The development of a sustainability risk assessment model for construction projects: A case study on the Jordanian construction industry

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Declaration

I declare that this thesis is my own work and has not been submitted in support of an application for another degree or qualification at this or any other education institution. To the best of my knowledge and belief, the thesis contains no materials previously published or written by another person, except where due acknowledgement is made.

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Abbreviations

- AHP: Analytic Hierarchy Process
- BBN: Bayesian Belief Network
- BM: the Bayesian method
- BPF: The British Property Federation
- BREEAM: The Building Research Establishment Environmental Assessment Method
- CSBC: The Construction and Sustainable Building Centre
- EIA: Environmental Impact Assessment
- EMV: The Expected Monetary Value
- ESTIDAMA: The Estidama Pearl Rating System
- FAR: Floor Area Ration
- FMEA: Failure Mode and Effect Analysis
- FTA: Fault Tree Analysis
- GORD: Gulf Organization for Research & Development
- GSAS: Global Sustainability Assessment System
- IPCC: The Intergovernmental Panel on Climate Change
- JEA: the Jordanian Engineers Association
- JGBG: The Jordan Green Building Guide
- LEED: Leadership in Energy and Environmental Design
- MDGs: The Millennium Development Goals
- PERT: Programme Evaluation and Review Technique
- PIM: Probability-Impact-Matrix
- PMI: Project Management Institution
- QSAS: Qatar Sustainability Assessment System
- SDGs: The Sustainable Development Goals

- SPSS: Statistical Package for the Social Sciences
- UN: United Nations
- UNEP: United Nations Environment Program
- UNEP: United Nations Environment Programme
- WBCSD: The World Business Council for Sustainable Development
- WCED: World Commission on Environment and Development

Abstract

The construction industry has significant environmental effects. Jordan is one of the countries in the world that is dealing with population growth, a shortage of resources, and unrestricted pollution, for this reason, the construction industry plays a significant role global climate system which in turn may have a detrimental impact on the globe if it is not modified totally in favor of the construction sustainable development. Consequently, this thesis presents research work that aims to develop a sustainability risk assessment model for construction projects, particularly in the Jordanian construction industry, based on the combination of the Analytic Hierarchy Process (AHP) and the Bayesian method (BM). This model contributes to implementing the dimensions of sustainable development in the Jordanian construction industry that pertain to the economy, environment, and society dimensions. The research approach for this project is abductive through a mixed-method (qualitative and quantitative) approach to data collection and analysis. The literature review conceptually reviews the risk classifications within sustainability, interpreting the relationship that exists between construction risk management and the elements of sustainable construction. The literature review was utilised to synthesise the specific objectives of construction sustainability and identify the key risk reduction aspects for the implementation of these objectives in the Jordan administration. A focus group method was employed as a primary data collection tool, with a group comprising eight experts and engineers in the construction industry who discussed sustainability-related risks. In addition, a second primary data collection took place through a questionnaire, completed by 402 different professionals and engineers from the Jordanian construction industry. Three case studies from the Jordanian construction industry were conducted, with the purpose of validating the findings and the proposed sustainability risk analysis and management model. The three cases comprised a building construction project, a road and infrastructure project, and a waste landfill project. The proposed model can play a significant role in developing the sector into a sustainable one based on the risk management assessment model and utilizing it to comprehend sustainability practices and effectively apply them. This will help the industry to make changes and improvements and it should also be the starting point, particularly, for work in this area in the Jordanian context. The main findings from this research project demonstrate that sustainable development is a dynamic concept that has evolved and will continue to evolve over time, to meet the social, environmental, and economic needs of present and future generations. Risk management has undergone a similar transformation, going from a mere one-off intervention for risk relief, to being a cross-cutting component for the achievement of truly globally sustainable development. Jordan’s construction industry cannot escape the insertion of risk management or ignore its relationship with sustainable development, not only because it is limited in renewable non-renewable resources with a constantly increasing population, but also because Jordan generates emissions that impact global warming. The developed model has proved its validity for linking sustainability-related risks in the construction industry with risk management in Jordan.

Key words: sustainability, sustainable construction, construction industry, sustainability-related risks, risk management

Chapter One

Chapter One: Introduction

1.1 Introduction

This chapter discusses the background of this research, and describes the research problems, research justification and research questions. Based on these, the aim and objectives have been developed, and this chapter presents the overall research methodology, describing how the research aim and objectives can be achieved. Details of this study's contributions to knowledge are presented at the end of the chapter.

1.2 Research Background

Since the 1970s, after the United Nation's conference that was held in Stockholm, addressing humans and the environment, the concept of sustainability has been a key topic of debate that has attracted researchers, practitioners and organisations from different sectors worldwide to address the social and ecological crises. Therefore, many companies have adopted sustainability in their strategies to cope with the current demand for the protection of our environment (Sánchez, 2015).

According to the World Commission on Environment and Development (WCED, 1987), sustainability can be defined as the development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (cited in Bansal, DesJardine, 2014, p. 71). Nevertheless, there is an extended multiplicity of definitions, standards, and articles that define sustainability in different fields. This diversity shows the lack of understanding of the concept of sustainability and the difficulty of applying sustainability to the processes of organisations (Espindola et al., 2020).

According to the United Nations (UN 2030 Agenda, 2016), 17 goals need to be achieved to ensure that a country is sustainable and to protect our planet. These goals were introduced in the 2030 Agenda for Sustainable Development, and they were called the Sustainable Development Goals (SDGs). They are: No Poverty, Zero Hunger, Good Health and Well-being, Quality Education, Gender Equality, Clean Water and Sanitation, Affordable and Clean Energy, Decent Work and Economic Growth, Industry Innovation and Infrastructure, Reduced Inequality, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action, Life Below Water, Life on Land, Peace and Justice, Strong Institutions and Partnerships to achieve the Goal.

Two of these goals are connected directly to the construction industry: sustainable cities and communities, and innovation and infrastructure (UN 2030 Agenda, 2016). The reason for having two goals for the construction industry is that it is one of the top three contributors to the carbon emissions that cause global warming and it consumes a huge amount of energy and resources (Ma et al., 2017). In addition, there are several UN goals that are indirectly related to the construction industry. The process of sustainable construction contributes to people's access to good health and high welfare, achieves gender equality, and increases access to clean water and organised sanitation that befits their human dignity. Also, sustainable building reduces energy consumption and its costs for individuals and increases the chances of equality for individuals. As linking construction to sustainability development reduces air pollution and the presence of wastewater, it leads to a clean environment enjoyed by all individuals from all classes of society without differentiation. This is one of the most prominent goals of the UN for sustainability: to reduce the inequality among all people and classes, even in the air they breathe (Ma et al., 2017).

Early this century, the concept of the green building, initially considered a fringe movement, but later on it was accepted by the construction industry and it still inspires designers, contractors and the whole industry (Kibert, 2013). The concept of the green building is similar to sustainability and considered to be the early start of sustainability, as it is related to the design and construction of buildings, and applying resource-efficient techniques and ecologically based principles (Kibert, 2013). Therefore, it could be concluded that the construction industry has successfully passed the milestone of recognising the importance of integrating sustainable development into the core of the industry's practices (Eid, 2004).

Traditionally, any project has had to meet the three main targets of time, cost and quality. However, the recent environmental problems facing the world and the limitation on resources have added sustainability (and sustainable buildings) to these targets (Zolfani et al., 2018), figure 1-1 below shows the four main project targets.

Figure 1-1: The Four Main Project Targets

The construction industry is well known internationally for its low productivity, because it has a reputation for suffering from delays, being over budget, and/or not meeting the required quality for projects, compared to other industries (Egan, 2002). However, construction projects and the construction industry in general have a huge impact on the national economy and other industries. According to the US Bureau of Labour Statistics reports, 6.34 million people were employed in the construction industry in 2015 (Timofeeva et al., 2017). This shows that the industry has a significant impact on any country's economy (Eid, 2004).

Despite the success of the green building movement and awareness in the industry of the importance of sustainability, challenges arise with the actual implementation of sustainability in the construction industry (Kibert, 2013). The development of sustainable construction depends on two factors: the development of the science and technology of the process and tools, and people's acceptance of sustainable construction (Zhang et al., 2014). As technology has advanced, projects have increased in complexity, and risk management has proved to be an essential and vital tool for managing and delivering more successful projects according to their planned time, cost, quality and sustainability. Many governments around the world have made the achievement of sustainability goals and the consideration of risk management compulsory in construction projects. Risk management is vitally important in the current construction environment; a sustainable building is one that manages its risks and achieves an economic, social, and environmental balance for the fulfilment of its durability. Risk management and sustainability are becoming more and more prevalent issues on the agenda of all interest groups in general and engineers in particular. Therefore, these areas should be approached from a practical and grounded approach.

The improvement of the construction industry relies on the development of the construction process itself (Finnemore et al., 2000). According to the Project Management Institution (PMI), construction projects are divided into five managerial phases with every phase having its own duty, time and cost (PMI, 2017). Risks and uncertainties appear in every phase of the process; according to Latham (1994), there are no construction projects that carry no risk. The improvement of the construction process is a substantive issue; many researchers have discussed ways of improving it. Latham (1994), in his research on the development of the UK construction industry, concluded that a saving of up to 30% could be made if proper improvements were made in the industry, especially in the communication part of the process. Moreover, the UK Department for Business, Innovation, and Skills (2013) introduced a strategy for the improvement of the construction industry called Construction 2025, while many other examples can be found throughout the literature review presented in this research.

It is worth noting that managing risk is a matter of durability and sustainability. In modern construction, one of the critical success factors in construction projects is comprehensive risk management. Several research results have shown that improvement in the risk analysis and management process will and can improve the construction process. Williams (1994) proposed that the risk register is essential to the risk management process, and Ward (1999) also worked on the risk register and its contents. Baker et al. (1998) showed in their comparison between the use of qualitative and quantitative risk analysis techniques that almost 80% of companies use mixed techniques and 20% use qualitative techniques alone. Pfeifer et al. (2015) focused on the quantification of the risks associated with project performances and he concluded that these risks are responsible for delays in project completion. Gładysz et al. (2015) proposed a PERT-based mixed linear programming model that supports time-related project risk management.

Taking into account the above, risk management can be used to reduce risks related to sustainability that may affect the environment and people in particular. Risk management and its tools help to create a sustainable infrastructure and buildings that promote better integration in several aspects, such as the environmental and social aspects of building and construction policies as well. Sustainability-related risk management can reduce the carbon footprint and the impact on the environment. Furthermore, it assists with managing air quality, using sustaibaile building materials and the use of rare resources. Bello et al. (2020) stated that the risk management model helps managers and companies to recognise several prevailing human-related issues, including resilience, mitigation, preparedness, adaptation and sustainable development, which are outlined in the project plans, and which can greatly affect human lives. The regulatory framework of each country should require the implementation of tools that allow the systemic identification of the risks to which construction projects are exposed, and to have a risk control method, which facilitates the planning of risk reduction strategies in the construction companies.

Jordan is a developing country in the Middle East. According to UN reports, Jordan has made important achievements in the past decade regarding economic, social and environmental development (HLPF-Jordan, 2017). It is also one of the first countries in the region and globally to consider and take action over the Millennium Development Goals (MDGs). Despite all these achievements and the interest from the government, the UN describes Jordan as highly urbanised with limited natural resources, and according to the Environmental Performance Index (EPI) for sustainable countries, it is ranked 62 out of 180. The World Bank Report (2009) highlighted the major environmental problems that Jordan faces, such as air quality, water scarcity, land degradation, biodiversity conservation and solid waste management. The Jordanian construction industry is one of the most important sectors affecting the national economy. It contributes 8% of the total GDP (Ministry of Planning and International Cooperation, 2015), and it is also the biggest resource-consuming industry, therefore sustainability principles are being increasingly applied in construction as awareness of the importance of the sector increases. Although the government is showing an interest in applying sustainability and in being part of the UN 2030 Agenda (HLPF-Jordan, 2017), until now, there have been no rules making the application of sustainability compulsory in the Jordanian construction industry.

1.3 Defining the Problem and Research Justification

The construction industry has significant environmental effects. It consumes 40–50% of the world's energy, 40% of the raw materials, and 50% of the world's water. It also contributes significantly to waste production, contributing 40% of global greenhouse gas emissions and 40% of the world's solid garbage. Across this industry, sustainability assessment models have been developed and applied in the last decade in order to address and reduce the environmental impacts of projects (John et al. 2013). In the last ten years, resident numbers have increased significantly, leading to an increase in construction in order to provide people with suitable places to live. Accompanying these increases is a huge urban consumption of various resources. In the urban field, specialists have previously paid attention to the time, cost, and quality goals of their construction projects. However, the construction industry has given less attention to sustainable practices.

As we can see, the modern era's expanding construction industry is a result of the expanding population and the rising need for homes and commercial buildings to accommodate it. As we previously indicated, the time, cost, and quality of construction projects received more attention than the sustainability principles. (Kibert, 2013). However, recently several entities, companies and governments have begun to develop and apply sustainability practices to their systems.

Jordan is a developing country facing a great shortage of natural resources. This is the motivation behind its adoption of sustainability concepts in different industries in order to become one of the leading countries in the region in terms of sustainability (HLPF-Jordan, 2017). In fact, despite the Jordanian national adoption of the concept of sustainability, the application of sustainable development in the construction sector is still lacking. In Jordan, there are only ten buildings registered in the LEED system, demonstrating that the adoption of sustainability in Jordan is general and far too weak.

The population tends to grow faster than the resources found. This is the reality of today in an overpopulated world and with more and more resources used; the earth does not have time to regenerate. These are two aspects that clearly highlight the development issues for the planet and for our future and they undoubtedly characterise the relevant issues with the idea of sustainable development. People around the world tend to think that the world’s resources are limitless, but they are not as limitless as we thought (Lankoski, 2016).

There are many different definitions of sustainability, and no one definition has yet been agreed upon. The notion of sustainability and the risks connected to it in the construction industry have become difficult to define, and there is still no clear explanation of how to do so in the construction field in particular. Therefore, through the introduction of the concepts of sustainability and sustainable development, the need for holistic approaches and solutions has been recognised, including in the Hashemite Kingdom of Jordan, where all problems are interrelated. As the problems are mostly global, they must be processed on a global basis. In Jordan, natural resources are running out, there is unlimited pollution, a visible and irreversible loss of biodiversity, and the already proven effects of climate change. Jordan and the whole world must not continue without tracking these facts. It could have catastrophic consequences in the not-so-distant future if they do not participate in the rapid transition to more sustainable development (Robinson, 2004).

As mentioned earlier, sustainable construction is based on three main pillars: economic, environmental and social. It should be noted that the majority of researchers and organisations base their research on the following two topics; energy-related problems (such as energy consumption, emission reductions, recycling, and so forth) and economic issues (i.e., life cycle cost assessment, cost-benefit analysis, etc.) (Nawaz et al., 2019). This is a reason why this research focuses on the topics of social and environmental risk problems in particular in the Jordanian construction industry.

The aforementioned premise and background allowed the researcher to define the research problem. The research problem involves entails determining the most appropriate way to integrate sustainability dimensions in Jordan's construction industry utilizing the risk management process. That is, how to build and use risk management model in Jordan`s construction industry to generate sustainable buildings and specifically mitigate hazards for humans and the environment. The research proposes and examines the application of sustainability-related risk management to reduce the hazards related to sustainability. This is for the purpose of promoting Jordanian sustainable practices and the interest in protecting the environment and human beings through this model.

1.4 Research Questions

1. What is sustainability, and how should it be used in sustainable construction practices?
2. What current risk management frameworks and methods are to be used to identify and analyse risks in the construction industry?
3. What are the sustainability-related risks in the Jordanian construction industry?
4. How can a new risk assessment and analysis model that takes sustainability risks into consideration be developed and tested in the Jordanian context?

1.5 Aim

The aim of this research is to develop a risk assessment and analysis model to manage the sustainability-related risks in the Jordanian construction industry.

1.6 Objectives

The specific objectives are:

1- To undertake a literature review and identify sustainability, sustainable construction and sustainable rating systems, and compare these rating systems with the UN SDGs and EIA reports to produce the list of sustainability-related hazards for the proposed model.

2- To investigate the current risk management frameworks and methods in the construction industry, and analyse and compare these methods in order to develop a theoretical basis for the new model.

3- To check and modify the initial sustainability-related hazards and their applicability in the Jordanian construction industry.

4- To find the highest sustainability-related risks in the Jordanian construction industry, for use in the final proposed model.

5- To develop a new risk model for sustainability risk analysis and assessment using the Analytic Hierarchy Process and Bayesian Belief Network for managing and assessing these sustainability-related risks.

6- To validate the proposed model by conducting three case studies.

7- To produce recommendations for the improvement of risk management and sustainability in Jordanian construction projects.

1.7 Overview of Research Methodology

A combination of primary and secondary data was collected and considered in this research in order to find answers to the research questions and to meet the objectives, figure 1-2 below shows the roadmap of this research.

The secondary data collection started with the literature review discussing sustainability, sustainable construction and the best practise applying sustainability. In order to produce the initial potential sustainability-related risks and achieve triangulation throughout the process, the researcher derived insights from the resemblance that common sustainable construction risks had with a number of leading sustainability standards, such as LEED, BREEAM, GSAS and ESTIDAMA. Further reference was made to the key principles of the UN SDGs, EIA reports and other publications in that area. Finally, risk management was proposed as a tool to apply for sustainable construction.

After that, the literature review continued, undertaking to research risk management processes and best practices in the industry, and to compare the available methods to develop the theoretical basis for the development of a new model. In this research, a four-step risk management process framework is adopted: risk identification, risk analysis, risk response, and risk monitoring. Afterwards, the literature review was continued to compare the current risk analysis methods. Although most of the methods are mature and have been used in the industry before, due to the uncertainties and the unavailability of data and risks, i.e., the relatively new sustainability-related risks, the Bayesian Belief Network (BBN) and the Analytic Hierarchy Process (AHP) were chosen as a combination method for the risk analysis and assessment in the proposed model. They were selected for their ability to work with uncertainties and the unavailability or absent of data, as will be discussed and described in the following chapters.

Meanwhile, the primary data collection began with a focus group conducted with eight experts from the Jordanian construction industry. This discussion identified the sustainability-related risks that affect the Jordanian construction industry, as well as the causes of these risks.

In the second part of the primary data collection, a questionnaire was distributed to experts, engineers and managers working in the construction industry in Jordan. The questionnaire asked the participants to rate sustainability-related risks based on their impact and frequency, thus producing the final list of sustainability-related risks.

With the end of the questionnaire, the risk identification phase was concluded and the model was fully developed. The next part of the research comprised three case studies to check the reliability and validity of the proposed model. The case studies were conducted in three different projects from the Jordanian construction industry to check the model's applicability.

Finally, recommendations for the improvement of risk management and sustainability in construction projects were drawn up, in order to help the industry, move towards sustainable practices.

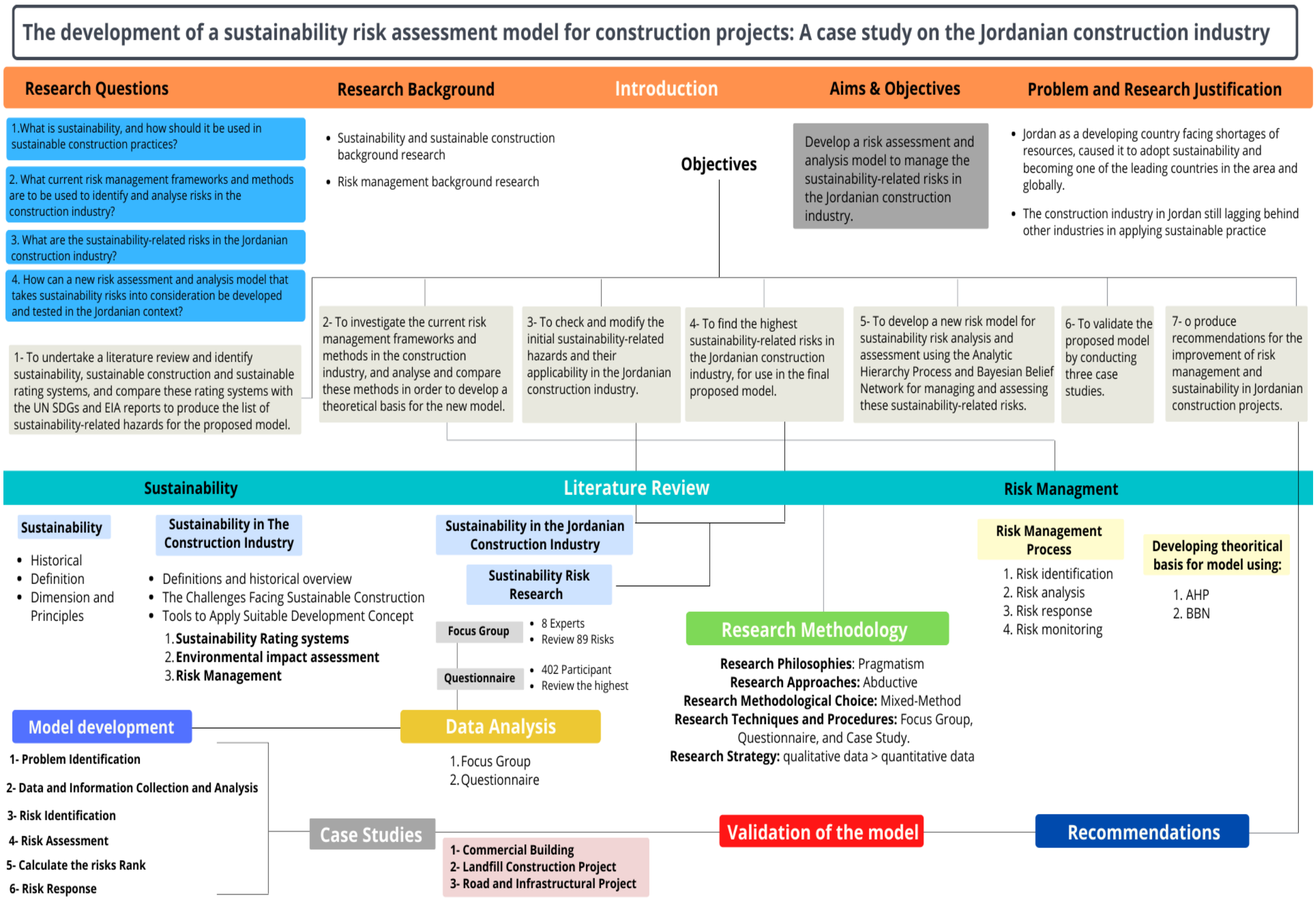

Figure 1-2: Research Road Map

1.8 Contribution to Knowledge

Constructions around the world no longer face the same environmental issues that they were exposed to a few years ago. Therefore, contemporary engineers and researchers seek to align the sustainability approach and risk management in their projects, plans, and research. In spite of the fact that risk management is a sensitive variable in sustainable development, limited research has been conducted on this relationship. Accordingly, this research will contribute to:

- Enriching the literature on ways to improve and develop sustainable construction for construction professionals by compiling a list of sustainability-related risks in the construction industry as a whole.

- Enriching the literature on the main risks facing the achievement of sustainability in the construction industry and improving risk management and producing a list of sustainability-related risks in the context of the Jordanian construction industry. Identifying a model for managing sustainability-related risks in construction projects based on two approaches: The Analytic Hierarchy Process (AHP) and the Bayesian Belief Network methods (BBN).

- Presenting a proposed model through which construction professionals can analyse and manage quantitative and qualitative risk data and information effectively and efficiently. Forming the basics for smart risk thinking, assessment, and identification processes for all current sustainability-related risks in the industry, thus increasing knowledge about dealing with the uncertainties that appear in that data through expert judgement using AHP and BBN.

1.9 Thesis Structure

Chapter 1 – Introduction. The first chapter of the thesis introduces the background of this research and the Jordanian construction industry, as well as defining the problem of the research and its justification. It also outlines the research questions, aims and objectives. Finally, it provides an overview of the research methodology and the study's contribution to knowledge.

Chapter 2 – Sustainability. This chapter starts by defining sustainability, its importance and the need for it. It also shows the contribution of the construction industry to applying sustainability concepts, and the tools that are used to apply sustainability in the construction industry. It discusses sustainability in the Jordanian construction industry and lastly, it proposes the initial potential sustainability-related risks.

Chapter 3 – Risk management. This chapter starts with the introduction of risk management and its process, and it illustrates the methods used in the industry. Finally, it shows the development of the theoretical basis for the adopted model.

