environmental (Table 2.9), social (Table 2.10) and technical (Table 2.11) aspects are listed below with the references.

Table 2.8. *Economic sustainable construction objectives*

Reference Study	Economic Sustainability Objectives
Hill and Bowen (1997)	Ensuring financial affordability for intended beneficiaries
	Promoting employment creation
	Utilization of full-cost accounting and real-cost pricing to set prices and tariffs
	Enhancing competitiveness in the market place by adopting policies and practices that advance sustainability
	Choosing environmentally responsible suppliers and contractors
	Investing some of the proceeds from the use of non-renewable resources in social and human-made capital, to maintain the capacity to meet the needs of future generations
Sourani and Sohail (2005)	Promoting employment creation
	Using life-cycle costing
	Supporting local economies
Akadiri et al. (2012)	Improved productivity
	Consistent profit growth
	Employee, supplier and client satisfaction
	Minimized defects
	Shorter and more predictable completion time
	Lower cost projects with increased cost predictability
	Delivering services that provide best value to clients and focus on developing client business
Hussin et al. (2013)	Consideration of life-cycle costs
	Internalization of external costs
	Consideration of alternative financing mechanisms
	Developing appropriate economic instruments to promote sustainable consumption
	Considering the economic impact on local structures
Kim and Park (2013)	Reduced risks and costs through whole life-cycle costing
	Better decision-making through informed balance of quality and cost
	Increased shareholders' value and satisfaction
	More efficient design and construction
	Stronger long-term relationships through partnering arrangements
Atombo et al. (2015)	Reducing operation and maintenance cost
	Increasing revenue (sale price or rent)
	Energy-efficient and conservation of resources and materials
Enhassi et al. (2016)	Ensuring financial affordability
	Employment creation
	Adopting full-cost accounting
	Enhancing competitiveness
	Sustainable supply chain management
	Choosing environmentally responsible suppliers and contractors
	Maintaining capacity to meet the needs of future generations
	Optimized long-term economic value

Table 2.9. *Environmentally sustainable construction objectives*

Reference Study	Environmental Sustainability Objectives
Hill and Bowen (1997)	Extracting fossil fuels and minerals, producing persistent substances and foreign to nature, at rates which are not faster than their slow redeposit into the Earth's crust
	Reducing the use of four generic resources used in construction namely, energy, water, materials and land
	Maximizing resource reuse, and/or recycling
	Utilization of renewable resources in preference to non-renewable resources
	Minimizing air, land and water pollution, at global and local levels
	Creation of a healthy, non-toxic environment
	Maintaining and restoring the Earth's vitality and ecological diversity
	Minimizing damage to sensitive landscapes, including scenic, cultural, historical and architectural
Sourani and Sohail (2005)	Using renewable resources in preference to non-renewable resources
	Maximizing resource reuse and/or recycling
	Minimizing air, land and water pollution at global and local levels
Akadiri et al. (2012)	Minimizing polluting emissions
	Preventing nuisance from noise and dust by good site and depot management
	Waste minimization and elimination
	Preventing pollution incidents and breaches of environmental requirements
	Habitat creation and environmental improvement
	Protection of sensitive ecosystems through good construction practices and supervision
	Green transport plan for sites and business activities
	Energy efficiency at depots and sites
	Reduced energy consumption in business activities
	Design for whole-life costs
	Use of local supplies and materials with low-embodied energy
	Lean design and construction avoiding waste
	Use of recycled/sustainable products
	Water and waste management
Hussin et al. (2013)	Increasing material efficiency by reducing the material demand of non-renewable goods
	Reducing the material intensity via substitution technologies
	Enhancing material recyclability
	Reducing and controlling the use and dispersion of toxic materials
	Reducing the energy required for transforming goods and supplying services

Table 2.9. *(Cont'd)*

Reference Study	Environmental Sustainability Objectives
Hussin et al. (2013)	Supporting the instruments of international conventions and agreements
	Maximizing the sustainable use of biological and renewable resources
	Considering the impact of planned projects on air, soil, water, flora and fauna
Kim and Park (2013)	Reducing waste and reserve natural resources
	Improving building performance and minimizing energy consumption
	Holistic, sustainable and appropriate environmental solutions
Atombo et al. (2015)	Improvement of air and water quality
	Minimization of energy and water consumption
	Reduction of waste disposal
	Climate stabilization
	Ozone layer protection
	Natural resource conservation
	Open space, habitat and biodiversity protection
Enhassi et al. (2016)	Waste management
	Prudent use of the four generic construction resources (water, energy, material and land)
	Avoiding environmental pollution
	Reducing water use
	Reducing net land disturbance
	Reducing net emissions

Table 2.10. *Social sustainable construction objectives*

Reference Study	Social Sustainability Objectives
Hill and Bowen (1997)	Improving the quality of human life, including poverty alleviation
	Making provision for social self-determination and cultural diversity in development planning
	Protecting and promoting human health through a healthy and safe working environment
	Implementing skills training and capacity enhancement of disadvantaged people
	Seeking fair or equitable distribution of the social costs of construction
	Seeking equitable distribution of the social benefits of construction
	Seeking intergeneration equity

Table 2.10. *(Cont'd)*

Reference Study	Social Sustainability Objectives
Sourani and Sohail (2005)	Improving the quality of human life, including poverty alleviation
	Making provision for social self-determination/enhancement
	Diversity - including making provision for cultural diversity in development planning
	Protecting and promoting human health through a healthy and safe working environment
	Training and development - including implementing skills training and capacity enhancement of disadvantaged people
	Seeking fair or equitable distribution of the social costs and benefits of construction
	Seeking intergenerational equity
	Participation of stakeholders
	Social inclusion
	Improving the image of construction
	Employment - including equal employment opportunities
	Recruitment and retention
	Equality
	Respecting to people – workforce and employee satisfaction, working in occupied premises, working environment
	Compensation and benefits, working hours, forced labor, freedom of association and collective bargaining
Akadiri et al. (2012)	Provision of effective training and appraisals
	Equitable terms and conditions
	Provision of equal opportunities
	Health, safety and conducive working environment
	Maintaining morale and employee satisfaction
	Participation in decision-making
	Minimizing local nuisance and disruption
	Minimizing traffic disruptions and delays
	Building effective channels of communication
	Contributing to the local economy through local employment and procurement
	Delivering services that enhance the local environment
	Building long-term relationships with clients and local supplies
	Corporate citizenships
	Delivering services that provide best value to clients and focus on developing client business
Hussin et al. (2013)	Enhancing a participatory approach by involving stakeholders
	Promoting public participation
	Promoting the development of appropriate institutional frameworks
	Consideration of the influence on the existing social framework
	Assessment of the impact on health and the quality of life

Table 2.10. *(Cont'd)*

Reference Study	Social Sustainability Objectives
Kim and Park (2013)	Increased employee motivation and enhanced productivity
	Increased capacity to innovate and improve efficiency
	Improving communication and collaborations among project participants
Atombo et al. (2015)	Enhancing occupant comfort and health
	Reducing liability
Enhassi et al. (2016)	A positive condition marked by a strong sense of social cohesion
	Equity of access to key services including health, education, transport, housing and recreation
	Improving equal employment opportunities
	Improving contribution to the community
	Reducing impact on heritage

Table 2.11. *Technical sustainable construction objectives*

Reference Study	Technical Sustainability Objectives
Hill and Bowen (1997)	Construct durable, reliable and functional structures
	Pursue quality in creating the built environment
	Use serviceability to promote sustainable construction
	Humanize larger buildings
	Infill and revitalize existing urban infrastructure with a focus on rebuilding mixed-use pedestrian neighborhoods
Enhassi et al. (2016)	Construction of durable and functional structures
	Structural quality

To sum up, economic, environmental and social aspects are stated as three pillars of sustainable construction in previous studies. Considering the characteristics of megaprojects, sustainable construction objectives have become important and it is essential to maintain those objectives in order to get a sustainable outcome from construction megaprojects.

2.3. Literature Review on Risk Management

Literature review about risk management is mentioned below. Firstly, definition of risk and risk management are stated. Then, risk management processes including risk identification, risk assessment, risk response and risk monitoring stages are examined in detail.

2.3.1. Definition of Risk

In the general context, risk is defined as *the possibility that something bad, unpleasant or dangerous may happen* (Longman Dictionary, 2019). Considering the definition of risk in the general context, project management field agrees on the point that risk is an uncertainty, yet risk does not have to affect in a negative way, risk can have positive effect as well.

ISO 31000 (2009) defines risk as an effect of uncertainty on objectives. There are some underlined points considering the definition of risk. First of all, effect is stated as deviation from the expected which can be either positive and/or negative. Secondly, objectives may differ in terms of financial, health and safety, and environmental aspects and they can be applied at different levels. Third, characterization of risks can be done considering the potential events and/or consequences. Fourth, the expression of risk is presented in terms of the consequences of an event and likelihood. Finally, it is important to understand the notion of an event and its consequences and likelihood.

According to PMI (2009), risks are uncertain future events or conditions which may or may not occur. PMI (2009) points out distinguishing risks from risk-related features like cause and effect. Causes may give birth to risks because they may be emerged at any time. On the other hand, effects are future events that have impact on one or more project objectives. Project risks are considered as individual risks and overall project risk. Individual risks may affect one or more project objectives either positively or negatively. Overall project risk is stated as sum individual risks on a project.

PMBoK Guide (2013) states project risk as an uncertain event or condition. Project objectives such as scope, schedule, cost, quality may be affected positively or negatively in case of the occurrence of the project risks. Positive risks are referred as opportunities, and negative risks are commonly referred as threats considering the obtained outcomes from the risks. Origins of project risk arise from the existing uncertainties in the projects. If the risks are known, they can be identified and analyzed. As a result, the anticipated risks can be managed. If the known risks cannot be able to be managed, some precautions can be taken in advance. Unknown risks cannot be managed but management strategies can be enhanced beforehand.

2.3.2. Definition of Risk Management

Mhetre et al. (2016) state risk management as a process which specifies and assesses the project risks and suggests the action plans to deal with the threats on a project. It is emphasized that all steps should be implemented regarding the risk management process to eliminate the threats. According to Çeliktaş and Ünlü (2018), risk management is the process of determining, assessing and minimizing the risk factors that may adversely affect the probability of an institution or organization. ISO 31000 (2009) defines risk management as coordinated activities to direct and control an organization with regard to risk. In order to manage risks in an effective way, some principles should be integrated into risk management. The principles are creating and protecting value, being an integral part of all organizational processes, being part of decision-making, addressing uncertainties explicitly, being systematic, structured and timely, seeking for the best available information, adapting with the company's profile, considering human and cultural factors, being transparent and inclusive, being dynamic, iterative and responsive to change, facilitating continual improvement of the organization. Yıldız (2012) mentions risk management in construction industry as a systematic and continuous process of identifying risks in the project environment, assessing the impact of the risks on project objectives and developing strategies to manage risks.

2.3.3. Risk Management Processes

Banaitiene and Banaitis (2012) state a typical risk management process into four categories; risk identification, risk assessment, risk mitigation and risk monitoring. Like Banaitiene and Banaitis (2012), Thevendran and Mawdesley (2004) mention the four stages of risk management process which are risk identification, risk analysis, risk response and risk monitoring. On the other hand, Baker et al. (1999) underline that five steps should be involved for an extensive risk management process. Five steps of risk management process are risk identification, risk estimation, risk evaluation, risk response and risk monitoring. Dey (2010) examines risk management process into six stages which are risk management planning, risk identification, qualitative risk analysis, quantitative risk analysis, risk response planning, risk monitoring and control. In this context, risk management processes are examined in terms of risk identification, risk assessment, risk response, risk monitoring and control for the rest of this chapter.

2.3.3.1. Risk Identification

Risk identification is important because the anticipated risk can be managed to achieve project objectives in advance (Iqbal et al., 2015). Banaitiene and Banaitis (2012) state that risk identification is the first and the most important step in risk management. In this step; potential risk event conditions in the construction project are determined and the further steps of risk management processes are enhanced by results obtained from the risk identification step.

There are several approaches for the risk management processes. Dziadosz and Rejment (2015) review that the brainstorming, the Delphi technique, the checklists, the expert's evaluation, the periodic document reviews are the most common methods for risk identification step. In addition, Wang et al. (2004) developed a risk mitigation framework for construction projects and risks are identified considering the hierarchical level of the risks. Level I presents the highest importance of the risks while Level III is the lowest importance. Tah and Carr (2000) classify risk into risk breakdown structure. Project risks are categorized considering the external and internal risks. External risks are stated as relatively uncontrollable and internal risks are relatively more controllable in comparison to the external risks. Hierarchical risk breakdown structure proposed by Tah and Carr (2000) can be seen in Figure 2.6.

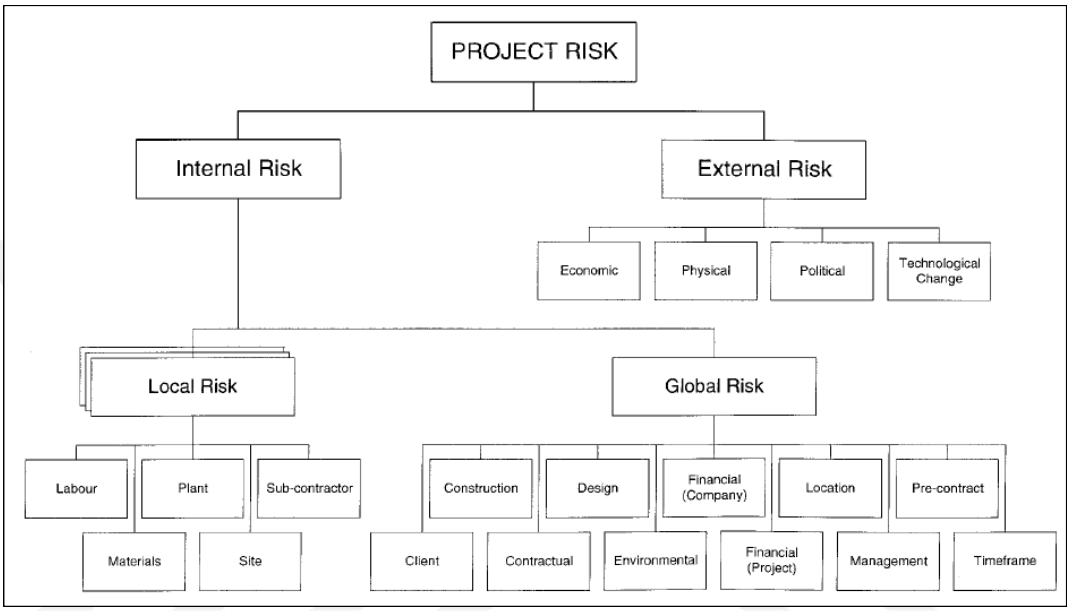

Figure 2.6. Risk breakdown structure (Tah and Carr, 2000)

2.3.3.2. Risk Assessment

Valis and Koucky (2009) mention risk assessment as a part of risk management processes that enables a structured process to identify how may the objectives be affected. The risk assessment stage provides a detailed understanding of cause, consequences or probabilities of risks. For the risk assessment step, Valis and Koucky (2009) emphasize that it is important to respond the questions like what can happen and why, what are the consequences, what is the probability of their future occurrence, are there any factors that mitigate the consequence of the risk or that reduce the probability of the risk. Morete and Vila (2010) define risk assessment as a process of prioritizing risks to fulfill the further analysis by assessing the probability of occurrence and impact of the risks.

Mhetre et al. (2016) categorize risk assessment methods under quantitative and qualitative methods. Quantitative methods provide a framework to quantify the possible outcomes for a project in a more realistic way under uncertainties. For instance, sensitivity analysis is implemented to identify the uncertain project component that have a higher impact on the outcome of the project. Scenario analysis enables to evaluate different scenarios. Monte Carlo simulation is utilized to quantify the effect of uncertainties and risks on project budget and schedule by simulation with randomly chosen values. In addition, decision tree diagrams can be used for formulating the problem and evaluating options. Qualitative methods are performed considering the likelihood and impact of a risk. In contrast to quantitative methods, qualitative methods are easy to apply and time-saving. For the qualitive methods, probability-impact risk rating matrix is known as the most common way to prioritize risks. Likelihood and impact values are assigned to the risks and the risks are considered as high-risk if they have a high impact and high likelihood value.

Risk analysis is stated as Perform Qualitative and Quantitative Risk Analysis in PMBoK (2013). Perform Qualitative Risk Analysis is the process of prioritization of the risks in order to decrease the level of uncertainty and to focus on the high-priority risks. In this analysis, probability of occurrence of the identified risks and their the impact on the project objectives are assessed. Risk probability and impact assessment, probability and impact matrix, risk quality data assessment, risk categorization, risk urgency assessment, expert judgment are the techniques for performing qualitative risk analysis. As an illustration, risks are classified high risk, moderate risk and low risk in probability and impact matrices. Classification of risks is done according to the probability and impact of the identified risks. As a result, risks can be rated for objectives including cost, time, scope etc. In brief, qualitative risk analysis can be considered as a key process to reduce the influence of bias and to concentrate on the critical risks more. Moreover, Perform Qualitative Risk Analysis can enable to lay the foundation for Perform Quantitative Risk Analysis in case of necessity. Besides qualitative risk analysis, Perform Quantitative Risk Analysis is a numeric assessment method to determine the effect of identified risks on overall project objectives. There are various tools and methods to perform quantitative risk analysis. For instance, data can be gathered by interview or probability distribution diagrams. As modelling techniques; sensitivity analysis, expected monetary value analysis, modeling and simulation are included. The focus of modeling techniques is to determine the effect of the risks on a project outcome like time and cost.

Simmons et al. (2017) examine risk analysis in terms of deterministic methods, semi-quantitative risk analysis and probabilistic risk analysis. Deterministic methods can enable to consider the impact of the identified risks whether the risks are manageable or capable of being managed. This approach sets a framework for ‘if this happens, this is the consequence’. The consequences can be determined either scenario test, stress test or reverse stress test. In semi-quantitative risk analysis, risks are categorized by comparative scores. As a result, a risk can be demonstrated by making comparison among the other identified risks. According to Simmons et al. (2017), risk matrices allow users to make a simple visual comparison of different risks. Risk matrices are comprised of two dimensions which are severity and probability. Severity is stated as unwanted consequences with a scale from minor to catastrophic. Probability is the situation that whether the risk will happen or not. Like severity scale, probability has a scale in risk matrix. Rare, unlikely, possible, likely and almost certain are mentioned as probability scales. ‘Rare’ corresponds to no globally reported event; whereas ‘almost certain’ corresponds to the occurrence. In probability-impact risk matrix, risks are visualized by color coding. Tolerable risks are presented with green and intolerable risks are presented with red. Probability and impact matrix with color coding can be found in Figure 2.7.

LIKELIHOOD	CONSEQUENCES				
	Insignificant	Minor	Moderate	Major	Severe
Almost Certain	M	H	H	E	E
Likely	M	M	H	H	E
Possible	L	M	M	H	E
Unlikely	L	M	M	M	H
Rare	L	L	M	M	H

Figure 2.7. Probability impact matrix (Simmons et al., 2017)

Probabilistic risk analysis enables to obtain probability distributions by running simulations considering different levels of probability and severity values. Monte Carlo simulation can be given as an example for the probabilistic risk analysis method.

In brief, risk assessment can be performed either utilizing quantitative methods or qualitative methods. Qualitative risk assessment methods enable to prioritize risks that are determined in the risk identification step. On the other hand, the overall effect of the identified risk factors on project objectives are determined in quantitative risk assessment methods. The most commonly used risk assessment methods in the construction sector are mentioned below.

McCabe et al. (1998) mention that Bayesian networks is a probabilistic approach. In Bayesian networks, uncertainty is handled considering probability theory and conditional dependence. Bayesian networks are constructed by defining nodes and arrows. Variables are demonstrated by nodes and conditional dependence relationships are demonstrated by arrows. The belief network is developed by constituting the relationship among variables and conditional dependences. Luu et al. (2009) utilize Bayesian belief networks (BBN) to quantify the probability of delay in construction projects in developing countries. Cause-effect relationships among the risk factors that affect delay in construction projects are determined to enhance a belief network model to quantify risks for schedule delays and assign conditional probabilities to the factors.

According to Avlijaš (2019), Monte Carlo simulation is a quantitative risk assessment technique that enables to iterate randomly chosen input variables (e.g., cost estimates or activity durations) many times to get outputs like probability distributions. It is emphasized that Monte Carlo simulation technique is commonly used especially in time and cost management of the construction projects.

Habek and Molenda (2017) mention that Failure Mode and Effect Analysis (FMEA) is a qualitative method to identify possible failures in a design, manufacturing or assembly process. Failure modes represent the things that may fail, errors or defects. Effect analysis represents the consequences of the failures. In FMEA, failures are prioritized considering the consequences, frequencies of occurrences and detection. Risk Priority Numbers (RPNs) is used for measuring the failures. RPN is a score that can be obtained by multiplying probability of the failure by severity of the failure and probability of not detecting the failure. Carbone and Tippett (2004) propose a method of extension of the FMEA format to assess project risks. The main focus of RFMEA is to guide risk contingency planning for the critical risks in the early stages of the project. Failures are prioritized by RPN values in FMEA. On the contrary, RFMEA approach deals with the risks not the failures. Like FMEA method, RPN is calculated by multiplying likelihood by impact and detection values in RFMEA. In contrast to FMEA method, RFMEA suggests guidelines for likelihood, impact, and detection values for the users. Risk score is considered which is the multiplication of likelihood and impact values in RFMEA. The users will identify the risk factors in terms of the risk score values and risk prioritized values in a more visualized way. As a result, it will be focused more on the most imminent risks and action plans will be taken in advance.

The Cross-Impact method is enhanced by Gordon and Helmer in 1966 to clarify the question “Can forecasting be based on perceptions about how future events may interact?” (Gordon, 1994). According to Bañuls et al. (2016), Cross-Impact Analysis (CIA) is utilized to determine the relationships between events in order to deal with the uncertainties in the future. Therefore, CIA is widely used for the generation and analysis of the scenarios under uncertainty. Han and Diekmann (2001) propose risk-based go/no-go decision model for companies that would like to enter international construction markets. The aim of the model is to assess uncertainties related with the international market, reduce risks and develop strategies in advance. For the go/no-go decision model, the cause effect relationships map is constituted with CIA method (see Figure 2.8). The cause-effect relationship map includes five set of variables which are country conditions, contractor’s decision strategies and variables impacted by country conditions or decision strategies, probable outcomes of the project and outcome variables as project probability and other benefits. The advantage of utilizing CIA method in this model is that the constructed CIA relationships are flexible and modifiable according to the country conditions, project conditions and decision maker’s strategies. As a result, the go/no-go decision model will enable to include various number of variables, model relationships among decision variables and consider the uncertainty in decision process and assess the effect of uncertainty on the overseas construction project.

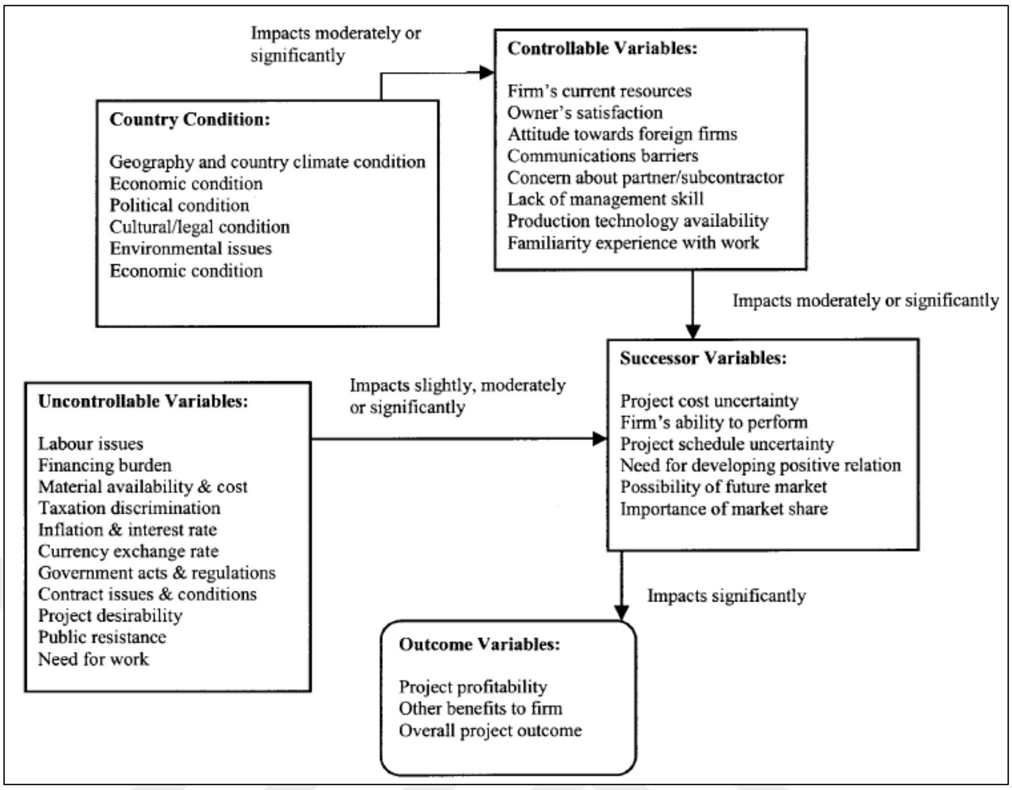

Figure 2.8. Cross-impact analysis cause–effect relation map (Han and Diekmann, 2001)

Multi-criteria decision making (MCDM) is a field of operational research. Due to the fact that the real life does not have single criterion for the choices, the decision alternatives are evaluated taken into consideration of multiple choices in order to obtain better decisions for the future (Ishizaka and Siraj, 2018). Velasquez and Hester (2013) summarize MCDM methods with their advantages, disadvantages and areas of application as shown in Table 2.12.