Chapter 4 – Methodology. This chapter explains the choice of philosophy, approach and strategies used in this research. Also, discusses the type of data collection techniques used and the time horizon of the research. Finally, it shows how the researcher will validate the findings.

Chapter 5 – Diagnosis of Sustainability-related Risks in The Jordanian Construction Industry. This chapter presents the analysis and the results of the focus group and questionnaire data. The results of the focus group are analysed and presented thematically, while the questionnaire data are presented and analysed descriptively and statistically, starting with general information about the respondents and then moving on to the probability and impact of sustainability-related risks.

Chapter 6 – Risk Assessment Model development. This chapter shows the steps that were taken to develop the sustainability-related risk assessment model for the Jordanian construction industry. It starts with the identification of the problem, then moves on to the data collection and analysis, followed by the risk identification and risk assessment. It then shows the calculation of the risks' ranking and risk response steps.

Chapter 7 – Validation of the model. This chapter presents the three case studies carried out on three different projects in the Jordanian construction industry, to check and validate the model. The first case study was a commercial building, while the second was an infrastructure project for the construction of a road. The final project was the construction and rehabilitation of a waste landfill. Then, the results are presented and compared for the three case studies, confirming that the model is valid and giving different rankings for sustainability-related risks, depending on the projects characteristics. Finally, it shows the discussions with the three project managers validating the need, content, structure and applicability of the developed model.

Chapter 8 – Discussion, Recommendations and Conclusion. This is the last chapter of the thesis. It starts by reviewing the aim and objectives, and the methods used to achieve them, then the contribution to knowledge. In addition, it presents the most important findings of the study. Finally, it presents the limitations of the research and gives recommendations for future research.

1.10 Conclusion

This chapter addressed several important elements of the study. It provided a comprehensive background on the subject of the research as a whole and defined the sustainability concept as a development process that works to meet the needs of the present without compromising the ability of future generations to meet their own needs. The background section also discussed risk management in the construction industry, linking risk management specifically to sustainability-related risks. This study aims to create a model that effectively evaluates and manages the risks related to sustainability in the State of Jordan. The research problem was defined, which is to implement the dimensions of sustainability in the risk management process in the construction industry in Jordan. The research questions, aim and objectives were explicitly stated. The chapter also gave an overview of the methodology employed, which focused on qualitative and quantitative methods that were complementary to each other. Finally, the chapter described the extent of the research's contributions to the literature and the construction industry. From here, we move on to the next chapter on sustainability.

Chapter Two

Chapter Two: Sustainability and its relation with construction industry

2.1 Introduction

This chapter aims to pinpoint and provide all the critical theories and knowledge that are associated with sustainability, sustainability in the construction industry at large, and sustainability in the Jordanian construction context. The sustainability section reviews the history of sustainability, a chronology of its different definitions in publications, and its different dimensions and principles, incorporating social, ecological and economic aspects. This chapter also discussed the long-term and short-term development goals, technology and good governance.

The debate persists on whether humans are responsible for the ever-noticeable climate change, especially changes in temperature resulting in extreme weather conditions such as the increased number of hurricanes, flooding, rising sea levels, or whether the climate has always been changing and humans just happen to be living in a century when temperatures are increasing. Many government organisations, such as the Intergovernmental Panel on Climate Change (IPCC) and United Nations Environment Programme (UNEP), were formed to research climate change and provide evidence to inform the debate. Regardless of the earlier debate, and as reported by IPCC (2007, p 2), “global greenhouse gas emissions due to human activities rose by 70% between 1970-2004”. UNEP (2009, p.11) also stated that “Today, it is widely accepted that human activities are contributing to climate change.” These types of organisations have a lot of influence on society by shaping people’s opinions and perspectives on climate change and what we as a society should be doing about it.

Sustainability cannot be defined simply, as more than one definition has been provided and new definitions are constantly being added. Sustainability carries several possible meanings whenever definitions are formulated. According to the Cambridge Dictionary, sustainability is “the quality of causing little or no damage to the environment and therefore able to continue for a long time”, while the WCED defines sustainability as “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Bansal and DesJardine, 2014, P. 71). Another definition can be found in Shrivastava (1995) as “the potential for reducing long-term risks associated with resource depletion, fluctuations in energy costs, product liabilities and pollution and waste management”.

Fundamentally, sustainability consists of three dimensions, social, ecological and economic, as illustrated in Figure 2-1 below.

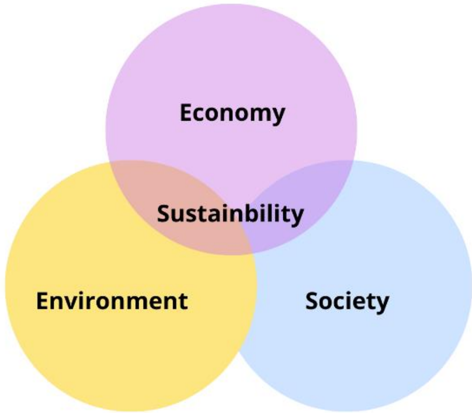

Figure 2-1: Sustainability Dimensions

Achieving sustainability, on the other hand, depends on the compromises that are made between these three dimensions in the short and long terms (Talbot and Venkataraman, 2011). Economic sustainability entails the maximisation of returns while preserving the associated capital, or assets, while the ecological aspects relate more to the preservation of biological and physical systems. Social sustainability, on the other hand, focuses on stabilising social and cultural systems in a manner that results in intergenerational equity (Munasinghe, 1993).

It is agreed that the simplification of sustainability pillars as pertains to the above inadequately reflects the complexity of the real world. According to the UN 2030 Agenda for Sustainable Development, 17 SDGs need to be accomplished for any country to achieve sustainability. These 17 goals cover all aspects of life, including the social, ecological and economic. For governments to reinforce sustainability, the public sector should set a clear direction, review and monitor frameworks and regulations, and finally attract investment. Going through the 17 goals, it can be seen that two of them are directly related to the construction industry – infrastructure and sustainable cities and communities. However, as mentioned earlier, there are also a number of UN goals indirectly related to the construction industry.

The process of sustainable construction contributes to human health and high levels of well-being, it ensures gender equality, increases access to safe drinking water and provides organised sanitation. In addition, sustainable construction reduces energy consumption and increases the chances of equality for people. By linking construction with sustainability, we can reduce air pollution and the presence of polluted lakes or water surfaces. This thus ensures a clean, hygienic and unpolluted environment where all people from all walks of life benefit, without discrimination, and these are the most important of the UN goals that indirectly link to the construction industry. This shows the importance of the construction industry in achieving sustainability.

2.2 Sustainability

With the new awareness of sustainability practice, it has become a significant pillar in the planning of future development. This section will discuss sustainability theories, providing a historical overview and definition, and then discussing the dimensions and principles of sustainability.

2.2.1 Historical Overview of Sustainability

There was a rapid growth in awareness of sustainability after World War II and this has been sustained through the development of economics and industries, and increases in population, and environmental and human problems. As Wang et al. (2000) mentioned, there will always be discussions on whether humans are responsible for climate change or whether they are just affected by it. Analyses presented by Meadows et al. (1972) showed the connection between natural resources and economic growth, and stated that natural resources are not necessary for the needs of human beings to be met. A considerable number of studies followed, expressing the concept of sustainability and respecting the universe.

From 1950 to 1972, several events took place that heightened the discussion about sustainability. With regard to environmental development, during the 1950s and 1960s, people started to consider environmental problems. In 1968 and 1972, two events were organised by the UN on international environmental development, and an environmental programme was launched, aiming to provide leadership that was considerate towards the global environment (UN, 2011). Following the development of the sustainability concept during the period 1987–2012, seven conferences on the topic were held. In 1980, the term ‘sustainable development’ was defined for the first time at the International Union for Conservation of Nature and Natural Resources (IUCN et al., 1980). In addition, the UN endorsed an economic, social and environmental framework proposed by the World Commission on Environment and Development (WCED, 1987). Ten years later (in the 1990s), the Rio Earth Summit generated Agenda 21 for executing “sustainable development globally”.

More recently, the Millennium Declaration in 2000 identified the fundamental values and principles that are essential in international relations. The Millennium Development Goals were established to achieve these values at the global level by 2015 and they served as the basis for the work of the UN during this period, to ensure environmental sustainability.

Sustainability was certified by the Millennium Ecosystem Assessment for a period of four years starting from 2001, and at the request of the United Nations. During those four years, the situation in the world changed radically. Countries’ demand for resources increased, and this caused a gap in supply and demand; resorting to importing and exporting operations was the main solution to meet countries’ needs. The increasing demand for resources has increased the urgency of moving towards sustainable living. This is being achieved through several methods, the most important of which are the adoption of renewable energies, recycling, and awareness-raising.

In 2009, after the strongly worded statement issued by senior climate scientists at the Copenhagen Climate Council, the world learned that the planet was under a global threat, focused on climate change, due to the massive increase in the burning of fossil fuels and the overuse of natural resources (IPCC, 2021). Hence, global standards have been published that must be adhered to in order to mitigate this threat, including monitoring and reducing the average global surface temperature, maintaining sea levels, mitigating ocean acidification, and monitoring and dealing with new climatic events.

It has become important to make significant changes to prevent ecosystems from deteriorating and to meet the increasing demand for services by making comprehensive changes to the private and public sectors. The framework for sustainable development has been strengthened in order to reduce carbon dioxide emissions and slow down the increase in the temperature of the earth, lessening it by two degrees and preventing its devastating effects (Global Sustainable Development Report, 2019).

The UN is the most important body that takes care of sustainability in the 2000s. On the commercial front, the World Business Council for Sustainable Development (WBCSD) has helped its member companies to move their business to a sustainable model. Several certificates can be given as a reward for companies that transform their business into one that employs a sustainable approach and follows sustainable practices (Youmatterworld, 2021). Among those certificates are those awarded by: B-Corp movement, the Rainforest Alliance, the Fairtrade Foundation, and the Conscious Capitalism Movement.

Moreover, various commercial entities have opened up the way for a circular economy. Through it, companies and societies can align the way they use natural resources across their supply chains to the same way that nature uses them. Examples include environmental business models such as growing mushrooms from coffee leftovers (Youmatterworld, 2021).

Between 2000 and 2015, five conferences were held to discuss sustainability: The Third Conference of Sustainable European Cities (Hanover) in 2000 (Sustainablecities.eu, 2000); The World Conference on Sustainable Development ("Rio + 10", Johannesburg) in 2002 (Iaea, 2002); The Aalborg + 10 Conference in 2004 (Sustainablecities.eu, Aalborg +10, 2004); The International Conference on Climate Change in 2009 (Archive, 2021); RIO + 20 June 2012 Conference (un, 2012).

In addition, two main programmes were launched: the Communication from the Commission to the Council and the European Union in 2006 (Europa, 2021) and The Sixth Environmental Action Program of the European Union in 2001 (Europa, 2012), and one summit was held: The United Nations Summit on Sustainable Development in 2015 (un, 2015).

2.2.2 Definition of Sustainability

Sustainability is not a single or simply defined concept. Many definitions have been given for this term, and new definitions are continually being added, each author defining it differently.

Hence, there is still no one description of how to achieve it (Lankoski, 2016). It has been accused of being indefinable since every time a definition has been formulated, it has left out some of the possible meanings (Robinson, 2004).

The current conception of sustainability is included in the Brundtland report, also known as "Our Common Future" (Brundtland, 1987) and first published in 1987. This document for the United Nations initially warned against the negative environmental consequences of economic development and globalisation. For this reason, the United Nations seeks to provide solutions to the problems posed by industrialisation and population growth.

Simply put, sustainability is managing resources to meet the present needs without compromising the future needs. It takes into account, and balances, economic growth, environmental protection, and social well-being (Liu, 2017). Sustainability is above all the assumption that nature and the environment are not inexhaustible sources of resources and require rational conservation and use (Costanza & Daly, 1992). Sustainability is about promoting social development by striving for integration between communities and local cultures. It strives to achieve satisfactory standards in quality of life, health, and education (Adecesg, 2021). Sustainability is the process by which we can foster economic growth that creates equal wealth for all without harming the environment (Youmatter, 2021).

Sustainable is a kind of progress that keep this delicate balance today without jeopardising the tomorrow resources. To achieve this, many rules must be applied and waste and debris must be reduced. Thanks to these actions, we will be able to fight against climate change and global warming (Kuhlman, 2010). Ultimately, sustainability is based on the principle that indistinguishable resources cannot be consumed, that the natural environment should be protected and that everyone has access to equal and fair opportunities (Kuhlman, 2010).

2.2.3 Dimensions and Principles of Sustainability

Fundamentally, sustainability consists of three dimensions: social, ecological, and economic. Furthermore, engineers and those responsible within the construction industry use these principles of sustainability when considering what the future should look like. These principles are defined as a guide to the maintenance of natural resources and the structure and function of nature, to meet basic human needs. It obliges project managers and engineers to not participate in activities where the concentration of substances extracted from the earth would increase. Furthermore, they should not participate in activities where the concentration of substances produced by human society would also increase in nature, or activities that may cause nature to deteriorate in a physical way. In addition, they must not participate in activities that create situations that prevent people from acting to meet their basic needs.

Going through the UN goals, these principles are linked to construction directly and indirectly. Simply, the direct goals are to have sustainable infrastructure, cities and communities. Indirectly connected to the UN goals is guaranteeing good health for all people; sustainability principles steer construction in a way in which we can maintain or create good physical, emotional, and mental health, which is related to the UN goals. At the societal level, following the sustainability principles helps to maintain or establish influence over the social system to which it belongs, whether by participating in decision making, having a say, or receiving democratic rights in the community. The principles of sustainability can increase people's welfare by increasing the chances of having a good environment in which they can learn and have the opportunity to improve through education, adaptability, personal growth, access to knowledge, etc., linking to the UN goal of increasing welfare. Sustainability principles call for fair, equal and impartial treatment, with the diversity that exists in the world receiving the same clean environment without bias. Ultimately, the sustainability principles help people to experience the meaning or significance of being a member of a social system, and by following these principles, people will have a feeling of purpose, compassion, and opportunity for reform. Figure 2-2 presents the sustainability principles.

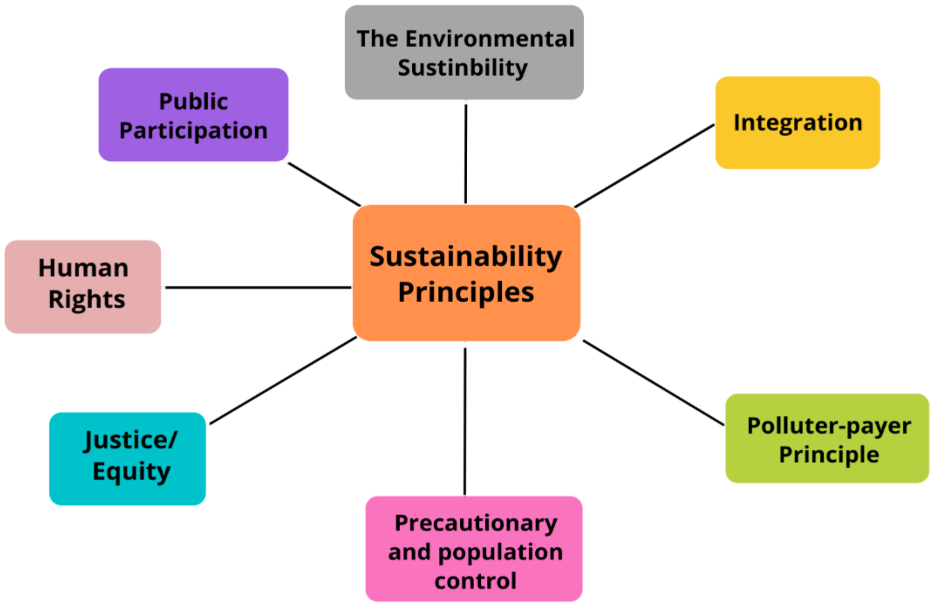

Figure 2-2: Sustainability Principles

The principles of sustainability are about the conservation of resources, both qualitatively and quantitatively. Sustainability principles are related to environmental matters. Their usefulness is that they can be used as a starting point to evaluate environmental policies, that is, those formulated by national and sub-national governments. Similarly, they could be adapted to evaluate corporate policies and particular projects.

According to Mensah, (2019), the most widely accepted principles start with **the environmental sustainability principle**. This principle focuses on achieving comfort and the current lifestyle for humanity and the conservation of biodiversity, ecosystems and production systems. Economic growth has a limit, beyond which people will exhaust plant resources and irreversibly damage ecosystems. Operating an ecological system can be achieved by consuming renewable resources at a lower rate. For non-renewable resources such as fossil fuel, deep aquifers, mineral ores, etc. the sustainable consumption rate cannot be higher than the renewable resource rate.

The second principle lies in **integration**. Brundtland (1987, P.55) reported that: "The common theme throughout this strategy for sustainable development is the need to integrate economic and ecological considerations in decision making.". So, it is necessary to ensure that every time decisions are made in the public or private sphere, issues related to sustainability are considered.

The third principle is **the polluter-payer principle**. This principle states that the companies must pay to avoid contamination or to remedy the damage caused. So, companies must pay for appropriate control measures to prevent contamination or, in the worst case, its remediation.

The fourth principle is the **precautionary principle and population control**. Here, if any activity presents a high but known risk, preventive action is required, rather than precautionary action.

The fifth principle is **justice or equity.** Equity is the equal treatment between unequals to guarantee the right of all to an acceptable quality and standard of living. (Mensah, 2019).

The sixth principle is **human rights,** currently, respect for human rights is recognised under sustainable development. In addition, human rights and the environment are interrelated and interdependent. Of course, human rights cannot be ensured in a degraded or polluted environment, making it impossible to enjoy a healthy life where there is exposure to toxic products and contaminated water.

The seventh principle is **public participation**, the best way to deal with environmental issues is with the citizens' participation(Mensah, 2019). Every citizen must have adequate access to information on the environment, including information on activities and materials that pose a threat to their communities. In addition, everyone must have the opportunity to participate in the processes of decision making. Countries must promote and facilitate community awareness and participation by making the information available for all. In any case, taking this principle into account from the conception of projects and public policies will strengthen their social licence and help to achieve long-term sustainability.

2.3 Sustainability in The Construction Industry

The construction industry, like many other fields, faces a cultural border that strikes and slows down the evolution of practices. In a world where we must act for the common good and with respect for the earth's capacity to regenerate, practices must change and priorities must be revised. In a sense, it is more important to focus on what is authoritative in a project rather than who has authority (Yilmaz & Bakış, 2015). Sustainable development transforms industries so that they take into account not only economics but also environmental and social factors. The sustainable observation leads industries to realise that the viability of their activities is intimately linked to the viability of the company itself, in a context where it depends on its environment. In this regard, the construction industry is no exception. The sustainable construction industry supports the establishment of sustainable buildings – also called "green" or "ecological" buildings – that take into account the efficient use of resources and the need to be concerned with environmental externalities (Yilmaz & Bakış, 2015). The future achievements of the sustainable construction industry will have to be based on new paradigms. It will not only focus on the energy efficiency of projects but also on the priority elements, which are human and ecological habitats, water, energy, materials and resources, without neglecting the financial aspect. Mjakuškina, Kavosa and Lapin (2019) mentioned that, in sustainability, the construction industry must restore a certain balance in the weight of the decision-making criteria, so that the environment, the social and the economy are weighted more. In addition, cities, neighbourhoods and buildings need to be redefined to be environmentally friendly.

2.3.1 Definitions and Historical Overview

Today, with the increasing level of migration from the countryside to cities, more than half of the world's population lives in cities. This number is expected to keep increasing to reach two-thirds of the world's population by 2050 (Tartaglia et al., 2014). Cities are responsible for 70% of greenhouse gas emissions, as well as the depletion of agricultural land and natural resources. This is due to the excessive consumption of energy and resources, poor waste management, sewage, and transportation systems (Sharifi & Murayama. 2013).

Undeniably, the construction industry is well known as a large consumer of raw material and energy, and for large land usage. An excessive use of resources such as water, materials, energy and fossil fuels on a global scale is pushing the construction sector and the governance of the built environment towards rapid changes (John et al., 2013). Policy, law and regulation makers around the world are accordingly demanding that the construction sector implements sustainable innovations in relation to products and processes to provide a more sustainably built environment (Hellstrom, 2007).

According to the United Nations Environment Program (UNEP 2009), the construction industry has become a large energy consumer that uses 40–50% of global energy, 40% of global raw materials, and 50% of water. It is also a major waste contributor that releases 40% of global greenhouse gas emissions and produces 40% of the solid waste worldwide.

However, the construction industry and the building sector have huge potential to reduce pollution and achieve savings in energy, due to the flexibility of its demands (IPCC, 2007). This illustrates why sustainable buildings and communities are often considered a priority for sustainability in the world (Butera, 2010). Climate change has increased concerns over the depletion of the environment and its resources. Different international researchers have confirmed that the built environment is the most promising sector for a fast transition to sustainability (Hoseini et al., 2013). Through this scenario, many examples of sustainable urban environments around the world are showing the advantages of sustainability.

2.3.2 The Challenges Facing Sustainable Construction

Although governments and environmental organisations are pushing the building industry to apply sustainability in the construction process, sustainable construction is still facing plenty of challenges. According to Kibert, (2013), some changes are needed in order to help companies apply sustainability to the industry:

- The construction process itself needs to be changed and updated to cope with current sustainability standards and to ensure the lowest environmental impact.
- The technology used in the construction industry is in need of development to minimise the consumption of resources and the environmental impact.
- There is a lack of skilled and qualified workers, despite all the new technologies and designs for sustainability, so labourers and workers needed to be trained.
- Multiple policies and laws have to be developed to deal with the new processes.
- There will be an additional cost, as green building materials and technologies can add significantly to the costs of a project.
- Governments need to develop financial incentives for sustainable construction, such as priority review by building departments, accelerated approval for sustainable projects, reduction in impact fees, and/or property taxes for a specific period.
- Industry professionals need to be educated and trained on the need, the process, and the approaches for creating green buildings.
- Performance-based design fees, revising contracts for design and construction services to offer incentives to meet and exceed project goals with respect to resource consumption and environmental impacts.

2.3.3 Tools to Apply the Sustainable Development Concept

With the level of multiplicity and potential vagueness of the concept, it is essential to overcome the challenges faced by devising the necessary tools to guide, measure, and assess the application of sustainable concepts in the construction industry. Among such tools are sustainability rating systems.

2.3.3.1 Sustainability Rating Systems

Green building rating (or certification) systems are a type of tool that rates or rewards relative levels of compliance or performance in accordance with specific environmental goals and requirements. Rating systems and certification systems are frequently used interchangeably.

Green building rating systems are of two types: single-attribute, which mainly focuses on energy or water; and multi-attribute, focusing on addressing emissions, toxicity and overall environmental performance, in addition to water and energy. Although the philosophy, approach, and certification methods vary across these systems, a mutual objective is that projects awarded are designed to reduce the overall impact of the construction industry on human health and the natural environment.

Green building rating systems exist to address every project type from small houses and commercial buildings to entire neighbourhoods. There are rating systems available for new construction, which focus on decisions made in the planning and design processes and actions taken through construction, as well as for existing buildings, focusing on operations and maintenance throughout the life of the building. Rating systems for neighbourhoods focus on the integrated development of new sustainable neighbourhoods, compared to single building rating systems. A primary reason for the use of rating systems is to clearly define, implement and measure green building strategies, as well as their outcomes and impacts on the environment.

The number of green building rating systems is increasing rapidly. Now, there are over 30 rating systems worldwide. While most rating systems have many similarities, some of them are unique as they have the criteria developed to suit the local climate, context and culture. While it is possible to directly compare the value of buildings in any place in the world, making a similar direct comparison of the sustainable features and rating of the same building is quite complex.

The following is a description of a number of certification systems worldwide, some well-known globally (LEED and BREEAM) while others are more known regionally in the Middle East (Estidamas's Pearl Rating System and the GASA Global Sustainability Assessment System). Their details are given in Table 2-1. By analysing and comparing these systems, a better understanding of the certification systems can be achieved.

(1) The Building Research Establishment Environmental Assessment Method (BREEAM)

This was published by the Building Research Establishment (BRE) in the United Kingdom in 1990 as a voluntary rating system. BREEAM is the first developed rating system worldwide, with over 250,000 projects in more than 70 countries around the world. Version 2018 is the latest version at the time of this study. BREEAM had a big influence on the development of building regulations and codes, making them better able to suit global efficiency needs.

BREEAM assesses various types of construction such as new construction (offices, industrial and retail units, data centres, education and healthcare premises, prisons, courthouses, multi-residential institutions, non-residential institutions, and leisure). It also covers in-use buildings refurbishment, code for sustainable homes, and sustainable communities.

BREEAM consists of ten criteria that are consistent throughout all types of certification: Management, Health and Wellbeing, Energy, Transport, Water, Materials, Waste, Land Use and Ecology, Pollution, and Innovation, with the last one being considered a bonus. Rated buildings are provided the status of a pass, good, very good, excellent, and outstanding.

(2) Leadership in Energy and Environmental Design (LEED)

Published by the US Green Building Council (USGBC) in 1998 as a voluntary rating system, LEED is the world's most used rating system with 80,000 projects worldwide in 162 countries. LEED V4.1 2019 is the most recent version at the time of writing.

The LEED rating system can be used to assess new construction, existing buildings, commercial interiors, retail, schools, homes, healthcare, and communities. There is also a separate guide for core and shell projects.

LEED has seven criteria for evaluating sustainability and they are consistent throughout all types of certifications (with the exception of Neighbourhood Development). They are: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation in Design, and Regional Priority, with the last criterion being considered a bonus. Rated buildings or communities are provided the status of certified, silver, gold or platinum.

(3) The Estidama Pearl rating system

This was published by the Abu Dhabi Urban Planning Council in the United Arab Emirates (UAE) in 2010. The word Estidama means 'Sustainability' in the Arabic language. It is mandatory for any new building in the UAE and it is free. Estidama was the first system of its kind in the Middle East and was developed due to the need to establish buildings and sustainable urban planning and design in the UAE through a customised system that suits its local context. It accordingly became part of the Plan Abu Dhabi 2030.

Pearl focuses on the stakeholders and specialists in the processes of planning, design and construction. It includes a cultural dimension as a fourth dimension, adding to the three existing sustainability dimensions (economy, environment, and society) in an attempt to give privacy and spatial impact to the assessment process (Estidama, 2010). Elgendy (2014) pointed out that the development of the Pearl rating system relied on BREEAM and LEED and came as an attempt to acknowledge the shortcomings of and differences between the two methods.

The Estidama Pearl Rating System is a unified document for three different standards varying in rating size. It includes a guide for assessing the sustainability of villas, buildings and communities. It represents a compulsory standard for all types of buildings, especially for urban planning and design projects in the UAE.

Pearl consists of seven criteria and they are consistent throughout all types of certification. They are: Integrated Development, Natural Systems, Liveable Buildings, Precious Water, Resourceful Energy, Stewarding Materials, and Innovating Practice.

(4) Global Sustainability Assessment System (GSAS)

This was designed in 2009 by the GORD (Gulf Organization for Research & Development) in collaboration with T. C. Chen (Centre for Energy Studies and Building Simulation) at the University of Pennsylvania (USA) under the name QSAS (Qatar Sustainability Assessment System). It was then changed to GSAS (Global Sustainability Assessment System). GSAS has been taught as part of the curriculum in Qatar universities. The fourth version in 2019 was the latest version at the time of the research (QSAS, 2010).

GSAS has eight criteria for evaluating sustainability and they are consistent throughout all types of certifications: Urban Connectivity, Site, Energy, Water, Materials, Indoor Environment, Cultural and Economic Value, and Management and Operations.

The GSAS rating system can be used to assess new construction, existing buildings, commercial buildings, new and existing parks, schools, residential buildings, healthcare facilities, community facilities, hotels, mosques, sports buildings and venues, and railways. Also, there is a separate guide for core and shell projects.

After the large expansion of the construction field in the Gulf region, with Qatar winning the bid to host the World Cup in 2022, the need emerged to set up a classification and assessment system for the sustainability of urban development and buildings, to reduce the multiple negative environmental impacts of these while meeting the local and regional needs of Qatar.

Table 2-1: Sustainability Rating Systems Comparison

	LEED	**BRAEEM**	**PEARL RATING**	**GSAS**
Organisation	US Green Building Council	BRE Global LTD	AD Urban Planning Council	Gulf Organization for Research & Development
Year	1998	1991	2010	2009
Location of Use	International	International	Local	Local
Mandatory by Law	No	No	Yes	No
Accredited Professionals & Enforcement	LEED AP (Voluntary)	BREEAM Accredited Professional (Mandatory)	Pearl Qualified Professional (Mandatory)	GORD Qualified Professional
Minimum Standards	8 prerequisites	Minimum standards are tiered based on the rating: 4 to 26 credits for Pass to Outstanding	20 required credits	At least level zero
Number of points	110 (including 10 bonus points)	132 (including 10 innovation points)	180 points	
Number of Credits	57 credits	49 credits	86 credits	54 credits
Types of construction covered	New Construction, Existing Buildings Commercial Interiors Core & Shell Retail Schools Homes Neighbourhood development Healthcare	New Construction (offices, industrial and retail units, data centres, education and healthcare facilities, prisons, law courts, multi residential institutions, non-residential institutions, assembly & leisure) In-Use Refurbishment	New construction (office, retail, multi-residential, school and mixed-use) neighbourhood development villa (homes)	New construction, existing buildings, commercial buildings, new and existing parks, schools, residential buildings, healthcare facilities, communities, hotels, mosques, sports buildings and venues,

		Code for Sustainable Homes Communities		railways, core and shell projects
Credit Categories	- Sustainable Sites - Water Efficiency - Energy and Atmosphere - Materials and Resources - Indoor Environmental Quality - Innovation in Design - Regional Priority	- Management - Health & Wellbeing - Energy - Transport - Water - Materials - Waste - Land Use & Ecology - Pollution - Innovation	- Integrated Development - Natural Systems - Liveable Buildings - Precious Water - Resourceful Energy - Stewarding Materials - Innovating Practice	- Urban connectivity - Site - Energy - Water - Materials - Indoor environment - Cultural and economic value - Management and operations
Rating Classification and Benchmark (% Points)	Platinum ≥ 73% Gold ≥ 55% Silver ≥ 45% Certified ≥ 36%	Outstanding ≥ 85% Excellent ≥ 70% Very Good ≥ 55% Good ≥ 45% Pass ≥ 30%	5 Pearl ≥ 92% 4 Pearl ≥ 69% 3 Pearl ≥ 58% 2 Pearl ≥ 44% 1 Pearl ≥ 11%	One star $0 \leq x \leq 0.5$ Two stars $0.5 \leq x \leq 1$ Three stars $1 \leq x \leq 1.5$ Four stars $1.5 \leq x \leq 2$ Five stars $2 \leq x \leq 2.5$ Six stars $2.5 \leq x \leq 3$
Assessment/Review	Design & Construction Review by Green Building Certification Institute through a network of third-party certification bodies	Design stage and post-construction assessment by trained and licensed BREEAM assessors	Design & Construction Review by AD Urban Planning Council Assessors	Design & Construction Review by Gulf Organization for Research & Development Assessors

2.3.3.2 Environmental Impact Assessment (EIA)

According to Glasson et al. (2019), Environmental Impact Assessment (EIA) is a procedure that includes studies, technical reports and consultations that allow those responsible to estimate the consequences that a certain project, installation, or activity will have on the environment. It is an analysis from which an objective judgement can be formed, a judgement that can then be used to approve or reject a project, solely for environmental purposes. The introduction of the EIA concept has produced a significant shift in the way that the processes, design and execution of human activities are approached. Prior to the entry into force of the regulations on this matter, the evaluation of the viability of a project was based only on technical, economic, and social criteria, and not environmental ones. In the 1970s, with the first meetings on the environment, the need to incorporate the environmental variable as a factor for guaranteeing sustainable progress began to be seen, as a worsening of the problems in the environment was detected, both globally and locally. EIA is one of the most useful tools for environmental protection since it incorporates variables that were not previously taken into account (Glasson et al., 2019). EIA is an analysis process that anticipates the future negative and positive environmental effects of certain actions and allows alternatives to be selected that increase the benefits and reduce the impacts. For this reason, it is necessary to promote control and the adoption of preventive, corrective, or compensatory measures in those actions likely to produce negative effects on the environment, thereby deteriorating the quality of life of citizens.

The EIA process is valuable to any construction project or project proposal and it takes into account the economic, cultural and social impacts and their effects on human health, both beneficial and harmful, before making a final decision on projects (Glasson et al., 2019). The objective of the EIA is to forecast environmental impacts early in the project planning process, allowing appropriate means to be found to reduce the potential negative effects. Also, it aims to form projects commensurate with the local environment based on predictions that help decision-makers to make their decisions to achieve several benefits. Among the benefits that users of EIA may reap is reducing the time and cost involved in implementing and designing projects, as well as avoiding the costs associated with treatment and clean-up, and avoiding being penalised by the laws and regulations related to the environment.

The main components of EIA differ in different countries, but most of them include these stages (CBD, 2010):

- ❖ **Screening,** to identify projects and developments that require a full or partial impact assessment.
- ❖ **Scoping,** which is based on legislative requirements, public participation, expert knowledge and international conventions. This stage helps to identify appropriate alternative solutions to avoid negative impacts on biodiversity and to derive terms of reference for impact assessment.

- **Evaluating,** to assess the effects and develop suitable alternatives. At this point, a prediction of potential environmental impacts is made. These predictions are specified for a project, and the proposed alternatives are detailed.
- **Reporting,** to report the EIA. Here, the environmental management plan is also attached and a summary is provided for the general public. This summary is not technical. Then, this statement is reviewed so that a decision can be made based on it.
- **Making the decision,** at this stage, a decision is made on the approval or rejection of the project, and on the terms to be agreed upon.
- **Monitoring, compliance, enforcement, and environmental auditing,** the expected effects and the proposed mitigation measures are monitored. Compliance is also checked in the Environmental Management Plan. This is for the purpose of identifying unexpected effects and failed mitigation measures, as addressing them in a timely manner mitigates losses.

2.3.3.3 Risk Management

While the concept of risk, in general, addresses the occurrence possibility of something bad, unpleasant, or dangerous (Longman Dictionary, 2019), project risks tend to be more focused and specific. PMI identifies risks through association with risk-related features, such as cause and effect, where the former results in risks as they occur, and the latter entails potential events that impact the project's key objectives. Project risks are measured individually or in generality across a certain project, where the overall risk resembles the sum of the associated individual risks with their impact on scope, schedule, cost and quality. Risks could be positive (opportunities) or negative (threats) in light of their most potential outcome. The main aim of risk management is to avoid project uncertainties, as the identified risks can be assessed and analysed (Coscun, 2019). Indeed, Mhetre et al. (2016) define project risk management as a method for recognising and evaluating project risks, leading to appropriate action plans.

Banaitiene and Banaitis (2012) identify a number of key stages in the standard risk management process: risk identification, risk assessment, risk mitigation and risk monitoring. Risk identification, being the earliest stage, draws its importance from the identification of anticipating risks ahead of their management (Iqbal et al., 2015). Risk assessment, according to Valis and Koucky (2009), entails clarifying how project objectives may be affected by providing a detailed understanding of causes, consequences or probabilities. Risk mitigation entails the development of multiple alternatives to counter the anticipated risks (PMBoK, 2013), and to reduce, transfer, mitigate or accept them. Risk mitigation also entails exploiting or enhancing the risks that hold positive opportunities. Risk monitoring is the final stage (Gajewska & Ropel, 2011), where the developed risk responses are expected to be concluded, and where any emerging new risks are also identified.

In the construction industry, there is a difference between ordinary risks and sustainability-related risks. The most common risks in the construction industry are an explosion at the construction site, leakage of flammable liquid, radioactive, oxidiser, combustible, corrosive, and miscellaneous hazards. The collapse of a building or falls by workers are other ordinary hazards or risks that are not related to the environment, but are related to the project itself. (National Research Council, 2011). As for sustainability-related risks, they are the risks that affect the environment, society, and also the economy. For example, the risks of polluting the environment surrounding the project, whether that be the air, a lake, water surfaces or something else, may affect the cleanliness of the environment and the surrounding community. Construction, stone carving and casting works can lead to the volatilisation of many polluting materials, toxic or non-toxic. This can be sand, dust, mud, sludge, or any other material. The materials that are produced from construction work may mix with the air and pollute it. If there are lakes or water surfaces nearby to the construction project, they can be polluted due to air pollution or due to the discharge of these materials into the water bodies. This leads to real risks to the environment surrounding the construction project, whether from air or water pollution.

Also, a risk associated with sustainability may result from the use of energy or fossil fuels in the project. The resulting emissions could increase climate change and global warming. To elaborate, the phases of a construction project typically necessitate work with machines, such as drilling, sculpting and lifting, and these machines run on fossil fuels. These machines pollute the air around the construction site, which has a negative impact on the surrounding environment and the community that lives nearby. The polluted environment caused by the project's use of machines that run on fossil fuels increases gas emissions into the atmosphere, which increases the greenhouse effect and contributes to global warming and climate change.

So, ordinary risks are related to the project and its workers only; they are not directly related to the surrounding environment. As for the risks associated with sustainability, they are risks that have a very direct impact on the environment and the society in which the project is located (National Research Council, 2011).

2.4 Sustainability in Jordan

2.4.1 Introduction to The Hashemite Kingdom of Jordan

The Hashemite Kingdom of Jordan (Jordan for short) is a country in the Middle East, Western Asia, on the east bank of the Jordan River – where the name originally came from. It is bordered by Saudi Arabia to the south, Palestine to the west, Iraq to the east, and Syria to the north. The country is almost landlocked with only a small shore on the Red Sea in the southwest. Jordan is a relatively small, semi-arid country with an area of 89,342 km2 (34,495 sq. mi) and a population numbering 10 million, making it the 11^{th} most populous Arab country (Jordan Department of Statistics, 2018).

Jordan has been classified by the World Bank as an “upper-middle-income” country, although the percentage of people living under the poverty line has reached 15% of the whole population. The Jordanian economy is one of the smallest economies in the region with a GDP of US$41.692 billion and a high percentage of poverty and unemployment. The Jordanian economy is divided into trade and finance, which account for almost one-third of the GDP, while the industrial sector represents 26% of the total GDP; manufacturing 16.2%; construction 4.6%; and mining 3.1%. The most promising in this sector is construction. Tourism is a cornerstone of total GDP, being a large source of employment, hard currency and economic growth. In 2010, there were 8 million visitors to Jordan (United Nations Development Programme, 2018). In the UN HLPE (2017) report, Jordan was described as highly urbanised with shortages in natural resources, moreover, the country lack in manufacturing and agriculture sectors, the main sector in the country is the service sector which makes the country's economy vulnerable to external impacts2.4.2 Jordanian Construction Industry

The construction industry is one of the most promising and important industries in Jordan and it is sensitive to changes in economic and social activity (Ministry of Planning and International Cooperation, 2017). As mentioned earlier, it makes a huge contribution to the country’s GDP and, according to Alkilani et al. (2013), the industry employed 20% of the total workforce in 2013. Al Momani (2000) indicates that the government in Jordan makes a big contribution to the construction sector in many different ways. Moreover, the Jordanian Construction and Contractor’s Association (2014) confirmed that the government invested 5 billion US dollars between 2012 and 2017 in different projects.

The Jordanian construction industry faces multiple major challenges, like any other developing country in the world. These problems and challenges include a lack of collaboration between parties involved in the industry, a skill shortage, a lack of safety in the work environment, the usage of old technologies and software, the failure to employ appropriate risk management techniques, and a huge shortage in various resources (Alshdiefat et al., 2013).

2.4.2 Sustainability in the Jordanian Construction Industry

As mentioned previously, the construction industry is one of the biggest sectors in terms of consuming resources and it has a huge impact on the environment. The same goes for the Jordanian construction industry. According to the Ministry of Energy and Mineral Resources (2017), the construction industry accounts for 40% of the energy used, 40% of the waste production, 38% of the GHC emissions, and 21% of the drinkable water. Moreover, Jordan imports 96% of its energy, with an estimated cost of 4.6 billion JDs (£4.23 billion). Also, in terms of water resources, Jordan is considered the fourth poorest country in the world (UN-Habitat, 2008). Therefore, the Jordanian government has been paying attention to sustainable development in general and sustainable construction in particular, in order to minimise pollution and improve energy efficiency.

According to (Lacave, 2021), sustainable and green construction principles are yet to be adopted in Jordan. Despite its economic and environmental benefits, the notion of sustainable building has failed to gain hold in the Kingdom. Many buildings in Jordan have the potential to be sustainable, yet they are not certified. It is difficult to obtain certification for the construction of a sustainable building in Jordan. In regard to (Lacave, 2021), Jordan is struggling to restructure its construction industry to be more sustainable due to a shortage of competent specialists as well as market restrictions such as poor customer demand and a lack of loan facilities.

Despite architects and contractors' deeper grasp of sustainability issues and its numerous benefits, Jordanian owners and developers are mostly unaware of the benefits of sustainability and prefer to neglect sustainability components of construction projects. (Salous, 2020) In Jordan, various challenges restrict the transition to a sustainable construction industry, the most significant of which are a lack of appreciation, reluctance to change, high starting costs, and a variety of other reasons that contribute to the absence of sustainable employment. In order to transition to the principles of sustainability, various solutions must be found and quick action must be taken. (Salous, 2020)

Jordan's construction industry is regarded as one of the most essential areas for boosting economic growth, since it provides jobs, employment, and money. Jordan's construction sector has grown considerably in recent years as a result of massive governmental expenditures and infrastructure projects. (ALI, H, S. F. NSAIRAT, 2009) These massive projects require and use enormous amounts of materials, water, and energy. Furthermore, they create vast quantities of items that are damaging to the environment and have long-term effects on the economy and society. As a consequence of the numerous issues that public works face, there is an increased demand from the public sector to include sustainability into its projects. These problems include a shortage of finances for public projects, population expansion, a scarcity of water resources, environmental issues, climate change, and greenhouse gas emissions from a variety of industries, particularly the building industry. (ALI, H, S. F. NSAIRAT, 2009)

According to Agenda 21 (Johannesburg Summit 2002), Jordan is a developing country with two major problems: a scarcity of natural resources such as water and an increase in environmental degradation. (UN, 2017) These issues are caused by Jordan's building operations, which are mostly responsible for pollution, dust, trash, and energy consumption. In truth, Jordan imports 97% of its oil and gas from other countries. This demonstrates that Jordan lacks the required resources to meet the economic demands of rising population. In light of this circumstance, and in response to rising energy prices and a scarcity of water, the government established a vision to push toward sustainable building in order to ensure the relevance of natural resources in Jordan's growth plan and to improve Jordanians' quality of life. (Al-Rashdan, D, et al, 1999)

Jordanian Green Building Council (Jordan GBC) was founded in 2009 to emphasize the relevance of environmental construction issues. (Alkilani, S.G, Jupp, J.R. , 2012) Jordan 2025: A National Vision and Strategy was released in 2015 as a 10-year socioeconomic framework for achieving national development goals. The plan outlines the possibilities, goals, and policies that Jordan intends to implement in order to support its green economy. In regard to Jordan’s

Way to Sustainable Development, Jordan primary priority is for environmentally sustainable building.

There are several issues confronting sustainability in construction, including a bad environment, a lack of skills and expertise, and insufficient economic levels. The notion of sustainability is very new in Jordanian society. (Abu-Ghazalah, 2008) This suggests that there is a shortage of adapting sustainable construction since Jordanians are more knowledgeable about old methods than about sustainable construction. Furthermore, Jordanian engineers have a broad variety of information about traditional building procedures and abilities that exceed what they have about sustainable practices. These difficulties might have a detrimental influence on the adoption of sustainability in construction, and hence the success of this type of construction. (Alkilani, S.G, Jupp, J.R., 2012). The following are some examples of barriers:

• The present public procurement and contract development procedure;

• A lack of rules and government assistance; (Friedrich-Ebert-Stiftung, Royal Scientific Society of Jordan and the, 2013)

• Higher initial cost as well as a long-term investment

• Professionalism, skill, and knowledge are lacking.

• Inadequate coordinated strategy and public funding;

• A scarcity of incentives and demand. (alnsour, 2012)

In this sense, there is no doubt that the Jordanian government has been trying to support and encourage the application of sustainability in the country, with particular attention to the construction industry. On the national level, the government has paid attention to sustainability, as according to the UN HLPE (2017) report, Jordan has made considerable economic, social and human development achievements over the past decades, investing significantly in infrastructure, human resources, and improving upon living standards. Jordan was one of the first countries in the region to try achieving the Millennium Development Goals (MDGs). The government's achievements in the first ten years were stunning: poverty was reduced massively, the mortality rates for mothers and infants under five were significantly lowered, and universal primary education was achieved (HLPE, 2017). Furthermore, Jordan is committed to the 2030 Agenda. The Government of Jordan opted to prepare its first Voluntary National Review and to present it at the High-Level Political Forum in the July 2017 session. Between 2012 and 2014, Jordan was heavily engaged at all levels in the global consultations for the development of the post-2015 agenda. Furthermore, Her Majesty Queen Rania Al-Abdullah was one of the 27 eminent world leaders who provided advice to the UN Secretary-General on the shape of the 2030 Agenda's framework (HLPE, 2017).

On the sustainable construction level, Jordan has ten LEED-certified buildings, three of which are LEED platinum, four of which are gold and three are silver. In 2009, a year after the 2008 financial crisis and the huge increase in prices, Jordan's national building code department, which is the department responsible for the development of the building code in the Ministry of Public Work and Housing (MoPWH), established a committee called the Jordan Green Building Guide (JGBG). The aim of this committee was to develop a green building rating system with the help of the construction and sustainable building centre (CSBC) at the Royal Scientific Society, with help from professionals in the private and public sectors.

The JGBG rating system was published in 2015 and it was developed based on the American rating system LEED and the British rating system BREEAM, taking into consideration the Jordanian construction industry's culture and respecting energy and water scarcity. It addresses:

- Sustainable sites
- Water efficiency
- Energy and atmosphere
- Materials and resources
- Indoor environmental quality
- Innovation in operations and regional priority (using local products)

Even though Jordan has its own established rating system, the Jordanian government did not make it mandatory. However, to promote this rating level, the government gave incentives to create sustainable buildings. For example, owners and developers who adopt the JGBG rating system will be entitled to an increase in the Floor Area Ration (FAR). The JGBG has four levels: Level A is entitled to a 25% increase in the FAR allowed, while for Level B this is a 20% increase, for Level C it is 15%, and for Level D is a 10% increase in the FAR allowed.

2.4.3 Risk management in the Jordanian Construction Industry

Jordan's construction sector is one of the most significant economic sectors due to the range and complexity of its sub-sectors. It has grown slowly over the previous years, since growth is driven by a variety of interconnected elements, the most significant of which are the overall political atmosphere, a secure investment environment, and enough infrastructure. There is no question that construction is an important industry in any economy; it impacts and is impacted by a country's gross domestic product (GDP) (Cox & Townsend, 1998). Construction projects are difficult and time-consuming endeavors. Projects must be developed in compliance with applicable rules and standards, culminating in working drawings and specifications that define the work enough for completion in the field. The construction sector requires good business processes to be used.

The numerous variables and complicated linkages that exist between factors that must be considered in the process, coordination, and usage of various types of labor skills, materials, and equipment utilized to construct a project necessitate the daily use of effective business procedures. Bethke (2003). When risk management is implemented early in the project, it helps to increase the degree of trust in the project and the information accessible to all stakeholders.

As a result, risk management assists project owners in anticipating potential difficulties and taking the required procedures to avoid or at least mitigate their influence on project objectives. In Jordan, there are various hurdles and difficulties to risk management in construction organizations that prohibit consulting and contracting firms from implementing risk management in projects.