Table 2.12. *Summary of MCDM methods (Velasquez and Hester, 2013)*

Method	Advantages	Disadvantages	Area of Application
Multi-Attribute Utility Theory (MAUT)	Takes uncertainty into account; can incorporate preferences.	Needs a lot of input; preferences need to be precise.	Economics, finance, actuarial, water management, energy management, agriculture
Analytic Hierarchy Process (AHP)	Easy to use; scalable; hierarchy structure can easily be adjusted to fit many-sized problems; not data-intensive.	Problems due to interdependence between criteria and alternatives; can lead to inconsistencies between judgment and ranking criteria; rank reversal.	Performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning.
Case-Based Reasoning (CBR)	Not data-intensive; requires little maintenance; can be improved over time; can adapt to changes in environment.	Sensitive to inconsistent data; requires many cases.	Businesses, vehicle insurance, medicine, and engineering design.
Data Envelopment Analysis (DEA)	Capable of handling multiple inputs and outputs; efficiency can be analyzed and quantified.	Does not deal with imprecise data; assumes that all input and output are exactly known.	Economics, medicine, utilities, road safety, agriculture, retail, and business problems.
Fuzzy Set Theory	Allows for imprecise input; takes into account insufficient information.	Difficult to develop; can require numerous simulations before use.	Engineering, economics, environmental, social, medical, and management.
Simple Multi-Attribute Rating Technique (SMART)	Simple; allows for any type of weight assignment technique; less effort by decision makers.	Procedure may not be convenient considering the framework.	Environmental, construction, transportation and logistics, military, manufacturing and assembly problems.
Goal Programming (GP)	Capable of handling large-scaled problems; can produce infinite alternatives.	Its ability to weight coefficients; typically needs to be used in combination with other MCDM methods to weight coefficients.	Production planning, scheduling, health care, portfolio selection, distribution systems, energy planning, water reservoir management, scheduling, wildlife management

Table 2.12. *(Cont'd)*

Method	Advantages	Disadvantages	Area of Application
ELECTRE	Takes uncertainty and vagueness into account.	Its process and outcome can be difficult to explain in Layman's terms; outranking causes the strengths and weaknesses of the alternatives not to be directly identified	Energy, economics, environmental, water management, and transportation problems.
PROMETHEE	Easy to use; does not require assumption in which criteria are proportionate.	Does not provide a clear method by which to assign weights.	Environmental, hydrology, water management, business and finance, chemistry, logistics and transportation, manufacturing and assembly, energy, agriculture.
Simple Additive Weighting (SAW)	Ability to compensate among criteria; intuitive to decision-makers; calculation is simple; does not require complex computer programs.	Revealed estimates do not always reflect the real situation; obtained results may not be logical.	Water management, business, and financial management.
Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS)	Has a simple process; easy to use and program; the number of steps remains the same regardless of the number of attributes.	Its use of Euclidean Distance does not consider the correlation of attributes; difficult to weight and keep consistency of judgment.	Supply chain management and logistics, engineering, manufacturing systems, business and marketing, environmental, human resources, and water resources management.

Future is unknown in risk management field, so it is important to analyze the alternatives to make better decisions and decrease the level of risk factors in advance. Therefore, several MCDM tools are utilized in construction risk management field.

AHP is a multicriteria decision making method that allow to make pairwise comparisons among alternatives in a hierarchal way (Saaty, 1990). Aminbakhsh et al. (2013) state that health and safety risks are the most important risks in construction projects. Thus, safety risk assessment method is proposed to be a guide to the decision-makers in construction projects. Safety risks in construction projects are prioritized by utilizing AHP with the adaptation of cost of safety (COS) theory. With the implementation method of this method, a rational budget with more realistic objectives will be set up by taking into consideration of health and safety environment in construction projects. Hastak and Shaked (2000) propose a model for international construction risk assessment (ICRAM-1) that assists users to specify the potential risks in an international market. Potential risks are analyzed considering the three interrelated levels which are risks at macro, market and project levels. ICRAM-1 is formed by utilizing AHP and weighs for risk indicators are determined regarding the influences from macro level, market level, project level risks to the international construction project. All in all, high risk indicators, impact of country and market environment on a specific project, and overall project risk can be obtained from the ICRAM-1.

The analytic network process (ANP) is a multi-criteria decision method like AHP, yet ANP is more comprehensive and complementary than AHP. ANP method can be addressed when the decision problems can be structed in a network (Ergu et al., 2014). Bu-Qammaz (2007) developed a decision support tool to assess risks in international construction projects for bidding decisions by utilizing analytic network process technique. After the risk identification step, ANP model was constituted by Hierarchical Risk Breakdown Structure (HRBS) to demonstrate potential dependence between risk categorizes and risk sources. The main aim of International Construction Project Risk Assessment Model (ICRM) is to determine the relative priorities of risk factors which are obtained from the ANP model.

Morote and Vila (2010) state that linguistic assessments are preferred in risk assessment rather than numerical assessments. Risk assessment is carried out if there is a vagueness or lack of data. Thus, data cannot be defined with precise values. The obtained data is stated with the linguistic terms including low probability, serious impact, or high risk based on a mathematical logic. Tah and Carr (2000) propose a construction project risk management model by using fuzzy logic. After the risk identification step, the relationships among risk factors, risks and their consequences are demonstrated on cause and effect diagrams. The relationships between risk resources and consequences on project performance indicators are determined by using fuzzy logic. As a result, risks and consequences of risks in terms of time, cost, quality and safety performance measures can be explained as a linguistic variable by the utilization of fuzzy logic. Dikmen et al. (2006) develop a fuzzy risk assessment method to rate cost overrun risk in international construction projects. Proposed methodology for fuzzy risk rating includes five main steps. First of all, risks are identified by using influence diagrams. Secondly, each variable is defined by membership function to determine the degree of a fuzzy risk score including low risk, low-to medium risk, medium risk, medium-to-high risk and high risk. Then, relationships between risks and influencing factors are constructed by IF…THEN rules. Afterwards, fuzzy operations are implemented to the constructed rules in the third step in order to obtain fuzzy cost overrun risk rating. Finally, project risk level is determined by the final risk rating calculated from the fourth step.

SMART (Simple Multi-Attribute Rating Technique) is stated as a weighting method that enables to make simple decisions (Risawandi, 2016). Schramm and Morais (2012) propose a decision support model with the implementation of SMARTER (Simple Multi-Attribute Rating Technique Exploiting Ranking) technique for selecting and evaluating suppliers in the construction sector. SMARTER model assists to manage the selection process of suppliers and enable to make more strategic decisions for the management team. The model is constituted by determination of suppliers, definition of criteria set that are used for the selection of the suppliers, application of SMARTER and evaluation of the selected supplier. As a result, ranking of the suppliers is determined by SMARTER method based on 9 criteria including quality management system, unit price, cost reduction plans, transport cost, rejection level, request for assistance answered, lead time, time flexibility and quantity flexibility. As a result, the developed model will enable to decrease the risks related with the decision-making process considering the determination process of suppliers.

All in all, various risk assessment methods are utilized in construction projects. The main aim of risk assessment process is to specify and demonstrate the relationship between the impact and consequences of the risk factors in advance. It can be concluded from the previous studies that risks related with the time, cost, quality and safety issues are the most common objectives investigated for the risk assessment process in construction projects.

2.3.3.3. Risk Response

PMBoK (2013) states risk response as a process of enhancing alternatives to mitigate or decrease the threats determined in the previous stages on project objectives. Avoid, transfer, mitigate and accept are the strategies for threats that have negative impact on project objectives. On the other hand, if risks do have positive impacts on project objectives; exploit, enhance, share and accept are stated as strategies for positive risks or opportunities. Wang et al. (2004) state the importance of management of risks in international construction projects in developing countries. Therefore, they suggest a risk management framework to implement effective mitigation strategies that measure risks in international construction projects. The proposed methodology enables to categorize risks in hierarchical levels, and if the risks are in the higher hierarchical level and if there is an influencing relationship among the risks under the hierarchy risk levels, attention should be paid on these risks and they should be mitigated first.

2.3.3.4. Risk Monitoring and Control

Risk monitoring and control is essential because the identified risks can be collected and monitored in this stage (Gajewska and Ropel, 2011). Control risk is mentioned as the final stage of the risk management process in PMBoK (2013). In this stage, the developed risk response plans are fulfilled and the identified risks are tracked. If it is thought that new risks may be emerged, new risks are specified as well. Moreover, the overall risk management process is reviewed. Risk reassessment, risk audits, variance and trend analysis, technical performance measurement, reserve analysis and meeting are the tools and techniques for the risk monitoring and control step.

Carrying out risk management processes are essential for the construction projects in order to foresee the potential events in the future and take necessary actions to achieve project objectives in advance. Previous studies in the construction risk management field mainly focus on project objectives like time, cost, quality and safety issues in order to minimize threats on those objectives. However, the aforementioned project objectives are not sufficient enough to evaluate construction megaprojects as successful or not. In this context, a risk assessment approach is proposed for sustainable construction of megaprojects and the proposed risk assessment approach is explained for the further part of this thesis.

CHAPTER 3

STEPS OF THE RESEARCH

This chapter presents the research steps for the proposed Risk Assessment Method for Sustainable Construction of the Megaprojects (RAMSCOM). The research consists of mainly four steps. First of all, a preliminary conceptual model is established according to the literature review carried out for the sustainable construction objectives and risk factors for the megaprojects. Then, the preliminary conceptual model is developed as a risk assessment method which is called Risk Assessment Method for Sustainable Construction of the Megaprojects (RAMSCOM). In the next step, implementation of the RAMSCOM is demonstrated on a hypothetical megaproject, and then tested on a real megaproject. The final step, namely as discussion of findings step, introduces the interpretation process of the data obtained from the RAMSCOM.

The steps of the research process is presented in Figure 3.1, and each research step is explained in detail throughout this chapter.

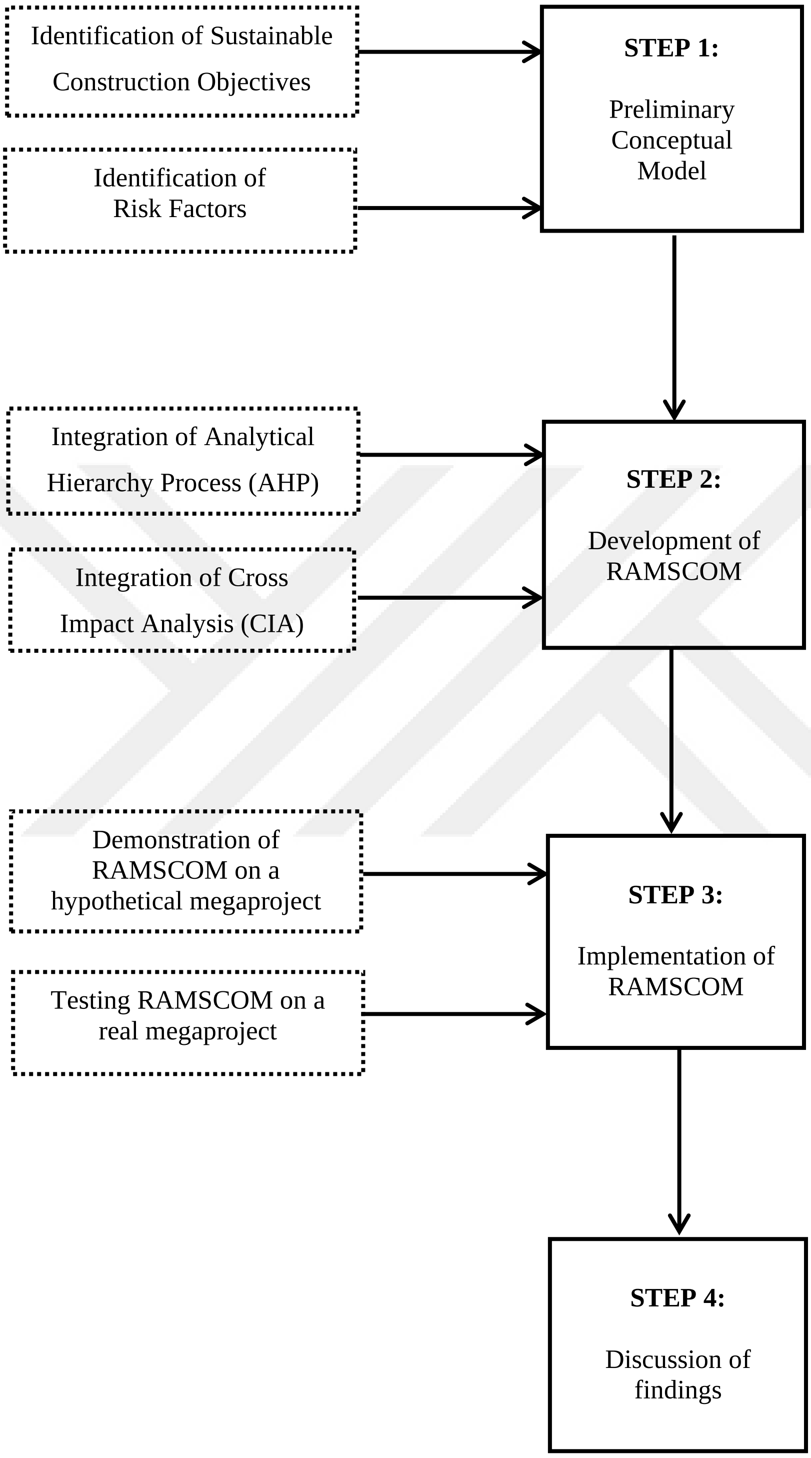

Figure 3.1. Steps of the research process

3.1. Step 1: Preliminary Conceptual Model

Preliminary conceptual model is formed according to the literature review conducted about sustainable construction objectives and risk factors for the megaprojects. In total, 20 sustainable construction objectives are identified through literature review. Then, same procedure is utilized to determine risks for megaprojects as well. Finally, the relationships between sustainable construction objectives and risk factors are demonstrated on a preliminary conceptual model. The identified sustainable construction objectives and risk factors are stated in Chapter 4.

3.2. Step 2: Establishment of RAMSCOM

In this step, the preliminary conceptual model is developed as a risk assessment method in order to show the relationships between sustainable construction objectives and risk factors in a more quantified way. The quantification process of the preliminary conceptual model consists of two main parts. In the first part, quantification process of sustainable construction objectives is carried out by utilizing AHP. AHP is proposed to identify the relative importance of the sustainable construction objectives. The risk assessment process begins with the second part. CIA is proposed in order to determine dependency values of each sustainable construction objective. The calculation process of the expected dependency values is done according to the cross-impact and probability of occurrence of the risk factors. As a result, the proposed risk assessment method which is called RAMSCOM enables to determine which sustainable construction objective is more vulnerable regarding the importance of the objectives. A more detailed information about the development stages of RAMSCOM is provided in Chapter 5.

3.3. Step 3: Implementation of RAMSCOM

The implementation of RAMSCOM is explained on a hypothetical megaproject. Then each implementation process is demonstrated in Chapter 5. Thereafter, RAMSCOM is tested on a real megaproject as presented in Chapter 6.

3.4. Step 4: Discussion of Findings

In this step, the data obtained from RAMSCOM is presented with visual aids including vulnerability chart and heat map. The visual aids are aimed to develop appropriate strategies to mitigate risks on sustainable construction objectives. Details about the results and findings are discussed after the implementation of the RAMSCOM on a hypothetical and a real construction megaproject.

In this chapter, research steps have been summarized. The research begins with the constitution of the preliminary conceptual model. Then, the proposed risk assessment method for sustainable construction of megaprojects is stated. Subsequently, case study is utilized for the demonstration and testing of the proposed risk assessment method. The following chapter begins with the first step of the research methodology which is the establishment of the preliminary conceptual model for sustainable construction of megaprojects.

CHAPTER 4

PRELIMINARY CONCEPTUAL MODEL

In this chapter, the identified sustainable construction objectives and risk factors are mentioned. Subsequently, preliminary conceptual model is presented regarding the identified objectives and risk factors.

4.1. Identification of Sustainable Construction Objectives

A detailed literature review about sustainability, sustainable development and sustainable construction was presented in Chapter 2. The main focus of this part in Chapter 4 is to specify sustainable construction objectives for the preliminary conceptual model.

In the literature, sustainable construction dimensions are stated as the integration of economic, environmental and social dimensions of sustainability by various authors (Sourani and Sohail, 2005; Hill and Bowen (1997); Akadiri et al., (2012); Hussin et al., (2013); Kim and Park (2013); Atombo et al., (2015); Enhassi et al., (2016)). In brief, economic aspects of sustainable construction objectives are mentioned with the keynotes including financial issues, employment, procurement, recycling of materials; environmental aspects of sustainable construction objectives are stated with the main themes including natural resource conservation, environmentally friendly construction materials, reduction of the pollutants, reduce-recycle-reuse of the products, procurement; social aspects of sustainable construction objectives are clarified with the expressions like employment, satisfaction of people, welfare, healthy and safe environment, local people and environment.

As Coskun et al. (2018) point out the fact that some of the sustainable construction objectives are mentioned as both economic and environmental; or both environmental and social; or both economic and social sustainability. As an illustration, employment creation is stated as an economic sustainability by Enhassi et al. (2016). On the other hand, Sourani and Sohail (2005) mention the same issue as a social sustainability. Kim and Park (2013) emphasize more efficient design and construction as an economic sustainability. Hussin et al. (2013) approach the energy-efficient issue as an environmental sustainability.

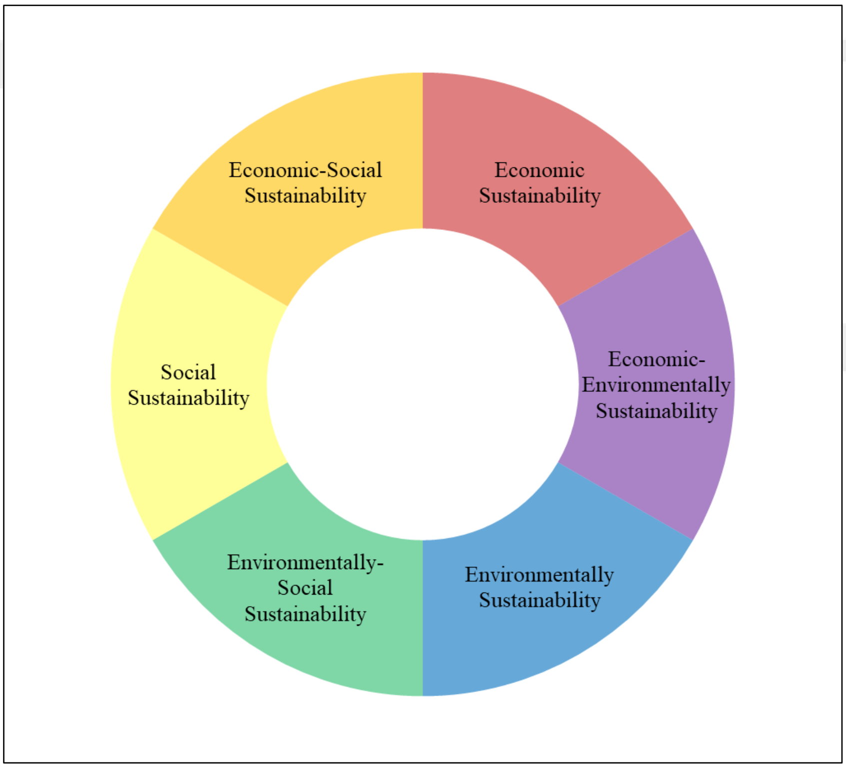

Figure 4.1. Sustainable construction dimensions

In Figure 4.1, it is demonstrated that how the sustainable construction objectives are categorized for the next stages of the research steps.

All in all, the identified sustainable construction objectives are categorized into six main categories; namely economic sustainability, environmental sustainability, social sustainability, economic-environmental sustainability, environmental-social sustainability and economic-social sustainability. In total, 20 sustainable construction objectives are identified according to the literature review and the identified sustainable construction objectives are presented in Table 4.1. In addition; code numbers are assigned for each sustainable construction objective.

Table 4.1. *Identified sustainable construction objectives*

Sustainable Construction Dimensions	ID	Code Number	Sustainable Construction Objectives
Economic Sustainability	1	SO_1	Feasibility and financial affordability of the megaproject
	2	SO_2	Optimized long-term economic value
	3	SO_3	Effective project management and management of resources
Economic-Environmental Sustainability	4	SO_4	Energy efficiency for all phases of the megaproject
	5	SO_5	Utilization of local materials and supplies
	6	SO_6	Reduction, reuse and recycling of materials
	7	SO_7	Optimization of site layout
Environmental Sustainability	8	SO_8	Reduction of emissions, wastes, pollutants and noise
	9	SO_9	Choice of environmentally friendly materials and products
	10	SO_{10}	Natural resource conversation and preference of renewable resources
	11	SO_{11}	Enhancing biodiversity
Environmental-Social Sustainability	12	SO_{12}	Preservation of cultural identity and reducing the impact on heritage due to the megaproject
	13	SO_{13}	Minimizing local nuisance and disruption
	14	SO_{14}	Providing a healthy and safe environment for all phases of the megaproject
Social Sustainability	15	SO_{15}	Delivering services that enhance the local environment
	16	SO_{16}	Provision of equal opportunities
	17	SO_{17}	Enhancing quality of life and providing customer and employee satisfaction
Economic-Social Sustainability	18	SO_{18}	Supporting local economies
	19	SO_{19}	Providing equal employment creation
	20	SO_{20}	Zero defects policy

4.2. Identification of Risk Factors for Megaprojects

Risk identification is the first step of risk management process that is mentioned in Chapter 2. Due to long-life cycle of megaprojects, there are some risk factors may threaten the achievement of a sustainable outcome from megaprojects. Therefore, it is important to determine the threats in advance. In this part of Chapter 4, risk factors for the sustainable construction of megaprojects are identified.

Construction megaprojects consist of many risk factors and the identified risk factors in the literature are presented below.

Diéguez et al. (2014) identify risk factors in megaprojects in terms of construction risks, operation and maintenance risks, labor risks, financial and/or economic risks and force majeure risks. Construction risks are stated as cost overruns, delay in schedule, organizational problems and problems with the design. Operation and maintenance risks including high operation cost, poor construction quality, operation capacity or quality are the risks related with the operational phase of the projects. Labor risks can be experienced due to poor training of labor or accident at construction site. Financial and/or economic risks include lower profitability, liquidity risks, financial restriction, availability of funds etc. Force majeure risks are stated as wars, natural disasters, extreme weather conditions and terrorism.

Youjie (2001) states risks associated with large-scaled infrastructure projects as technical, organizational, external and project management risks. Technical risks include inexperienced designers, changes in technology used; organizational risks are lack of prioritization of the project objectives, inadequate funding, resource conflicts; external risks are stated as change in laws, poor geological conditions and weather, and force majeure risks; project management risks are poor allocation of resources and inadequate project planning. The common failures for infrastructure projects are listed due to the delay in completion time, cost overrun, technical failures, financial failures of the contractors, government interferences, uninsured losses, increased price and shortages, technical obsolescence of the plant, incompetence, poor management, expropriation and financial insolvency of the host government.

Boateng (2014) summarizes risk sources for construction megaprojects in terms of social, technical, economic, environmental and political risks. Inability to obtain land, higher compensation costs, community and legal actions, delays due to disputes, personal threats, vandalism and damage, cost overruns, involvement of multiple stakeholders are mentioned as social risk types. Vagueness of project scope, ground conditions, inadequate project analysis, inaccurate cost estimate, low quality, technical difficulties, change in design, supply chain breakdown and time overrun are listed as technical risk types. Economic risks include change in government funding, taxation changes, political instability, wage inflations, inflation change, fluctuation in foreign exchange rate, change in material price, economic recession, catastrophic environmental effects, technical difficulties in project. Environmental risks are stared as pollution and unfavorable climate conditions. Finally, political risks contain change in policies and funding, political interferences, change in government, lack of political support, termination of project, legislative changes and protectionism.

Sigmund and Radujkovic (2014) propose a risk breakdown structure for construction projects. Risks are divided into two main categories which are external and internal sources of risks in the project. Risk categorization can be found in Table 4.2.

Table 4.2. *Risk categorization for construction projects (Sigmund and Radujkovic, 2014)*

External Risks					
Legal risks	**Political risks**	**Economic risks**	**Social risks**	**Natural risks**	**Technical risks**
Ownership	Government shifts	Monetary politics	Strikes	Earthquakes	Historic design documentation
Laws	Political elections	Inflations	Ecology	Floods	Not evidenced changes
Regulations and standards	Conventions	Financing type changes	Culture	Fires	Past problems register
Work and construction approvals			Seasonal working	Extreme temperatures	
Project Risks					
Management risks	**Design documentation**	**Human factor**	**Delivery and logistics**	**Contractual risks**	
Not realistic goals	Insufficient investigation	Users	Insufficient materials	Contract type	
Bad control	Expert estimations	Omission	Not available workers	Prices	
Arrangements	Bad design documentation	Workers	Not approachable areas	Chain of control	
Organization		Motivation			

The aforementioned risk factors for megaprojects and the risk factors for small and medium-scaled construction projects are common in terms of financial, political, legislative, physical, technical, contractual and managerial aspects. Nevertheless, the achievement of sustainable construction cannot be obtained disregarding the risk factors for environmental aspect. There are some critical success factors for sustainable construction of megaprojects emphasized by various authors considering the environmental and social aspects. According to Arul and Prasannan (2016), environmental critical success factors for the implementation of green construction are penalties for poor waste management, waste auditing, setting up energy saving policies for all phases of megaprojects, legislation on environmental policies and procedure, strict environmental regulations, financial investment in green technology and manager's awareness on the environment and protection of the environment. Banihashemi et al. (2017) and Hosseini et al. (2018) state the factors to obtain sustainability outcome from megaprojects as legalizing essential policies for the implementation of sustainability principles in megaproject, well-defined sustainability goals as a scope, knowledge and awareness of sustainability among stakeholders. In terms of social sustainability, it is important to assess the needs of people and fulfill health and safety protocols as well.