Looking back at the history of Jordanian construction industry and the number of projects that were suspended during construction or experienced problems with cost and schedule overruns, as well as some of the reasons for project failure, there is evidence that the concept of risk management is neglected during the planning phase of these projects. In Jordan, the total number of businesses working in the construction industry sector registered in the three chambers of industry (Amman, Zarqa, and Irbid) in 2014 amounted to 2842, compared to 2980 in 2013. (Gharaibeh, 2019)

There are various facts concerning the state of risk management procedures in Jordanian construction projects. Despite the fact that the Jordanian construction market is relatively small and experiencing several challenges and problems, the Jordanian contractors and consultants have an acceptable level of knowledge of the risk management concept; However, the inability to connect the use of risk management with important project objectives and the challenge of defending the value contributed by using risk management techniques in construction are the reasons for the lack of use of this concept in construction projects. (Gharaibeh, 2019)

In order to anticipate and manage risks throughout the project life cycle, the use of risk management often required resource allocation and specific project teams. When the project team in Jordan is busy with project responsibilities and everyday project work, it is typically tough to do this. Therefore, clients should promote the use of risk management by allocating enough resources and funds to be used in this process as well as increasing awareness among project stakeholders about the value of risk management to construction contractors and consultants in order to improve the application of risk management in construction. This what prevent many stakeholders from paying attention to the risk management issues. (Gharaibeh, 2019)

Furthermore, it is critical that leadership, not just the project team, supports and buys into the risk management approach, and that what can be consider absent in some way in Jordan. If Jordan truly adopted risk management, it would have a number of advantages, the most significant of which is improved and enhanced communication among project stakeholders, which will benefit the project and promote project success. It can also prevent project delays and cost overruns by using risk management at the very beginning of the project's development. (Gharaibeh, 2019)

Through effective risk management, Jordan may create a mitigation strategy to deal with these risks, avoiding these issues altogether or at least reducing their negative effects on the project. Due to the complexity of the projects themselves, the technical difficulties that may cause significant schedule delays, cost overruns, and occasionally problems with quality and performance, risk management is a crucial procedure in the construction industry. The use of risk management aids in addressing these issues at the project's early phases and developing a mitigation strategy to address them if they materialize with the least amount of expense and effort. (Gharaibeh, 2019)

2.5 Risk Resources

This section demonstrates the secondary data collection done as part of the literature review. It describes how the data were collected and analysed, and finally displays the results in the two tables in appendices 13 and 12.

This research investigates the risks faced within construction projects, particularly sustainability-related risks, while focusing on the Jordanian context. It drew insights from the resemblance that common sustainable construction risks had with a number of leading sustainability standards such as LEED, BREEAM, GSAS, and ESTIDAMA. In addition, further reference was made to the key principles of UN sustainable goals (SDGs) and EIA reports, in order to form the basis of a thorough research identifying key sustainability-related risks.

2.5.1 Data Collection

The data collection was done by critically reviewing different tools used in the industry to achieve sustainability, like rating systems and EIA, with the key principles of the UN sustainable goals (SDGs) and other literature discussing the concept of sustainability-related risks.

To achieve triangulation in the sources of the identified sustainability-related risks, firstly, the research studied the rating systems, and compared and analysed them as discussed in section 2.3.3.1. Secondly, the research studied the UN SDGs that concerned sustainability and construction. The third set of data was collected from the EIA reports, which considered more than one report widely in the general world, as described in section 2.3.3.2. Finally, other authors, papers and researchers who highlighted the construction industry's effects on the environment and humans around us have been considered.

2.5.2 Data Analysis

The triangulation of the data analysis resources for sustainability-related risks was accomplished by having at least three main reference or resources for the identified hazards.

For example, the first group (natural resources) is associated with two risks: the excessive use of raw materials, and the excessive consumption of both renewable and non-renewable resources. It can be seen that both risks are mentioned in different leading sustainability standards such as LEED, BREEAM, GSAS, and ESTIDAMA, and also the UN sustainability goals mentioned them both in goals 7.1, 7.2, 7.3, 7a, 7b and 12.2. In addition, the excessive use of raw materials has been mentioned by four authors and the excessive consumption of renewable and non-renewable resources has been mentioned by six authors, as discussed in different EIA reports.

The two tables in appendices 12 and 13 show how the researcher collected, compared and analysed the data in order to produce the sustainability-related hazards list for the developed model. In the first table, the hazards are listed in the first column and they are categorised under: Socio-economic Conditions; Public and occupational health; Impact on the ecosystem; Air quality; Soil; Water; Waste management; Chemicals or hazardous materials; Biodiversity; Managerial; and Impact on natural resources. The second and third columns show the sources where the risk is mentioned, either rating systems, the UN goals, or both. While the second table presents the same hazards and their categories compared with EIA and other literature review data.

2.6 Conclusion

This chapter gave a historical overview of sustainability, starting from the history of World War II to the 2000s. Several definitions of sustainability were given, which varied with the changes of the era that required changes in definitions. The dimensions and principles of sustainability were enumerated, and sustainability in the construction industry was discussed. As for the definitions of sustainability, a brief historical overview of the evolution of these definitions over the ages has been given. In addition, the most important challenges facing sustainable construction and the most important tools that can be used in the suitable development concept have been identified. Among the issues that were explained in the chapter are sustainability rating systems, EIA, risk management, and risk resources. In this chapter, the construction industry in Jordan was discussed, in addition to several issues related to the Jordanian construction industry, including the concept of sustainability in this industry. All this led to the conclusion that Jordan has begun to move towards sustainability in its construction industry, but it is considered to be in its infancy and it has not yet been made mandatory. Furthermore, the application of sustainability in this industry faces many challenges. There are 89 sustainability-related risks that may affect the environment and humans, as well as many potential impacts on natural resources. However, there are many solutions, agreements, and regulations that will help mitigate these risks. This may lead us to employ risk management in the context of sustainability, which will be discussed in the next chapter.

Chapter Three

Chapter Three: Risk Management in the construction industry context

3.1 Introduction

This chapter will discuss risk management and the risk management process. The risk management process section will delve deeper into the process's various steps, which include risk identification, risk analysis, risk response, and risk monitoring. Under the risk analysis section (quantitative and qualitative analyses) different risk analysis methods will be discussed, such as; the Bayesian method (BM), Analytic Hierarchy Process (AHP), Decision method, Decision Tree Analysis, The Expected Monetary Value (EMV), Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), Monte Carlo Method, Programme Evaluation and Review Technique (PERT), Scenario Analysis, Sensitivity Analysis, Fuzzy Logic and Break-Even Analysis. Also, this section will explain the chosen methods. The following sections will discuss risk management in the construction industry, project phases, risks in project phases, and risk treatment in the construction industry.

In our fast-moving world, we come across many risks and uncertainties every day, in professional as well as social life. These risks and uncertainties can have a small impact, such as being late for a meeting, or they can have a huge impact that might force companies to go out of business without previous warning. They not only affect the risk management of projects but are also part of people's daily decision-making processes. Sometimes these decisions are easy and based on common sense, and sometimes they are more complicated; whichever, it is safe to say that our lives are an endless circle of decision making.

However, before going through the risk management process in detail, there are some basic concepts and definitions, linked directly to both risk management and decision making, that need to be clarified. These are hazards, risks, certainty, and uncertainty. A hazard is an undesirable outcome in the process of meeting objectives, performing a task, or engaging in an activity. According to the Oxford Dictionary, the risk is the chance or the possibility of losing or the counter consequences. Cooper and Chapman (1985) also defined risk as the possibility of physical damage or injury, financial loss, or delay as an impact of uncertainty associated with an action. The PMI defined risk as "an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives" (PMBOK® Guide; PMI, 2017 P.397). Wideman (1986) described risk as the possibility or the chance of an action affecting a project in a negative way. Godfery (1996) also defined risk as the possibility of an adverse event, depending on the circumstances.

In the decision-making process, certainty, uncertainty, and risk are directly connected to each other and must be explained together to be understood. Certainty is the state where all the factors affecting the decision are defined and quantified and the decision-making process will result in a predictable outcome. On the other hand, this is hardly the situation in life or in construction projects and it can only happen in a closed system. In regular life situations and construction projects, one or more factors are usually undefined and decision making will be done under risk or uncertainty. A decision that has been taken under conditions of risk is a decision that the decision-maker has made rationally with a degree of certainty based on previous data and history of similar situations. To understand this properly, let us take the example of a decision-maker who needs to estimate the cost of the steel structure of a building based on his previous experience and available data. if such data and information were not available and the estimator did not have related previous experience, then the decision will be made under a degree of uncertainty and risk.

Another concept that needs to be understood is risk exposure, which is the mathematical way to quantify how much an event of risk can affect the construction project. According to all the previous definitions of risk, there are two independent factors or components of risk: consequences or risk impact, and risk probability. The impact of a risk can be financial loss, quality loss, time loss, or even casualties and deaths. However, the data are not always available to calculate the risk quantitatively, so a qualitative evaluation is usually made to characterise the risk consequences or impact as low, medium, or high.

Risk probability is exactly the same as any other mathematical probability of an event – it is a random value and we can use mathematical methods to find the mean, dispersion, and all the other parameters. These values depend on previous relevant data about similar risks; however, as with risk impact, it is not always easy to find previous data, so it will depend on the availability of the data and the experience of the decision-makers. Risk probability will have an estimated value from 0 to 1. In conclusion, the risk exposure is the risk impact multiplied by the risk probability (Risk = Probability × Impact) (Carter et al., 1994).

Applying risk management from the early stages of a project and upgrading them phase by phase during the construction process will help to discover these risks and uncertainties, meaning that they can then be managed and controlled. This will help any construction project to be delivered with four main targets, which are time, cost, quality and sustainability.

3.2 Risk Management Process

According to Flanagan and Norman (1993. p.2), “Risk management is a discipline for living with the possibility that a future event may cause adverse effects”. Risk management is a process to ensure that everything has been done to guarantee that the objectives of the project are met, taking into consideration the project limitations and constraints (Clark et al., 1990). According to Wu et al. (2014), risk management is the process of identifying, analysing, and either accepting or mitigating the risks. When a project starts to experience problems and show failures in the process, everyone needs an answer from the project manager. This shows that risk managers have a huge effect on the delivery of a project with respect to its objectives (Tsiga et al., 2017). Good risk management will maximise the effect of positive events and minimise the negative events, thus increasing the chance of delivering the project targets (Szymański et al., 2017). The Project Management Institution (PMI) describes the risk management process as risk management planning, risk identification, qualitative risk analysis, quantitative risk analysis, risk response planning and implementing, and risk monitoring and control for a project (PMBOK® Guide, PMI, 2017). According to Smith (1999), risk management is a continuous process and has to be done in every phase of a project.

Theoretically, risk management is a simple process, consisting of a few general steps to identify the risks, assess and manage them. However, these steps are different from one researcher to another. According to Perry and Hayes (1985), risk management is a linear process consisting of only three steps, as shown in Figure 3-1:

1. Risk identification: the step where all the risks are identified.
2. Risk analysis: assessing the identified risks and measuring their probability and impact.
3. Risk response: taking action on the risks identified in step 1.

Figure 3-1: Perry and Hayes (1985) Risk Management Steps

According to this process, risk management is a sequence consisting of identifying the risks and managing them. However, many other researchers have proposed that it is a cyclical process because every risk that is responded to might produce a new risk that needs to be identified, analysed, and responded to, making it a cyclical process. For example, other authors such as Chapman (1997), as shown in Figure 3-2, have proposed a cyclical process consisting of 9 steps as follows:

1. Define: the first step is to define the project and find all the relevant information about the project.
2. Focus: provide a strategic risk management plan at the operational level.
3. Identify: identify all the risks.
4. Structure: test the assumed risks from the step before.
5. Ownership: agree on the ownership of the risks between the client and the contractor.
6. Estimate: identify the areas of risks and uncertainties.
7. Evaluate: measure the risks according to the previous steps.
8. Plan: the plan should be ready to be applied.
9. Manage: this is where the action on the risks will be taken and the risks will continue to be monitored.

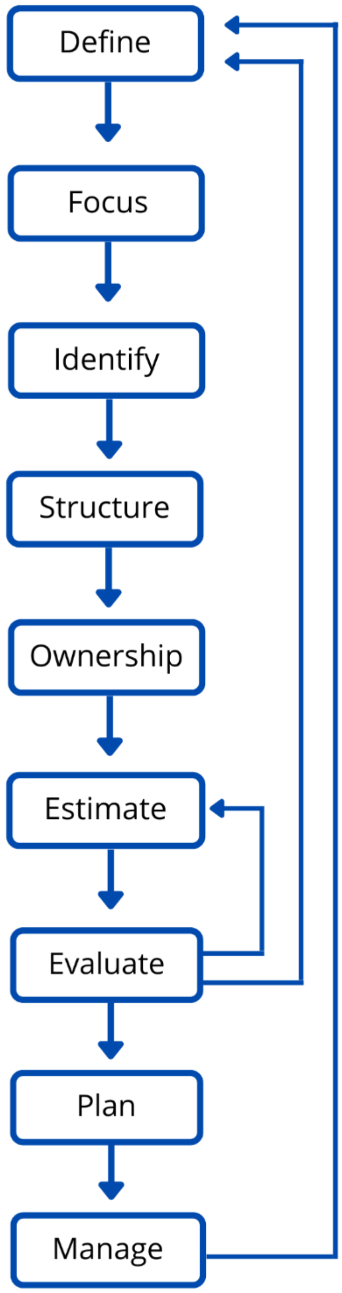

Figure 3-2: Chapman (1997) Risk Management Steps

According to Cartel et al. (1994), risk management is a cyclical process consisting of six steps, as shown in Figure 3-3:

1. Risk identification and documentation: the step where all the risks become known.
2. Risk quantification and classification: assessing the identified risks and measuring their probability and impact.
3. Risk modelling (Risk analysis): measuring the risks according to the previous steps.

4. Risk reporting and strategy development: planning the action that will be taken in the next step.

5. Risk mitigation, reduction, and optimisation: this is where the action on the risks is taken.

6. Risk monitoring and control: keep monitoring and reporting in case anything changes, or new risks appear.

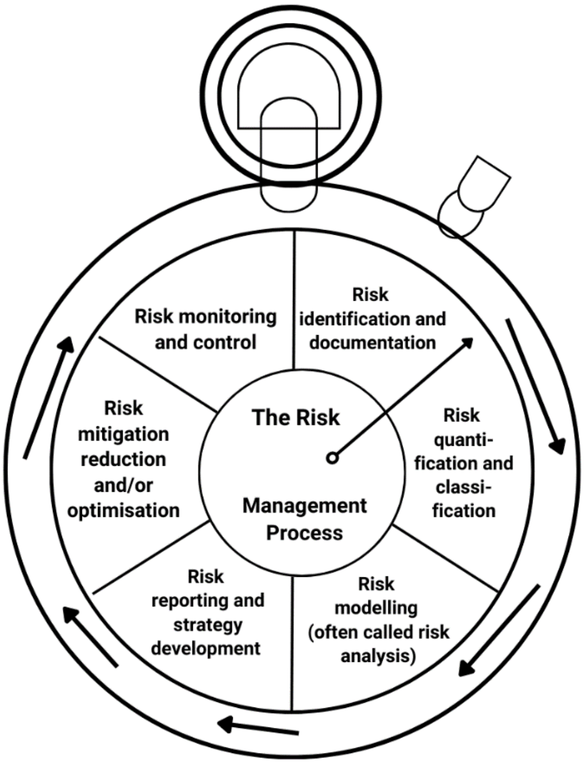

Figure 3-3: Cartel et al. (1994) Risk Management Steps

Kliern and Ludin (1997) divided their risk management model into four phases as shown in Figure 3-4 below:

1. Risk identification: the step where all the risks become known.

2. Risk analysis: assessing the identified risks and measuring their probability and impact.

3. Risk control: taking the appropriate action on the risks measured previously.

4. Risk reporting: keep monitoring and reporting in case anything changes or new risks appear.

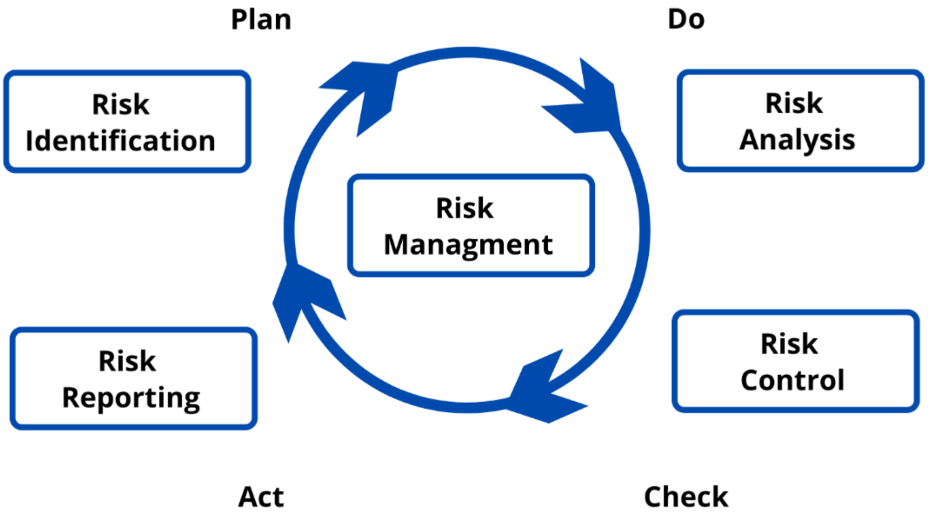

Figure 3-4: Kliem and Ludin (1997) Risk Management Steps

All the risk management processes discussed above appear relatively similar. In general, it can be concluded that the main steps of a risk management process are: risk identification, risk analysis, risk responses, and risk monitoring. Other steps that have been suggested can be considered as sub-steps and combined under the main four steps. In this study, as shown in Figure 9 below, the risk management process that was adopted is a cyclical process consisting of the four major phases:

1. Risk identification: the step where all the risks are identified.
2. Risk analysis: assessing the identified risks and measuring their probability and impact.
3. Risk response: taking the appropriate action on the identified risks.
4. Risk monitoring: keep monitoring and reporting in case anything changes, or new risks appear.

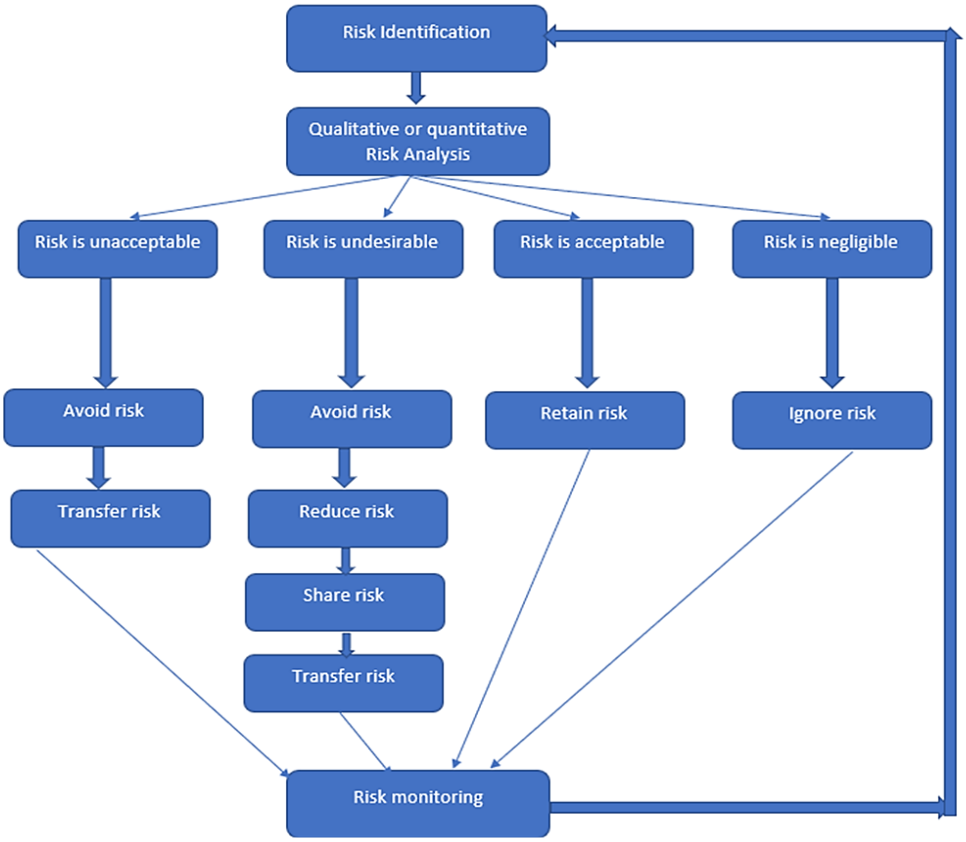

Figure 3-5: Proposed Risk Management Process

3.2.1 Risk Identification

According to the PMBOK® Guide, risk recognition and identification must be done as a proactive step so that risk managers can assess risks and deal with them. Unless risks are recognised and defined, they can never be dealt with. On the other hand, it is impossible to define risks completely. From this, the importance of risk management becomes clear, as it is based on covering the basic risks comprehensively. The process of defining risks in the construction industry is either forward-looking or in line with the project's steps and stages. The initial risks may be clear in the early phases of the project, and other unexpected and expected risks may appear during implementation (PMI, 2017). The possible risks must be identified at the initial stages of a construction project and that they are recorded in a planned manner. Hence, these risks must be visible and accessible to everyone involved in the construction project (Lock, 2013). To compile this risks list, the sources of the risk, the risk itself, and the impact of the risk on the project have to be identified. This step is heavily reliant on the experience of the decision makers involved in this process, as well as the availability of previous data from similar projects. However, in the absence of appropriate methods and techniques, risk managers may overlook some significant risks that could jeopardise the project. To identify risks, various techniques such as brainstorming, interviews, questionnaires, the Delphi technique, expert system, etc. are used in this step (Lock, 2013).

This research used a critical review of the available literature as well as other well-known resources like the UN SDGs, rating systems and the EIA. These were used to identify the sustainability-related risks associated with the construction industry involving the environment and humans, as mentioned in the previous sustainability chapter (section 2.5). A total of 89 sustainability-related risks were identified in the suggested risk assessment model of this research. Then a focus group was conducted on the 89 risks to identify the risks that affect the construction industry, in Jordan in particular.

3.2.2 Risk Analysis

The goal at this stage is to arrange the risks in order of priority by describing the risks accurately and completely. Once the first step is completed and all risks are identified, the next step in the process is to evaluate them individually to determine their impacts or consequences, as well as the probability of their occurrence. This is a critical and accurate step because it will show who these risks may affect and categorise them based on their importance. In this stage, those identified risks are investigated in terms of their probability of occurrence and how they affect the project. The causes of the risks, and their importance and severity must be analysed and evaluated.

According to the PMBOK® Guide (PMI, 2017) risk analysis can be qualitative, quantitative, or a combination of both. Using the right method for risk assessment depends on many factors, such as the size of the project, the time and the money available for risk management, and the availability of the information. This is due to the extra cost and time involved in quantitative analysis.

The relationship between risks and various other factors within the project must be understood. There are risks that can completely halt project work, and there are risks that only add minor inconveniences to the project's work stages.

In this research, the risk assessment model used both qualitative and quantitative methods to analyse the sustainability-related risks. In the qualitative part, a risk matrix was created using a questionnaire distributed in Jordan, while the quantitative part of the model used a Bayesian Belief Network (BBN) and The Analytic Hierarchy Process (AHP) to analysis the risk.

3.2.2.1 Qualitative Risk Analysis

A general rule for assessing a risk is to multiply the probability of its occurrence by the impact or the consequence, whatever it is a qualitative or quantitative method. While the qualitative methods are easier to produce, easier to understand and less complicated, they are only applicable to small projects that do not need accurate results or numerical results. This method does not work with complicated projects since it is not that accurate (Lock, 2013).

Risk = Probability × Consequence

Once the risks are identified in the last step, they should be described and categorised into groups in the risk register, according to their sources (Patterson & Neailey, 2002). This will help to assess the risk. According to Godfrey (1996), these categories can be political, environmental, planning, financial, economic, etc.

After the risks are identified and since there are no accurate numerical numbers to describe risk in qualitative analysis, the consequences of the risks and their probability will be given numbers from 1 to 5. For consequences, 1 stands for minor effects and 5 for catastrophe, while for probability, 1 is rarely and 5 is certain. Depending on the results, the risk response will then be chosen.

3.2.2.2 Quantitative Risk Analysis

Quantitative methods are more accurate, and the results are numerically presented, which makes these methods better for complicated projects. However, carrying out a quantitative risk analysis is not required for every project; it requires specific risk analysis software and experience of developing risk models. In addition to consuming extra time and cost, it is usually used for large, complex and strategically important projects (PMI, 2017). As previously mentioned, the main difference between qualitative and quantitative analysis is the available highly accurate data that lead to accurate results, which can show how much the risk will cost in terms of time, money, quality or the effect on the environment.

The PMBOK® Guide (PMI, 2017) shows the most commonly used and best-known risk management techniques. Most of the techniques mentioned in the book are quantitative methods such as Programme Evaluation and Review Technique (PERT), Failure Models and Effect Analysis (FMEA), Fault Tree Analysis (FTA), and Risk Matrix, among others.

3.2.2.3 Example of Risk Analysis Methods Used in Different Industries

This section will describe, compare and analyse the most widely used methods for risk management in the construction industry and others. Most of them can be considered qualitative or quantitative, depending on the accuracy of the data available.

(1) Bayesian Method (BM)

In recent years, the Bayesian method (BM) seems to have attracted interest from researchers due to its ability to solve complex model systems. This theory was developed by Thomas Bayes in the 16th century (1701–1761). Bayes' theory was introduced for the field of statistics and mathematics but it has also been used for a long time in other fields for data analysis and risk management (Ferson, 2005). It works on the factorisation of variables' joint distribution based on conditional dependencies. The main objective of BM is to compute the distribution probabilities in a set of variables according to the observation of some variables and the prior knowledge of others (Weber et al., 2012). Furthermore, details of this method will be presented in the model development chapter, as it is one of the chosen methods for the proposed model.

(2) Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method that was introduced and developed by Thomas L. Saaty in 1980 while he was working for the US Army. It is an efficient tool for decision makers to help them deal with complex decision making by setting priorities for the alternatives and reducing the complex process to pairwise comparisons (Bhushan & Raj, 2004). According to Emrouznejad and Marra (2017), AHP is flexible, straightforward, convenient, and instinctive for decision makers. Also, it decreases the bias of the decision-making process by checking the consistency of the alternatives. And it is helpful where there are uncertainty and risk. Additionally, extra details of this method will be presented in the model development chapter, as it is one of the chosen methods for the proposed model.

(3) Decision Method

This is one of the simplest and easiest methods to use in decision making. It was introduced by Pugh (1981) and it is a graphical method that presents the values in columns and rows. It can be either a qualitative or a quantitative method. It has been known by many names, for example, risk matrix, decision grid, prioritisation matrix, problem matrix, Pugh matrix and Pugh method (Barringer, 2008). There are two types of decision matrices: the basic matrix and the weighted matrix. The former consists of establishing a set of criteria options that are scored and summed in order to gain a total score that can then be ranked. Importantly, it is not weighted to allow a quick selection process. The weighted decision matrix operates in the same way as the basic decision matrix but it introduces the concept of weighting the criteria in order of importance (Abdollah et al., 2015).

(4) Decision Tree Analysis

This is a type of statistical method represented in a graphical way for decision making under special conditions. It is used to decide if the decision made under the special condition is the ideal decision or not (Mittal et al., 2017). Moreover, it can be used to scale the decision after it has been made by observing its impact under assumed conditions, which can provide a picture of what to expect in similar situations in the future (Olivas, 2007). Decision tree analysis, as the name suggests, has a tree-like structure. Basically, it displays an algorithm under given conditions. Many sequential problems and their effects are considered before making a decision. In other words, it is a type of flowchart in which each point denotes a test and its corresponding result (Dey et al., 2012).

(5) Expected Monetary Value (EMV)

This is a mathematical-statistical method that gives the outcome of seniors depending on the probability and impact of the risk. It is an easy method that gives the total senior for positive and negative results (PMI, 2017). The expected monetary value is used to quantify the risks and it usually works on the financial part of risks. This technique is used in medium- to high-cost projects where there are sufficient resources and the failure of the project cannot be risked because the stakes are high. The EMV can be calculated using the equation below:

EMV = $\sum_{n-1}^{n} value_n \times probability_n$

Once the EMV of each identified risk is calculated individually, the total EMV of the project can be calculated by adding all the EMVs of all the risks together, regardless of whether they are positive or negative (Costa, 2016).

(6) Failure Mode and Effect Analysis (FMEA)

Failure modes and effects analysis (FMEA) is a methodology in product development and operations management for the analysis of potential failure modes within a system; failures are classified by their severity and likelihood (Snee & Rodebaugh, 2008). A successful FMEA activity helps a team to identify potential failure modes, based on past experience with similar products or processes. Failure modes are any errors or defects in a process, design, or item, especially those that affect the customer, and they can be potential or actual (Ambekar et al., 2013).

(7) Fault Tree Analysis (FTA)

This method was first developed for the US Army in 1962. Fault tree analysis (FTA) is a top-down approach. It provides a graphical representation of the events that might lead to failure, and it is another well-established and well-understood technique, widely used to determine system dependability (Vesely et al., 1981). In fault trees, the logical connections between faults and their causes are represented graphically. FTA is deductive in nature, meaning that the analysis starts with a top event (a system failure) and works backward from the top of the tree towards the leaves of the tree to determine the root causes of the top event. The results of the analysis show how different component failures or certain environmental conditions can combine to cause the system to fail. After the construction of a fault tree, the analyses are carried out on two levels (Ortmeier & Schelhorn, 2006). The FTA method consists of the following steps: first define the top event or the primary event, which is the failure condition for the study. Secondly, create the limits of the FTA. Then inspect the system to check if the elements relate to each other and to the primary event. The fourth step is to construct the fault tree, and analyse the fault tree to eliminate the events that cause failure. Finally, a corrective action plan is created for preventing failures and a contingency plan is used to deal with failures when they occur.

(8) Monte Carlo Method

This is an old method used for the atomic bomb in World War II but it did not become widely used until the spread use of computers and software. It also depends on probability and statistical laws and huge distributions of random numbers (Vose, 2008). A Monte Carlo simulation is a computerised mathematical technique that allows people to account for risk in quantitative analysis and decision making. The technique is used by professionals in such widely disparate fields as finance, project management, energy, manufacturing, and engineering. Three steps are required in the simulation process: the first step is sampling random input variables X, then evaluating model output Y, and finally statistical analysis on the model output.

(9) Programme Evaluation and Review Technique (PERT)

This is software used for scheduling and organising tasks in a project but the availability of entering different probabilities for different tasks makes it a risk assessment method. PERT clearly illustrates task dependencies (ADEAK, 2011). A PERT chart presents a graphic illustration of a project as a network diagram consisting of numbered *nodes* (either circles or rectangles) representing events or milestones in the project, linked by labelled *vectors* (directional lines) representing tasks in the project. The direction of the arrows on the lines indicates the sequence of tasks. These are called *dependent* or *serial* tasks. Other tasks are not dependent on the completion of one to start the other and they can be undertaken simultaneously. These tasks are called *parallel* or *concurrent* tasks. Tasks that must be completed in sequence but that do not require resources or a completion time are considered to have *event dependency*. These are represented by dotted lines with arrows and they are called *dummy activities*. Numbers on the opposite sides of the vectors indicate the time allotted to the task.

(10) Scenario Analysis

Scenario analysis has various practical applications, including risk management, strategy, and planning. It mainly concerns the financial part of the project by predicting different scenarios for the project and seeing what the results will be. It can also be used to monitor the project (Maack, 2001). To conduct scenario analysis, the first step is to define the risk or issue, then recruit a team with appropriate skills to analyse the scenario. The factors affecting the risk are identified, then the data/information needed is obtained and reviewed. After that, a methodology is developed for how to technically answer the questions. The results of the analysis are documented, making all assumptions and how they were derived explicit. Later a peer-review process is set up for verifying the model (Tourki et al., 2013).

(11) Sensitivity Analysis

Also known as the "what…if" method, it can be used as a quantitative or qualitative method depending on the inputs of the model. Sensitivity analysis has been used in different fields from economics and biology to engineering, but the most important use of this method is in decision making and model development. It analyses how different values for independent variables can affect the dependent variables under specific conditions. In other words, it analyses how sensitive the system is by measuring how much the output will change by changing one input (PMBOK, 2013). The procedure of this method consists of four steps, starting from determining the uncertainty of each input of the system, then identifying the most important outputs of the model. After that the model is run several times with different inputs, finally calculating the sensitivity of the model by using the results obtained from the model.

(12) Fuzzy Logic

The concept of fuzzy logic was first introduced in the 1965 part of the fuzzy set theory by Dr. Lotfi Zadeh at the University of California while working on computers understanding natural language similar to human thinking. The computer binary system uses either 1 or 0 to state the fact or the truth about anything, but in real life, the choices are not always 1 or 0; the truth in most cases is somewhere between 1 and 0 (Abdelgawad, Fayek, 2010) in fuzzy logic, 1 and 0 are the extreme answers, but usually, it is not tall or short, cold or hot; the answer could have a degree of truth ranging between 1 and 0, for example, 0.33 tall or 0.75 hot.

In the risk assessment process, fuzzy logic consists of three steps. The first is fuzzification, which is the transformation of the real variables to a linguistic variable; these linguistic variables will be none, very low, low, medium, high, or very high risk. Then there is fuzzy inference, which is the way that the fuzzy logic system performs. It uses a set of rules such as <When> and <Then> on a linguistic level. The statement using these rules can be seen as

<When> Input a <And> Input b … Input x <Or> Input y … <Then> Output. Finally, there is defuzzification. This step is the last step of the fuzzy logic, which is the transformation of the result of the fuzzy interface output variable to the final answer of the existence of the risk.

(13) Break-Even Analysis

Also known as cost-volume-profit analysis, it has been used by project managers to manage projects by showing the relationship between cost, production volume, and profit (Richards, 2001). Traditional break-even analysis is a relatively common managerial tool used for a wide variety of purposes for nearly all types of decision making. Break-even analysis (sometimes called profit contribution analysis) is an important tool that allows comparative studies between costs, revenues and profits. It is typical to graphically depict break-even as the point where a firm's total cost and total revenue curves intersect. This is the sales point where both variable and fixed costs are covered by the sales volume for the relevant range. If the break-even point is not achieved, that business will (or should) eventually go out of business (Casavant et al., 1984).

To do a break-even calculation on a product, first, determine the cost of the product. Then determine the average selling cost. After that, subtract the result of the first step from the second, which gives you your profit per unit. Then determine the total investment required for that product. And finally, divide the result from the third step into the fourth. The result is break-even.

Table 3-1 below provides a summary of the above risk analysis methods.

Table 3-1: Risk Analysis Methods

Method	Structure& use	Example	Advantages	Disadvantages
Bayesian Method (BM)	* probability distribution method * quantitative method	1- Risk assessment of oil refineries (Mkrtchyan et al., 2022). 2- Probabilistic data analytics for predicting and understanding breast cancer survival (Dag et al., 2022). 3- Mapping forest restoration probability and driving archetypes using BBN and SOM (Peng et al., 2022).	1- Addresses uncertainty with regard to other available data. 2- Can be used in data mining. 3- Takes subjective information and can work without data. 4- Can help with decision making and is natural and rational.	1- Prior distribution 2- Zero preservation.

Analytic Hierarchy Process (AHP)	* structure: network * quantitative method * decision making	1- Flood hazard mapping using GIS and AHP (Antony et al., 2022). 2- An AHP model for multiple-criteria prioritisation of seismic retrofit solutions in gravity-designed industrial buildings (Andreolli et al., 2022). 3-Prioritisation of resilience criteria and performance indicators for road emergencies crisis response (Aziz et al., 2022).	1- Flexible, straightforward, convenient, and instinctive. 2- Has the ability to check inconsistencies and it decreases the bias. 3- Decomposes the decision problems into their basic components and builds hierarchies of criteria, which show the importance of each component by pairwise comparisons.	1- A misleading ranking. 2- A high number of pairwise comparisons (n (n−1)/2).
Decision Method	* structure: graphical method * qualitative or quantitative * decision making	1- Design of an impact attenuator for passive safety on roads using Pugh matrix (Montaleza et al., 2022). 2- A single centre multi-modality plan comparison and clinical decision matrix for nodal oligometastatic disease (Jackson et al., 2018). 3- The selection and verification of kenaf fibres as an alternative friction material using the weighted decision matrix method (Abdollah et al., 2015).	1- Simple to use and complete. 2- Evaluates all events and how each one will impact the overall performance. 3- Has the ability to assign weights and scores to criteria.	1- Overlooks the real problem by concentrating on details of little significance. 2- Its assignment of weights and scores is subjective and sensitive analysis is necessary to support decisions.
Decision Tree Analysis	* structure: graphical method * qualitative or quantitative * decision making	1- Financial management risk control based on decision tree algorithm (Li et al., 2022). 2- Representing and analysing sequential satellite mission design decisions through anisomorphic trees and directed graphs	1- Its explicit nature and transparency. 2- It sets out all the available alternatives clearly, making it possible to trace each alternative to its conclusion. 3- It is a graphical method that can be understood easily.	1- Its instability 2- Time consuming to build

		(Short et al., 2022). 3- The ability of decision tree analysis in real-time practical fault management to detect a gearbox fault (Saimurugan et al., 2015).		
Expected Monetary Value (EMV)	* structure: network * qualitative or quantitative * decision making	1- Minimising lost circulation non-productive time using expected monetary value and decision tree analysis (Alkinani et al., 2021). 2- Risk evaluation of the use of the umbrella contract for the construction project for medium voltage distribution in South Surabaya Region using the expected monetary value (Purnomo et al., 2021). 3- Decision criteria in production strategy selection for petroleum field development (Santos et al., 2017).	1- It gives you an average outcome of all identified uncertain events. 2- It helps to select the best decision with a back-up of objective data. 3- It helps with a make or buy decision during the procurement planning process. 4- This technique does not require any costly resources, only experts' opinions.	1- Affects the final outcome by missing the inclusion of positive risks. 2- This technique involves expert opinions; therefore, personal bias may affect the result.
Failure Mode and Effect Analysis (FMEA)	* structure: network * qualitative or quantitative * decision making	1- Failure mode and effect analysis (FMEA) to identify and mitigate failures in a hospital rapid response system (RRS) (Ullah et al., 2022). 2- Modified failure mode and effect analysis to mitigate sustainable related risk in the palm oil supply chain (Anugerah, 2021). 3- A prioritisation model for HSE risk assessment using combined failure mode and effect	1- FMEA provides the designers with an indication of the predominant failures that should receive considerable attention while the product is being designed. Also, it can track product failure modes, their causes, and effects, which provides extremely valuable knowledge for future product and process design, so actions can be taken to eliminate or reduce project failures.	1- FMEA is time consuming and it is very hard to trace failure through FMEA charts. In addition, the relationship between different failure components is disregarded.

		analysis and a fuzzy inference system in the Iranian construction industry (Ardeshir et al., 2018).		
Fault Tree Analysis (FTA)	*structure: network * qualitative or quantitative * decision making	1- Analysis of the impact of a pandemic on the control of the process safety risk in major hazards industries using a Fault Tree Analysis approach (Ashraf et al., 2022). 2- Safety evaluation of leak in a storage tank using fault tree analysis and risk matrix analysis (Ikwan, 2021). 3- A risk analysis model for mining accidents used a fuzzy approach based on FTA (Yasli & Bolat, 2018).	1- It is a graphical method. 2- It is easy to read and understand, and it can quickly show the critical paths. 3- It can handle a combination of failures. 4- It exposes the need for control or protective actions to diminish the risk.	1- Fault trees may become very large and complex. 2- It requires detailed knowledge of the design, construction, and operation of the system. 3- It is a time-consuming method. 4- It is not practical on systems with large numbers of safety-critical failures.
Monte Carlo Method	* structure: simulation * quantitative * decision making	1- Life-cycle oriented risk assessment using a Monte Carlo simulation (Züst et al., 2022). 2- Reliability analysis of thermal error model based on DBN and Monte Carlo method (Liu et al., 2021). 3- Construction dust-induced occupational health risk was assessed using Monte-Carlo simulation (Tong et al., 2018).	Monte Carlo simulation is flexible and easy to change. Changes in the system variables can be made to select the best solution among the various alternatives. Simulation is best suited to the analysis of complex and large practical problems when it is not possible to solve them through a mathematical method. Finally, in the simulation, the experiments are carried out with the model without disturbing the system.	It takes a long time to develop a good simulation model, and in certain cases simulation models can be very expensive. Another disadvantage is that simulation does not always generate optimal solutions.

Programme Evaluation and Review Technique (PERT)	* structure: network * qualitative or quantitative * decision making	1- Project evaluation and review technique (PERT) analysis in the renovation project of the Church of St. John the Evangelist, Jakarta (Mariana, 2021). 2- Construction service project scheduling analysis using Critical Path Method (CPM), Project Evaluation and Review Technique (PERT) (Yuliarty, 2021). 3-A probabilistic model for application to investment cash flows using PERT (Velasco et al., 2018).	1- It gives the project manager information about the likelihood of completing a project on time and on budget by viewing PERT activities and events independently and in combination. 2- Through department coordination, PERT analysis improves planning and decision making by integrating and presenting data from multiple departments. 3- The What-if analysis in PERT requires that project activities be sequenced in a network under a set of rules specifying critical and sub-critical paths.	1- This software is focused on project time and resource estimation, as well as the likelihood of the project's timely completion within costs, rather than on managing the risks, especially sustainability risks, which is what our model requires. As a software, it has disadvantages such as subjective analysis and being resource intensive.
Scenario Analysis	*structure: network , simulation *qualitative or quantitative *decision making	1- A Life Cycle-Based Scenario Analysis Framework for Municipal Solid Waste Management (Istrate et al., 2022). 2- Scenario analysis on medical treatments of patients with knee osteoarthritis (Tan et al., 2022). 3- Assessing impacts of land use policies on environmental sustainability of oasis landscapes with scenario analysis: the case of northern China (Gong et al., 2021).	1- Creating scenarios is a way to be proactive about possible upcoming changes. 2- It will provide the designers with an indication of the different scenarios to avoid failures.	1- There are way too many alternatives and variables, which makes it a time-consuming method 2- It is very hard to trace scenarios.

Sensitivity Analysis	* structure: network, simulation * qualitative or quantitative * decision making	1- Sensitivity analysis for vulnerability mitigation in hybrid networks (Ur-Rehman et al., 2022). 2- Global sensitivity analysis for optimal climate policies: Finding what truly matters (Miftakhova, 2021). 3-Comprehensive sensitivity analysis and process risk assessment of large scale pharmaceutical crystallisation processes (Öner et al., 2020).	1- It is easy to use by decision makers. 2- It helps to identify the input variables that have the most effect on the outputs. 3- It is easy to automate and can test multiple changes at one time.	1- it can test multiple changes in the inputs but does not study the relationships between them. 2- It is concerned with the output caused by a change in the input, but it does not give the probability for that change.
Fuzzy Logic	*structure: network * qualitative or quantitative * decision making	1- Criteria-based fuzzy logic risk analysis of wind farms operation in cold climate regions (Mustaf et al., 2022). 2- A new fuzzy risk management model for production supply chain economic and social sustainability (Đurić et al., 2019). 3- A hybrid model based on modular neural networks and fuzzy systems was used for the classification of blood pressure and hypertension risk diagnosis (Melin et al., 2018).	1- Fuzzy logic models accept inputs as a combination of numerical and linguistic inputs, while other models use either numerical or linguistic inputs. 2- When the data are not that accurate or not available, they can be easily described in fuzzy logic. 3- Fuzzy models are easy to understand and easy to use. 4- Fuzzy models usually need less time to be produced.	1- Fuzzy logic is the most used part of a model, not a model itself. Other models and methods could sometimes be more accurate and are better in the comparison between alternatives.

Break-Even Analysis	*structure: network * qualitative or quantitative * decision making	1- A global analysis of the break-even prices to reduce atmospheric carbon dioxide via forest vegetation and avoided deforestation (Chu et al., 2022). 2- Design of optimal heat exchanger network with fluctuation probability using break-even analysis (Hafizan et al., 2020). 3- A break-even analysis model was applied to urban renewal investments to evaluate the share of social housing financially sustainable for private investors (Morano et al., 2017).	1- It measures profits and losses at different levels of production and sales. 2- It can predict the effect of changes in sales prices, and analyse the relationship between fixed and variable costs. 3- It predicts the effect of cost and efficiency changes on profitability.	1- Break-even charts may be time consuming to prepare. 2- It can also only be applied to a single product or a single mix of products. 3- It assumes that production and sales are the same.

3.2.2.4 Methods Adopted in this Study

This risk assessment model targeted sustainability-related risks. As previously discussed, this type of risk is a new concept, and it holds uncertainty and unavailability, meaning that the model needs to be able to manage data under uncertainties and the unavailability of data from previous constructions.

This research followed different methods to ensure the accuracy of the collected data. From the start, the research tried to achieve triangulation during the collection of data to find more than one resource for each risk. Then a focus group with Jordanian experts helped to identify the risks applicable to the Jordanian construction industry and their causes.

In the qualitative risk analysis part of the model, to ensure the accuracy of the collected data, the research used a questionnaire that was completed by 402 participants, to rank the risks using a risk matrix. From this, a list of the highest risk ranks (high, very high) was generated for quantitative analysis.

In the quantitative part of the model, the research used a combination of BBN and AHP methods, for their ability to analysis risk under uncertainties and in the absence of risk data. The BBN can achieve that with its ability to calculate the probability of a variable (risk) from the changes in other dependent values (causes of the risk), using conditional probability. In this model, the probability of sustainability-related risks was calculated from the probability of their causes, using BBN.

In addition, the impact of the risk was predicted using AHP. This method is flexible, straightforward, convenient, and instinctive for decision making. It deals with uncertainties by decomposing the decision problems into their basic components and it builds hierarchies of criteria that show the importance of each component through pairwise comparisons. It can also work with accurate data or scale data, depending on the availability of the data.

3.2.3 Risk Response

In the context of risk analysis, risks must be faced by minimising their active impact on the project. Action must be taken on the risks that have been identified and classified into groups. A distinction can be made here between measures to deal with risks and measures that can be linked with the causes and effects of those risks. The most important thing here is to focus on those measures that are related to dealing with the risk itself, not its cause. This is justified because these measures reduce the expected damage and loss (Dallas, 2006). According to Lock (2013), the risk management process includes risk response strategies such as risk-sharing, risk transfer, risk reduction, and risk avoidance. Sharing the risk implies that the risk should be shared and divided among the project participants, such as stakeholders, contractors, subcontractors, or an insurance company. If no other solutions are available to effectively deal with the risk, the only option is to transfer it entirely to other project participants or insurance company. The best and ideal way to deal with risk is to avoid and eliminate it, but this is not always easy because the risk may be associated with a significant portion of the project. If the risk cannot be avoided entirely, it must be reduced to an acceptable level. This can be accomplished by lowering the likelihood or severity of the event.

3.2.4 Risk Monitoring

This final step consists of basically monitoring all of the risks and ensuring that everything is going as planned. Some risks can be avoided; others are unavoidable. Financial risk and environmental risk are two examples of risks that must be constantly monitored. The risk management system keeps track of the project's entire risk framework. Every change in a factor or risk is immediately apparent to everyone. Risk management also allows the project to stay on track. An emergency plan should be developed in case the risks that have been addressed occur or if an unaddressed risk occurs. This plan should detail how to respond to these risks if they become a reality. At this stage, the risks are not completely eliminated, but rather there is monitoring and continuous operational monitoring of the risk control measures and their effectiveness. Through variance analysis, it is ensured that the risk corresponds to the state of risk that the project management is seeking to reach, and this is monitored. At this point, reports are generated on the progress of those measures, in addition to research and management of new risks that may arise on the scene, and reports that detail the amount of damage and loss that the project may face.

3.3 Risk Management in the Construction Industry

This section presents the specific characteristics of the construction industry that make it different from other industries with regard to handling risks. This makes it more difficult to deal with risks.

Any project in any industry around the world has three main goals to achieve: finishing the project or product within the agreed time and budget and with the required quality. It is well known that the construction industry lags behind other industries in achieving these goals (Latham, 1994; Egan, 1998; Egan, 2002).

Many studies have been conducted for the purpose of improving the construction industry. Latham (1994) carried out research with the aim of developing the UK construction industry and making recommendations to the government. It concluded that a saving of up to 30% could be made if proper improvement occurred in the industry, especially in the communication part of the process. Egan's (1998) research concentrated on improving the UK construction industry in terms of its quality and efficiency. According to his research, 80% of construction inputs are repeated, therefore the industry should learn from other industries about how to improve and change the process with continuous improvements in the product and the process itself. He concluded that a reduction of up to 10% in the time and costs of the construction process could be made annually. In 2002, Egan published a paper showing the three key factors that can accelerate change in the process: client leadership, integrated teams, and addressing people's problems, especially health and safety problems.

Hammer and Champy (1993) introduced an approach for improving the performance of any business. This approach was called business process re-engineering (BPR). However, Love and Li (1998) argued that BPR is not sufficient for the construction industry and they introduced construction process re-engineering (CPR), which is an approach particularly designed for the construction industry.

In 2013, the UK Department for Business, Innovation and Skills introduced a strategy for improvement in the construction industry called Construction 2025. It suggests that by 2025 the construction industry will have 30% lower costs and a 50% reduction in delivery times and emissions. Finally, it predicts a 50% improvement in exports.