To conclude, there are risks factors that may affect the sustainable construction of a megaproject. In Table 4.3, the identified risk factors are listed according to the literature review done. The total number of identified risk factors is 38, and the risk factors are categorized as financial, policy and law, society, physical, technical, organizational and managerial, client, contractual and environmental factors. Moreover, code numbers are assigned for each risk factor.

Table 4.3. *Identified risk factors for megaprojects*

Category	ID	Code Number	Risk Factors
Financial	1	RF_1	Exchange rate fluctuation
	2	RF_2	Change in inflation rate
	3	RF_3	Change in interest rates
	4	RF_4	Change in taxation policies
Policy and Law	5	RF_5	Instable political environment
	6	RF_6	Emergence of civil strife, war and terrorism issues
	7	RF_7	Difficulty in getting permits due to bureaucracy
	8	RF_8	Vagueness of policies and regulations
	9	RF_9	Change in laws and regulations
Society	10	RF_{10}	Public reaction towards the project (strike, rebellion etc.)
	11	RF_{11}	Vagueness of needs of community
Physical	12	RF_{12}	Unforeseen weather conditions
	13	RF_{13}	Unexpected physical conditions
Technical	14	RF_{14}	Design team's lack of experience on sustainable construction principles

Table 4.3. *(Cont'd)*

Category	ID	Code Number	Risk Factors
Technical	15	RF_{15}	Complexity of design
	16	RF_{16}	Low constructability
	17	RF_{17}	Inaccurate or incomplete design drawings
	18	RF_{18}	Changes in the amount of work due to defective work, rework or poor quality of construction
	19	RF_{19}	Low productivity
	20	RF_{20}	Unavailability of labor
	21	RF_{21}	Unavailability of sub-contractor
	22	RF_{22}	Unavailability of construction materials
	23	RF_{23}	Defective construction materials
	24	RF_{24}	Technology
	25	RF_{25}	Problems with the construction site
Organizational and Managerial	26	RF_{26}	Inaccurate cost, time and resource allocation estimation
	27	RF_{27}	Inexperienced or noncompetitive contractor
	28	RF_{28}	Lack of organization and coordination among project stakeholders
	29	RF_{29}	Lack of audits on occupational health and safety procedures
Client	30	RF_{30}	Client's reluctant attitude towards sustainable construction
	31	RF_{31}	Client's lack of knowledge about sustainable construction
	32	RF_{32}	Change orders or additions
	33	RF_{33}	Inadequate funding or delay in progress payments
Contractual	34	RF_{34}	Ill-defined scope of work and contract specification
	35	RF_{35}	Contractual dispute resolution process
	36	RF_{36}	Inappropriate contract type, project delivery system and bidding type
Environmental	37	RF_{37}	Ineffective waste management
	38	RF_{38}	No audits for poor waste management

4.3. Establishment of the Preliminary Conceptual Model

The preliminary conceptual model is established according to the identified sustainable construction objectives and risk factors. The conceptual model aims to demonstrate that each sustainable construction objective is exposed to the risk factors.

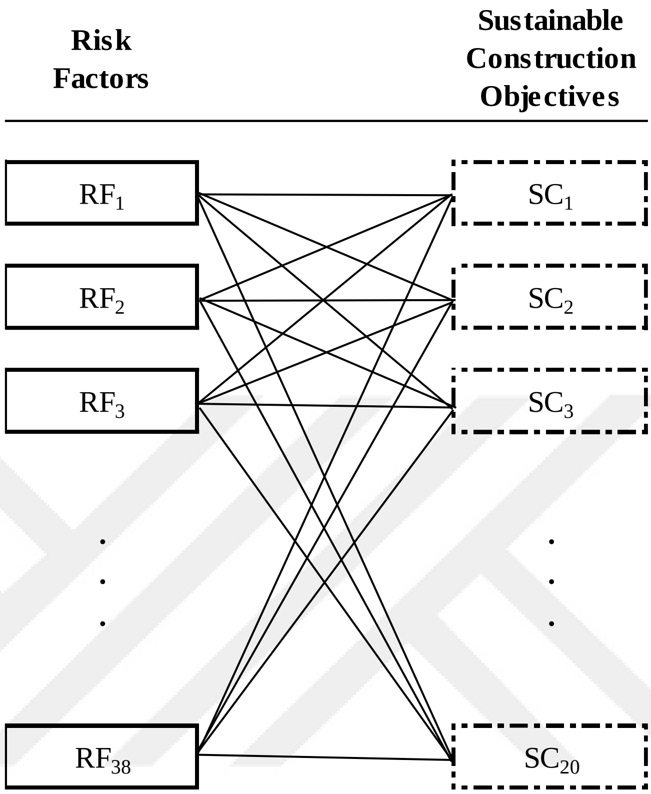

Figure 4.2. Preliminary conceptual model

The conceptual model does not explain level of influence of risk factors on the sustainable construction objectives. Therefore, the following chapter explains how relationships among sustainable construction objectives and risk factors are established and quantified.

CHAPTER 5

RISK ASSESSMENT METHOD FOR SUSTAINABLE CONSTRUCTION OF MEGARPOJECTS (RAMSCOM)

This chapter begins with the development process of RAMSCOM. The framework for the RAMSCOM is mentioned regarding the integration of AHP and CIA into RAMSCOM with the provision of the theorical background of the methods. This chapter concludes with the explanation of how RAMSCOM is utilized. The implementation of RAMSCOM is mentioned on a hypothetical mega construction project as well.

5.1. Development of RAMSCOM

The development of RAMSCOM is explained for this part of the chapter. Basically, the quantification process of the relationships demonstrated in the preliminary conceptual model are mentioned in two parts. First part introduces the prioritization of sustainable construction objectives and second part explains the proposed risk assessment approach for sustainable construction objectives.

5.1.1. Prioritization of Sustainable Construction Objectives

Sustainable construction objectives may vary considering the function of the construction megaproject, and it is important the determine the most important objectives for a megaproject. AHP is the methodology utilized for the prioritization process of sustainable construction objectives. The theoretical background and integration of AHP into RAMSCOM are explained below.

5.1.1.1. The Theoretical Background of AHP

> Absolute judgement is the identification of the magnitude of some simple stimulus...whereas comparative judgement is the identification of some

relation between two stimuli both present to the observer. Absolute judgment involves the relation between a single stimulus and some information held in short-term memory, information about some former comparison stimuli or about some previously experienced measurement scale... To make the judgement, a person must compare an immediate impression with impression in memory of similar stimuli…

Arthur L. Blumenthal
(as cited in Saaty, 2008, p. 85)

Saaty (1994) states that AHP is a multicriteria decision-making method and the factors are organized hierarchically. The implementation process of AHP is explained by Saaty (2008) in four steps. In the first step, the problem is defined. In the second step, the hierarchy among the factors is structured decreasing from an overall goal to factors and subfactors. In the third step, pairwise comparison matrices are constructed taking into consideration of consistency ratio. In the fourth step, priorities of the factors are done according to the weights assigned.

After the organization of hierarchy among factors, the scale used for the pairwise comparison matrices are provided in Table 5.1. Basically, the scale is utilized for determining whether an alternative is more important or less important than another alternative.

Table 5.1. *The fundamental scale of absolute numbers (Saaty, 2008)*

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favor one activity over another
4	Moderate plus	

Table 5.1. *(Cont'd)*

Intensity of Importance	Definition	Explanation
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
1.1-1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Pairwise comparison matrices are constructed as shown in (5.1), and the numbers are assigned considering the degree of importance between two alternatives.

$$\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{12}} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & a_{nn} \end{bmatrix} \tag{5.1}$$

After assigning the values from Table 5.1, the consistency ratio should be calculated in order to check the consistency of the matrix. Consistency ratio is estimated as division of the consistency index by random consistency ratio.

$$CR = \frac{CI}{RI} \tag{5.2}$$

Random consistency index values for the calculation process of consistency ratio of the matrices are provided in Table 5.2.

Table 5.2. *Random consistency index values (Aminbakhsh et al., 2013)*

Size of the Matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency Index	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

$$CI = \frac{\lambda max - n}{n-1} \tag{5.3}$$

Consistency index is calculated by the formula given above. In the given formula, λ_{max} corresponds to the largest eigenvalue of the matrix and n represents the size of the matrix. λ_{max} is calculated as follows. First, priority vector of the factor and corresponding column sum according to the values assigned for the pairwise comparison matrix is multiplied. This process is applied for each factor. Then, results regarding for each factor are summed and eigenvalue for the n-sized matrix is obtained.

Saaty (1994) mentions that if the result obtained from the calculation of consistency ratio is less than 10%, the result is acceptable. This means that, the matrix is consistent and reliable.

Once the consistency of the matrices is checked, the final step is to calculate the priorities of the factors. The priorities are obtained by multiplication of row sum of the factor by the one over number of factors. Since there is a hierarchy, there are two types of weights. Global weight represents the weights for the factors and local weight represents the weight for the sub-factors.

5.1.1.2. Integration of AHP into RAMSCOM

Each megaproject varies in size, function, location etc. Sustainable construction objectives may differ from one megaproject to another. Hence, it is important to outline the framework of the project objectives in advance. In order to prioritize sustainable construction objectives, AHP is utilized for the development of the RAMSCOM. The main aim of this method is to reduce contradiction while setting the importance among sustainable construction objectives.

The utilization of AHP in RAMSCOM will be as follows. First of all, a hierarchical relationship between sustainable construction objectives are structured. Factors affecting sustainable construction are listed as economic sustainability, economic-environmental sustainability, environmental sustainability, environmental-social sustainability, social sustainability and economic-social sustainability. Under each factor, sub-factors are placed regarding their categorizes mentioned in Chapter 4. Then, code numbers are assigned for each factor and sub-factor.

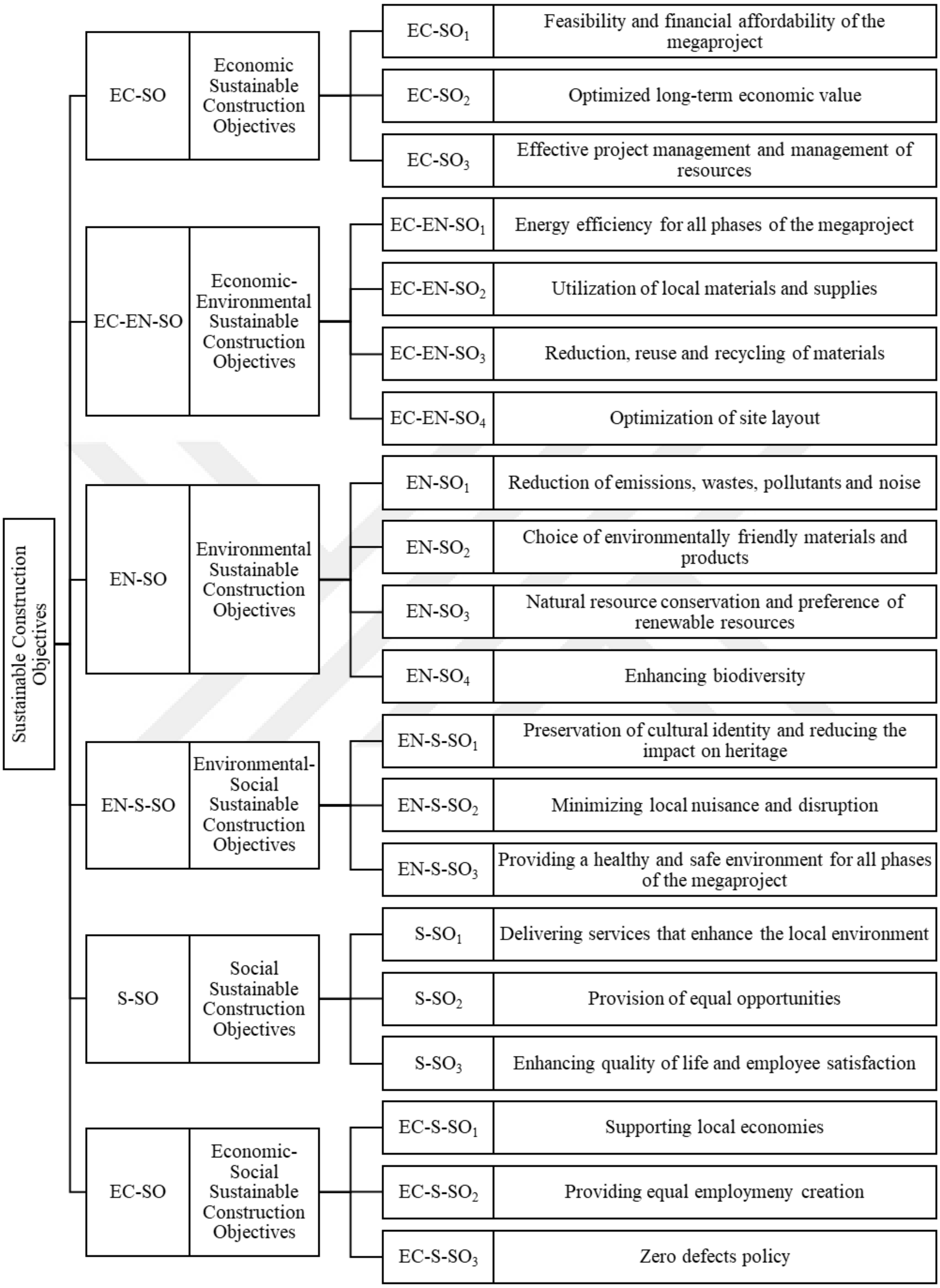

Figure 5.1. Sustainable construction objectives in a hierarchical organization

The weight for each sustainable construction objective is calculated by the pairwise comparison matrices. The numerical scale utilized for the pairwise comparison matrices is provided in Table 5.3.

Table 5.3. *Numerical scale for pairwise comparisons matrices*

Numerical Scale	Definition
1	Equal significance of the two elements
3	Low significance of one element compared to another
5	Strong significance of one element compared to another
7	Confirmed dominance of one element over another
9	Absolute dominance of one element over another
Reciprocals (1/x)	A value attributed when activity i is compared to activity j

After assigning numerical scale for the pairwise comparison matrices, weights of the factors and sub-factors are determined. First of all, global weights of the 6 main sustainable construction objectives are calculated by taking into consideration of consistency of the matrix. Then, the local weight for each sub-factor in the corresponding hierarchy are estimated. As a final step, global weights for each sub-factor among other sustainable construction objectives are calculated by multiplication of the priority weight and the global weight of the related category.

5.1.2. Risk Assessment of Sustainable Construction Objectives

Each construction project has project scopes to achieve. Yet, the project objectives expose to the risk factors and those risk factors may be obstacles for the achievement of the predetermined project objectives. As it was mentioned in the beginning of this chapter; time, cost and quality criteria are utilized for the judgement of the project as successful or unsuccessful (Atkinson, 1999). Current risk assessment processes, explained in Chapter 2, mainly focus on the risks that are related with time, cost and quality. Nevertheless, the circumstances of world have been changing and the construction projects have been adapting to the changes as well. In order to address the changes in today's and future's world, the scale of the construction projects is enlarged more and more. Therefore, the success or failure of the megaprojects cannot be evaluated by the traditional construction project's success criteria. Megaprojects can be considered as successful by the achievement of a sustainable outcome, and it is important to determine the threats for the achievement of the sustainable construction in advance. Dikmen and Birgönül (2017) emphasize that all dimensions of sustainability should be integrated into risk management field rather than the traditional risk management approach. In this sense, CIA is utilized in order to assess risks on megaprojects considering the all dimensions of sustainable construction, and the theoretical background and integration of CIA into RAMSCOM are examined for the second part of this chapter.

5.1.2.1. The Theoretical Background of CIA

Cross-impact method is developed by Theodore Gordon and Olaf Helmer in 1966. Gordon (1994) states cross impact as an analytical approach for forecasting future events. One event or more events may have influence on other event, and cross-impact method considers the interrelations between events.

Main advantage of CIA is the cross-impact matrix, and the cross-impact matrix enables to construct influences among factors (Kuru, 2015). Scholzund and Tietje (2002) mention the initial procedure of cross matrix that is utilized to determine influences among factors. First of all, factors for the case are determined and placed in the matrix. It is highlighted that there is no strict numerical scale for the impact matrix. The scale is formulated as a case-specific and the magnitude of the impact values should be explained. Then, the impact matrix is filled by taking into account how much the factor in each column affects the factor in each row. Huang et al. (2009), Spoerri et al. (2009), Vester (1998) mention that two characteristics of the impact factor can be obtained according to the impact values assigned for each factor. Active sum refers to the sums of each row of the impact matrix. Passive sum represents the sums of each column of the impact matrix. All in all, the values obtained from row sum indicate the level of effect on other factors, and the values obtained from column sum demonstrate the level of being affected from other factors.

The procedure mentioned above is illustrated on a cross-impact matrix in Table 5.4. In order to evaluate relationships between factors, the impact scale utilized for the cross-impact matrix is given in Table 5.5.

Table 5.4. *Example of a cross-impact matrix*

	$Factor_1$	**$Factor_2$**	**$Factor_3$**	**$Factor_4$**	**$Factor_5$**	**Active Sum**
$Factor_1$	0	3	3	3	3	12
$Factor_2$	3	0	3	2	0	8
$Factor_3$	0	0	0	0	1	1
$Factor_4$	3	0	3	0	0	6
$Factor_5$	1	3	3	2	0	9
Passive Sum	7	6	12	7	4	

Table 5.5. *Impact values assigned for the example cross-impact matrix*

Impact Value	**Definition**
0	No influence
1	Slight influence
2	Medium influence
3	Strong influence

It can be concluded from the example cross impact matrix that $Factor_3$ is the most affected factor; whereas the least affected factor is $Factor_5$ among other four factors.

Considering the active sum value of $Factor_1$, $Factor_1$ does have a significant impact on the other four factors.

Scholzund and Tieje (2002), Spoerri (2009), Vester (1998), Wiek et al. (2008) state the final step of this procedure as visualization of the overall results obtained from active sum and passive sum in a chart. Factors included in the matrix are defined considering the active sum and passive sum scores. In the chart, horizontal line represents the passivity scores and vertical line represents the activity scores. The arithmetic means of the activity and passivity scores divide the chart into four regions; named as active, passive, ambivalent and buffering. Active variables do have strong influence on other variables, yet passive variables are influenced by other variables. Ambivalent variables are affected from other variables, but at the same time they do have influence on other variables. Buffering variables are affected slightly from other variables and they affect other variables slightly. A representation of the chart with four regions is provided in Figure 5.2.

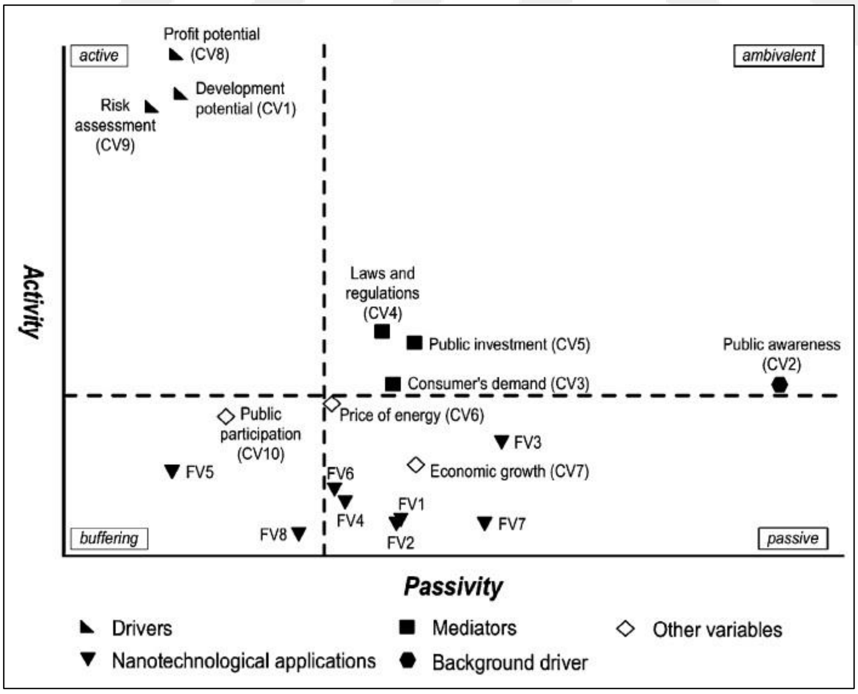

Figure 5.2. Cross-impact chart
(Wiek et al., 2008)

5.1.2.2. Integration of CIA into RAMSCOM

Risk assessment approach for sustainable construction objectives is performed by utilization of probability-impact matrix. The identified sustainable construction objectives and risk factors in Chapter 4 that are included in the cross-impact matrix can be observed respectively in Table 5.6 and Table 5.7.

Table 5.6. *Identified sustainable construction objectives for the RAMSCOM*

Sustainable Construction Dimensions	ID	Code Number	Sustainable Construction Objectives
Economic Sustainability	1	EC-SO_1	Feasibility and financial affordability of the megaproject
	2	EC-SO_2	Optimized long-term economic value
	3	EC-SO_3	Effective project management and management of resources
Economic-Environmental Sustainability	4	EC-EN-SO_1	Energy efficiency for all phases of the megaproject
	5	EC-EN-SO_2	Utilization of local materials and supplies
	6	EC-EN-SO_3	Reduction, reuse and recycling of materials
	7	EC-EN-SO_4	Optimization of site layout
Environmental Sustainability	8	EN-SO_1	Reduction of emissions, wastes, pollutants and noise
	9	EN-SO_2	Choice of environmentally friendly materials and products
	10	EN-SO_3	Natural resource conversation and preference of renewable resources
	11	EN-SO_4	Enhancing biodiversity
Environmental-Social Sustainability	12	EN-S-SO_1	Preservation of cultural identity and reducing the impact on heritage due to the megaproject
	13	EN-S-SO_2	Minimizing local nuisance and disruption
	14	EN-S-SO_3	Providing a healthy and safe environment for all phases of the megaproject
Social Sustainability	15	S-SO_1	Delivering services that enhance the local environment
	16	S-SO_2	Provision of equal opportunities
	17	S-SO_3	Enhancing quality of life and providing customer and employee satisfaction
Economic-Social Sustainability	18	EC-S-SO_1	Supporting local economies
	19	EC-S-SO_2	Providing equal employment creation
	20	EC-S-SO_3	Zero defects policy

Table 5.7. *Identified risk factors for the RAMSCOM*

Category	ID	Code Number	Risk Factors
Financial	1	FRF_1	Exchange rate fluctuation
	2	FRF_2	Change in inflation rate
	3	FRF_3	Change in interest rates
	4	FRF_4	Change in taxation policies
Policy and Law	5	$PLRF_1$	Instable political environment
	6	$PLRF_2$	Emergence of civil strife, war and terrorism issues
	7	$PLRF_3$	Difficulty in getting permits due to bureaucracy
	8	$PLRF_4$	Vagueness of policies and regulations
	9	$PLRF_5$	Change in laws and regulations
Society	10	SRF_1	Public reaction towards the project (strike, rebellion etc.)
	11	SRF_2	Vagueness of the needs of community
Physical	12	PRF_1	Unforeseen weather conditions
	13	PRF_2	Unexpected physical conditions
Technical	14	TRF_1	Design team's lack of experience on sustainable construction principles
	15	TRF_2	Complexity of design
	16	TRF_3	Low constructability
	17	TRF_4	Inaccurate or incomplete design drawings
	18	TRF_5	Changes in the amount of work due to defective work, rework or poor quality of construction
	19	TRF_6	Low productivity
	20	TRF_7	Unavailability of labor
	21	TRF_8	Unavailability of sub-contractor
	22	TRF_9	Unavailability of construction materials
	23	TRF_{10}	Defective construction materials
	24	TRF_{11}	Technology
	25	TRF_{12}	Problems with the construction site
Organizational and Managerial	26	$OMRF_1$	Inaccurate cost, time and resource allocation estimation
	27	$OMRF_2$	Inexperienced or noncompetitive contractor
	28	$OMRF_3$	Lack of organization and coordination among project stakeholders
	29	$OMRF_4$	Lack of audits on occupational health and safety procedures
Client	30	$CLRF_1$	Client's reluctant attitude towards sustainable construction
	31	$CLRF_2$	Client's lack of knowledge about sustainable construction
	32	$CLRF_3$	Change orders or additions

Table 5.7. *(Cont'd)*

Category	ID	Code Number	Risk Factors
Client	33	$CLRF_4$	Inadequate funding or delay in progress payments
Contractual	34	CRF_1	Ill-defined scope of work and contract specification
	35	CRF_2	Contractual dispute resolution process
	36	CRF_3	Inappropriate contract type, project delivery system and bidding type
Environmental	37	ERF_1	Ineffective waste management
	38	ERF_2	No audits for poor waste management

Cross-impact matrix is formed by placing the risk factors for megaprojects that are placed on the vertical axis of the matrix, and sustainable construction objectives are placed on the horizontal axis of the matrix (see Table 5.8).