Everything mentioned above shows how much the construction industry falls behind other industries; risk management is therefore one of the ways to improve the industry.

3.3.1 Project Phases

Every construction project is a cycle of stages. Every stage has start and end times, a budget, and a set of tasks. The British Property Federation (BPF) (1983) proposes five phases for any construction project as follows: firstly, the concept, then preparation to brief, followed by design development, tendering, and construction. Flanagan and Norman (1993) divided the construction process into four stages: the investment decision, the design, construction, and occupancy. Moreover, the Construction Industry Board (1997) also proposed a five-phase construction process: getting started, defining the project, assembling the team, designing and constructing, and completion and evaluation.

3.3.2 Risks in Project Phases

Risk is involved in every phase of every project, regardless of the size or type of the construction project. Every phase of the construction process is different from other phases, which means that there are different risks and therefore different approaches are required for risk management. At the end of every phase, the risk needs to be identified and assessed again before moving on to the next phase.

According to Smith (1999), every phase has its own concerns and its own risk. In the early stages of the project, the main concern will be value management and how to improve the design objectives, while the design phase is more concerned about engineering and how to achieve the required quality with minimum cost. The construction phase is more about quality management without rework. Smith (1999) adds that the more progress is made, the more the risks will be decreased.

At the beginning of any project, the uncertainties and risks are highest. As the project continues, the risks and uncertainties start to diminish. Godfrey (1996) said that the relationship between progress and uncertainties is inverse; as an example, the cost assumptions and uncertainty will become facts while the project is progressing.

3.3.3 The environmental risks

There are several environmental risks that may result from construction projects. These risks are summarised as the following (Rahman, 2014).

At the outset, there are the risks of land degradation that may occur as a result of large construction projects. Such projects cause significant disruption in the surrounding lands. These projects may reshape the terrain, remove dead vegetation, and expose the soil to erosion. The project's removal of soil may result in an issue with airborne dust. Therefore, these pollutants may be transmitted through water to natural rivers and waterways, and this is what causes groundwater pollution. The erosion of loose and exposed soil leads to the deterioration of water quality in water bodies due to the silt caused by the construction project. When heavy rains fall, there may be flash floods in nearby areas in rivers, and therefore, landslides and the collapse of unstable slopes may occur (Rahman, 2014).

Water pollution is another environmental risk associated with construction projects. Construction projects can pollute and degrade the quality of the water around them. They may also have a negative impact on the aesthetic value of water, thus preventing its use. During the construction phases of a construction project, the potential for soil erosion increases, as do the risks to water quality. The vegetation cover is removed and the soil is exposed to the risk of erosion. In rainy conditions, the risk of water contamination increases. Rain contributes to sediments being transferred from water projects to rivers where they accumulate, thus increasing water pollution (Rahman, 2014).

The problem of air pollution is another environmental risk that may arise as a result of construction projects. The air in construction projects can be polluted by any of the activities that occur during the construction process. The release of chemical impurities from heavy metals, the burning of waste, the emission of smoke and fumes, acid, toxic bases, and other air pollutants are examples of these activities. There are several stages such as grading, filling, and removal, and these stages increase the dust particles that pollute the atmosphere. Construction equipment also emits emissions that pollute the air and degrade its quality (Rahman, 2014).

The dangers of noise and vibration are also environmental risks. Construction equipment emits noises as a result of the vibrations it causes during construction activities. The intensity of these vibrations and noises varies according to the construction activities, the equipment used, and the operating situation and location. The negative effects on neighbouring areas are only temporary (Rahman, 2014).

3.3.4 Risk Treatment in the Construction Industry

The previous sections showed how construction management is lagging behind other industries in achieving its goals, and it has special features, making it even harder to manage. According to Ruddock (1994), nearly 60% of the construction companies in the UK faced failure, making the industry one of the worst in the UK. In this section, will show how risk management has been dealt with before in the construction industry.

Research on how to deal with risk in construction was carried out by the University of Manchester Institute of Science and Technology (UMIST) with the support of the Science and Engineering Research Council (Hayes et al., 1987). This resulted in a report called Risk Management in Engineering Construction. One of the major findings of the research was that risks in construction projects were either ignored or dealt with in a bad way, and to cover all the risks and uncertainties, 10% or more was added to the total cost. According to Adeleke et al.'s (2018) research, project owners, consultants, and contractors do not systematically apply risk management in the construction industry, which negatively impacts projects' performance.

According to Perry (1986), risk management is not just rules that need to be applied; it must be creative and special to every project. Williams (1994) stated that a risk register is essential to the risk management process, while Ward (1999) worked on the risk register and its content. Patterson and Neailey (2002) proposed a complete risk register database, while Raz and Michael (2001) researched many different tools and how they could be used in the risk management process. They reviewed 38 tools used in different successful companies. Mohammadipour, F., & Sadjadi, S. J. (2016) suggested a multi-objective mixed integer linear through programming for minimizing "project total extra cost", "project total risk enhancement" and "project total quality reduction" subjected to the project duration. This model's risk register considers only the risk related to the project duration due to the client's needs, and it neglects any risk that is not related to the client's needs.

Baker et al. (1998) showed in their comparison between the use of qualitative and quantitative risk analysis techniques that almost 80% of companies use mixed techniques and 20% use qualitative techniques alone. Only a small percentage of companies and managers use quantitative techniques. Akintoye and MacLeod, (1997) reported almost the same result as Baker et al. (1998). Raftery et al. (2001) carried out qualitative analysis in their research: What Are Risk Attitudes. Also, Tah and Carr (2000) researched how fuzzy logic could be used as a qualitative risk analysis technique. Dey (2001) used the AHP as a qualitative risk analysis technique. According to Bowers (1994), there is a sufficient number of quantitative risk analysis techniques; however, without the appropriate data, they are worth nothing. Zhao et al. (2016) proposed a fuzzy-based risk assessment model to determine the most critical risk that affects project success, by calculating the likelihood of occurrence, the magnitude of impact, and the risk criticality of a set of risk factors. Acebes et al. (2014) focused on a methodology for project control under uncertainty. They limited their work to the risk assessment, and they did not explore the possible solutions. Particularly, they integrated EVM with project risk analysis. The goal was to help project managers know whether the project's deviations from the planned values were within the "expected" deviations derived from activity planned variability. Kumar and Yadav (2015) analysed the correlation between risk factors and project outcomes with regard to software risk analysis. Rodríguez et al. (2016) addressed information technology projects and proposed a risk assessment method based on a combination of Fuzzy Analytic Hierarchy Process and Fuzzy Inference System.

Baker et al. (1999) investigated the risk response techniques used in construction projects, and they found that 90% of the risk responses used were risk reduction. Barnes (1991, 1983) showed risk sharing in contracts and how to allocate risks in construction contracts. Berkeley et al. (1991) addressed risk action and management's role in the risk management process. Flanagan and Norman (1993) described the role of the client in the risk management process. Katavic (1994) showed risk reduction in the early phases of investment projects. Winston (1998, 1999) showed the use of computers in decision making under uncertainty. Burchett and Tummala (1998) presented a risk management model for project selection. Baccarini and Archer (2001) developed a methodology of project choice based on estimating the project's total risk and comparing this with the risks of other projects by introducing the overall risk rating. Kosztyán (2015) proposed a matrix-based model, concentrating on tasks rather than concentrating on the risk. This model implies that tasks which have a high probability of not being completed have to be eliminated. Moselhi and Deb (1993) used the multi-objective decision-criteria method to choose a project under conditions of uncertainty. Pfeifer et al. (2015) focused on the risk associated with project performances, and the identification of those tasks that lead to delays in project completion. They developed the model to maximise project delay, and they found that critical tasks are not always found in the critical path.

Risk management is an important component of addressing environmental risks in the construction industry (Berg, 2016). Construction projects involve many risks, and compliance with safety standards is one of the proactive measures put forward by risk management. In most cases, the focus is on managing normal risks that are not related to the environment. The risks that workers may suffer, such as falling, injury, death, and others, are the risks focused upon. However, the risks associated with the environment are often overlooked, because most project implementers deal with environmental risks only after they occur. Project managers' dealings with environmental risks are often ambiguous, and this can be attributed to the fact that they can be costly to project owners (Berg, 2016). The environment cannot be compared to a human being, for the human being defends his rights, so we find that the greatest interest is directed towards people and the risks associated with them. However, the environment is the silent victim here; it is exposed to dangers, and cannot defend itself. The construction industry can continue to harm it if construction projects are poorly managed. This highlights the importance of risk management to reduce environmental risks and treatment costs (Berg, 2016).

3.4 Conclusion

This chapter discussed risk management in detail. Risk management is a discipline living with the possibility that a future event may cause adverse effects. Risk management is a linear or cyclical process comprising several steps: risk identification, risk analysis, risk response, and risk monitoring. In its cyclical form, it has several forms, all of which look relatively the same. In the first step, risk identification, then we have qualitative and quantitative risk analysis. In the quantitative risk analysis, several methods can be used were explained, each of these methods has a unique structure, as well as advantages and disadvantages. In the risk response step, we can avoid a risk, reduce it, share it, or transfer it. The last step, risk monitoring, aims to ensure that everything is going to plan. This chapter talked about risk management in the construction industry. It examined how risk management is important in this sector as it helps the construction industry to outperform other industries by enhancing its safety and reducing the damages that can result from it. Risks and risk management exist in all the project phases; therefore, it is important to conduct qualitative and quantitative studies and calculations based on the probabilities of those risks at all stages of the project, to be safe for humans and the environment.

Chapter Four

Chapter Four: Methodology

4.1 Introduction

This chapter discusses the various research methodological considerations and the justification for the use of different approaches and methods. This chapter comprises nine sections designed to accomplish the research objectives and research questions. Firstly, this chapter highlights the research methodology model adopted in this study, then reviews the research philosophies to justify the philosophy and assumptions employed in the research. The research approach section presents the inductive, abductive, and deductive approaches. The purposes of the research design and methodological choice are discussed in sections 4.5 and 4.6. Several research strategies are employed to assist the research study. The data collection and analysis procedures are presented in section 4.8, and finally the validity, reliability, and ethical considerations are discussed at the end of the chapter.

The research methodology is the way, plan or path that any researcher has to follow to achieve the research aim and objectives. Choosing the right research methodology will lead to successful and valid data collection, which will be used to contribute to existing knowledge. The research methodology is significantly identified by many authors. Crotty (1998) described it as the action plan or the guide of the research study, which is used to connect the method with the research questions**.** Creswell (2003) referred to it as the systematic approach adopted to achieve the research objective and aims. A good definition by Collis and Hussey (2014) of the research methodology is the general approach used in the research process from an explanation of the theoretical foundation to the data collection and data analysis. Another perspective focuses on the research approach, techniques, and strategies to represent the whole research, illustrated by (Chakrabarti, 2009). Figure 4-1 highlights the research methodology adopted in this thesis.

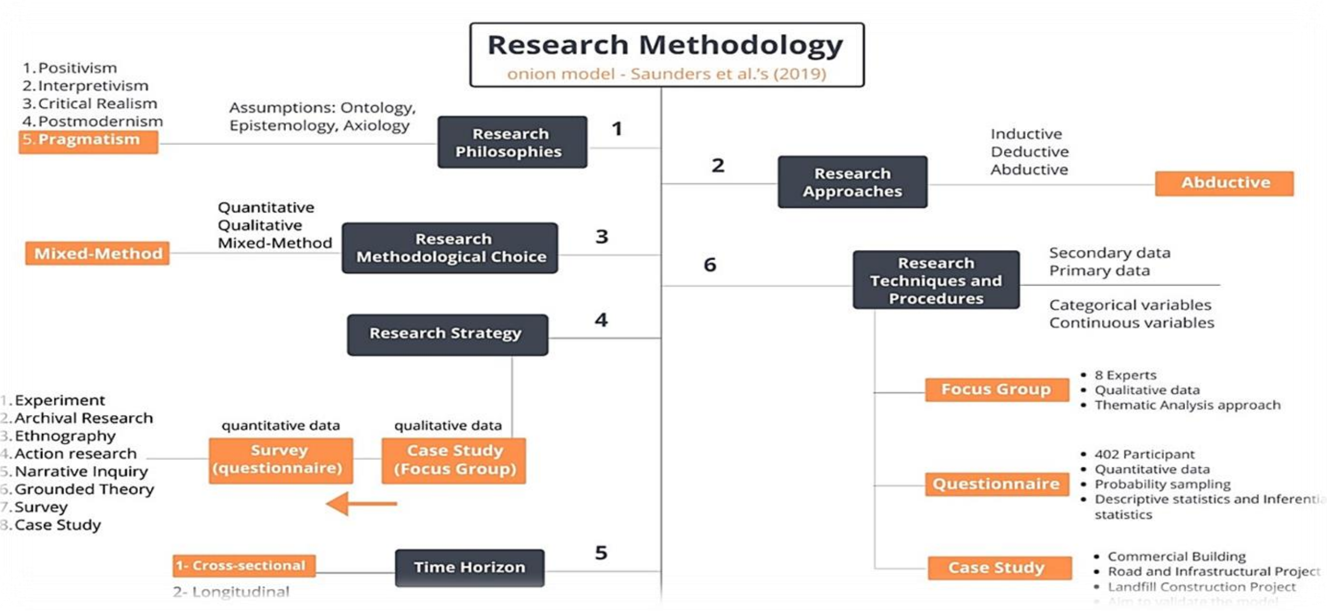

Figure 4-1: Research Methodology

4.2 Research Methodology Model

The research methodology elements should be indicated and recognised before starting the research to ensure its success. Understanding and choosing the correct model are at the heart of the research methodology, which shows the exact components that will be presented in the methodological considerations. A number of models have been proposed and utilised to draw up the procedures of a research methodology. In 1998, Kagioglou et al. designed the Nested model, which contains three layers; research philosophy, research approach, and research techniques (see Figure 4-2). Firstly, it considered the research philosophy as the first outer layer, with the inner layers comprising the research approach and research techniques. Secondly, it distinguished the research approach used to generate and test the research strategies. The last inner layer contains the research techniques, which are closely connected with the second layer. This layer embraces the final stage, which is the data collection method, i.e., questionnaire, interview, case study etc.

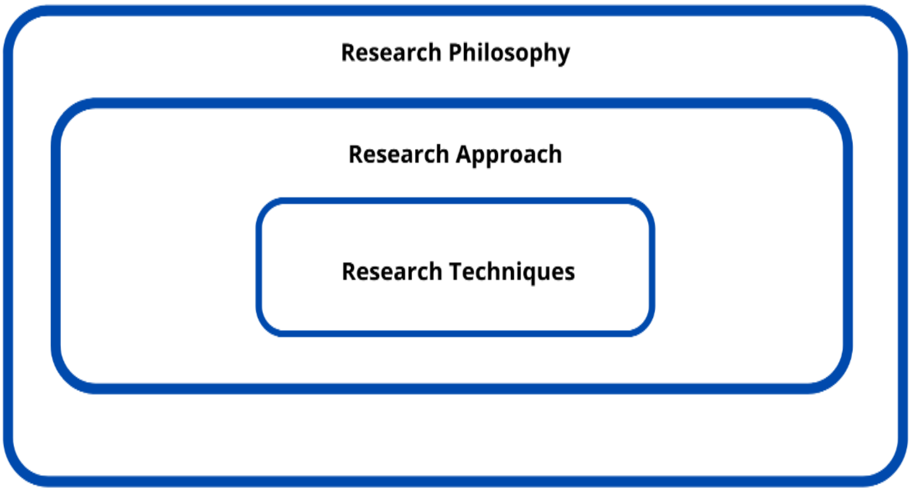

Figure 4-2: The Nested Model

Another research methodology model was presented by Creswell (2014), as shown in Figure 4-3. This model is designed through a process that includes three components: a research philosophical worldview; a research design that relates to the first element; and the research methods or research procedures, which aim to translate the approach into practice.

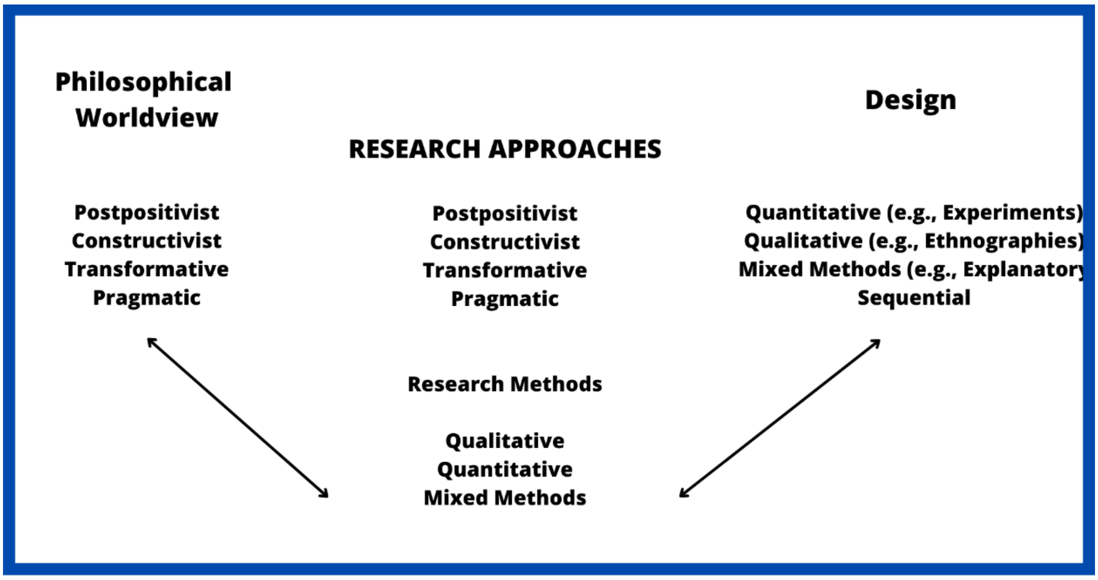

Figure 4-3: Creswell's (2014) Model

In 2019, Saunders et al. developed an updated version of the onion model, which was designed in 2007. It comprises six layers in the shape of an onion. As shown in Figure 4-4, it contains the research philosophy, research approach, research methodological choice, research strategies, time horizon, research techniques, and procedures for data collection and data analysis. Compared to the other research methodology models above, this research model appears more complicated. However, it can be seen clearly that this research model provides the researcher with clear directions for the research methodology process. It is organised in a way that will help to achieve the research objectives, linked to the research questions. Moreover, it covers a broader understanding than the other models.

Therefore, this research onion model by Saunders et al. (2019) will be adopted in this research study. Accordingly, this chapter covers the layers of the onion model in sequence, while keeping in mind the research objectives and research question.

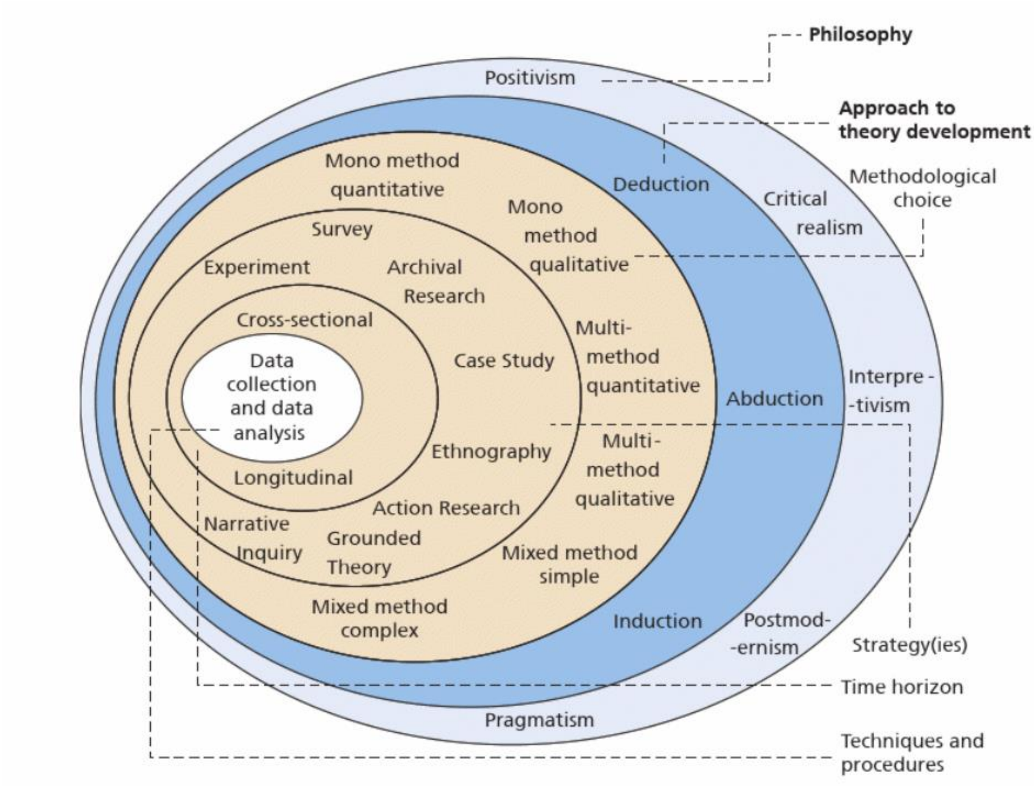

Figure 4-4: Saunders et al.'s (2019) Onion Model

4.3 Research Philosophies

The word philosophy is a combination of two words from the Greek language – the word "Phylos", which means love, and the word "Sophie", which means wisdom (Cavalier, 1990). Saunders et al. (2019) defined the research philosophy as the way of developing knowledge and of regarding the nature of knowledge. They also added that the outer layers are important for selecting the methods that will be used for data collection and analysis, in the context of boundaries and content. The first layer of this research model is the research philosophy. According to Saunders et al. (2019), the research philosophy is closely related to the beliefs and assumptions related to the knowledge presented. Moreover, the model incorporates two key elements that help to choose the correct research philosophy: considering the beliefs and assumptions related to the research, and explaining the major five research philosophies. It is beneficial for all researchers to adopt research philosophies that shape the nature of knowledge. There are multiple reasons why it is important to understand research philosophies. Initially, it is important to reflect on the research, making a clear decision about the research design in order to identify which research design should be adopted, and it helps to operate the chosen research design (Easterby et al., 2018). This section will review the philosophical assumptions illustrated by Saunders et al. (2019), then discuss objectivism and subjectivism, classify the five research philosophies, and finally present the justification for the research philosophy adopted in the research methodology.

4.3.1 Research Philosophical Assumptions

A considerable number of philosophical assumption perspectives have been discussed by authors. All scholars need to understand the philosophical assumptions so that they can accurately choose the most suitable research methodology, referred to as the chosen assumptions (Gill & Johnson, 2010). Similarly, Dainty (2008) pointed out the importance of adopting philosophical assumptions not only to choose the research methods, but also to assess the research problem, and collect and analyse the data.

The research philosophy can be classified in terms of the way of thinking into three types of assumptions: ontology, epistemology, and axiology. No one is better than the others; each one is used in a different context (Saunders et al., 2019). According to Smith et al. (2002), every research philosophy considers three philosophical assumptions, which are ontology "what?", epistemology "how?" and axiology "why?".

4.3.1.1 Ontology

The term 'ontology' has been defined as the nature of reality (Saunders et al., 2019). How the nature of reality is interpreted and determined may vary from one person to another; this depends on certain reality and the conceptualisations of each person (Gray, 2014; Yin, 2014). Two questions that are closely related to ontology assumptions are: (1) what is the nature of reality? and (2) what is the world like? (Saunders et al., 2019). In general, the ontological assumption is helpful for researchers to shape their research study regarding the research objects, objectives, and research questions (Saunders et al., 2019). However, the ideal ontology position is seeing the reality of the research and linking it to the research questions and objectives.

Two perspectives of ontology, objectivism (realism) and subjectivism, should be considered when adopting the ontology assumptions. Ontological objectivism assumes one true reality and it is independent of the social actors and of individual views. However, ontologically, subjectivism assumes nominalism and is socially constructed through culture and language with multiple realities and social actors (people).

This research study aims to develop a risk management model that is effective and suitable for the Jordanian construction industry. This means that this process will involve different professionals from this industry. Although their subjective opinion will affect the development of the model, this development will be based on the formulation of hypotheses. The hypotheses used in the model are validated with different methods, so they are not included in the examination of reality, where they are considered as one true reality. This research employs objectivism for one more reason – it uses a large sample in the questionnaire in order to understand risk management practices in the Jordanian construction industry. The orientation of the research is objectivism(realism) rather than subjectivism because the large sample generates one reality rather than providing multiple opinions (Saunders et al., 2019).