Table 5.8. *Cross-impact table*

			SUSTAINABLE CONSTRUCTION OBJECTIVES																			
			ECONOMIC			ECONOMIC-ENVIRONMENTAL				ENVIRONMENTAL				ENVIRONMENTAL-SOCIAL			SOCIAL			ECONOMIC-SOCIAL		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
			$EC\text{-}SO_1$	$EC\text{-}SO_2$	$EC\text{-}SO_3$	$EC\text{-}EN\text{-}SO_1$	$EC\text{-}EN\text{-}SO_2$	$EC\text{-}EN\text{-}SO_3$	$EC\text{-}EN\text{-}SO_4$	$EN\text{-}SO_1$	$EN\text{-}SO_2$	$EN\text{-}SO_3$	$EN\text{-}SO_4$	$EN\text{-}S\text{-}SO_1$	$EN\text{-}S\text{-}SO_2$	$EN\text{-}S\text{-}SO_3$	$S\text{-}SO_1$	$S\text{-}SO_2$	$S\text{-}SO_3$	$EC\text{-}S\text{-}SO_1$	$EC\text{-}S\text{-}SO_2$	$EC\text{-}S\text{-}SO_3$
RISK FACTORS	F	1	FRF_1																			
		2	FRF_2																			
		3	FRF_3																			
		4	FRF_4																			
	PL	5	$PLRF_1$																			
		6	$PLRF_2$																			
		7	$PLRF_3$																			
		8	$PLRF_4$																			
		9	$PLRF_5$																			
	S	10	SRF_1																			
		11	SRF_2																			
	P	12	PRF_1																			
		13	PRF_2																			
	T	14	TRF_1																			
		15	TRF_2																			
		16	TRF_3																			
		17	TRF_4																			
		18	TRF_5																			
		19	TRF_6																			
		20	TRF_7																			
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		22	TRF_9																			
		23	TRF_{10}																			
		24	TRF_{11}																			
		25	TRF_{12}																			
	OM	26	$OMRF_1$																			
		27	$OMRF_2$																			
		28	$OMRF_3$																			
		29	$OMRF_4$																			
	CL	30	$CLRF_1$																			
		31	$CLRF_2$																			
		32	$CLRF_3$																			
		33	$CLRF_4$																			
	C	34	CRF_1																			
		35	CRF_2																			
		36	CRF_3																			
	E	37	ERF_1																			
		38	ERF_2																			

The cross-impact of each risk factor on each sustainable construction objective is evaluated by cross-impact matrix, and the cross-impact scale utilized for the cross impact is provided in Table 5.9. The values from the impact scale can be assigned in order to determine the impact of the risk factors on each sustainable construction objective.

Table 5.9. *Cross-impact scale for the cross-impact matrix*

Impact Value	Definition
0	No impact
1	Very slight impact
2	Slight impact
3	Moderate impact
4	High impact
5	Very high impact

Then, probability of occurrences of the risk factors are determined considering the probability scale in Figure 5.3.

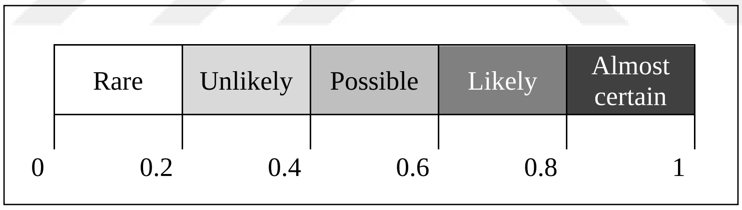

Figure 5.3. Probability scale for the cross-impact matrix

As it was mentioned in risk assessment part of Chapter 2, risk is calculated by multiplying probability and impact values of the risk factors. By taking into consideration of the probability and cross-impact values of risk factors, the expected dependency values for each sustainable construction objective and the expected influence value for each risk factor will be calculated. Expected dependency values for the sustainable construction objectives are calculated by sum of each column, and it represents the level of being affected from the risk factors. Expected influence values of the risk factors are calculated by sum of each row and it refers to the level of effect on sustainable construction objectives. The initial cross-impact matrix is revised by adding initial probability of occurrence values of the risk factors, influence value and dependency value parts (see Table 5.10).

Table 5.10. *Cross-impact matrix*

RISK FACTORS			Probability of Occurence	SUSTAINABLE CONSTRUCTION OBJECTIVES																				Expected Influence Value
				ECONOMIC			ECONOMIC-ENVIRONMENTAL				ENVIRONMENTAL				ENVIRONMENTAL-SOCIAL			SOCIAL			ECONOMIC-SOCIAL			
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
				EC-SO$_1$	EC-SO$_2$	EC-SO$_3$	EC-EN-SO$_1$	EC-EN-SO$_2$	EC-EN-SO$_3$	EC-EN-SO$_4$	EN-SO$_1$	EN-SO$_2$	EN-SO$_3$	EN-SO$_4$	EN-S-SO$_1$	EN-S-SO$_2$	EN-S-SO$_3$	S-SO$_1$	S-SO$_2$	S-SO$_3$	EC-S-SO$_1$	EC-S-SO$_2$	EC-S-SO$_3$	
F	1	FRF_1																						
	2	FRF_2																						
	3	FRF_4																						
	4	FRF_5																						
PL	5	$PLRF_1$																						
	6	$PLRF_3$																						
	7	$PLRF_4$																						
	8	$PLRF_5$																						
	9	$PLRF_6$																						
S	10	SRF_1																						
	11	SRF_2																						
P	12	PRF_1																						
	13	PRF_2																						
T	14	TRF_1																						
	15	TRF_2																						
	16	TRF_3																						
	17	TRF_4																						
	18	TRF_5																						
	19	TRF_6																						
	20	TRF_7																						
	21	TRF_8																						
	22	TRF_9																						
	23	TRF_{10}																						
	24	TRF_{11}																						
	25	TRF_{12}																						
OM	26	$OMRF_1$																						
	27	$OMRF_2$																						
	28	$OMRF_3$																						
	29	$OMRF_4$																						
CL	30	$CLRF_1$																						
	31	$CLRF_2$																						
	32	$CLRF_3$																						
	33	$CLRF_4$																						
C	34	CRF_1																						
	35	CRF_2																						
	36	CRF_3																						
E	37	ERF_1																						
	38	ERF_2																						
Expected Dependency Value																								

Then, vulnerability chart is formed. The vulnerability chart enables the interpretation of results from AHP and CIA. The vulnerability chart has two dimensions. The horizontal axis of the chart represents the weights of the sustainable construction objectives obtained from AHP. Expected dependency values for the sustainable construction objectives are located on the vertical axis of the chart. All in all, a sustainable construction objective is defined considering the global weight and expected dependency value in the vulnerability chart (See Figure 5.4).

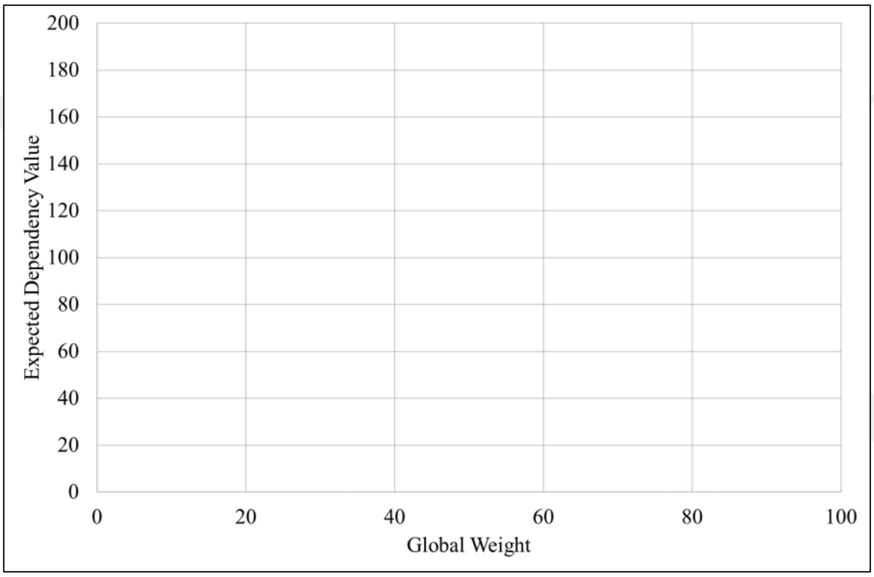

Figure 5.4. Vulnerability chart

The vulnerability chart is divided into regions considering the dependency values. The intervals between regions are determined by the reinterpretation of the cross-impact matrix. As mentioned in Chapter 2, probability-impact matrices include four risk regions named as low, medium, high and extreme according to the risk scores obtained from probability and impact values. For the cross-impact chart utilized in RAMSCOM, probability-impact values are turned into one-dimension and dependency regions are formed in order to represent the dependency values of the sustainable construction objectives in an overall perspective.

An expected dependency value for each sustainable construction objective is calculated by summing the results obtained from the multiplication of the probability and cross-impact values of each risk factor. Considering the probability and cross-impact values assigned for the cross-impact chart, the impact values range from 1 to 5 and the probability values range from 0 to 1. In order to determine the intervals of the regions in the cross-impact chart, probability-impact matrix is utilized (See Table 5.11).

Table 5.11. *Probability-impact matrix*

Probability \ Impact	**1**	**2**	**3**	**4**	**5**
0.2	0.2	0.4	0.6	0.8	1.0
0.4	0.4	0.8	1.2	1.6	2.0
0.6	0.6	1.2	1.8	2.4	3.0
0.8	0.8	1.6	2.4	3.2	4.0
1.0	1.0	2.0	3.0	4.0	5.0

According to the values in the probability-impact matrix, the dependency regions are named as low, medium, high and critical. In the probability-impact matrix (Table 5.11), low dependency region is between the values 0.2 and 0.6; medium dependency region is between 0.8 and 1.2; high dependency region is between 1.6 and 3.2; critical dependency region is between 3.0 and 5.0. The probability-impact matrix in Table 5.12 includes the overall risk score of a risk factor that have effect on a sustainable construction objective. The intervals for dependency regions are determined by taking into account the whole risk factors. Fundamentally, the results obtained from the initial probability-impact matrix are multiplied by the total number of the identified risk factors. As an illustration, the value 7.6 in Table 5.12 is calculated by the multiplication of 0.2 (See Table 5.11) and 38 (total number of identified risk factors).

Table 5.12. *Probability-impact matrix*

Probability \ Impact	1	2	3	4	5
0.2	7.6	15.2	22.8	30.4	38.0
0.4	15.2	30.4	45.6	60.8	76.0
0.6	22.8	45.6	68.4	91.2	114.0
0.8	30.4	60.8	91.2	121.6	152.0
1.0	38.0	76.0	114.0	152.0	190.0

The minimum and maximum intervals for the four dependency regions are summarized in Table 5.13.

Table 5.13. *Revised minimum and maximum interval values for the dependency regions*

Type of the Dependency Region	Minimum Value	Maximum Value
Low	7.6	22.8
Moderate	30.4	45.6
High	60.8	121.6
Critical	114	190

For the dependency regions, the revised minimum and maximum internal values are given in the Table 5.14.

Table 5.14. *Maximum and minimum interval values for the dependency regions*

Type of the Dependency Region	Minimum Value	Maximum Value
Low	7.60	22.80
Moderate	22.81	45.60
High	45.61	114.00
Critical	114.01	190.00

Dependency regions for the vulnerability chart represent the level of being affected of the sustainable construction objectives from the risk factors. As a result, the finalized interval values for the four dependency regions are integrated into the cross-impact chart (See Figure 5.5).

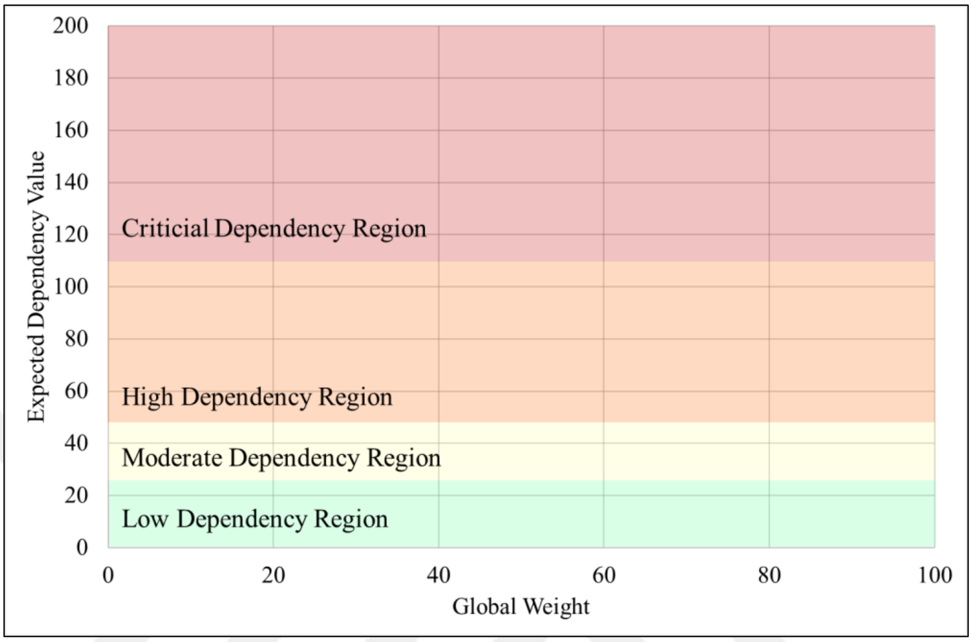

Figure 5.5. Dependency regions for the vulnerability chart

Additionally, a heat map based on the cross-impact matrix is provided in order to analyze the components of dependency values generated from the risk factors. Risks are categorized into four main groups. Fundamentally, probability-impact matrix is utilized in order to determine type of the risk factor. Proposed minimum and maximum interval values regarding the type of risk factors are given in Table 5.15.

Table 5.15. *Minimum and maximum interval values for the risk types*

Risk Type	**Minimum Value**	**Maximum Value**
Low	0.00	0.60
Moderate	0.61	1.20
High	1.21	3.00
Critical	3.01	5.00

5.2. Implementation of RAMSCOM

In this part, the procedure mentioned above is described in steps. In addition, the implementation of the RAMSCOM is demonstrated on a hypothetical megaproject including the explanation for each step.

The implementation of RAMSCOM includes five main steps. Each step is explained below.

Step 1 begins with the prioritization of sustainable construction objectives with AHP. Fundamentally, numerical scale is utilized in order to make pairwise comparisons among sustainable construction objectives. First of all, numerical scales are assigned to the first level of hierarchical pairwise comparison matrix by the user. The numerical scale for the pairwise comparison matrices is given in Table 5.3. After ensuring that the consistency ratio of the matrix is lower than 10%, the numerical scale is assigned to the second level of hierarchical pairwise comparison matrices. After checking the consistency ratios for each sub pairwise comparison matrices, global weight for each sustainable construction objective can be obtained, and the prioritization of the sustainable construction objectives will be done. The overall result for the global weights for each sustainable construction objective is provided in a tabular graph as well.

Step 2 continues with the risk assessment by utilization of CIA. Basically, cross-impact values for each risk factor are determined on a cross-impact matrix. The cross-impact values for the risk factors are assigned by utilizing the impact scale provided in Table 5.9. As a result, dependency values for each sustainable construction objective and influence values for each risk factor are obtained.

Step 3 proceeds with the assignment of probability values for each factor by the user. The user utilizes the probability scale provided in Figure 5.3.

Step 4 presents a cross-impact matrix. Cross-impact matrix is formed with the cross-impact and probability values of each risk factor. Consequently, expected dependency values for each sustainable construction objective and expected influence values for each risk factor are obtained, and the obtained results are analyzed with the helps of bar charts.

Step 5 summarizes the results obtained from the previous steps in a vulnerability chart and a heat map. First of all, vulnerability chart is utilized in order to demonstrate level of being affected of each sustainable construction objective from the risk factors by taking into consideration of the importance of the objectives. Then, the most vulnerable sustainable construction objectives are analyzed by the heat map in order to analyze and monitor the threats.

The overall process for RAMSCOM is summarized in Table 5.16.

Table 5.16. *Implementation process of RAMSCOM*

Step Number	Explanation of the Step	Input	Output
Step 1	Prioritization of the sustainable construction objectives	Assignment of the values to the pairwise comparison matrixes by the user	Global weights for the sustainable construction objectives
Step 2	Cross-impact table	Determining cross-impact values for each risk factor in the cross-impact matrix	Dependency values for each sustainable construction objective and influence values for each risk factor
Step 3	Probability of risk factors	Determining the probability of occurrence for each risk factor by the user	-

Table 5.16. *(Cont'd)*

Step Number	Explanation of the Step	Input	Output
Step 4	Cross-impact matrix	The results obtained from Step 1, Step 2 and Step 3	Expected dependency values for each sustainable construction objective and expected influence values for each risk factor
Step 5	Discussion of findings	The results obtained from Step 4	Vulnerability chart and heat map

The implementation of the RAMSCOM is mentioned by explaining each step on a hypothetical megaproject for the rest of this chapter.

Step 1: Prioritization of the sustainable construction objectives

First, values are assigned to the first level of hierarchical pairwise comparison matrix considering the numerical scale from 1 to 9 (Table 5.17).

Table 5.17. *Pairwise comparison matrix of the sustainable construction dimensions for the hypothetical megaproject*

Sustainable Construction Dimensions		EC-SO	EC-EN-SO	EN-SO	EN-S-SO	S-SO	EC-S-SO
1	EC-SO	1.00	0.14	0.33	0.14	3.00	0.20
2	EC-EN-SO	7.00	1.00	5.00	3.00	9.00	3.00
3	EN-SO	3.00	0.20	1.00	0.20	3.00	0.33
4	EN-S-SO	7.00	0.33	5.00	1.00	9.00	3.00
5	S-SO	0.33	0.11	0.33	0.11	1.00	0.14
6	EC-S-SO	5.00	0.33	3.00	0.33	7.00	1.00
Column Sum		23.33	2.12	14.67	4.79	32.00	7.68

In order to ensure the consistency of the judgments in the pairwise comparison matrix, consistency ratio (CR) was calculated using the largest eigenvalue, and the consistency index for the matrix includes 6 factors. λ_{max} for this matrix is 6.58 and CI is 0.12. As a result, CR is found as 0.09. Since, the CR is less than 10% the matrix is consistent.

Then, global weights for the sustainable construction dimensions are calculated. It can be concluded from the Table 5.18 that economic-environmental sustainability objective does have a major priority considering the other sustainable construction objectives.

Table 5.18. *Global weights of the sustainable construction dimensions for the hypothetical megaproject*

Sustainable Construction Dimensions		EC-SO	EC-EN-SO	EN-SO	EN-S-SO	S-SO	EC-S-SO	Row Sum	Global Weight
1	**EC-SO**	0.04	0.07	0.02	0.03	0.09	0.03	0.28	0.05
2	**EC-EN-SO**	0.30	0.47	0.34	0.63	0.28	0.39	2.41	0.40
3	**EN-SO**	0.13	0.09	0.07	0.04	0.09	0.04	0.47	0.08
4	**EN-S-SO**	0.30	0.16	0.34	0.21	0.28	0.39	1.68	0.28
5	**S-SO**	0.01	0.05	0.02	0.02	0.03	0.02	0.16	0.03
6	**EC-S-SO**	0.21	0.16	0.20	0.07	0.22	0.13	0.99	0.17
Column Sum		1.00	1.00	1.00	1.00	1.00	1.00	6.00	1.00

For the second level hierarchal pairwise comparison matrices, the procedure is applied only for the economic sustainability objectives. For the other five pairwise comparisons matrices, same procedures are applied to determine the weights for each sub-objective.

Like in the pairwise comparison matrix for the first level of hierarchy, values are assigned to the second level of hierarchical pairwise comparison matrices considering the numerical scale from 1 to 9 (Table 5.19).

Table 5.19. *Pairwise comparison matrix of the economic sustainability objectives for the hypothetical megaproject*

	Economic Sustainability	$EC\text{-}SO_1$	$EC\text{-}SO_2$	$EC\text{-}SO_3$
1	$EC\text{-}SO_1$	1.00	0.11	0.20
2	$EC\text{-}SO_2$	9.00	1.00	3.00
3	$EC\text{-}SO_3$	5.00	0.33	1.00
	Column Sum	15.00	1.44	4.20

Then, consistency of the matrix is checked considering the size of the matrix. λ_{max} for this matrix is 3.05 and CI is 0.02. Therefore, CR is found as 0.04. Since, the CR is less than 10%, the matrix is consistent.

The only difference of the second level of hierarchical pairwise comparison matrices is that, overall global weight for each economic sustainability objective is calculated by multiplication of the local weight of each economic sustainability objective with the global weight of their related category. The global weight for the economic sustainable construction objectives is calculated in Table 5.20.

Table 5.20. *Local and global weights of the economic sustainability objectives for the hypothetical megaproject*

	Economic Sustainability	$EC\text{-}SO_1$	$EC\text{-}SO_2$	$EC\text{-}SO_3$	Row Sum	Local Weight	Global Weight
1	$EC\text{-}SO_1$	0.07	0.08	0.05	0.19	0.06	0.00
2	$EC\text{-}SO_2$	0.60	0.69	0.71	2.01	0.67	0.03
3	$EC\text{-}SO_3$	0.33	0.23	0.24	0.80	0.27	0.01
	Column Sum	1.00	1.00	1.00	3.00	1.00	0.05

After applying the same procedure for the remaining sustainable construction objectives, the global weights for sustainable construction objectives are calculated. The results are provided in a tabular form (Table 5.21).

Table 5.21. *Global weights of the sustainable construction objectives for the hypothetical megaproject*

ID	Code Number	Sustainable Construction Objectives	Global Weight
1	$EC\text{-}SO_1$	Feasibility and financial affordability of the megaproject	0.30%
2	$EC\text{-}SO_2$	Optimized long-term economic value	3.15%
3	$EC\text{-}SO_3$	Effective project management and management of resources	1.26%
4	$EC\text{-}EN\text{-}SO_1$	Energy efficiency for all phases of the megaproject	22.42%
5	$EC\text{-}EN\text{-}SO_2$	Utilization of local materials and supplies	1.99%
6	$EC\text{-}EN\text{-}SO_3$	Reduction, reuse and recycling of materials	11.54%
7	$EC\text{-}EN\text{-}SO_4$	Optimization of site layout	4.24%
8	$EN\text{-}SO_1$	Reduction of emissions, wastes, pollutants and noise	3.96%
9	$EN\text{-}SO_2$	Choice of environmentally friendly materials and products	0.41%
10	$EN\text{-}SO_3$	Natural resource conversation and preference of renewable resources	2.36%
11	$EN\text{-}SO_4$	Enhancing biodiversity	1.10%
12	$EN\text{-}S\text{-}SO_1$	Preservation of cultural identity and reducing the impact on heritage due to the megaproject	7.48%
13	$EN\text{-}S\text{-}SO_2$	Minimizing local nuisance and disruption	1.78%
14	$EN\text{-}S\text{-}SO_3$	Providing a healthy and safe environment for all phases of the megaproject	18.72%
15	$S\text{-}SO_1$	Delivering services that enhance the local environment	0.52%
16	$S\text{-}SO_2$	Provision of equal opportunities	0.23%
17	$S\text{-}SO_3$	Enhancing quality of life and providing customer and employee satisfaction	1.96%
18	$EC\text{-}S\text{-}SO_1$	Supporting local economies	4.32%
19	$EC\text{-}S\text{-}SO_2$	Providing equal employment creation	10.50%
20	$EC\text{-}S\text{-}SO_3$	Zero defects policy	1.76%
Column Sum			100.00%

In addition, a bar chart is provided in order to make a quick comparison among sustainable construction objectives regarding their weights (See Figure 5.6).

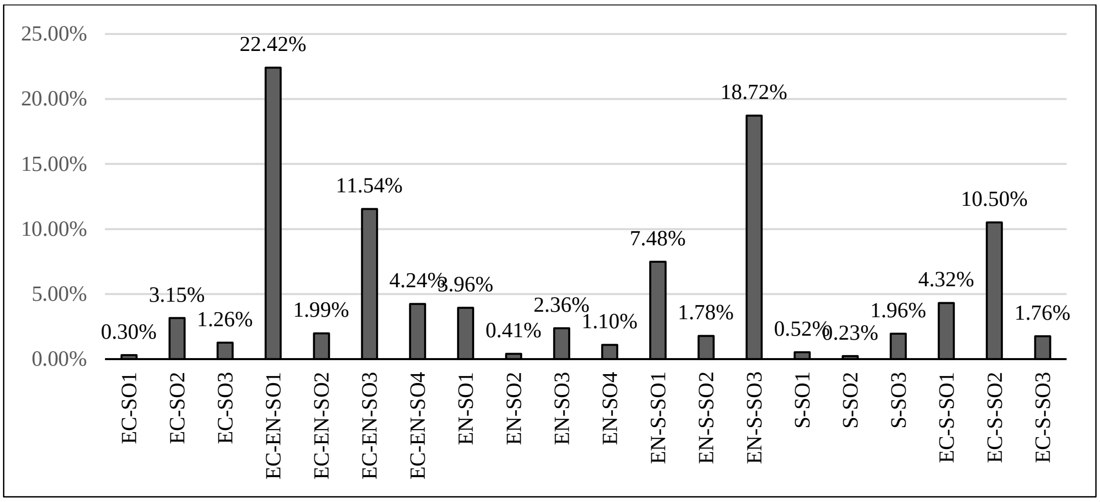

Figure 5.6. Global weights of the sustainable construction objectives in a bar chart

As a result, the sustainable construction objective named as energy efficiency for all phases of the megaproject (EC-EN-SO_1), providing a healthy and safe environment for all phases of megaproject (EN-S-SO_3) and reduction, reuse and recycling of materials (EC-EN-SO_3) are the most important three objectives for the achievement of a sustainable outcome from the hypothetical construction megaproject. On the other hand, the sustainable construction objective which is provision of equal opportunities (S-SO_2) does have a less priority for the hypothetical construction megaproject.

Step 2: Cross-Impact Values of Risk Factors

In this step, cross-impact matrix is filled considering the cross-impact of each risk factor. The impact for each risk factor is assigned considering the impact scale (See Table 5.9).

The cross-impacts of the risk factors are presented in Table 5.22. The dependency values for each sustainable construction objective and influence values for each risk factor are provided in the cross-impact table as well.

Table 5.22. *Cross-impact values of the risk factors*

			SUSTAINABLE CONSTRUCTION OBJECTIVES																				Influence Value
			ECONOMIC			ECONOMIC-ENVIRONMENTAL				ENVIRONMENTAL				ENVIRONMENTAL-SOCIAL			SOCIAL			ECONOMIC-SOCIAL			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
			EC-SO$_1$	EC-SO$_2$	EC-SO$_3$	EC-EN-SO$_1$	EC-EN-SO$_2$	EC-EN-SO$_3$	EC-EN-SO$_4$	EN-SO$_1$	EN-SO$_2$	EN-SO$_3$	EN-SO$_4$	EN-S-SO$_1$	EN-S-SO$_2$	EN-S-SO$_3$	S-SO$_1$	S-SO$_2$	S-SO$_3$	EC-S-SO$_1$	EC-S-SO$_2$	EC-S-SO$_3$	
RISK FACTORS	F	1	FRF_1	5	5	4	3	0	0	3	0	2	0	0	0	0	0	0	0	0	0	2	0	24.00
		2	FRF_2	5	5	4	3	0	0	3	0	2	0	0	0	0	0	0	1	0	3	4	0	30.00
		3	FRF_3	3	4	4	3	0	0	3	0	2	0	0	0	0	0	0	0	4	2	3	0	28.00
		4	FRF_4	3	2	2	3	0	0	3	0	2	0	0	0	0	0	0	2	3	3	3	0	26.00
	PL	5	$PLRF_1$	5	4	3	2	0	0	1	0	0	0	2	5	0	0	3	3	3	0	2	0	33.00
		6	$PLRF_2$	3	3	5	2	3	1	3	4	0	2	2	5	5	5	2	3	5	3	3	2	61.00
		7	$PLRF_3$	2	1	4	2	0	0	4	0	0	1	0	5	2	2	0	0	0	0	0	0	23.00
		8	$PLRF_4$	0	3	0	5	3	4	4	5	5	5	5	5	4	5	2	2	3	2	4	3	69.00
		9	$PLRF_5$	3	3	3	5	2	2	4	5	5	5	5	5	4	5	2	2	3	2	4	3	72.00
	S	10	SRF_1	0	0	5	0	0	0	2	0	0	0	0	0	0	5	0	0	3	0	0	0	15.00
		11	SRF_2	1	2	3	2	3	3	5	5	4	4	2	4	4	4	5	5	5	4	5	0	70.00
	P	12	PRF_1	3	4	3	4	0	0	4	2	2	3	0	4	2	2	0	2	2	1	0	3	41.00
		13	PRF_2	4	3	3	4	0	0	5	3	0	3	0	5	4	4	0	2	3	1	0	3	47.00
	T	14	TRF_1	4	4	4	5	4	4	3	2	5	5	4	5	0	2	3	3	3	3	1	3	67.00
		15	TRF_2	4	3	4	3	3	3	4	3	3	2	2	3	4	2	0	0	2	0	2	4	51.00
		16	TRF_3	5	3	5	5	3	3	2	1	1	1	0	1	3	2	1	3	3	0	0	4	46.00
		17	TRF_4	4	4	5	5	5	4	4	2	5	3	3	4	0	2	2	2	4	2	2	5	67.00
		18	TRF_5	5	5	5	4	1	3	2	3	0	3	1	3	3	2	1	0	3	0	0	5	49.00
		19	TRF_6	4	3	5	4	1	1	3	0	0	3	0	0	0	0	0	0	0	0	0	0	24.00
		20	TRF_7	3	2	4	5	4	0	5	0	0	0	0	0	0	0	2	3	4	4	3	0	39.00
		21	TRF_8	3	2	4	4	5	0	4	0	0	0	0	0	0	0	2	3	3	4	3	0	37.00
		22	TRF_9	3	3	3	3	5	4	4	4	5	4	0	3	0	2	3	2	1	3	0	2	54.00
		23	TRF_{10}	4	2	5	3	2	3	0	0	3	2	0	0	0	2	0	0	3	0	0	5	34.00
		24	TRF_{11}	5	3	5	4	2	3	3	4	2	3	3	3	3	3	1	1	3	2	2	5	60.00
		25	TRF_{12}	5	5	4	5	4	2	5	2	0	3	3	5	5	3	3	3	2	3	2	2	66.00
	OM	26	$OMRF_1$	5	5	5	5	3	4	3	2	2	2	2	0	3	0	0	5	4	2	3	3	58.00
		27	$OMRF_2$	5	3	5	4	1	0	3	2	0	2	2	2	3	1	0	4	3	2	2	5	49.00
		28	$OMRF_3$	4	3	5	5	0	0	5	3	3	2	2	3	2	2	0	0	2	2	2	3	48.00
		29	$OMRF_4$	3	3	5	3	0	0	3	4	0	0	2	3	5	5	0	0	5	1	0	3	45.00
	CL	30	$CLRF_1$	2	5	4	4	4	5	3	5	4	5	5	5	2	2	2	2	1	5	5	0	70.00
		31	$CLRF_2$	3	3	3	3	4	3	2	2	3	3	5	5	2	2	2	2	1	2	3	1	54.00
		32	$CLRF_3$	5	3	5	2	0	1	0	0	1	0	0	0	0	0	0	3	5	3	3	4	35.00
		33	$CLRF_4$	5	4	5	3	0	0	3	3	2	0	0	0	0	0	3	3	5	2	1	2	41.00
	C	34	CRF_1	4	5	5	5	5	5	4	3	5	5	5	5	3	3	4	5	5	4	4	5	89.00
		35	CRF_2	3	3	4	3	0	0	2	0	0	0	0	0	0	0	0	0	4	2	2	0	23.00
		36	CRF_3	5	5	3	5	3	3	4	0	0	2	2	4	3	2	2	5	5	5	4	0	62.00
	E	37	ERF_1	0	4	0	5	2	5	0	5	3	5	5	5	0	5	4	4	5	2	0	0	59.00
		38	ERF_2	0	4	0	3	0	2	0	5	3	5	5	5	0	5	2	4	3	1	0	0	47.00
Dependency Value				130.00	128.00	145.00	138.00	72.00	68.00	115.00	79.00	74.00	83.00	67.00	102.00	66.00	79.00	51.00	79.00	113.00	75.00	74.00	75.00	

Step 3: Probability of Risk Factors

In this step, probability of occurrence of the risk factors are determined according to the probability scale provide in Figure 5.3. The probability of occurrences of the risk factors are given in Table 5.23.

Table 5.23. *Probability of occurrences of risk factors for the hypothetical megaproject*

ID	Code Number	Risk Factors	Probability of Occurrence
1	FRF_1	Exchange rate fluctuation	0.80
2	FRF_2	Change in inflation rate	0.80
3	FRF_3	Change in interest rates	0.60
4	FRF_4	Change in taxation policies	0.60
5	$PLRF_1$	Instable political environment	0.80
6	$PLRF_2$	Emergence of civil strife, war and terrorism issues	0.20
7	$PLRF_3$	Difficulty in getting permits due to bureaucracy	0.50
8	$PLRF_4$	Vagueness of policies and regulations	0.60
9	$PLRF_5$	Change in laws and regulations	0.70
10	SRF_1	Public reaction towards the project (strike, rebellion etc.)	0.60
11	SRF_2	Vagueness of the needs of community	0.40
12	PRF_1	Unforeseen weather conditions	0.10
13	PRF_2	Unexpected physical conditions	0.10
14	TRF_1	Design team's lack of experience on sustainable construction principles	0.30
15	TRF_2	Complexity of design	0.30
16	TRF_3	Low constructability	0.20
17	TRF_4	Inaccurate or incomplete design drawings	0.60
18	TRF_5	Changes in amount of work due to defective work, rework or poor quality of construction	0.40
19	TRF_6	Low productivity	0.40
20	TRF_7	Unavailability of labor	0.20
21	TRF_8	Unavailability of sub-contractor	0.20
22	TRF_9	Unavailability of construction materials	0.30
23	TRF_{10}	Defective construction materials	0.40

Table 5.23. *(Cont'd)*

ID	Code Number	Risk Factors	Probability of Occurrence
24	TRF_{11}	Technology	0.30
25	TRF_{12}	Problems with the construction site	0.20
26	$OMRF_1$	Inaccurate cost, time and resource allocation estimation	0.50
27	$OMRF_2$	Inexperienced or noncompetitive contractor	0.30
28	$OMRF_3$	Lack of organization and coordination among project stakeholders	0.50
29	$OMRF_4$	Lack of audits on occupational health and safety procedures	0.30
30	$CLRF_1$	Client's reluctant attitude towards sustainable construction	0.60
31	$CLRF_2$	Client's lack of knowledge about sustainable construction	0.60
32	$CLRF_3$	Change orders or additions	0.70
33	$CLRF_4$	Inadequate funding or delay in progress payments	0.60
34	CRF_1	Ill-defined scope of work and contract specification	0.60
35	CRF_2	Contractual dispute resolution process	0.30
36	CRF_3	Inappropriate contract type, project delivery system and bidding type	0.60
37	ERF_1	Ineffective waste management	0.30
38	ERF_2	No audits for poor waste management	0.30

As a result, exchange rate fluctuation (FRF_1), change in inflation rate (FRF_2) and instable political environment ($PLRF_1$) are foreseen as the most probable risk factors for the achievement of sustainable construction objectives.

Step 4: Cross-Impact Matrix

Probability values and cross-impact values for each risk factor are gathered into a cross-impact matrix. The cross-impact matrix with the expected dependency values for each sustainable construction objective and the expected influence values for each risk factor are given in Table 5.24

Table 5.24. *Cross-impact matrix for the hypothetical megaproject*

			Probability of Occurence	SUSTAINABLE CONSTRUCTION OBJECTIVES																				Expected Influence Value
				ECONOMIC			ECONOMIC-ENVIRONMENTAL				ENVIRONMENTAL				ENVIRONMENTAL-SOCIAL			SOCIAL			ECONOMIC-SOCIAL			
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
				$EC\text{-}SO_1$	$EC\text{-}SO_2$	$EC\text{-}SO_3$	$EC\text{-}EN\text{-}SO_1$	$EC\text{-}EN\text{-}SO_2$	$EC\text{-}EN\text{-}SO_3$	$EC\text{-}EN\text{-}SO_4$	$EN\text{-}SO_1$	$EN\text{-}SO_2$	$EN\text{-}SO_3$	$EN\text{-}SO_4$	$EN\text{-}S\text{-}SO_1$	$EN\text{-}S\text{-}SO_2$	$EN\text{-}S\text{-}SO_3$	$S\text{-}SO_1$	$S\text{-}SO_2$	$S\text{-}SO_3$	$EC\text{-}S\text{-}SO_1$	$EC\text{-}S\text{-}SO_2$	$EC\text{-}S\text{-}SO_3$	
RISK FACTORS: F	1	FRF_1	0.80	4.00	4.00	3.20	2.40	0.00	0.00	2.40	0.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.60	0.00	19.20
	2	FRF_2	0.80	4.00	4.00	3.20	2.40	0.00	0.00	2.40	0.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	2.40	3.20	0.00	24.00
	3	FRF_3	0.60	1.80	2.40	2.40	1.80	0.00	0.00	1.80	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40	1.20	1.80	0.00	16.80
	4	FRF_4	0.60	1.80	1.20	1.20	1.80	0.00	0.00	1.80	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	1.20	1.80	1.80	1.80	0.00	15.60
PL	5	$PLRF_1$	0.80	4.00	3.20	2.40	1.60	0.00	0.00	0.80	0.00	0.00	0.00	1.60	4.00	0.00	0.00	2.40	2.40	2.40	0.00	1.60	0.00	26.40
	6	$PLRF_2$	0.20	0.60	0.60	1.00	0.40	0.60	0.20	0.60	0.80	0.00	0.40	0.40	1.00	1.00	1.00	0.40	0.60	1.00	0.60	0.60	0.40	12.20
	7	$PLRF_3$	0.50	1.00	0.50	2.00	1.00	0.00	0.00	2.00	0.00	0.00	0.50	0.00	2.50	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	11.50
	8	$PLRF_4$	0.60	0.00	1.80	0.00	3.00	1.80	2.40	2.40	3.00	3.00	3.00	3.00	3.00	2.40	3.00	1.20	1.20	1.80	1.20	2.40	1.80	41.40
	9	$PLRF_5$	0.70	2.10	2.10	2.10	3.50	1.40	1.40	2.80	3.50	3.50	3.50	3.50	3.50	2.80	3.50	1.40	1.40	2.10	1.40	2.80	2.10	50.40
S	10	SRF_1	0.60	0.00	0.00	3.00	0.00	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	1.80	0.00	0.00	0.00	9.00
	11	SRF_2	0.40	0.40	0.80	1.20	0.80	1.20	1.20	2.00	2.00	1.60	1.60	0.80	1.60	1.60	1.60	2.00	2.00	2.00	1.60	2.00	0.00	28.00
P	12	PRF_1	0.10	0.30	0.40	0.30	0.40	0.00	0.00	0.40	0.20	0.20	0.30	0.00	0.40	0.20	0.20	0.00	0.20	0.20	0.10	0.00	0.30	4.10
	13	PRF_2	0.10	0.40	0.30	0.30	0.40	0.00	0.00	0.50	0.30	0.00	0.30	0.00	0.50	0.40	0.40	0.00	0.20	0.30	0.10	0.00	0.30	4.70
T	14	TRF_1	0.30	1.20	1.20	1.20	1.50	1.20	1.20	0.90	0.60	1.50	1.50	1.20	1.50	0.00	0.60	0.90	0.90	0.90	0.90	0.30	0.90	20.10
	15	TRF_2	0.30	1.20	0.90	1.20	0.90	0.90	0.90	1.20	0.90	0.90	0.60	0.60	0.90	1.20	0.60	0.00	0.00	0.60	0.00	0.60	1.20	15.30
	16	TRF_3	0.20	1.00	0.60	1.00	1.00	0.60	0.60	0.40	0.20	0.20	0.20	0.00	0.20	0.60	0.40	0.20	0.60	0.60	0.00	0.00	0.80	9.20
	17	TRF_4	0.60	2.40	2.40	3.00	3.00	3.00	2.40	2.40	1.20	3.00	1.80	1.80	2.40	0.00	1.20	1.20	1.20	2.40	1.20	1.20	3.00	40.20
	18	TRF_5	0.40	2.00	2.00	2.00	1.60	0.40	1.20	0.80	1.20	0.00	1.20	0.40	1.20	1.20	0.80	0.40	0.00	1.20	0.00	0.00	2.00	19.60
	19	TRF_6	0.40	1.60	1.20	2.00	1.60	0.40	0.40	1.20	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.60
	20	TRF_7	0.20	0.60	0.40	0.80	1.00	0.80	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.60	0.80	0.80	0.60	0.00	7.80
	21	TRF_8	0.20	0.60	0.40	0.80	0.80	1.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.60	0.60	0.80	0.60	0.00	7.40
	22	TRF_9	0.30	0.90	0.90	0.90	0.90	1.50	1.20	1.20	1.20	1.50	1.20	0.00	0.90	0.00	0.60	0.90	0.60	0.30	0.90	0.00	0.60	16.20
	23	TRF_{10}	0.40	1.60	0.80	2.00	1.20	0.80	1.20	0.00	0.00	1.20	0.80	0.00	0.00	0.00	0.80	0.00	0.00	1.20	0.00	0.00	2.00	13.60
	24	TRF_{11}	0.30	1.50	0.90	1.50	1.20	0.60	0.90	0.90	1.20	0.60	0.90	0.90	0.90	0.90	0.90	0.30	0.30	0.90	0.60	0.60	1.50	18.00
	25	TRF_{12}	0.20	1.00	1.00	0.80	1.00	0.80	0.40	1.00	0.40	0.00	0.60	0.60	1.00	1.00	0.60	0.60	0.60	0.40	0.60	0.40	0.40	13.20
OM	26	$OMRF_1$	0.50	2.50	2.50	2.50	2.50	1.50	2.00	1.50	1.00	1.00	1.00	1.00	0.00	1.50	0.00	0.00	2.50	2.00	1.00	1.50	1.50	29.00
	27	$OMRF_2$	0.30	1.50	0.90	1.50	1.20	0.30	0.00	0.90	0.60	0.00	0.60	0.60	0.60	0.90	0.30	0.00	1.20	0.90	0.60	0.60	1.50	14.70
	28	$OMRF_3$	0.50	2.00	1.50	2.50	2.50	0.00	0.00	2.50	1.50	1.50	1.00	1.00	1.50	1.00	1.00	0.00	0.00	1.00	1.00	1.00	1.50	24.00
	29	$OMRF_4$	0.30	0.90	0.90	1.50	0.90	0.00	0.00	0.90	1.20	0.00	0.00	0.60	0.90	1.50	1.50	0.00	0.00	1.50	0.30	0.00	0.90	13.50
CL	30	$CLRF_1$	0.60	1.20	3.00	2.40	2.40	2.40	3.00	1.80	3.00	2.40	3.00	3.00	3.00	1.20	1.20	1.20	1.20	0.60	3.00	3.00	0.00	42.00
	31	$CLRF_2$	0.60	1.80	1.80	1.80	1.80	2.40	1.80	1.20	1.20	1.80	1.80	3.00	3.00	1.20	1.20	1.20	1.20	0.60	1.20	1.80	0.60	32.40
	32	$CLRF_3$	0.70	3.50	2.10	3.50	1.40	0.00	0.70	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00	2.10	3.50	2.10	2.10	2.80	24.50
	33	$CLRF_4$	0.60	3.00	2.40	3.00	1.80	0.00	0.00	1.80	1.80	1.20	0.00	0.00	0.00	0.00	0.00	1.80	1.80	3.00	1.20	0.60	1.20	24.60
C	34	CRF_1	0.60	2.40	3.00	3.00	3.00	3.00	3.00	2.40	1.80	3.00	3.00	3.00	3.00	1.80	1.80	2.40	3.00	3.00	2.40	2.40	3.00	53.40
	35	CRF_2	0.30	0.90	0.90	1.20	0.90	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.60	0.60	0.00	6.90
	36	CRF_3	0.60	3.00	3.00	1.80	3.00	1.80	1.80	2.40	0.00	0.00	1.20	1.20	2.40	1.80	1.20	1.20	3.00	3.00	3.00	2.40	0.00	37.20
E	37	ERF_1	0.30	0.00	1.20	0.00	1.50	0.60	1.50	0.00	1.50	0.90	1.50	1.50	1.50	0.00	1.50	1.20	1.20	1.50	0.60	0.00	0.00	17.70
	38	ERF_2	0.30	0.00	1.20	0.00	0.90	0.00	0.60	0.00	1.50	0.90	1.50	1.50	1.50	0.00	1.50	0.60	1.20	0.90	0.30	0.00	0.00	14.10
Expected Depedency Value				58.70	58.40	64.20	59.00	29.00	30.00	48.90	31.80	36.20	34.20	31.20	42.90	25.20	31.40	22.30	33.80	48.40	33.50	38.10	30.30	

In addition, expected dependency values for each sustainable construction objective are demonstrated in a bar chart (See Figure 5.7). The most affected three sustainable construction objectives are effective project management and management of resources (EC-SO_3), energy efficiency for all phases of the megaproject (EC-EN-SO_1) and optimization of site layout (EC-EN-SO_4).

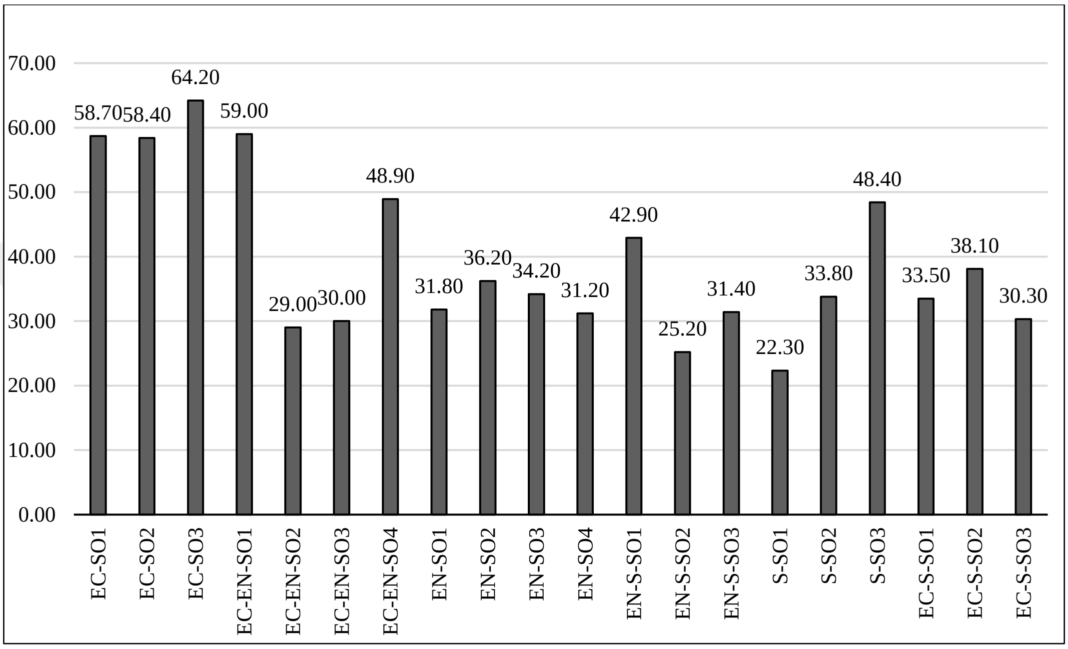

Figure 5.7. Expected dependency values of the sustainable construction objectives for the hypothetical megaproject

Besides the expected dependency bar chart for sustainable construction objectives, expected influence values for risk factors are presented as well (See Figure 5.8). As a result, ill-defined scope of work and contract specification (CRF_1), change in laws and regulations ($PLRF_5$) and client's reluctant attitude towards sustainable construction ($CLRF_1$) are the most important threats for the achievement of a sustainable outcome from the hypothetical megaproject.

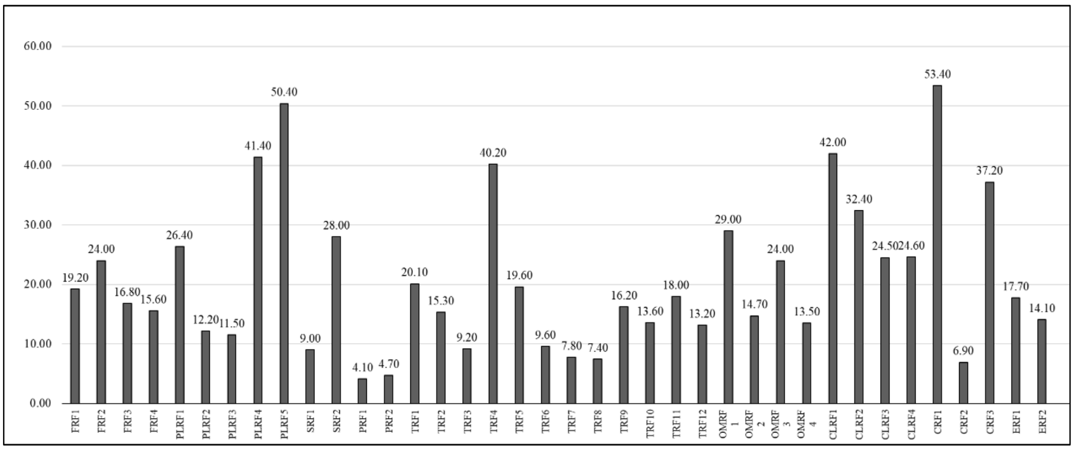

Figure 5.8. Expected influence values of the risk factors for the hypothetical megaproject

Step 5: Vulnerability Chart and Heat Map

A vulnerability chart and a heat map are presented in order to analyze overall findings regarding the global weights and expected dependency values for sustainable construction objectives.

Firstly, expected dependency level for each sustainable construction objectives are demonstrated on a vulnerability chart with dependency regions. Fundamentally, global weights for the sustainable construction objectives obtained from Step 1 are located on the horizontal axis and expected dependency values obtained from Step 4 on the vertical axis. The main advantage of the vulnerability chart is that it allows to track each sustainable construction objective in terms of their importance and level of vulnerability. The vulnerability chart for the hypothetical megaproject is provided in Figure 5.9.