4.3.1.2 Epistemology

The epistemology assumption describes the acceptable knowledge in the research, and whether it is valid or legitimate knowledge in a special field of research and study (Saunders et al., 2019). In addition, it answers the questions of (1) how we can know what we know; (2) what is considered acceptable knowledge; (3) what constitutes good quality data; (4) and what kind of contribution to knowledge we can make. Different types of knowledge are based on the nature of data, i.e., whether they are numerical, textual, or visual data, facts, opinions, narratives or stories.

Deciding on an epistemological assumption for the research is useful for researchers in terms of selecting appropriate methods. According to Saunders et al. (2019), two perspectives refer to the epistemology assumption with different dimensions. The objectivism perspective outlines natural science as a type of acceptable knowledge, such as facts, numbers, observable phenomena, and law-like generalisations. In contrast, the subjectivism perspective embraces the art and humanities type of acceptable knowledge, such as opinions, written, spoken, and visual data, individuals, and contexts. Acknowledgement of meaning is considered to be good-quality data in this subjectivism perspective, in contrast with objectivism, which involves observing the facts.

This research study employed a qualitative approach for the first stage of data collection, which involved gathering the opinions of experts through a focus group to understand the sustainability-related risks in the Jordanian construction industry. This means that the study's orientation should be epistemological subjectivism, highlighting the meanings of knowledge. The second stage of the research data collection utilises a quantitative approach that involves facts and numbers from a large sample, gathered through a questionnaire. This makes the initial orientation of research **epistemological objectivism**, testing the facts by collecting and analysing the statistical data. This can be employed with a large population as a generalisation contribution to knowledge.

4.3.1.3 Axiology

The third and last assumption is axiology, which describes the role of value and ethics in the research (Saunders et al., 2019). Moreover, it explains how the researchers deal with values, and it values the participants during the research. In general, it clarifies how values or choices can impact the researcher's judgement. Every researcher is influenced by his values or his experience in two ways: value-free and value-laden. It is essential to demonstrate the axiological skills in the research to articulate the values for judgements. Hill (1984) illustrated the difference between value-free and value-laden. When the research contains an unbiased contribution of the researcher feelings or experiences then it is value-free, while it is value-laden when they are considering their feelings, personal values, beliefs, or past experiences. In addition, the researcher's past experience can influence this aspect – the more experience the researchers have, the more their research will be unbiased, detached, and value-free.

The identification of the axiology assumption should be in perspective to objectivism and subjectivism according to the value-free and value-laden. According to Saunders et al. (2019), objectivism reflects value-free detachment from the researchers and participants' own values, whereas subjectivism is associated with being value-laden as the researcher is biased and can be influenced by their values.

In this research study, regarding the axiology assumption orientation, the values of the researcher and of the participants had no role in the research process, which makes the research objective and without bias. Therefore, this research employs the objectivism perspective, which refers to value-free, because the nature of the research indicates more statistical data and empirical equations.

4.3.2 Type of Research Philosophies

According to Saunders et al.'s (2019) onion model that this research adopted, there are five main research philosophies: positivism, interpretivism, critical realism, postmodernism, and pragmatism. Bryman (2016) described positivism and interpretivism as the extreme opposites to each other in the research philosophy. However, positivism represents all the objectivism perspectives in the research, while interpretivism indicates the subjectivism perspective. Consequently, the other three philosophies can be considered for both objectivism and subjectivism.

4.3.2.1 Positivism

Positivism is the first philosophy of the onion model; it is generally explained by the three assumptions that have been explained above: ontology, epistemology, and axiology (Saunders et al., 2019). Crowley and Henry (2009) pointed out the positivism philosophy considers objective knowledge, so the researcher can observe, measure the facts, and generalise the numbers. Characterising positivism in terms of regarding the nature of reality, it is real and independent, and it shows one true reality. In addition, this philosophy refers more to a value-free approach in its axiology philosophical assumption, as it is detached and neutral over the topic of the research and provides an objective position. Consequently, the research usually follows the deductive approach with a large sample and it is highly structured. Thus, it utilises quantitative methods for analysing the data. Overall, this philosophy is completely objective and the opposite of the following philosophy – interpretivism.

4.3.2.2 Interpretivism

Interpretivism philosophy, as mentioned before, is completely the opposite of positivism. Therefore, it adopts the subjective knowledge or meaning of the social action (Bryman, 2016). It reflects the subjective perspective through the three assumptions in different aspects. Ontologically, it assumes a social reality that is principally constructed through culture and language; a subjective multiple meaning through which people see, interpret, and experience the numerous realities (Collis & Hussey, 2014; Robson & McCartan, 2016). The standard knowledge is mostly theories that focus on types of knowledge such as narratives, stories, and a new understanding of the world view. Axiologically, this leads to value-bound research, as the researcher is an essential part of what is researched and the research reflects his own values. As a result, the inductive approach is adopted in this philosophy, involving a small sample in contrast with positivism. It employs a qualitative method to analyse the data that can be widely interpreted.

4.3.2.3 Critical Realism

The term 'critical realism' means that what we get is what we see through direct realism. In addition, Saunders et al. (2019) added that the philosophy of critical realism explains that what we see or experience, is what structures and shapes the reality and observable events. While considering a philosophy in the research, it is essential to clarify the reality through some of the assumptions (Fleetwood, 2005). The critical realism philosophy is used to understand the research through the sensation of the researcher's experience, and the mental process during the research (Saunders et al., 2019). Referring to the ontology assumption, Bhaskar (2008) developed three layers to explain critical realism: the empirical, the actual, and real events. Moreover, the nature of reality is objectively structured. Epistemologically, the knowledge is historically situated, the facts are social constructions, and the contribution to some knowledge is also historically positioned. The role of value means that critical realism is value-laden research because the researcher is biased by world views and cultural experience, but tries to avoid this bias and be as objective as possible. Thus, researchers using critical realism are flexible with a wide range of methods to choose from throughout the research, to fit the research subject.

4.3.2.4 Postmodernism

This philosophy highlights the role of language and the power of relations, as defined by Saunders et al. (2019). It rejects modern objectivism, which makes this philosophy's orientation one that leans towards interpretivism, acknowledging the role of language is inadequate and is always partial to reality. Regarding the three assumptions, postmodernism discusses the nominal and rich reality, which is socially constructed through the power of relations, as explained by Flick (2009) and Saunders et al. (2019). The acceptable truth and knowledge are explained and controlled ideologically. Regarding the type of knowledge, epistemologically, it is the absence of knowledge that represents meanings and the interpretation of voice. Thus, the value of the researcher is shaped through reflexive research. Overall, the typical method in this philosophy includes a wide range of qualitative data analyses. Three features of postmodernism were discussed by Smith et al. (2015): firstly, it is a scientific critically progress for being irregular that rejects complete belief and value; secondly, it is closely related to the progress of modernism excess; thirdly, it supports interpretivism by including an ontological position that is the complete opposite of those of realism and positivism.

4.3.2.5 Pragmatism

The last research philosophy in the onion model is the pragmatism philosophy, which mostly answers all the questions that are relevant to the research. In addition, it helps to understand in depth all the assumptions of research (Saunders et al., 2019). Significantly, it emphasises all the concepts that are relevant as they support action (Kelemen & Rumens, 2008). Furthermore, it is the philosophy that reunites or resolves all the other theories, concepts, ideas, hypotheses, and research findings that focus on the research problem and research questions (Creswell, 2014). Therefore, what matters most in this philosophy is the reality as practical effect on the ideas and value of knowledge to successfully solving problem and suggest future practice (Saunders et al., 2019). Johnson and Christensen (2014) pointed out this philosophy provides a systematic way of combining quantitative and qualitative methods and approaches. According to Saunders et al. (2019), The ontology defines the pragmatism as a complex nature of reality, rich in the practice of ideas, and flow of experience and practices. Epistemologically, the meaning of knowledge depends on specific contexts, especially the theories and knowledge which are considered as the successful ones for this philosophy. In addition, this knowledge focuses on a problem, solving the problem, and future practices as a contribution. Axiologically, the values, beliefs, and doubts of the researcher are initiated through the research. This philosophy focuses on solving the research problem through the research question. Therefore, it allows a wide range of methods to be used, even mixed or multiple, and finally, it emphasises the solutions of the research problem.

4.3.3 Justification of Research Philosophy Adopted

This research study aims to develop a model to manage the sustainability-related risks in the Jordanian construction industry. This subject requires multiple views to understand the complex nature of reality in the research. The developed model has characterised the research problem and the means to approach it. There are several major reasons for adopting the pragmatism philosophy: (1) as mentioned above, the research requires an advanced and complex nature of reality, and this is from an ontological perspective; (2) this research uses a mixed-method approach of both quantitative and qualitative methods to answer the research questions; (3) following on from the previous reasons, this study represents both objectivism and subjectivism perspectives to understand the complexity of the developed model.

4.4 Research Approach

According to the onion model adopted in this research methodology, the research approach is the next layer. Assessing the correct research approach is an important contribution to achieving the research aim and objectives, while limitations can also be another factor for choosing a particular approach (Matthews & Ross, 2010). The research approach can be described as how the research and the theory will be developed. Originally there were two main research approaches that could be followed: inductive or deductive (Dray, 2014). Recently, a new approach was introduced which is a mix between inductive and deductive, called abductive (Saunders et al., 2019). This section will discuss all these approaches and show the justification for the one selected for the research.

4.4.1 Inductive Approach

The inductive approach is an approach where the researcher has an observation about a specific incident or phenomenon and turns it into a theory through surveillance, collection of data, and data analysis (Saunders et al., 2019). In general, this approach focuses on creating a new theory, which is totally different from the deductive approach (Bergman, 2008). In addition, this approach mainly suits the type of research where there is little existing research on the topic, and the aim is to create a new theory. Furthermore, Collin and Hussey (2014) stated that the inductive approach is "a theory that is developed from the observation of empirical reality". Figure 13 shows the inductive approach, which is usually called the "bottom-up" approach or the "hill-climbing" approach since it starts from observation and ends with a theory. Inductive researchers have uncertainty until the end (Bryman, 2007).

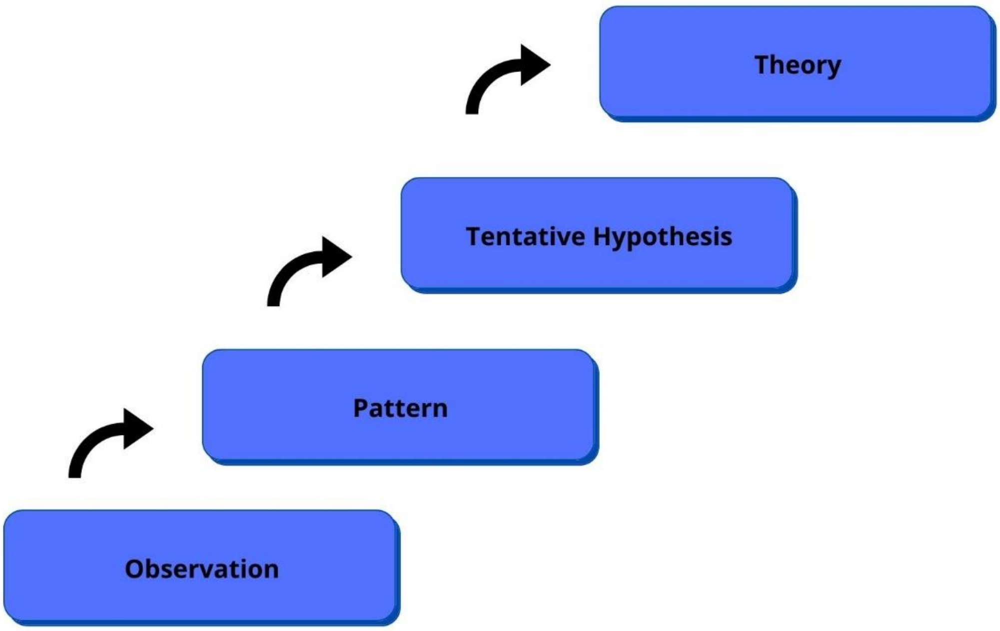

Figure 4-5: Inductive Approach

4.4.2 Deductive Approach

In contrast, the deductive approach can be viewed as the opposite of the inductive approach. In this approach, the theory has already been founded and published by other researchers and the researcher who follows this approach usually wants to develop the theory or just test it and confirm it (Saunders et al., 2019; Robson & McCartan, 2016). Figure 4-6 illustrates the deductive approach, starting from a theory down to its confirmation. Because of that, this approach is known as the "top-down" or "waterfall" approach. In this approach, the researcher is usually more certain since he uses theory, facts, and data that have already been validated (Bryman, 2007).

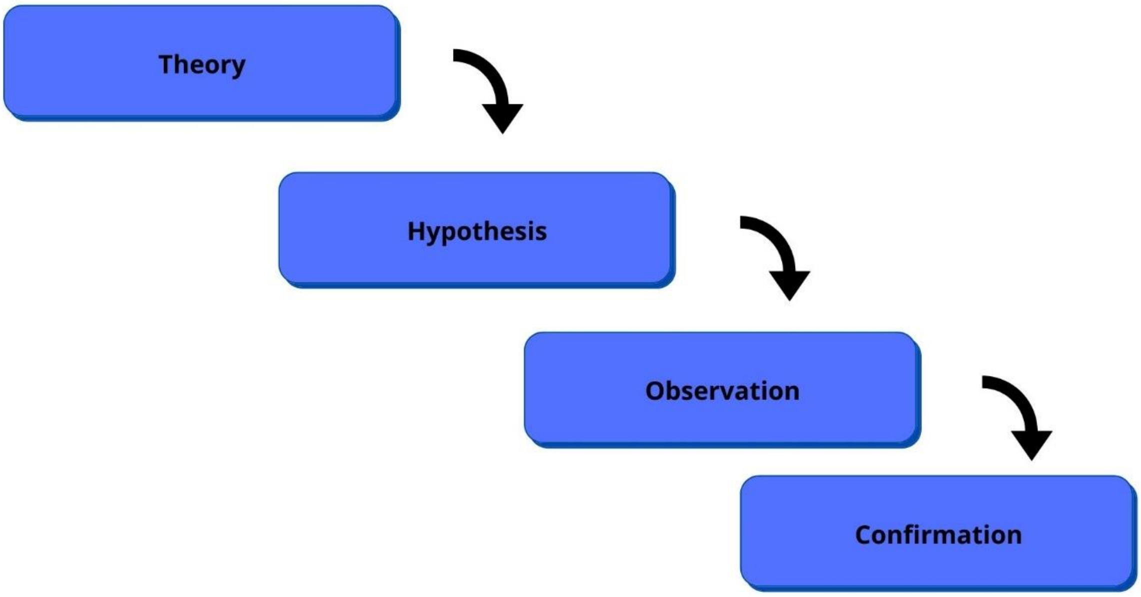

Figure 4-6: Deductive Approach

4.4.3 Abductive Approach

This approach combines the two approaches mentioned before. It involves data collection to explore the hypothesis, identify the themes, then test a framework. Saunders et al. (2019) explained this approach as mixing the inductive (data to theory) and deductive (theory to data) and moving back and forth (see Figure 4-7). It is mainly converting observation into theory, the theory into confirmed theory, or the other way around. Therefore, the researcher is flexible to move between two approaches for the theory development.

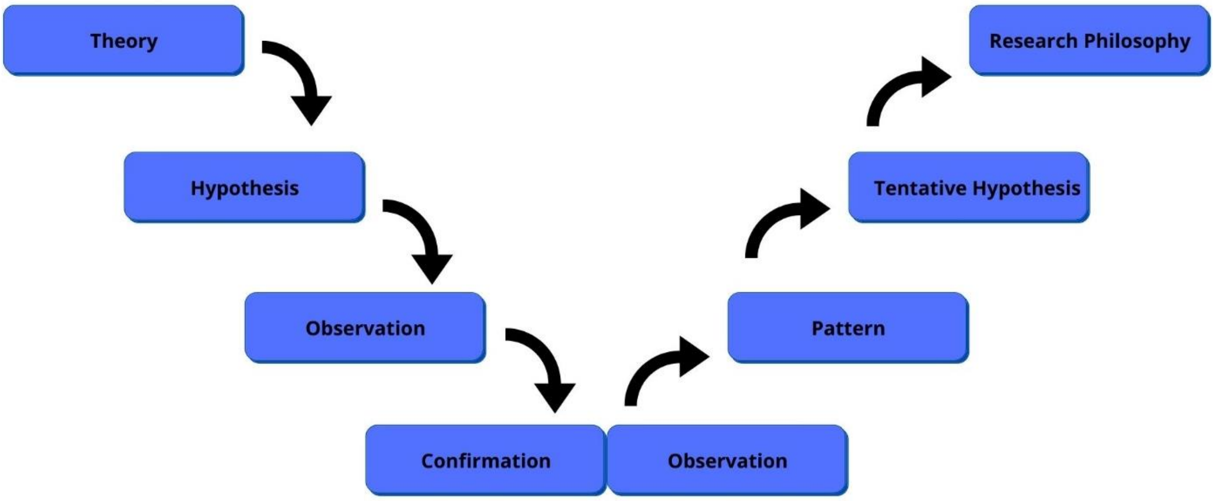

Figure 4-7: Mixed Approach (Abductive Approach)

4.4.4 Justification of Research Approach Adopted

This research study adopts the abductive approach based on the stages of the research. In the first stage, the inductive approach was founded in the data collection of the sustainability-related risks using the focus group strategy to develop the hypotheses of the research (theory). In the second stage, the deductive approach was employed by testing the collected data from the first stage and the deductive approach was used for the statistical analysis of the questionnaire responses. Thus, this research adopts the abductive approach, which combines both approaches. Finally, the philosophy adopted in this research is pragmatism, as it is usually related to the abductive approach.

4.5 Research Methodological Choice

The third layer of the model adopted in this research is the methodological choice. There are three possible types of methods: the mono method, multi methods for either quantitative or qualitative approaches, and mixed method, simple or complex. In the mono method, only one research technique is applied in the research, either quantitative or qualitative. With multiple methods, two quantitative or qualitative research techniques are employed, depending on the nature of the research and whether it is exploratory, descriptive, explanatory, evaluative, or a mix of them, using surveys, interviews, or other techniques (Saunders et al., 2019). In mixed methods, a combination of quantitative and qualitative techniques is employed in the same research, either concurrently or sequentially. According to this research, which examines the construction industry in Jordan, it may be a risk to choose a mono method. Therefore, a mixed method has been adopted, involving a wide range of data resources to assist the research aim. The nature of the data gathered in the research is the main factor differentiating the three types of research method – quantitative, qualitative, and mixed methods – numerical data (quantitative), non-numerical data (qualitative), and a mix of data (mixed methods).

4.5.1 Quantitative Research Method

The quantitative method is a descriptive, exploratory method used for the testing and validation of a theory. The outcome data from this research design is usually highly reliable numerical data that can be transformed into usable statistics, and it is mostly objective (Denscombe, 2010). The data collection techniques in these methods are structured, inflexible, and suitable for relatively large samples. Therefore, according to Grbich (2013), the outcome of quantitative data is usually generalisable to a larger population. This research design is strongly connected to positivism and the deductive approach (Walsh et al., 2015). However, it can also be undertaken in pragmatism philosophy (Saunders et al., 2019).

The data collection of a quantitative research method can be a single technique through a mono method or multi-data techniques through multi-methods. They correspond with the use of questionnaires and statistical analysis of the data. According to Bryman (2006), the quantitative multi-method is mainly employed to overcome the weakness of the mono method and to provide a wide range of data collection and data analysis techniques. The primary research strategy in this method is a survey, which is normally performed through a questionnaire and quantitative data analysis.

This research study cannot adopt this method alone, as it is insufficient for the data collection and data analysis in general. In the second stage of the research, this method was used with a questionnaire, but it is still not the final stage due to the limitation of data collection in this method.

4.5.2 Qualitative Research Method

The qualitative method is also a descriptive, exploratory method but it is used to understand reasons and motivations, to uncover trends in thoughts, and to dig deep into a problem. The output will be non-numerical. The data collection techniques in these methods are unstructured and flexible, using more open-ended questions. They suit a relatively smaller sample size, like focus groups, unstructured interviews, and questionnaires. This method is usually associated with inductive research since the data collected and the outcomes are not numerical (Robson, 2002). In addition, it relates to interpretive philosophy (Denzin & Lincoln 2018). Qualitative research is considering the description, narration of data collection, and perceptions more than measurements (Kumar, 2014).

Some of the most significant features of this research are that: firstly, it is used to study the significant aspects of the social world (Bryman & Bell, 2015). Secondly, it enables an in-depth understanding of the participants' perspective of the research topic (Denzin & Lincoln, 2018). Another point of using this method is to explain, understand, explore, discover, and clarify the beliefs and experiences of participants in the situation (Kumar, 2014). Table 4-1 shows the main differences between quantitative and qualitative research.

A major reason for not choosing this research method on its own in this research is the difficulty of generalisation, because it uses a small sample (Bryman, 2016). The problem of research bias is illustrated by Kumar (2014). However, in the first stage of this research, the qualitative method was adopted through a focus group to understand the participants' perceptions of sustainability-related risks.

Table 4-1: Differences between Quantitative and Qualitative Strategies (Yin, 2003)

Topic	Quantitative research	Qualitative research
Research enquiry	Exploratory, descriptive and explanatory.	Exploratory, descriptive and explanatory.
Natural of questions and response	Who, what, when, where, why, how many. Relatively superficial and rational responses. Measurement, testing and validation.	What, when, where, why. Below the surface and emotional response. Exploration, understanding, and idea generation.
Sampling approach	Probability and non-probability methods.	non-probability methods.
Sample size	Relatively large	Relatively small
Data collection	Not very flexible. Interviews and observation. Standardized. Structured. More closed questions.	Flexible Interviews and observation. Less standardized. Less structured. More open-end and non-directive questions
Data	Numbers, percentages, means. Less detail or depth. Context poor. High reliability, low validity. Statistical inference possible.	Words, pictures, diagrams. Detailed and in-depth. Context rich. High validity, low reliability. Statistical inference not possible.
Cost	Relatively low cost per respondent Relatively high project cost	Relatively high cost per respondent Relatively low project cost

4.5.3 Mixed Methods

A combination of quantitative and qualitative approaches is used in this method to provide the research with a better understanding of the research problem (Saunders et al., 2019). Similarly, Creswell (2014) describes this method as collecting and analysing both quantitative and qualitative data for a deep investigation of the research phenomena. It is important to consider that this research method is strongly associated with two positions of philosophy: pragmatism and critical realism (Denscombe, 2010). It utilises the deductive approach when developing the theory through the qualitative methodology and then it tests the theory through a quantitative study. There are two types of mixed methods, simple and complex, as shown in the onion model. Saunders et al. (2019) further classified the way of combining quantitative and qualitative techniques into concurrent mixed methods, which simultaneously use quantitative and qualitative methods; sequential exploratory, which starts with qualitative research, followed by quantitative research; and sequential explanatory, which begins with quantitative methods followed by qualitative research. Finally, sequential multi-phase research starts with qualitative research in the first phase, then a quantitative method, and then a qualitative method to end.

There are some advantages of adopting this research method in any research. It will provide a deep understanding of the research problem (Creswell, 2014); it allows the flexibility of using the best research techniques and data for the research topic, problem, and objectives (Kumar, 2014); and it enhances the research findings with rich data collection.

4.5.4 Justification of Research Methodology Adopted

This research study adopts a mixed-method approach associated with the sequential exploratory classification. It starts with qualitative research (focus group), followed by quantitative research (questionnaire). Mixed methods can be useful for accomplishing the research objectives by combining statistical data with thematic data. It assesses the two approach perspectives of inductive and deductive (Jogulu & Pansiri, 2011). Subsequently, in the first stage of the research, data collection, a focus group is used to understand the participants' perceptions of the research topic. In the second stage of data collection, the questionnaire tests the perceptions of the developed model. The data are analysed according to the research methodology employed in each stage.

4.6 Research Strategy

Eight different types of research strategies were included in the adopted onion model. Saunders et al. (2019) stated that the research strategy is the action plan to achieve the research goal by answering the research questions through a suitable strategy. The research strategy is closely related to the third layer of the model with the quantitative, qualitative, and mixed methods. In addition, it is also associated with the second layer, the research approach, which can be inductive, deductive, or abductive.