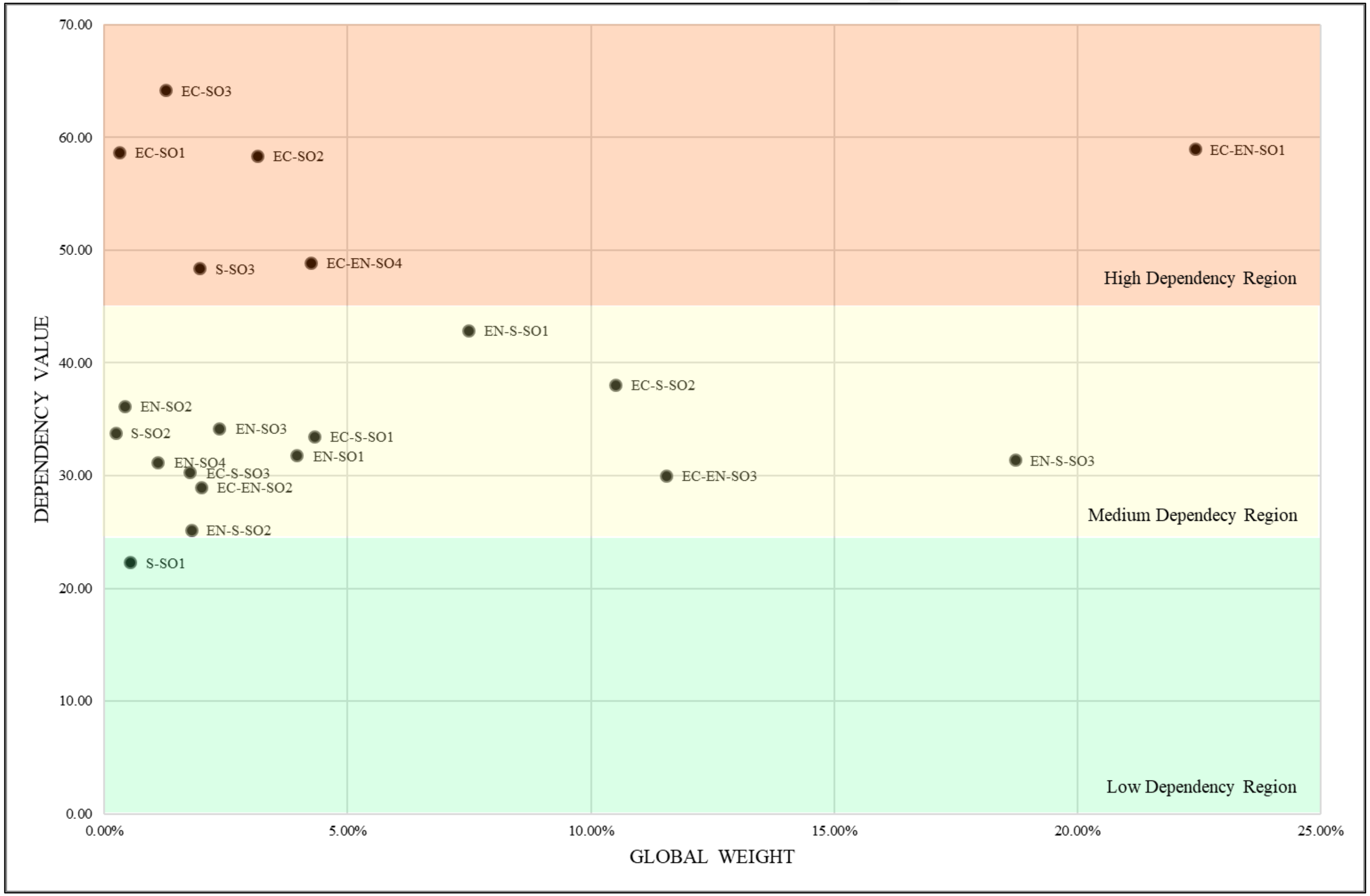

Figure 5.9. Vulnerability chart for the hypothetical megaproject

In summary, sustainable construction objective named as energy efficiency for all phases of megaproject (EC-EN-SO_1) is the most important project objective for the hypothetical project. However, it is the most affected sustainable construction objective from the risk factors considering the expected level of dependency among other objectives. If the foreseen risks occur in future, the project objective with the highest global weight will expose to the threats and the probability of the achievement of a sustainable outcome from the hypothetical megaproject will be affected more. Providing a healthy and safe environment for all phases of the megaproject (EN-S-SO_3) and reduction, reuse and recycling of materials (EC-EN-SO_3) are the other important project objectives, yet their level of expected dependency values are not critical. If the expected dependency values are considered, the most vulnerable three objectives affected from the risk factors are effective project management and management of resources (EC-SO_3), energy efficiency for all phases of the megaproject (EC-EN-SO_1), feasibility and financial affordability of the megaproject (EC-SO_1).

In addition, a heat map is provided in order to analyze the most vulnerable sustainable construction objectives in detail. The heat map demonstrates the components of expected dependency values due to the probability and cross-impact values of risk factors for each sustainable construction objective. The heat map can be examined in Table 5.25.

Table 5.25. *Heat map for the hypothetical megaproject*

				Probability of Occurence	SUSTAINABLE CONSTRUCTION OBJECTIVES																				Expected Influence Value
					ECONOMIC			ECONOMIC-ENVIRONMENTAL				ENVIRONMENTAL				ENVIRONMENTAL-SOCIAL			SOCIAL			ECONOMIC-SOCIAL			
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
					EC-SO_1	EC-SO_2	EC-SO_3	EC-EN-SO_1	EC-EN-SO_2	EC-EN-SO_3	EC-EN-SO_4	EN-SO_1	EN-SO_2	EN-SO_3	EN-SO_4	EN-S-SO_1	EN-S-SO_2	EN-S-SO_3	S-SO_1	S-SO_2	S-SO_3	EC-S-SO_1	EC-S-SO_2	EC-S-SO_3	
RISK FACTORS	F	1	FRF_1	0.80	4.00	4.00	3.20	2.40	0.00	0.00	2.40	0.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.60	0.00	19.20
		2	FRF_2	0.80	4.00	4.00	3.20	2.40	0.00	0.00	2.40	0.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	2.40	3.20	0.00	24.00
		3	FRF_3	0.60	1.80	2.40	2.40	1.80	0.00	0.00	1.80	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40	1.20	1.80	0.00	16.80
		4	FRF_4	0.60	1.80	1.20	1.20	1.80	0.00	0.00	1.80	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	1.20	1.80	1.80	1.80	0.00	15.60
	PL	5	$PLRF_1$	0.80	4.00	3.20	2.40	1.60	0.00	0.00	0.80	0.00	0.00	0.00	1.60	4.00	0.00	0.00	2.40	2.40	2.40	0.00	1.60	0.00	26.40
		6	$PLRF_2$	0.20	0.60	0.60	1.00	0.40	0.60	0.20	0.60	0.80	0.00	0.40	0.40	1.00	1.00	1.00	0.40	0.60	1.00	0.60	0.60	0.40	12.20
		7	$PLRF_3$	0.50	1.00	0.50	2.00	1.00	0.00	0.00	2.00	0.00	0.00	0.50	0.00	2.50	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	11.50
		8	$PLRF_4$	0.60	0.00	1.80	0.00	3.00	1.80	2.40	2.40	3.00	3.00	3.00	3.00	3.00	2.40	3.00	1.20	1.20	1.80	1.20	2.40	1.80	41.40
		9	$PLRF_5$	0.70	2.10	2.10	2.10	3.50	1.40	1.40	2.80	3.50	3.50	3.50	3.50	3.50	2.80	3.50	1.40	1.40	2.10	1.40	2.80	2.10	50.40
	S	10	SRF_1	0.60	0.00	0.00	3.00	0.00	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	1.80	0.00	0.00	0.00	9.00
		11	SRF_2	0.40	0.40	0.80	1.20	0.80	1.20	1.20	2.00	2.00	1.60	1.60	0.80	1.60	1.60	1.60	2.00	2.00	2.00	1.60	2.00	0.00	28.00
	P	12	PRF_1	0.10	0.30	0.40	0.30	0.40	0.00	0.00	0.40	0.20	0.20	0.30	0.00	0.40	0.20	0.20	0.00	0.20	0.20	0.10	0.00	0.30	4.10
		13	PRF_2	0.10	0.40	0.30	0.30	0.40	0.00	0.00	0.50	0.30	0.00	0.30	0.00	0.50	0.40	0.40	0.00	0.20	0.30	0.10	0.00	0.30	4.70
	T	14	TRF_1	0.30	1.20	1.20	1.20	1.50	1.20	1.20	0.90	0.60	1.50	1.50	1.20	1.50	0.00	0.60	0.90	0.90	0.90	0.90	0.30	0.90	20.10
		15	TRF_2	0.30	1.20	0.90	1.20	0.90	0.90	0.90	1.20	0.90	0.90	0.60	0.60	0.90	1.20	0.60	0.00	0.00	0.60	0.00	0.60	1.20	15.30
		16	TRF_3	0.20	1.00	0.60	1.00	1.00	0.60	0.60	0.40	0.20	0.20	0.20	0.00	0.20	0.60	0.40	0.20	0.60	0.60	0.00	0.00	0.80	9.20
		17	TRF_4	0.60	2.40	2.40	3.00	3.00	3.00	2.40	2.40	1.20	3.00	1.80	1.80	2.40	0.00	1.20	1.20	1.20	2.40	1.20	1.20	3.00	40.20
		18	TRF_5	0.40	2.00	2.00	2.00	1.60	0.40	1.20	0.80	1.20	0.00	1.20	0.40	1.20	1.20	0.80	0.40	0.00	1.20	0.00	0.00	2.00	19.60
		19	TRF_6	0.40	1.60	1.20	2.00	1.60	0.40	0.40	1.20	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.60
		20	TRF_7	0.20	0.60	0.40	0.80	1.00	0.80	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.60	0.80	0.80	0.60	0.00	7.80
		21	TRF_8	0.20	0.60	0.40	0.80	0.80	1.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.60	0.60	0.80	0.60	0.00	7.40
		22	TRF_9	0.30	0.90	0.90	0.90	0.90	1.50	1.20	1.20	1.20	1.50	1.20	0.00	0.90	0.00	0.60	0.90	0.60	0.30	0.90	0.00	0.60	16.20
		23	TRF_{10}	0.40	1.60	0.80	2.00	1.20	0.80	1.20	0.00	0.00	1.20	0.80	0.00	0.00	0.00	0.80	0.00	0.00	1.20	0.00	0.00	2.00	13.60
		24	TRF_{11}	0.30	1.50	0.90	1.50	1.20	0.60	0.90	0.90	1.20	0.60	0.90	0.90	0.90	0.90	0.90	0.30	0.30	0.90	0.60	0.60	1.50	18.00
		25	TRF_{12}	0.20	1.00	1.00	0.80	1.00	0.80	0.40	1.00	0.40	0.00	0.60	0.60	1.00	1.00	0.60	0.60	0.60	0.40	0.60	0.40	0.40	13.20
	OM	26	$OMRF_1$	0.50	2.50	2.50	2.50	2.50	1.50	2.00	1.50	1.00	1.00	1.00	1.00	0.00	1.50	0.00	0.00	2.50	2.00	1.00	1.50	1.50	29.00
		27	$OMRF_2$	0.30	1.50	0.90	1.50	1.20	0.30	0.00	0.90	0.60	0.00	0.60	0.60	0.60	0.90	0.30	0.00	1.20	0.90	0.60	0.60	1.50	14.70
		28	$OMRF_3$	0.50	2.00	1.50	2.50	2.50	0.00	0.00	2.50	1.50	1.50	1.00	1.00	1.50	1.00	1.00	0.00	0.00	1.00	1.00	1.00	1.50	24.00
		29	$OMRF_4$	0.30	0.90	0.90	1.50	0.90	0.00	0.00	0.90	1.20	0.00	0.00	0.60	0.90	1.50	1.50	0.00	0.00	1.50	0.30	0.00	0.90	13.50
	CL	30	$CLRF_1$	0.60	1.20	3.00	2.40	2.40	2.40	3.00	1.80	3.00	2.40	3.00	3.00	3.00	1.20	1.20	1.20	1.20	0.60	3.00	3.00	0.00	42.00
		31	$CLRF_2$	0.60	1.80	1.80	1.80	1.80	2.40	1.80	1.20	1.20	1.80	1.80	3.00	3.00	1.20	1.20	1.20	1.20	0.60	1.20	1.80	0.60	32.40
		32	$CLRF_3$	0.70	3.50	2.10	3.50	1.40	0.00	0.70	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00	2.10	3.50	2.10	2.10	2.80	24.50
		33	$CLRF_4$	0.60	3.00	2.40	3.00	1.80	0.00	0.00	1.80	1.80	1.20	0.00	0.00	0.00	0.00	0.00	1.80	1.80	3.00	1.20	0.60	1.20	24.60
	C	34	CRF_1	0.60	2.40	3.00	3.00	3.00	3.00	3.00	2.40	1.80	3.00	3.00	3.00	3.00	1.80	1.80	2.40	3.00	3.00	2.40	2.40	3.00	53.40
		35	CRF_2	0.30	0.90	0.90	1.20	0.90	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.60	0.60	0.00	6.90
		36	CRF_3	0.60	3.00	3.00	1.80	3.00	1.80	1.80	2.40	0.00	0.00	1.20	1.20	2.40	1.80	1.20	1.20	3.00	3.00	3.00	2.40	0.00	37.20
	E	37	ERF_1	0.30	0.00	1.20	0.00	1.50	0.60	1.50	0.00	1.50	0.90	1.50	1.50	1.50	0.00	1.50	1.20	1.20	1.50	0.60	0.00	0.00	17.70
		38	ERF_2	0.30	0.00	1.20	0.00	0.90	0.00	0.60	0.00	1.50	0.90	1.50	1.50	1.50	0.00	1.50	0.60	1.20	0.90	0.30	0.00	0.00	14.10
Expected Depedency Value					58.70	58.40	64.20	59.00	29.00	30.00	48.90	31.80	36.20	34.20	31.20	42.90	25.20	31.40	22.30	33.80	48.40	33.50	38.10	30.30	

The most vulnerable and important sustainable construction objective was examined as energy efficiency for all phases of the megaproject (EC-EN-SO_1) from the vulnerability chart provided in Figure 5.9. If the critical risks are ignored, the most important project objective will be exposed to the risk factors, and hypothetical megaproject will be failed to satisfy the sustainability requirements for the megaproject. Therefore, it is important to analyze and track the threats that have a major contribution to generate the expected dependency value for this objective. If the heat map provided in Table 5.25 is observed, the most critical risk factor can be examined as change in laws and regulations ($PLRF_5$). The probability of occurrence of the risk factor is assigned as 0.70, yet this risk factor is a country related risk factor and the probability of occurrence of the risk factor cannot be controlled easily. Other parameter that affects the type of the risk is the cross-impact value assigned for the risk factor. The cross-impact value for this risk factor is assigned as the highest value considering the numerical scale given for the matrix. Since the probability of occurrence of the risk factor cannot be controlled, it is important to control the impact of the risk factor by developing more resilient strategies to the changes in order to eliminate the threat. From the overall point of view; financial, technical, organizational and managerial, contractual and law related risk factors are included in the high-risk category. The probability of occurrences of the financial risk factors cannot be controlled easily because they are external risk factors. Yet, impact of the financial related risk factors can be decreased. For this reason, it is important to focus on the project related risk factors in order to reduce the expected dependency value for the sustainability construction objective namely energy efficiency for all phases of the megaproject (EC-EN-SO_1). In comparison to the external risk factors, probability of occurrences and impact values of the project related risk factors can be decreased by developing risk mitigation strategies. As an illustration, organization and management related risk factors can be eliminated by hiring experienced project management team.

The proposed model named as RAMSCOM has been mentioned in this chapter. The main focus of this chapter has become the development processes of RAMSCOM and its implementation on a hypothetical construction megaproject. In the following chapter, RAMSCOM will be presented on a real construction megaproject, and results will be discussed considering the sustainability aspect of the megaproject.

CHAPTER 6

IMPLEMENTATION OF RAMSCOM INTO A REAL CONSTRUCTION MEGAPROJECT

This chapter continues with the implementation of RAMSCOM in a real construction megaproject. Firstly, a brief information about the company is given. Then, the characteristics of the construction megaproject that is utilized for the implementation process of RAMSCOM is mentioned. Thereafter, implementation of RAMSCOM is stated in detail regarding the information given about the construction megaproject. The chapter concludes with the findings and results obtained from the implementation process of RAMSCOM on a real construction megaproject.

6.1. Overview of the Construction Company

The company was founded in 1979 and commence its corporate activities in 1985. The company has become prominent especially in residence, dwelling, building, workplaces, culture centers, sport centers, health centers, touristic complexes, highways, junctions, tunnels, pipe lines, sewage and watering systems and energy. The company has a portfolio of superstructure projects with total area of about 1.000.000 m^2, and it has reached a business volume in the amount of 950 million dollars abroad. Moreover, the company opened branches in Dubai, Abu Dhabi, Saudi Arabia, Syria, Oman, Ukraine, Turkmenistan, Russia and Tatarstan, and trying to expand construction activities in the areas like Romania, Nigeria and Georgia. The company makes investment not only in construction sector but also different sectors including energy, mining, aviation, tourism, petrol, agriculture and food.

6.2. Overview of the Megaproject

The selected megaproject for the implementation process of RAMSCOM is a hospital project that has a capacity of 1099 beds in an area of 250.000 m^2. The megaproject is carried out in İstanbul, Turkey. The start date of the megaproject is 19 November of 2013. The contract type of the megaproject is FIDIC Red Book, and the payment type is unit price. Contract price of the megaproject is 391,530,574.49 TL. The role of the company is contractor. Design of the megaproject is done by a German company. The owner of the project is Istanbul Project Coordination Unit (IPKB) The fund of the megaproject is supported by Islamic Development Bank and Ministry of Health.

6.3. Implementation of RAMSCOM

An interview is carried out with the project coordinator of the Istanbul Project Coordination Unit (IPKB). The content of the interview begins with a brief talk about the megaproject. Then, the expert is informed about sustainable construction and risk management concepts. Finally, RAMSCOM is disscussed and usability of the RAMSCOM is tested on the real megaproject. The implementation process of RAMSCOM on the real megaproject is explained below.

Step 1: Discussion on Global Weights of Sustainable Construction Objectives

First of all, identified sustainable construction objectives are mentioned and the identified objectives are found reasonable. Then, the expert assigned values to the first level pairwise of comparison matrices for sustainable construction objectives considering the numerical scale from 1 to 9 (See Table 6.1). According to the expert, each sustainable construction dimension does have equal importance, so the expert assigned equal values to the first level of pairwise comparison matrix.

Table 6.1. *Pairwise comparison matrix of the sustainable construction dimensions for the real megaproject*

	Sustainable Construction Dimensions	EC-SO	EC-EN-SO	EN-SO	EN-S-SO	S-SO	EC-S-SO
1	**EC-SO**	1.00	1.00	1.00	1.00	1.00	1.00
2	**EC-EN-SO**	1.00	1.00	1.00	1.00	1.00	1.00
3	**EN-SO**	1.00	1.00	1.00	1.00	1.00	1.00
4	**EN-S-SO**	1.00	1.00	1.00	1.00	1.00	1.00
5	**S-SO**	1.00	1.00	1.00	1.00	1.00	1.00
6	**EC-S-SO**	1.00	1.00	1.00	1.00	1.00	1.00

Then, the expert assigned values to the second level of hierarchal pairwise comparison matrices considering megaproject. The second level of pairwise comparison matrices including economic sustainability (See Table 6.2), economic-environmental sustainability (See Table 6.3), environmental sustainability (See Table 6.4), environmental-social sustainability (See Table 6.5), social sustainability (See Table 6.6) and economic-social sustainability (See Table 6.7) filled by the expert are provided below.

Table 6.2. *Pairwise comparison matrix of the economic sustainability objectives for the real megaproject*

	Economic Sustainability	$EC\text{-}SO_1$	$EC\text{-}SO_2$	$EC\text{-}SO_3$
1	$EC\text{-}SO_1$	1.00	0.33	3.00
2	$EC\text{-}SO_2$	3.00	1.00	5.00
3	$EC\text{-}SO_3$	0.33	0.20	1.00

Table 6.3. *Pairwise comparison matrix of the economic-environmental sustainability objectives for the real megaproject*

Economic-Environmental Sustainability		EC-EN-SO$_1$	EC-EN-SO$_2$	EC-EN-SO$_3$	EC-EN-SO$_4$
4	**EC-EN-SO$_1$**	1.00	7.00	5.00	5.00
5	**EC-EN-SO$_2$**	0.14	1.00	0.50	1.00
6	**EC-EN-SO$_3$**	0.20	2.00	1.00	5.00
7	**EC-EN-SO$_4$**	0.20	0.33	0.20	1.00

Table 6.4. *Pairwise comparison matrix of the environmental sustainability objectives for the real megaproject*

Environmental Sustainability		EN-SO$_1$	EN-SO$_2$	EN-SO$_3$	EN-SO$_4$
8	**EN-SO$_1$**	1.00	1.00	9.00	9.00
9	**EN-SO$_2$**	1.00	1.00	9.00	9.00
10	**EN-SO$_3$**	0.11	0.11	1.00	1.00
11	**EN-SO$_4$**	0.11	0.11	1.00	1.00

Table 6.5. *Pairwise comparison matrix of the environmental-social sustainability objectives for the real megaproject*

Environmental-Social Sustainability		EN-S-SO$_1$	EN-S-SO$_2$	EN-S-SO$_3$
12	**EN-S-SO$_1$**	1.00	0.11	0.33
13	**EN-S-SO$_2$**	9.00	1.00	5.00
14	**EN-S-SO$_3$**	3.00	0.20	1.00

Table 6.6. *Pairwise comparison matrix of the social sustainability objectives for the real megaproject*

Social Sustainability		S-SO$_1$	S-SO$_2$	S-SO$_3$
15	**S-SO$_1$**	1.00	3.00	0.33
16	**S-SO$_2$**	0.33	1.00	0.14
17	**S-SO$_3$**	3.00	7.00	1.00

Table 6.7. *Pairwise comparison matrix of the economic-social sustainability objectives for the real megaproject*

Economic-Social Sustainability		$EC\text{-}S\text{-}SO_1$	$EC\text{-}S\text{-}SO_2$	$EC\text{-}S\text{-}SO_3$
18	**$EC\text{-}S\text{-}SO_1$**	1.00	3.00	3.00
19	**$EC\text{-}S\text{-}SO_2$**	0.33	1.00	1.00
20	**$EC\text{-}S\text{-}SO_3$**	0.33	1.00	1.00

The consistency ratios for the first level and second level of pairwise comparison matrices are checked, and it is seen that the CR values of the pairwise comparison matrices are less than 10%. The finalized global weights of the sustainability objectives for the real megaproject are provided in Table 6.8.

Table 6.8. *Global weights of the sustainable construction objectives for the real megaproject*

ID	Code Number	Sustainable Construction Objectives	Global Weight
1	$EC\text{-}SO_1$	Feasibility and financial affordability of the MCP	4.34%
2	$EC\text{-}SO_2$	Optimized long-term economic value	10.56%
3	$EC\text{-}SO_3$	Effective project management and management of the resources	1.77%
4	$EC\text{-}EN\text{-}SO_1$	Energy efficiency for all phases of the MCP	10.37%
5	$EC\text{-}EN\text{-}SO_2$	Utilization of local materials and supplies	1.45%
6	$EC\text{-}EN\text{-}SO_3$	Reduction, reuse and recycling of materials	3.70%
7	$EC\text{-}EN\text{-}SO_4$	Optimization of site layout	1.15%
8	$EN\text{-}SO_1$	Reduction of emissions, wastes, pollutants and noise	7.50%
9	$EN\text{-}SO_2$	Choice of environmentally friendly materials and products	7.50%
10	$EN\text{-}SO_3$	Natural resource conversation and preference of renewable resources	0.83%
11	$EN\text{-}SO_4$	Enhancing biodiversity	0.83%
12	$EN\text{-}S\text{-}SO_1$	Preservation of cultural identity and reducing the impact on heritage due to the MCP	1.19%
13	$EN\text{-}S\text{-}SO_2$	Minimizing local nuisance and disruption	12.47%
14	$EN\text{-}S\text{-}SO_3$	Providing a healthy and safe environment for all phases of the MCP	3.01%

Table 6.8. *(Cont'd)*

ID	Code Number	Sustainable Construction Objectives	Global Weight
15	S-SO_1	Delivering services that enhance the local environment	4.05%
16	S-SO_2	Provision of equal opportunities	1.47%
17	S-SO_3	Enhancing quality of life and providing customer and employee satisfaction	11.14%
18	EC-S-SO_1	Supporting local economies	10.00%
19	EC-S-SO_2	Providing equal employment creation	3.33%
20	EC-S-SO_3	Zero defects policy	3.33%
Column Sum			100.00%

In addition, a bar chart is provided in order to make a quick comparison among sustainable construction objectives regarding their global weights (See Figure 6.1).

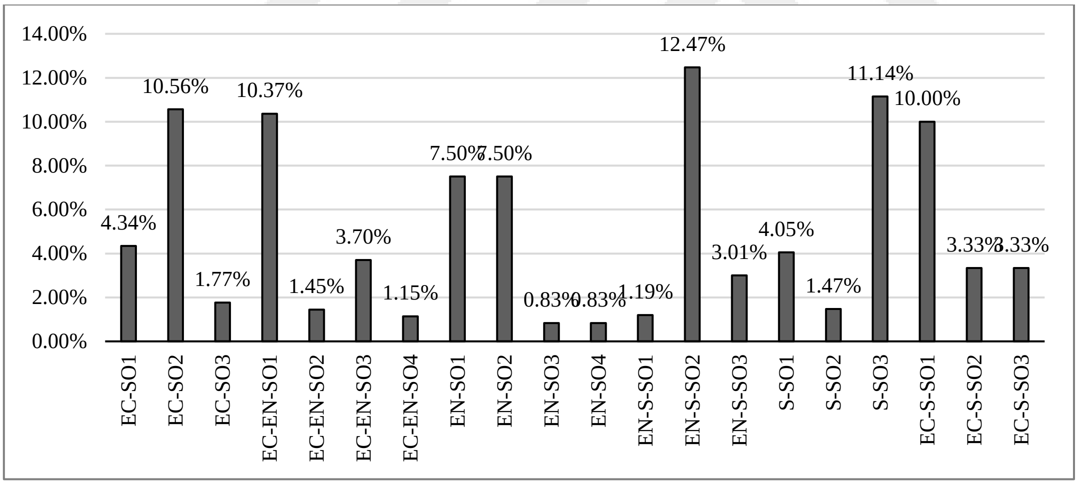

Figure 6.1. Global weights of the sustainable construction objectives in a bar chart

According to the values assigned by the expert; minimizing local nuisance and disruption (EN-S-SO_2), enhancing quality of life, and providing customer and employee satisfaction (S-SO_3), optimized long-term economic value (EC-SO_2) are obtained as the most important three objectives for the megaproject.

Considering the circumstances of the megaproject, the construction is carried out next to the old hospital building, and it may have some adverse effects on the local people. However, the construction does not disturb the usage of the old hospital building because patients are still using this building. Moreover, the new hospital building has been constructing because the current capacity of the old hospital building has become insufficient to encounter the needs of the public. Finally, the new hospital building is a megaproject, and it is important to consider the long-term economic value of the megaproject. All in all, the most important objectives obtained from the pairwise comparison matrices are disscussed with the expert, and the expert found the aforementioned objectives reasonable.

Step 2: Discussion on Risk Factors and Cross-Impact Values of the Risk Factors
In this step, identified risk factors are stated and they are found reasonable. Then, the cross-impact values for each risk factor are disscussed with the expert and cross-impact values of the risk factors are revised. The revised cross-impact values are given in Table 6.9.

Table 6.9. *Revised cross-impact values of the risk factors*

			SUSTAINABLE CONSTRUCTION OBJECTIVES																				
			ECONOMIC			ECONOMIC-ENVIRONMENTAL				ENVIRONMENTAL				ENVIRONMENTAL-SOCIAL			SOCIAL			ECONOMIC-SOCIAL			Influence Value
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
			$EC\text{-}SO_1$	$EC\text{-}SO_2$	$EC\text{-}SO_3$	$EC\text{-}EN\text{-}SO_1$	$EC\text{-}EN\text{-}SO_2$	$EC\text{-}EN\text{-}SO_3$	$EC\text{-}EN\text{-}SO_4$	$EN\text{-}SO_1$	$EN\text{-}SO_2$	$EN\text{-}SO_3$	$EN\text{-}SO_4$	$EN\text{-}S\text{-}SO_1$	$EN\text{-}S\text{-}SO_2$	$EN\text{-}S\text{-}SO_3$	$S\text{-}SO_1$	$S\text{-}SO_2$	$S\text{-}SO_3$	$EC\text{-}S\text{-}SO_1$	$EC\text{-}S\text{-}SO_2$	$EC\text{-}S\text{-}SO_3$	
RISK FACTORS – F	1	FRF_1	5	5	4	3	0	0	3	0	2	0	0	0	0	0	0	0	2	2	3	0	29.00
F	2	FRF_2	5	5	4	3	0	0	3	0	2	0	0	0	0	0	0	1	3	3	4	0	33.00
F	3	FRF_3	3	4	4	3	0	0	3	0	2	0	0	0	0	0	2	2	4	2	3	0	32.00
F	4	FRF_4	3	3	2	3	0	0	3	0	2	0	0	0	0	0	2	2	3	3	3	0	29.00
PL	5	$PLRF_1$	5	5	5	2	2	0	2	0	0	2	2	5	0	0	3	3	3	0	2	0	41.00
PL	6	$PLRF_2$	4	4	5	2	3	1	3	4	0	2	2	5	5	5	4	3	5	3	3	2	65.00
PL	7	$PLRF_3$	2	3	5	3	0	0	5	0	0	1	0	5	2	2	0	0	0	0	0	0	28.00
PL	8	$PLRF_4$	3	3	5	5	3	4	4	5	5	5	5	5	4	5	2	2	3	2	4	3	77.00
PL	9	$PLRF_5$	3	4	3	5	2	2	4	5	5	5	5	5	4	5	2	2	3	2	4	3	73.00
S	10	SRF_1	3	2	5	3	0	0	3	0	0	0	0	0	5	5	0	0	3	0	0	1	30.00
S	11	SRF_2	1	2	3	2	3	3	5	5	4	4	2	4	4	4	5	5	5	4	5	0	70.00
P	12	PRF_1	3	4	3	4	2	1	4	2	2	3	2	4	2	2	4	2	2	3	2	3	54.00
P	13	PRF_2	4	4	5	4	2	0	5	3	0	3	2	5	4	4	1	2	3	1	0	3	55.00
T	14	TRF_1	4	4	4	5	4	4	3	2	5	5	4	5	1	2	3	3	3	3	1	3	68.00
T	15	TRF_2	4	3	4	3	3	3	4	3	3	2	2	3	4	2	0	0	2	0	2	4	51.00
T	16	TRF_3	5	3	5	5	3	3	2	1	1	1	0	1	3	2	1	3	3	0	0	4	46.00
T	17	TRF_4	4	4	5	5	5	4	4	2	5	3	3	4	0	2	2	2	4	0	2	5	65.00
T	18	TRF_5	5	5	5	4	1	3	2	3	0	3	1	3	3	2	1	0	3	0	0	5	49.00
T	19	TRF_6	4	3	5	4	1	1	3	0	0	3	0	0	2	1	4	5	0	0	0	3	39.00
T	20	TRF_7	3	2	4	5	4	0	5	0	0	0	0	0	0	0	2	3	4	4	3	2	41.00
T	21	TRF_8	3	2	4	4	5	0	4	0	0	0	0	0	0	0	2	3	3	4	3	2	39.00
T	22	TRF_9	3	3	3	3	5	4	4	4	5	4	0	3	1	2	3	2	1	3	0	2	55.00
T	23	TRF_{10}	4	3	5	3	2	3	0	0	3	2	0	0	4	4	0	0	3	0	0	5	41.00
T	24	TRF_{11}	5	4	5	4	2	3	3	4	2	3	3	3	3	3	1	1	3	2	2	5	61.00
T	25	TRF_{12}	5	5	4	5	4	2	5	2	0	3	3	5	5	3	3	3	2	3	2	2	66.00
OM	26	$OMRF_1$	5	5	5	5	3	4	3	2	2	2	2	0	3	2	3	5	4	2	3	3	63.00
OM	27	$OMRF_2$	5	3	5	4	1	2	3	2	1	3	3	3	5	3	2	4	3	2	2	5	61.00
OM	28	$OMRF_3$	4	3	5	5	0	4	5	3	3	2	2	3	2	2	0	0	2	2	2	4	53.00
OM	29	$OMRF_4$	3	3	5	3	0	0	3	4	0	0	2	3	5	5	0	0	5	1	0	3	45.00
CL	30	$CLRF_1$	5	5	4	4	4	5	3	5	5	5	5	5	2	2	3	3	4	5	5	0	79.00
CL	31	$CLRF_2$	3	4	3	3	4	3	2	2	3	3	5	5	2	2	2	2	1	2	3	1	55.00
CL	32	$CLRF_3$	5	3	5	2	0	3	2	1	1	0	0	2	0	0	0	3	5	3	3	4	42.00
CL	33	$CLRF_4$	5	4	5	3	0	3	4	3	3	3	0	3	0	0	3	3	5	2	1	4	54.00
C	34	CRF_1	4	5	5	5	5	5	4	3	5	5	5	5	3	3	4	5	5	4	4	5	89.00
C	35	CRF_2	3	3	5	3	0	0	2	0	0	0	0	0	0	0	0	0	4	2	2	2	26.00
C	36	CRF_3	5	5	5	5	3	3	4	0	0	2	2	4	3	2	2	5	5	5	4	0	64.00
E	37	ERF_1	0	4	3	5	2	5	0	5	3	5	5	5	5	5	4	0	5	2	0	0	63.00
E	38	ERF_2	0	4	0	3	2	2	0	5	3	5	5	5	5	5	4	4	5	1	0	0	58.00
Dependency Value			140.00	140.00	161.00	142.00	80.00	80.00	121.00	80.00	77.00	89.00	72.00	108.00	91.00	86.00	74.00	83.00	123.00	77.00	77.00	88.00	

The numerical scale is utilized order to determine the impact of each risk factor on each sustainable construction objective. The value 5 refers to a significant impact of the risk factor on the sustainable construction objectives. As an illustration, the influence value of the risk factor named as vagueness of policies and regulations ($PLRF_4$) is 77. Fundamentally, $PLRF_4$ has significant impact on sustainable construction objectives including effective project management and management of resources ($EC\text{-}SO_3$), energy efficiency for all phases of the project ($EC\text{-}EN\text{-}SO_1$), reduction of emissions, wastes, pollutants and noise ($EN\text{-}SO_1$), choice of environmentally friendly materials and products ($EN\text{-}SO_2$), natural resource conservation and preference or renewable resources ($EN\text{-}SO_3$), enhancing biodiversity ($EN\text{-}SO_4$), preservation of cultural identity and reducing impact on heritage ($EN\text{-}S\text{-}SO_1$) and providing a healthy and safe environment for all phases of megaproject ($EN\text{-}S\text{-}SO_3$).

In the sense of sustainable construction objectives, the numerical scale represents the severity of the risk factors if the risk factors occur in the future. For instance, dependency value for the optimized long-term economic value ($EC\text{-}SO_2$) as an economic sustainable construction objective is 140. Fundamentally, this objective has become prominent due to the cross-impact values assigned for the risk factors. For instance, this objective is affected by the various risk factors, yet most critical risk factors are obtained as exchange rate fluctuation (FRF_1), change in inflation rate (FRF_2), instable political environment ($PLRF_1$), changes in amount of work due to defective work, rework or poor quality of construction (TRF_5), problems with the construction site (TRF_{12}), inaccurate cost, time and resource allocation estimation ($OMRF_1$), client's reluctant attitude towards sustainable construction ($CLRF_1$), ill-defined scope of work and contract specification (CRF_1), inappropriate contract type, project delivery system and bidding type (CRF_3).

Step 3: Discussion on Probability of Risk Factors

In this part, the probability of occurrences of 38 risk factors are asked to the expert. The probabilities of risk factors are assigned considering the country and project conditions. The probabilities assigned by the expert is given Table 6.10.

Table 6.10. *Probability of occurrences of risk factors for the real megaproject*

ID	Code Number	Risk Factors	Probability of Occurrence
1	FRF_1	Exchange rate fluctuation	0.90
2	FRF_2	Change in inflation rate	0.90
3	FRF_3	Change in interest rates	0.90
4	FRF_4	Change in taxation policies	0.70
5	$PLRF_1$	Instable political environment	0.80
6	$PLRF_2$	Emergence of civil strife, war and terrorism issues	0.40
7	$PLRF_3$	Difficulty in getting permits due to bureaucracy	0.80
8	$PLRF_4$	Vagueness of policies and regulations	0.40
9	$PLRF_5$	Change in laws and regulations	0.50
10	SRF_1	Public reaction towards the project (strike, rebellion etc.)	0.20
11	SRF_2	Vagueness of the needs of community	0.20
12	PRF_1	Unforeseen weather conditions	0.50
13	PRF_2	Unexpected physical conditions	0.85
14	TRF_1	Design team's lack of experience on sustainable construction principles	0.10
15	TRF_2	Complexity of design	0.90
16	TRF_3	Low constructability	0.70
17	TRF_4	Inaccurate or incomplete design drawings	0.40
18	TRF_5	Changes in amount of work due to defective work, rework or poor quality of construction	0.70
19	TRF_6	Low productivity	0.70
20	TRF_7	Unavailability of labor	0.10
21	TRF_8	Unavailability of sub-contractor	0.20
22	TRF_9	Unavailability of construction materials	0.60
23	TRF_{10}	Defective construction materials	0.80
24	TRF_{11}	Technology	0.80
25	TRF_{12}	Problems with the construction site	0.80

Table 6.10. *(Cont'd)*

ID	Code Number	Risk Factors	Probability of Occurrence
26	$OMRF_1$	Inaccurate cost, time and resource allocation estimation	0.80
27	$OMRF_2$	Inexperienced or noncompetitive contractor	0.70
28	$OMRF_3$	Lack of organization and coordination among project stakeholders	0.60
29	$OMRF_4$	Lack of audits on occupational health and safety procedures	0.40
30	$CLRF_1$	Client's reluctant attitude towards sustainable construction	0.30
31	$CLRF_2$	Client's lack of knowledge about sustainable construction	0.30
32	$CLRF_3$	Undocumented bill off quantities or change orders	0.80
33	$CLRF_4$	Inadequate funding or delay in progress payments	0.40
34	CRF_1	Ill-defined scope of work and contract specification	0.20
35	CRF_2	Contractual dispute resolution process	0.60
36	CRF_3	Inappropriate contract type, project delivery system and bidding type	0.20
37	ERF_1	Ineffective waste management	0.80
38	ERF_2	No audits for poor waste management	0.80

Exchange rate fluctuation (FRF_1), change in inflation rate (FRF_2), change in interest rates (FRF_3), instable political environment ($PLRF_1$), difficulty in getting permits due to bureaucracy ($PLRF_3$), unexpected physical conditions (PRF_2), complexity of design (TRF_2), defective construction materials (TRF_{10}), technology (TRF_{11}), problems with the construction site (TRF_{12}), inaccurate cost, time and resource allocation estimation ($OMRF_2$), undocumented bill off quantities or change orders ($CLRF_3$), ineffective waste management (ERF_1) and no audits for poor waste management (ERF_2) are foreseen as the most probable risk factors for the real megaproject.

Step 4: Discussion on Cross-Impact Matrix

Probability values and revised cross-impact values of the risk factors are presented into a cross-impact matrix. The finalized cross-impact matrix with influence values for each risk factor are provided in Table 6.11.

Table 6.11. *Cross-impact matrix for the real megaproject*

				Probability of Occurence	SUSTAINABLE CONSTRUCTION OBJECTIVES																				Expected Influence Value
					ECONOMIC			ECONOMIC-ENVIRONMENTAL				ENVIRONMENTAL				ENVIRONMENTAL-SOCIAL			SOCIAL			ECONOMIC-SOCIAL			
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
					EC-SO$_1$	EC-SO$_2$	EC-SO$_3$	EC-EN-SO$_1$	EC-EN-SO$_2$	EC-EN-SO$_3$	EC-EN-SO$_4$	EN-SO$_1$	EN-SO$_2$	EN-SO$_3$	EN-SO$_4$	EN-S-SO$_1$	EN-S-SO$_2$	EN-S-SO$_3$	S-SO$_1$	S-SO$_2$	S-SO$_3$	EC-S-SO$_1$	EC-S-SO$_2$	EC-S-SO$_3$	
RISK FACTORS	F	1	FRF$_1$	0.90	4.50	4.50	3.60	2.70	0.00	0.00	2.70	0.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.80	1.80	2.70	0.00	26.10
		2	FRF$_2$	0.90	4.50	4.50	3.60	2.70	0.00	0.00	2.70	0.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.90	2.70	2.70	3.60	0.00	29.70
		3	FRF$_3$	0.90	2.70	3.60	3.60	2.70	0.00	0.00	2.70	0.00	1.80	0.00	0.00	0.00	0.00	0.00	1.80	1.80	3.60	1.80	2.70	0.00	28.80
		4	FRF$_4$	0.70	2.10	2.10	1.40	2.10	0.00	0.00	2.10	0.00	1.40	0.00	0.00	0.00	0.00	0.00	1.40	1.40	2.10	2.10	2.10	0.00	20.30
	PL	5	PLRF$_1$	0.80	4.00	4.00	4.00	1.60	1.60	0.00	1.60	0.00	0.00	1.60	1.60	4.00	0.00	0.00	2.40	2.40	2.40	0.00	1.60	0.00	32.80
		6	PLRF$_2$	0.40	1.60	1.60	2.00	0.80	1.20	0.40	1.20	1.60	0.00	0.80	0.80	2.00	2.00	2.00	1.60	1.20	2.00	1.20	1.20	0.80	26.00
		7	PLRF$_3$	0.80	1.60	2.40	4.00	2.40	0.00	0.00	4.00	0.00	0.00	0.80	0.00	4.00	1.60	1.60	0.00	0.00	0.00	0.00	0.00	0.00	22.40
		8	PLRF$_4$	0.40	1.20	1.20	2.00	2.00	1.20	1.60	1.60	2.00	2.00	2.00	2.00	2.00	1.60	2.00	0.80	0.80	1.20	0.80	1.60	1.20	30.80
		9	PLRF$_5$	0.50	1.50	2.00	1.50	2.50	1.00	1.00	2.00	2.50	2.50	2.50	2.50	2.50	2.00	2.50	1.00	1.00	1.50	1.00	2.00	1.50	36.50
	S	10	SRF$_1$	0.20	0.60	0.40	1.00	0.60	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.60	0.00	0.00	0.20	6.00
		11	SRF$_2$	0.20	0.20	0.40	0.60	0.40	0.60	0.60	1.00	1.00	0.80	0.80	0.40	0.80	0.80	0.80	1.00	1.00	1.00	0.80	1.00	0.00	14.00
	P	12	PRF$_1$	0.50	1.50	2.00	1.50	2.00	1.00	0.50	2.00	1.00	1.00	1.50	1.00	2.00	1.00	1.00	2.00	1.00	1.00	1.50	1.00	1.50	27.00
		13	PRF$_2$	0.85	3.40	3.40	4.25	3.40	1.70	0.00	4.25	2.55	0.00	2.55	1.70	4.25	3.40	3.40	0.85	1.70	2.55	0.85	0.00	2.55	46.75
	T	14	TRF$_1$	0.10	0.40	0.40	0.40	0.50	0.40	0.40	0.30	0.20	0.50	0.50	0.40	0.50	0.10	0.20	0.30	0.30	0.30	0.30	0.10	0.30	6.80
		15	TRF$_2$	0.90	3.60	2.70	3.60	2.70	2.70	2.70	3.60	2.70	2.70	1.80	1.80	2.70	3.60	1.80	0.00	0.00	1.80	0.00	1.80	3.60	45.90
		16	TRF$_3$	0.70	3.50	2.10	3.50	3.50	2.10	2.10	1.40	0.70	0.70	0.70	0.00	0.70	2.10	1.40	0.70	2.10	2.10	0.00	0.00	2.80	32.20
		17	TRF$_4$	0.40	1.60	1.60	2.00	2.00	2.00	1.60	1.60	0.80	2.00	1.20	1.20	1.60	0.00	0.80	0.80	0.80	1.60	0.00	0.80	2.00	26.00
		18	TRF$_5$	0.70	3.50	3.50	3.50	2.80	0.70	2.10	1.40	2.10	0.00	2.10	0.70	2.10	2.10	1.40	0.70	0.00	2.10	0.00	0.00	3.50	34.30
		19	TRF$_6$	0.70	2.80	2.10	3.50	2.80	0.70	0.70	2.10	0.00	0.00	2.10	0.00	0.00	1.40	0.70	2.80	3.50	0.00	0.00	0.00	2.10	27.30
		20	TRF$_7$	0.10	0.30	0.20	0.40	0.50	0.40	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.30	0.40	0.40	0.30	0.20	4.10
		21	TRF$_8$	0.20	0.60	0.40	0.80	0.80	1.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.60	0.60	0.80	0.60	0.40	7.80
		22	TRF$_9$	0.60	1.80	1.80	1.80	1.80	3.00	2.40	2.40	2.40	3.00	2.40	0.00	1.80	0.60	1.20	1.80	1.20	0.60	1.80	0.00	1.20	33.00
		23	TRF$_{10}$	0.80	3.20	2.40	4.00	2.40	1.60	2.40	0.00	0.00	2.40	1.60	0.00	0.00	3.20	3.20	0.00	0.00	2.40	0.00	0.00	4.00	32.80
		24	TRF$_{11}$	0.80	4.00	3.20	4.00	3.20	1.60	2.40	2.40	3.20	1.60	2.40	2.40	2.40	2.40	2.40	0.80	0.80	2.40	1.60	1.60	4.00	48.80
		25	TRF$_{12}$	0.80	4.00	4.00	3.20	4.00	3.20	1.60	4.00	1.60	0.00	2.40	2.40	4.00	4.00	2.40	2.40	2.40	1.60	2.40	1.60	1.60	52.80
	OM	26	OMRF$_1$	0.80	4.00	4.00	4.00	4.00	2.40	3.20	2.40	1.60	1.60	1.60	1.60	0.00	2.40	1.60	2.40	4.00	3.20	1.60	2.40	2.40	50.40
		27	OMRF$_2$	0.70	3.50	2.10	3.50	2.80	0.70	1.40	2.10	1.40	0.70	2.10	2.10	2.10	3.50	2.10	1.40	2.80	2.10	1.40	1.40	3.50	42.70
		28	OMRF$_3$	0.60	2.40	1.80	3.00	3.00	0.00	2.40	3.00	1.80	1.80	1.20	1.20	1.80	1.20	1.20	0.00	0.00	1.20	1.20	1.20	2.40	31.80
		29	OMRF$_4$	0.40	1.20	1.20	2.00	1.20	0.00	0.00	1.20	1.60	0.00	0.00	0.80	1.20	2.00	2.00	0.00	0.00	2.00	0.40	0.00	1.20	18.00
	CL	30	CLRF$_1$	0.30	1.50	1.50	1.20	1.20	1.20	1.50	0.90	1.50	1.50	1.50	1.50	1.50	0.60	0.60	0.90	0.90	1.20	1.50	1.50	0.00	23.70
		31	CLRF$_2$	0.30	0.90	1.20	0.90	0.90	1.20	0.90	0.60	0.60	0.90	0.90	1.50	1.50	0.60	0.60	0.60	0.60	0.30	0.60	0.90	0.30	16.50
		32	CLRF$_3$	0.80	4.00	2.40	4.00	1.60	0.00	2.40	1.60	0.80	0.80	0.00	0.00	1.60	0.00	0.00	0.00	2.40	4.00	2.40	2.40	3.20	33.60
		33	CLRF$_4$	0.40	2.00	1.60	2.00	1.20	0.00	1.20	1.60	1.20	1.20	1.20	0.00	1.20	0.00	0.00	1.20	1.20	2.00	0.80	0.40	1.60	21.60
	C	34	CRF$_1$	0.20	0.80	1.00	1.00	1.00	1.00	1.00	0.80	0.60	1.00	1.00	1.00	1.00	0.60	0.60	0.80	1.00	1.00	0.80	0.80	1.00	17.80
		35	CRF$_2$	0.60	1.80	1.80	3.00	1.80	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40	1.20	1.20	1.20	15.60
		36	CRF$_3$	0.20	1.00	1.00	1.00	1.00	0.60	0.60	0.80	0.00	0.00	0.40	0.40	0.80	0.60	0.40	0.40	1.00	1.00	1.00	0.80	0.00	12.80
	E	37	ERF$_1$	0.80	0.00	3.20	2.40	4.00	1.60	4.00	0.00	4.00	2.40	4.00	4.00	4.00	4.00	4.00	3.20	0.00	4.00	1.60	0.00	0.00	50.40
		38	ERF$_2$	0.80	0.00	3.20	0.00	2.40	1.60	1.60	0.00	4.00	2.40	4.00	4.00	4.00	4.00	4.00	3.20	3.20	4.00	0.80	0.00	0.00	46.40
Expected Depedency Value					81.80	82.50	91.75	79.00	38.00	42.70	65.15	43.45	40.30	47.65	37.00	58.05	52.40	46.90	37.85	42.30	66.75	37.15	39.30	50.25	

Then, expected dependency values for each sustainable construction objective and expected influence values for each risk factor are discussed.

According to the expected dependency values for sustainable construction objectives, economic sustainability objectives including effective project management and management of resources ($EC\text{-}SO_3$), optimized long-term economic value ($EC\text{-}SO_2$) and feasibility and financial affordability of the megaproject ($EC\text{-}SO_1$) are the most affected objectives from the risk factors (See Figure 6.2).

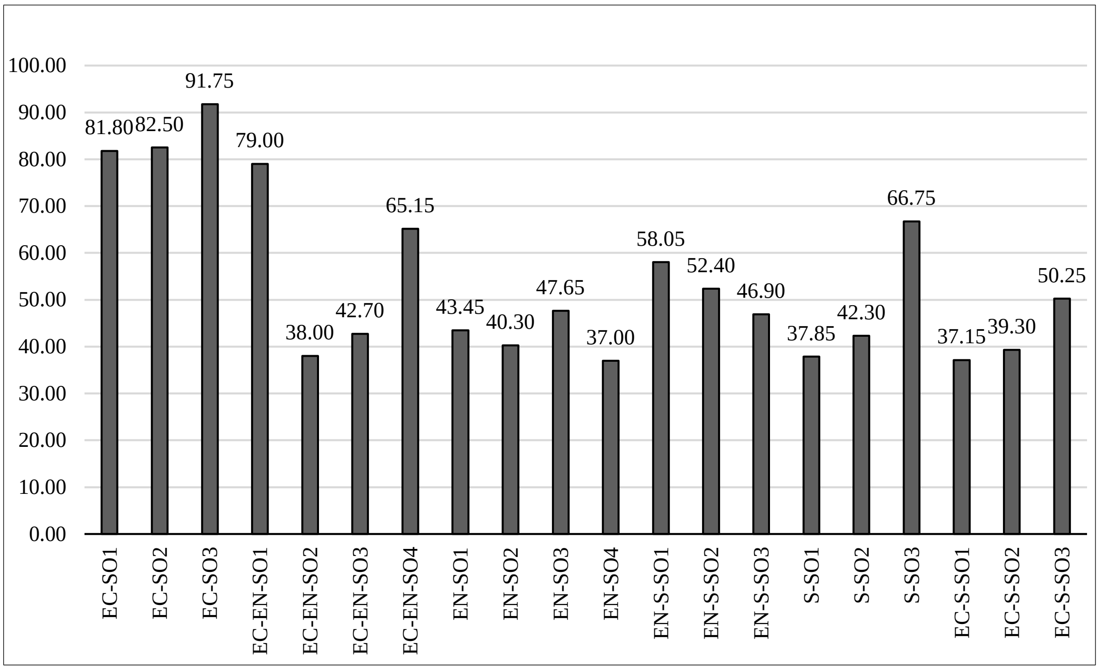

Figure 6.2. Expected dependency values bar chart for the real megaproject

The expected influence values for each risk factor are presented in a bar chart (See Figure 6.3). It can be concluded from the expected influence values that problems with the construction site (TRF_{12}), inaccurate cost, time and resource allocation estimation ($OMRF_1$) and ineffective waste management (ERF_1) are the most influential risk factors on the sustainable construction objectives.

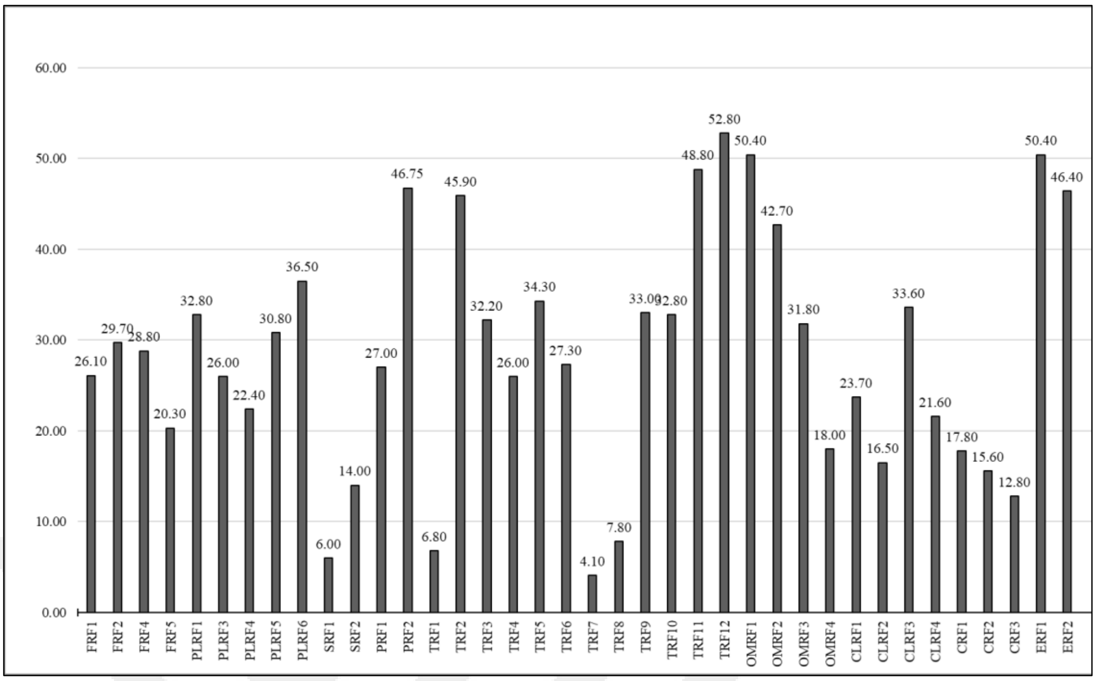

Figure 6.3. Expected influence values bar chart for the real megaproject

Step 5: Discussion on Overall Findings

The overall findings regarding the obtained global weights and expected dependency values for sustainable construction objectives are analyzed in this step. First of all, a vulnerability chart is presented in order to visualize each sustainable construction in terms of their global weights and expected dependency values. The vulnerability chart can be examined in Figure 6.4.

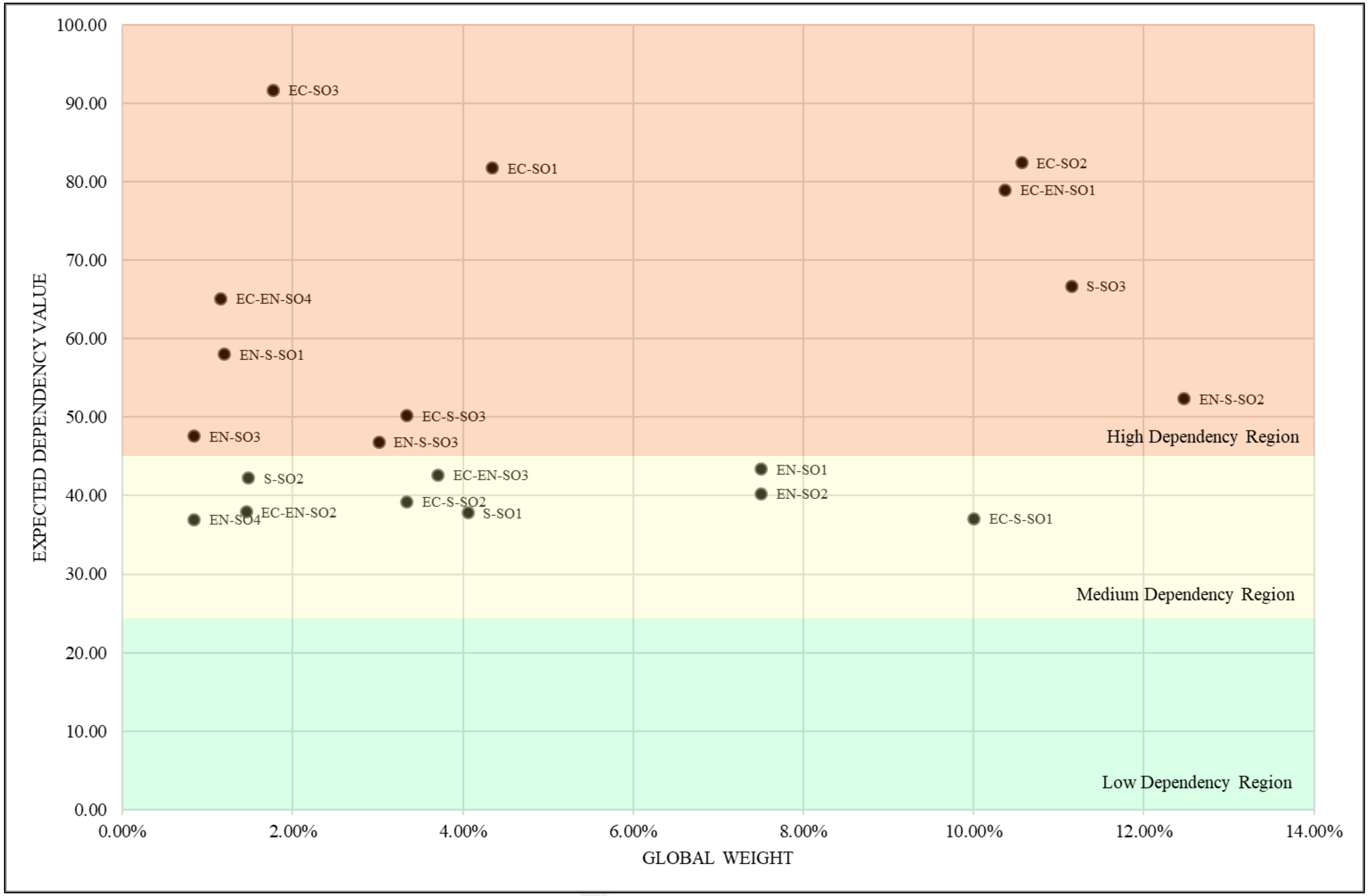

Figure 6.4. Vulnerability chart for the real megaproject

Considering the expected dependency values of effective project management and management of the resources ($EC\text{-}SO_3$), optimized long-term economic value ($EC\text{-}SO_2$) and feasibility and financial affordability of the megaproject ($EC\text{-}SO_1$), they are the most vulnerable sustainable construction objectives. If the sustainable construction objectives are considered in terms of their importance; optimized long-term economic value ($EC\text{-}SO_2$), energy efficiency for all phases of the megaproject ($EC\text{-}EN\text{-}SO_1$) and enhancing quality of life, and providing customer and employee satisfaction ($S\text{-}SO_3$) are the most vulnerable project objectives to achieve a sustainable outcome from the megaproject.

In addition, the most vulnerable sustainable construction objectives are discussed in order to analyze risks and to develop risk mitigation strategies. Each risk factor that has a significant impact on the achievement of the sustainable outcome from the megaproject are discussed on a heat map. The heat map is provided in Table 6.12.

Table 6.12. *Heat map for the real megaproject*

				Probability of Occurence	SUSTAINABLE CONSTRUCTION OBJECTIVES																				Expected Influence Value
					ECONOMIC			ECONOMIC-ENVIRONMENTAL				ENVIRONMENTAL				ENVIRONMENTAL-SOCIAL			SOCIAL			ECONOMIC-SOCIAL			
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
					EC-SO_1	EC-SO_2	EC-SO_3	EC-EN-SO_1	EC-EN-SO_2	EC-EN-SO_3	EC-EN-SO_4	EN-SO_1	EN-SO_2	EN-SO_3	EN-SO_4	EN-S-SO_1	EN-S-SO_2	EN-S-SO_3	S-SO_1	S-SO_2	S-SO_3	EC-S-SO_1	EC-S-SO_2	EC-S-SO_3	
RISK FACTORS	F	1	FRF_1	0.90	4.50	4.50	3.60	2.70	0.00	0.00	2.70	0.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.80	1.80	2.70	0.00	26.10
		2	FRF_2	0.90	4.50	4.50	3.60	2.70	0.00	0.00	2.70	0.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.90	2.70	2.70	3.60	0.00	29.70
		3	FRF_3	0.90	2.70	3.60	3.60	2.70	0.00	0.00	2.70	0.00	1.80	0.00	0.00	0.00	0.00	0.00	1.80	1.80	3.60	1.80	2.70	0.00	28.80
		4	FRF_4	0.70	2.10	2.10	1.40	2.10	0.00	0.00	2.10	0.00	1.40	0.00	0.00	0.00	0.00	0.00	1.40	1.40	2.10	2.10	2.10	0.00	20.30
	PL	5	$PLRF_1$	0.80	4.00	4.00	4.00	1.60	1.60	0.00	1.60	0.00	0.00	1.60	1.60	4.00	0.00	0.00	2.40	2.40	2.40	0.00	1.60	0.00	32.80
		6	$PLRF_2$	0.40	1.60	1.60	2.00	0.80	1.20	0.40	1.20	1.60	0.00	0.80	0.80	2.00	2.00	2.00	1.60	1.20	2.00	1.20	1.20	0.80	26.00
		7	$PLRF_3$	0.80	1.60	2.40	4.00	2.40	0.00	0.00	4.00	0.00	0.00	0.80	0.00	4.00	1.60	1.60	0.00	0.00	0.00	0.00	0.00	0.00	22.40
		8	$PLRF_4$	0.40	1.20	1.20	2.00	2.00	1.20	1.60	1.60	2.00	2.00	2.00	2.00	2.00	1.60	2.00	0.80	0.80	1.20	0.80	1.60	1.20	30.80
		9	$PLRF_5$	0.50	1.50	2.00	1.50	2.50	1.00	1.00	2.00	2.50	2.50	2.50	2.50	2.50	2.00	2.50	1.00	1.00	1.50	1.00	2.00	1.50	36.50
	S	10	SRF_1	0.20	0.60	0.40	1.00	0.60	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.60	0.00	0.00	0.20	6.00
		11	SRF_2	0.20	0.20	0.40	0.60	0.40	0.60	0.60	1.00	1.00	0.80	0.80	0.40	0.80	0.80	0.80	1.00	1.00	1.00	0.80	1.00	0.00	14.00
	P	12	PRF_1	0.50	1.50	2.00	1.50	2.00	1.00	0.50	2.00	1.00	1.00	1.50	1.00	2.00	1.00	1.00	2.00	1.00	1.00	1.50	1.00	1.50	27.00
		13	PRF_2	0.85	3.40	3.40	4.25	3.40	1.70	0.00	4.25	2.55	0.00	2.55	1.70	4.25	3.40	3.40	0.85	1.70	2.55	0.85	0.00	2.55	46.75
	T	14	TRF_1	0.10	0.40	0.40	0.40	0.50	0.40	0.40	0.30	0.20	0.50	0.50	0.40	0.50	0.10	0.20	0.30	0.30	0.30	0.30	0.10	0.30	6.80
		15	TRF_2	0.90	3.60	2.70	3.60	2.70	2.70	2.70	3.60	2.70	2.70	1.80	1.80	2.70	3.60	1.80	0.00	0.00	1.80	0.00	1.80	3.60	45.90
		16	TRF_3	0.70	3.50	2.10	3.50	3.50	2.10	2.10	1.40	0.70	0.70	0.70	0.00	0.70	2.10	1.40	0.70	2.10	2.10	0.00	0.00	2.80	32.20
		17	TRF_4	0.40	1.60	1.60	2.00	2.00	2.00	1.60	1.60	0.80	2.00	1.20	1.20	1.60	0.00	0.80	0.80	0.80	1.60	0.00	0.80	2.00	26.00
		18	TRF_5	0.70	3.50	3.50	3.50	2.80	0.70	2.10	1.40	2.10	0.00	2.10	0.70	2.10	2.10	1.40	0.70	0.00	2.10	0.00	0.00	3.50	34.30
		19	TRF_6	0.70	2.80	2.10	3.50	2.80	0.70	0.70	2.10	0.00	0.00	2.10	0.00	0.00	1.40	0.70	2.80	3.50	0.00	0.00	0.00	2.10	27.30
		20	TRF_7	0.10	0.30	0.20	0.40	0.50	0.40	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.30	0.40	0.40	0.30	0.20	4.10
		21	TRF_8	0.20	0.60	0.40	0.80	0.80	1.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.60	0.60	0.80	0.60	0.40	7.80
		22	TRF_9	0.60	1.80	1.80	1.80	1.80	3.00	2.40	2.40	2.40	3.00	2.40	0.00	1.80	0.60	1.20	1.80	1.20	0.60	1.80	0.00	1.20	33.00
		23	TRF_{10}	0.80	3.20	2.40	4.00	2.40	1.60	2.40	0.00	0.00	2.40	1.60	0.00	0.00	3.20	3.20	0.00	0.00	2.40	0.00	0.00	4.00	32.80
		24	TRF_{11}	0.80	4.00	3.20	4.00	3.20	1.60	2.40	2.40	3.20	1.60	2.40	2.40	2.40	2.40	2.40	0.80	0.80	2.40	1.60	1.60	4.00	48.80
		25	TRF_{12}	0.80	4.00	4.00	3.20	4.00	3.20	1.60	4.00	1.60	0.00	2.40	2.40	4.00	4.00	2.40	2.40	2.40	1.60	2.40	1.60	1.60	52.80
	OM	26	$OMRF_1$	0.80	4.00	4.00	4.00	4.00	2.40	3.20	2.40	1.60	1.60	1.60	1.60	0.00	2.40	1.60	2.40	4.00	3.20	1.60	2.40	2.40	50.40
		27	$OMRF_2$	0.70	3.50	2.10	3.50	2.80	0.70	1.40	2.10	1.40	0.70	2.10	2.10	2.10	3.50	2.10	1.40	2.80	2.10	1.40	1.40	3.50	42.70
		28	$OMRF_3$	0.60	2.40	1.80	3.00	3.00	0.00	2.40	3.00	1.80	1.80	1.20	1.20	1.80	1.20	1.20	0.00	0.00	1.20	1.20	1.20	2.40	31.80
		29	$OMRF_4$	0.40	1.20	1.20	2.00	1.20	0.00	0.00	1.20	1.60	0.00	0.00	0.80	1.20	2.00	2.00	0.00	0.00	2.00	0.40	0.00	1.20	18.00
	CL	30	$CLRF_1$	0.30	1.50	1.50	1.20	1.20	1.20	1.50	0.90	1.50	1.50	1.50	1.50	1.50	0.60	0.60	0.90	0.90	1.20	1.50	1.50	0.00	23.70
		31	$CLRF_2$	0.30	0.90	1.20	0.90	0.90	1.20	0.90	0.60	0.60	0.90	0.90	1.50	1.50	0.60	0.60	0.60	0.60	0.30	0.60	0.90	0.30	16.50
		32	$CLRF_3$	0.80	4.00	2.40	4.00	1.60	0.00	2.40	1.60	0.80	0.80	0.00	0.00	1.60	0.00	0.00	0.00	2.40	4.00	2.40	2.40	3.20	33.60
		33	$CLRF_4$	0.40	2.00	1.60	2.00	1.20	0.00	1.20	1.60	1.20	1.20	1.20	0.00	1.20	0.00	0.00	1.20	1.20	2.00	0.80	0.40	1.60	21.60
	C	34	CRF_1	0.20	0.80	1.00	1.00	1.00	1.00	1.00	0.80	0.60	1.00	1.00	1.00	1.00	0.60	0.60	0.80	1.00	1.00	0.80	0.80	1.00	17.80
		35	CRF_2	0.60	1.80	1.80	3.00	1.80	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40	1.20	1.20	1.20	15.60
		36	CRF_3	0.20	1.00	1.00	1.00	1.00	0.60	0.60	0.80	0.00	0.00	0.40	0.40	0.80	0.60	0.40	0.40	1.00	1.00	1.00	0.80	0.00	12.80
	E	37	ERF_1	0.80	0.00	3.20	2.40	4.00	1.60	4.00	0.00	4.00	2.40	4.00	4.00	4.00	4.00	4.00	3.20	0.00	4.00	1.60	0.00	0.00	50.40
		38	ERF_2	0.80	0.00	3.20	0.00	2.40	1.60	1.60	0.00	4.00	2.40	4.00	4.00	4.00	4.00	4.00	3.20	3.20	4.00	0.80	0.00	0.00	46.40
Expected Depedency Value					81.80	82.50	91.75	79.00	38.00	42.70	65.15	43.45	40.30	47.65	37.00	58.05	52.40	46.90	37.85	42.30	66.75	37.15	39.30	50.25	

The most vulnerable sustainable construction objective with the highest global weight was observed as optimized long-term economic value ($EC\text{-}SO_2$). In order to fulfill the sustainability requirements of the real megaproject, it is important to monitor and control the foreseen risks. As a first step, critical risks that have major contributions on the expected dependency value of $EC\text{-}SO_2$ should be determined. For instance, exchange rate fluctuation (FRF_1) is a critical risk for $EC\text{-}SO_2$. The probability of occurrence of the risk factor is assigned as 0.90 and cross-impact value for this risk factor is assigned as 5. Exchange rate fluctuation is an external risk factor and it is related with the country conditions. Thus, the probability of occurrence of the risk factor cannot be controlled easily. Yet, cross-impact value of the risk factor can be controlled by selecting appropriate contract type or payment method. Moreover, unexpected physical conditions (PRF_2) is obtained as the other critical risk factor for the achievement of the $EC\text{-}SO_2$.The probability of occurrence of the risk factor is foreseen as 0.85, and cross-impact value for this risk factor is assigned as 4. Considering the location of the site, İstanbul is located in the earthquake zone. As a result, the occurrence or non-occurrence of the earthquake cannot be controlled since it is a force majeure. It is important to decrease the impact of this factor by designing more stable structure and by employing experienced design and engineering team. Inaccurate cost, time and resource allocation estimation ($OMRF_1$) is a critical risk that has an impact on the achievement of the aforementioned sustainable construction as well. The probability of occurrence of $OMRF_1$ is foreseen as 0.80, and the cross-impact value of the risk factor is assigned as 5. The probability of occurrence of the risk factor can be controlled because it is a project related risk factor. If an experienced project management team is employed, the impact of the inaccurate cost, time, resource allocation estimations can be controlled as well. Problems with the construction site (TRF_{12}) is a project related risk factor and it is a critical risk factor. The probability of occurrence of the risk factor is 0.80, and the cross-impact of the risk factor is 5. The construction site is located in the city center. Especially within the working hours, the procurement of the construction materials may delay. As a solution, the arrival time of the construction materials can be arranged so that the delivery of the materials will be within non-working hours. All in all, the vulnerability chart and the heat map for the real megaproject are discussed with the expert, and the most vulnerable sustainable construction objectives that are obtained according to the values assigned by the expert are found reasonable. The first benefit of the RAMSCOM is that expert was able to analyze the most important objectives in terms of their vulnerability. If the importance of the sustainable construction objectives was not determined in advance, the expert would not be able to decide to focus on which objective more in order to meet the sustainability requirements of the real megaproject. Moreover, the expected dependency value bar chart enabled to examine the sustainable construction objectives in terms of their vulnerability. Therefore, expert was able to examine the most and the least vulnerable sustainable construction objectives. Besides, the risk factors were analyzed with the help of an expected influence value bar chart, and the expert could easily see the risks that have a higher influence on the sustainable construction objectives. As a final remark, vulnerability chart enables to analyze the overall findings. In the vulnerability chart, the expert was able to observe the sustainable construction objectives in terms of their importance and level of being affected from the risk factors. Heat map is provided to examine the risks regarding their category, and to determine the most critical risks that make sustainable construction objectives vulnerable.

In this chapter, implementation of RAMSCOM have been presented on the real megaproject. First, a brief information about the construction company and the megaproject have been given. Then, the implementation of RAMSCOM have been tested on a real megaproject, and the results obtained from the RAMSCOM have been discussed. The following chapter will present the conclusions regarding the contributions and limitations of the study. The following chapter will conclude with the recommendations and future work for the research.

CHAPTER 7

DISCUSSION OF FINDINGS AND CONCLUSION

This chapter presents the findings and conclusions from the study. First of all, contribution of the study is explained. Then, limitations regarding the study are addressed. This chapter concludes with some recommendations for the future work.

7.1. Contributions of the Study

The traditional risk assessment methods for the construction projects mainly focus on the project objectives such as time, cost, quality etc. The aforementioned criteria are short-term and project-based objectives, and they are not sufficient enough to evaluate the success of the megaprojects due to their long life-cycle. On the other hand, the proposed risk assessment approach enables to integrate sustainability concept into the risk management field. First of all, sustainable construction objectives are identified throughout the literature review. Then, risk factors that have potential impacts on the achievement of the sustainable construction objectives are determined. The cross-impact values for each risk factor on the sustainable construction objectives are specified on a cross-impact table. Thereafter, the probability of occurrences of the risk factors are determined considering the country and project conditions. As a result, expected dependency values for each sustainable construction objective are calculated which correspond to the level of being affected from the risk factors. Additionally, expected influence values for each risk factor are calculated as well in order to demonstrate the most influential risk factors on sustainable construction objectives. Finally, overall findings are presented on a vulnerability chart and a heat map.

The main contribution of the proposed risk assessment method is that it enables to enhance decision-making strategies by taking into consideration of the cross-impact values of the risk factors on the sustainable construction objectives. If the sustainable construction objectives are not associated with the risk factors, decision-maker may not be able to see the threats for the sustainable construction objectives to decide which sustainable construction objective should be focused on more. Moreover, the proposed risk assessment method provides visual aids including vulnerability chart and heat map. The main purpose of the visual aids is to make the outputs obtained from the proposed risk assessment method more meaningful to the decision-maker. As an illustration, vulnerability chart allows to analyze the sustainable construction objectives in terms of their importance and level of being affected from the risk factors. A comparison can be done easily among sustainable construction objectives regarding their importance and dependency levels, and the most vulnerable objectives can be determined from the vulnerability chart. Moreover, heat map enables to analyze the threats for sustainable construction objectives, and the risks that have significant impacts on the achievement of the sustainable construction objectives can be determined from the heat map. As a result, risk mitigation strategies can be enhanced by analyzing the relationships among risk factors and sustainable construction objectives.

All in all, the usability of the proposed risk assessment method was tested on a real megaproject. The main benefit of the proposed risk assessment method is that the expert has been able to evaluate the real megaproject in terms of sustainability and risk management aspects at the same time. The most vulnerable objectives regarding the values assigned by the expert have been presented, and the expert has been able to analyze the threats for the sustainable construction objectives in advance.

7.2. Limitations of the Study

The preliminary conceptual model is established according to the literature review conducted to identify the sustainable construction objectives and risk factors. Then, the proposed risk assessment method is developed based on the preliminary conceptual model. Even though the identified sustainable construction objectives and risk factors are discussed with the expert during the interview for the implementation of RAMSCOM on a real construction project, the identified sustainable construction objectives and risk factors can be checked and revised through a semi-structured interview with multiple experts.

Sustainable construction objectives are prioritized by AHP. However, Kabir and Hasin (2011) state that it is not possible to demonstrate the preferences of experts by crisp values. The other shortcomings of AHP are mentioned as utilization of crisp decision applications, dealing with unbalanced scale of comparisons, not taking into consideration of uncertainty, imprecise ranking and subjective judgment. For cross-impact analysis, initial probability of occurrences of the risk factors are considered. However, Gordon (1994) emphasizes that different scenarios like conditional occurrence and conditional non-occurrence of the risk factors should be integrated into the cross-impact analysis. The current study does not include the different scenarios regarding the conditional probabilities of the risk factors.

In addition, the proposed method is not automated. If the proposed risk assessment method is utilized in the future, the expert may consume a lot of time to discover how to use this method. Moreover, the usage of the proposed model requires time. Since, there are seven matrices for the prioritization of the sustainable construction objectives, and if the project objectives regarding the sustainability are not clear enough, experts may not easily decide the importance of the project objectives. In addition, experts may not agree on the cross-impact values of the risk factors and some revisions may be required.

7.3. Recommendations and Future Work

As a further research, the proposed risk assessment method can be developed as a decision-support tool. The interface of the decision-support tool can be designed as user-friendly in order to solve the problem regarding the time requirement of the current approach. In addition, the accessibility problem of the current risk assessment approach can be solved easily by commercializing the decision-support tool in order to address the experts who would like to utilize the decision-support tool.

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