4.6.1 Type of Research Strategy

There are a number of research strategies have discussed in this section: experiment, archival research, ethnography, action research, grounded theory, narrative inquiry, survey, and case study. Each research strategy is discussed considering whether or not it would be suitable for this research to answer the research questions and meet the objectives. It is pointed out that several strategies included in qualitative methods: case study, grounded theory, action research, narrative inquiry, and ethnography, which closely reflect the inductive approach (Myers, 2009; Saunders et al., 2019; Denscombe, 2010). Whereas quantitative methods include experimental research and survey strategies, which are associated with the deductive approach (Gill & Johnson, 2010; Saunders et al., 2019). Charmaz, (2014) and Saunders et al. (2019) showed that mixed-method research is intently involved with case studies, grounded theory, and surveys, which follow the abductive approach. Overall, this research study was conducted with two types of research strategies: the survey strategy and the case study strategy; they will be discussed in detail later. However, no one strategy is superior to others, and according to Saunders et al. (2019), the choice of the right method and strategy depends on the purpose of the research, and the type and availability of the data and information.

4.6.1.1 Experiment

According to Saunders et al. (2019), the experiment strategy is the first strategy to discuss due to its root in natural science, and psychological and social science research. It studies the probability of dependent and independent variables. However, it indicates explaining the hypotheses or theories rather than explaining the research questions. Similarly, Collis and Hussey (2014) defined the experiment strategy as scientifically investigating and studying the causal relationship between two types of variables. Cooper and Schindler (2014) state that in the first stage, the experiment strategy deploys the independent variables, then observes the dependent variables, which have already been studied.

Bryman and Bell (2015) categorised two types of experiments, which are field experiments and laboratory experiments. Field experiments are sited in the field; they use the available variables and can be of long duration, whereas laboratory experiments are located on site, control the use of variables, and have a short duration. Saunders et al. (2019) classified two types of experiments according to the use of variables: classical and quasi-experimental. The classical strategy depends on the random selection of participants through the experimental group or control group. The quasi-experimental strategy is where the participants are only available in the existing workgroup, which makes the selection of individuals for the experimental group or control group not random.

Collis and Hussey (2014) demonstrated that this type of strategy is closely associated with the quantitative method, deductive approach, and positivism philosophy. The experiment research strategy has advantages and disadvantages, illustrated by many authors. The main advantage of this strategy, as highlighted by Saunders et al. (2019), is that the researcher can have full control over the research process by selecting the sample and context of the investigation. The main disadvantage is the difficulty of establishing and obtaining external validity, which limits control of the research process (Saunders et al., 2019; Denscombe, 2010).

This research study will not adopt this type of strategy for several reasons. Firstly, it is not related to philosophical approach selected for the research, as pragmatism is the adopted philosophy while this strategy is associated with positivism. Secondly, the researcher has no control over the variables in this research study. Thirdly, it is not attached to the method and approach chosen.

4.6.1.2 Archival Research

This research strategy is mainly used or chosen because of the digitalisation of data and online archives, which provide the researcher with the flexibility of using the archival or documentary strategy (Saunders et al., 2019). The source of data in this strategy is initially online from around the world, such as visual and audio documents (posters, artefacts, digital records, DVDs, films, web images, TV programmes, and more). this strategic approach can produce valuable data, however, it is difficult to use this strategy because it is hard to describe all necessary information from different types of data (Saunders et al., 2019). The chosen data can be analysed quantitatively and qualitatively or both together.

This research study will not adopt this type of strategy as this type of research is not associated with this strategy. In addition, the type of data gathered in this research is not associated with the data employed in this strategy. However, the documentary research could be employed in the case study strategy, which is used in this research.

4.6.1.3 Ethnography

The term ethnography can broadly be defined as a strategy used by researchers to study the culture or social world of a group (Saunders et al., 2019). According to Watson (2011), ethnography is basically drawing upon the writer’s observation and involvement with people, focusing on the social words spoken or experiences over a cultural framework. It refers to a qualitative research method where the researchers reveal the views related to people and culture, then take actions based on the meaning of them (Saunders et al., 2019; Myers, 2009). Another definition of ethnography was provided by Robson and McCartan (2016): clarifying and interpreting the cultural and participant behaviour in the real world. Similarly, Collis and Hussey (2014) describe the ethnography strategy as the researcher understanding and interpreting the social world. In any research, ethnography means collecting data by engaging with a specific group by asking questions, conducting interviews, observing, understanding and analysing the discussion over a long period of time (Bryman & Bell, 2015).

John and Gill (2010) illustrated multiple factors that can be used to determine whether research is adopting the ethnography strategy: the purpose of the research, the availability of resources to the researcher, the setting of the research, and its aims and objectives. In terms of the choice of philosophy in this strategy, interpretivism philosophy is mainly associated with the ethnography strategy (Collis & Hussey, 2014). The inductive approach is strongly related to the ethnography strategy (Saunders et al., 2019). One of the advantages of this strategy is the wide range of methods that can be used to collect data; therefore, there is the flexibility to adopt multiple methods and approaches (John & Gill, 2010). However, as mentioned before, it takes a long period of time, and this can be one of the disadvantages of this strategy. In addition, there is no specific guide for the research process, as shown by John and Gill (2010).

This research is not adopting the ethnography strategy and it is not suitable for this research strategy for several reasons: (1) the limited time available for this research study; (2) the fact that this study is not aiming to study the behaviour of the participants; and (3) there is no protocol guide in ethnography to help the data collection process in general.

4.6.1.4 Action Research

The term ‘action research’ was first used in early 1946. Saunders et al. (2019, P. 190) state that the purpose of this strategy “is to promote organisational learning to produce practical outcomes through identifying issues, planning action, taking action and evaluating action”. Consistently, this strategy brings the theory to the first stage, then that theory is practised to make changes or improvements to the selected organisation by acting in accordance with the theory of knowledge that was created (Smith et al., 2015). In addition, it has been defined as the collaboration between the researcher and the organisation to mainly review the problem then present solutions to that problem (Bryman & Bell, 2015). Saunders et al. (2019) suggest that this strategy has three stages, similar to the Bryman and Bell (2015) definition: testing out the issue, understanding the customer and the project, and acting on the knowledge.

Although this type of research strategy is associated with qualitative research, it is different from other qualitative methods due to the collaboration between the researcher and client (Lodico et al., 2010). Therefore, action research strategy can use qualitative and quantitative methods for data collection. Moreover, multiple authors have associated the action research strategy with different philosophies: Bryman and Bell (2015) connected it with interpretivism, while Coghlan and Brannick (2014) showed that it linked with critical realism philosophy, and

Lodico et al. (2010) state that it is strongly linked to pragmatism philosophy due to its use of mixed methods of data collection. Two main advantages of the action research strategy are the flexibility of choice of research strategy or data collection methods (Lodico et al., 2010). Moreover, it addresses the research problem in a context to present a practical solution (Denscombe, 2010). On the other hand, two of the disadvantages of the action research strategy are the limited time (Saunders et al., 2019) and the fact that it focuses more on the organisation's improvement than the findings of the research (Bryman & Bell, 2015).

This type of strategy is not feasible for this research study for several reasons: (1) the limitation of time in this research; (2) the difficulty of having full access to the data through the organisation; and (3) the inability to generalise the findings. This research seeks to generalise the results over the research topic.

4.6.1.5 Narrative Inquiry

This term is used mainly to collect the participants' experiences and reconstruct them into narrative inquiry (Saunders et al., 2019). Therefore, this strategy requires the participants to provide details about themselves and their experience (Creswell, 2014). In general, the narrative inquiry strategy helps the researcher to analyse and recognise the gathered stories or experiences, then rewrite them into a general framework of narrative (Creswell, 2014). However, the data for a narrative inquiry research strategy can be collected from different techniques; the data is usually within a specific place or situation. In the research of narrative inquiry, data collection and data analysis can be done by a variety of ways. The number of participants may be small, one two, or three, and they are judged to be a typical the large sharing population (Chase, 2011). Saunders et al. (2019) state that a fairly large sample is required to be able to analyse the narratives. The nature of this strategy is intensive and time consuming, two reasons for attempting this strategy with small samples.

Narrative stories can be appropriate for research that employs a qualitative research strategy and uses interpretivism in the research questions and research objectives (Saunders et al., 2019). One of the advantages of this strategy is that it generates a large amount of data from a small sample (Saunders et al., 2019), whereas the data collection requirements and characteristics can be a challenge in this strategy.

This research will not employ the narrative inquiry strategy for two main reasons: (1) it is too time consuming; and (2) the research is not exploring the personal narrative story of participants, and it does not ask for personal details as narrative inquiry does.

4.6.1.6 Grounded Theory

According to Suddaby (2006), grounded theory is defined as producing meaningful theory from observation or data collection in the research context. It fundamentally means that theory is produced or conceptualised rather than testing a theory (Charmaz, 2014). Moreover, in this strategy, the researcher is interacting with the selected participants, aiming to collect and analyse the data over the research process to build a new theory. A variety of processes were recognised by Charmaz and Bryant (2016): data collection, coding, theoretical sampling, memo-writing, and report writing. Each process involves the research or the researchers in different perspectives.

One main advantage of this strategy is helping to build and develop different perspectives of the theory (Symom & Cassell, 2012), as this can also help to build evidence from reality through the data collection (Denscombe, 2010). On the other hand, Bryman and Bell (2015) demonstrated some disadvantages of the grounded theory strategy such as limited time to implement the theory in practice.

This research has not adopted this strategy, mainly because it is time consuming. Significantly, the literature review developed an initial perspective of how the construction industry harms the environment and humans around us. Therefore, the finding relates to sustainability-related risks, it is not compatible with the grounded theory.

4.6.1.7 Survey

The survey research strategy is mainly gathering the data from a population through methods such as a questionnaire. This strategy allows the researcher to gain a huge amount of data from a sample in an economical way. Furthermore, with a survey it is relatively easy to use and analyse the collected data. Martin and Guerin (2006) recommended a survey when the researcher wants to observe human behaviours, beliefs, and actions by collecting the data from people. Some key features of this strategy are presented by Denscombe, (2010). It provides a snapshot of a point in time rather than focusing on the process and the changes. Furthermore, sampling errors and bias could lead to findings that are not accurate and do not reflect the population.

This research strategy gathers the data quantitively and deductively using descriptive statistics (Saunders et al., 2019). In contrast, Dray (2014) pointed out that the data collected through a survey strategy can be quantitative and qualitative. Similarly, Bryman and Bell (2015) described survey data as being quantitative and qualitative, and gathered through questionnaires or structured interviews. A popular technique for collecting the data from a large population in this strategy is a questionnaire (Charities Evaluation Services, 2016; Saunders et al., 2019). There are also other techniques such as structured observation and structured interviews (Saunders et al., 2019).

Some advantages and disadvantages can be clearly identified in this survey strategy. Some of the advantages are the quickest and most cost-effective way to collect a large amount of data (McCartan, 2016). In addition, the strategy can be used to represent a large sample of the population through generalisation of the findings (Saunders et al., 2019). Moreover, the data can be analysed easily as this strategy provides a large amount of data (Robson and McCartan, 2016). Some of the drawbacks related to the data collected through this strategy is that it usually covers the topic in general rather than diving into depth into the investigation of the research. Other disadvantages related to the participants or respondents, as sometimes they do not report their beliefs or views accurately (Robson and McCartan, 2016).

This research study adopts a survey strategy due to its advantages for collecting data from the Jordanian construction industry. It uses a questionnaire and a semi-structured interview (see section 4.5) to explore sustainability in Jordan and the challenges facing sustainability, and to produce the final list of sustainable risks for the proposed model.

4.6.1.8 Case Study

The definition of a case study research strategy by Yin (2014) highlights the fact that it investigates in depth the research phenomenon or topic within its real-life context. This strategy tends to be used when the boundaries of the research topic, phenomenon, and context are not clear**.** Similarly, Bryman and Bell (2015) showed that a case study is used to deeply understand the case under investigation. A case study is useful for gaining a rich understanding of the context of the research; it answers the "how" and "why" questions.

Multiple techniques for data collection can be employed in this strategy for an in-depth understanding, validation, and investigation, such as focus groups and interviews**,** observation, archival records and documentation, and questionnaires (Saunders et al., 2019; Yin, 2014). A qualitative approach is particularly used in this strategy, but both qualitative and quantitative approaches can be used, depending on the case study in the research (Robson and McCartan, 2016; Yin, 2014). According to Yin (2014), there are two types of case study: single or multiple case studies. A single case study can be used to characterise a unique or a critical case; it gives the researcher an opportunity to observe and analyse a phenomenon. Multiple case studies focus on identifying several occurrences of an event and then generalising from the findings. Saunders et al. (2019) describe the choices for the research strategy and the methodology can be a mono methodology that uses either qualitative or quantitative methodology, or it can use more than one; multiple methods or mixed methods. The multi-method approach uses two data collection methods but both are qualitative or quantitative, while mixed methods uses a mixture of qualitative and quantitative methods.

This strategy has multiple advantages such as the use of mixed or multiple methods regarding the source of data, which simplifies the triangulation (Robson and McCartan, 2016). In addition, this strategy is useful for uncovering a wide range of issues within the case or the research topic (Yin, 2014). However, two drawbacks can be considered in this strategy according to Saunders et al. (2019) and Yin (2014): the complexity of this strategy can make the data difficult to analyse and the selection of participants unsuitable.

Pragmatism philosophy is the main philosophical position in this research study, while the abductive approach and mixed methods are the adopted methodological choice in this study. The choice of methods is based on the aim of deeply understanding the sustainability-related risks affecting Jordanian construction companies. The case study has the strong advantage of allowing triangulation. Therefore, the case study strategy was adopted in this research, particularly to validate and check the model developed in this study.

Yin (2014) showed the importance of defining the boundaries, unit of analysis, and selection of case studies. However, these three perspectives will help the case study to achieve the research aim, which is validating the model. In terms of the boundaries, Yin (2014) highlighted different boundaries that refer to the time, location, social group, and others. Three boundaries are encountered in this research: the experts in the Jordanian construction industry, the time of the research, and its geographical location. The experts need to be professional and to have experience in environmental and sustainable risks in construction. The time of the Ph.D. research is limited to three years, and there is no opportunity to have participants from overseas.

Multiple units of analysis can be included in the case study. The unit of analysis in this research study is environmental and social practices in the Jordanian construction industry. Consequently, the data were collected from project managers, risk managers, and university professors. All experts have experience, and they are involved in environmental and social risks. According to Creswell (2013), the number of cases selected in the research can be at least two and up to five. Regarding addressing the research needs, problems, and objectives, a single case study is adopted through a focus group to observe and analyse the phenomenon of the research. Moreover, the case findings of the focus group technique were used in the questionnaire later to develop the model. Three case studies are selected to check and validate the efficiency of the model; no data were gathered in these selected cases, they were only used to achieve the aim of validating the model.

4.7 Time Horizon

The time horizon is the fifth layer of the research onion, and it refers to the period of time during which the research was conducted. According to Saunders et al., (2009), time horizons can be either cross-sectional or longitudinal. Cross-sectional describes a study over a short period of time, while longitudinal research is usually conducted over a long period of time. This research will follow the cross-section time horizon as it aims to develop a risk assessment model and it is time limited over the Ph.D. period.

4.8 Research Techniques and Procedures

Different types of data collection and data analysis techniques were adopted in this research to represent the research questions, problems, and research objectives. Both quantitative and qualitative data were produced and analysed through several techniques and procedures. In general, the research techniques, procedures, validity and reliability, and ethical considerations will be discussed in the following sections.

4.8.1 Types of Data

According to Robson and McCartan (2016), the type of data collection should be selected based on the research problem, research questions, research aims, and objectives. Different sources can also be employed when considering the data collection (Saunders et al., 2019).

4.8.1.1 Secondary Data Collection

Secondary data can be either qualitative or quantitative. According to Lind et al. (2012), there are multiple types of secondary data: from the literature, census data, government information, financial data, organisational, reports, and records. The initial purpose of secondary data is to help the researcher to understand, investigate and develop full knowledge about the research topic.

In this research study, representing, collecting, and analysing the secondary data were achieved through the literature review. The sources of data can include academic books, academic or official websites, journal articles, databases, government reports, or organisational reports. However, Rabinovich and Cheon (2011) stated that one of the benefits of secondary data is the reduction of the biases that are present in the primary data collection such as a case study, interview, or other strategies. In this study, the secondary data were introduced in two stages; firstly, to identify sustainability and sustainable construction, and to find how construction has an impact on the environment and humans. Then from the knowledge gathered, an initial sustainability-related risks list was produced. The second phase of the secondary data collection explored the current methods used for risk management in the construction industry in general, including analysing and comparing these methods to develop the theoretical bases for the conceptual model in the research.

4.8.1.2 Primary Data Collection

The other type of data used in this research is primary data, which is gathered by the researcher through various methods. A popular primary data collection method can be used in the research such as interviews, questionnaires, observation, documentary analysis and a focus group; these are related to the quantitative, qualitative, or mix of methods (Saunders et al., 2019). Consequently, in this research study, the primary data were gathered through a focus group and a questionnaire to address the research objectives and research questions. Firstly, the focus group method aimed to review and observe the initial sustainability-related risks discussed in the literature review, to find the risks that applied to Jordan. A questionnaire was used to discover the highest impact risks in the Jordanian construction industry. The data collection and analysis methods used in this research will be discussed and analysed in detail in the following sections.

4.8.2 Type of Variables

When measuring the data numerically, different types of variables can be presented. Categorical and continuous are two types of variables recognised by Field (2013). Variables can be classified as dependent or independent, and they can be tested through parametric and non-parametric tests (Field, 2013).

4.8.2.1 Categorical Variables

This refers to data that cannot be measured numerically (Saunders et al., 2019). Three types of categorical variables are binary, nominal, and ordinal. Firstly, the binary variable includes two options such as true and false. Secondly, the nominal variable indicates more than one option. Thirdly, ordinal variables are based on logical order such as scoring or scaling from one to four, where one means the lowest and four means the highest (Field, 2013).

4.8.2.2 Continuous Variables

These are variables that can theoretically take any value and can be measured precisely (Dancey & Reidy, 2011). Two types of continuous variables are interval and ratio. An equal difference between the presented options is referred to as interval variables, while a ratio variable is expressed logically after showing the difference or comparing the options.

In this research study, categorical-ordinal variables were used as Likert scaling was employed in the questionnaire. A scale from one to five was used to rate the risks' impact and probability. According to Blumberg et al. (2014), these types of variables will be parametrically tested.

4.8.3 Data Collection, Data Analysis and Procedures

This research employed two types of data collection in two stages; the first stage included the focus group, then the results obtained from the first stage were used to design a questionnaire. The data collected through the focus group were transcribed and then analysed with a thematic approach. The questionnaire data, on the other hand, were analysed both descriptively and statistically. Finally, the model was validated through three case studies after analysing the data collected from the focus group and questionnaire.

4.8.3.1 Focus Group

Throughout this thesis, the term 'focus group' is used in some context in the research strategy under case study, research methods, and techniques. A focus group is based on interaction between participants to discuss a specific issue or part of the topic. It is a way to collect primary data in the case study strategy. Krueger and Casey (2009) identified a focus group as a "focus group interview" that basically focuses on open discussion about an issue, product, service, or specific topic. The moderator or the researcher may carry out and control the discussion through the participation of the group (Stewart & Shamdasani, 2014).

Saunders et al. (2019) recommended selecting the participants based on common characteristics related to the research topic. Consequently, this research study selected experts according to their experience of the environment and social risks in construction; they were project managers, risk managers, civil engineers, and university professors. Regarding the number of participants, there is no consensus on the ideal number of participants in a focus group. Back in 1998, Morgan suggested from 10 to 12 participants, while Krueger and Casey (2014) recommended from 5 to 8 participants, so that the researcher or moderator could control the discussion easily. Saunders et al. (2019) pointed out that the size of a focus group depends on the nature of the topic. For example, if the views that will be collected are about a product, then it can be a large group, while if the topic is more about emotional matters or obtaining views by rating the group's attitudes, then the researcher can use a smaller group. Considering the nature of the research topic, the researcher decided to contact 10 experts, but only 8 of them responded to officially participate in the study. Two were construction managers, two were civil engineers, two were risk managers, and two were academic university professors.

The focus group therefore consisted of one group of experts containing 8 participants. The participants were contacted through an invitation by email, asking them to take place in the study. The email explained the purpose of the research, and it suggested a time and date for the meeting. All of the participants were told about the structure of the meeting, and that they would be participating in a focus group containing eight experts in total. Two meetings took place on the Zoom meeting application; the first meeting lasted for an hour and a half, while the second meeting was for around two hours. The first meeting was conducted to basically discuss the initial risks in general, while the second meeting was conducted to discuss the causes of the risks. Therefore, the meetings were completed over two days, as logically it would be difficult for the participants to devote four hours in a day to the meeting. The participants were notified that they were free to leave at any time, free to answer in their own words and language, and that they would remain confidentiality anonymous for the research. At the beginning of the first meeting, all of the participants were informed about the research topic again and they were told the estimated time for the meeting. The researcher asked their permission to record the meeting. They were each asked for their name, years of experience, and profession. The initial risks list was introduced for them to discuss and check whether each risk was applicable in Jordan. The second meeting took place on the following day at the same time, with the same participants. In the second meeting, the experts were asked to assign two to three causes to each risk in the new list after the original list had been modified.

Data analysis is an important part of each research process (Bryman, Bell, 2015). The qualitative data gathered through the focus group were recorded, transcribed, and then analysed with thematic analysis. Saunders et al. (2019) described the thematic analysis approach, which is commonly used to identify, interpret, codify, report, and analyse qualitative data. Robson and McCartan (2016) advise that the thematic analysis approach can be inductively and deductively applied, depending on the codes and themes related to the research questions. Therefore, thematic analysis was used to analyse and transcribe the qualitative data from the focus group. This will be discussed in detail in the data analysis chapter.

4.8.3.2 Questionnaire

Researchers commonly use questionnaires to collect quantitative data, including participants' opinions, facts, views, behaviours, beliefs, and attitudes towards a specific topic (Saunders et al., 2019; Denscombe, 2010). Questionnaires have a structure, and researchers can organise the questions carefully then analyse the participants' responses (Kumar, 2014). The nature of the research topic can determine the aim of the questionnaire, which can be used to explore a topic or for description purposes (Saunders et al., 2019; Gray, 2014). In addition, there are two types of questionnaires, self-administered or researcher-administered, and they can be distributed via mail, in person, over the telephone, or online through the internet (Saunders et al., 2019; Gray, 2014). According to Bryman and Bell (2015) and Saunders et al. (2016), two types of questions that can be included in the questionnaire: open or closed questions. A closed question refers to questions that require the participants to select specific options or answers that have been decided by the researcher. On the other hand, open questions elicit longer, more extended developed answers, which have not been determined by the researchers.

In this study, a questionnaire survey was employed to ask the participants to rate the impact and probability of each risk, to later explore the highest risks that affect the environment and humans in the Jordanian construction industry. This helped to develop the model. The participants were experts from the Jordanian construction industry such as site engineers, civil engineers, project managers, risk managers etc. They were selected and contacted through LinkedIn social media networks, by filtering the professions and locations of the experts. In addition, other experts were contacted through email addresses obtained from the Jordan Engineers Association.

With a questionnaire, sampling can be either probability or non-probability sampling (Saunders et al., 2019). In general, probability sampling refers to distributing the questionnaire according to the overall population; the participants are selected based on a probabilistic mechanism that makes the probability of selecting the participants clear. On the other hand, non-probability sampling reflects the "selection of sampling techniques in which the chance or probability of each case being selected is not known" (Saunders et al., 2019).

Probability sampling contains four methods, as outlined by the Charities Evaluation Services (2016). Firstly, there is a simple random sample, where the selection of participants is random and the researcher must use the whole population. Secondly, systematic sampling means a non-random selection of participants, where a specific number of participants is selected from a specific source. Thirdly, a stratified sample is a complicated technique because it can be divided into two stages and in each phase, there is random sampling. The known facts of the population are selected then each participant is assigned to one group. Fourthly, in cluster sampling the population is divided into sub-populations then these groups are randomly selected, so all the participants are selected from the cluster. On the other hand, non-probability sampling does not contain any choices for defining the individual probability within the sample, and there are five methods for this type of sampling (Arif, 2011): model instance sampling, expert sampling, quota sampling, heterogeneity sampling, and snowball sampling.

In this research study, probability simple random sampling was used as the main sampling technique for the questionnaire to select the participants from the Jordanian construction industry. The sample included members of the Jordanian Engineering Association, which has 176,776 engineers in Jordan. According to Saunders et al. (2019) Table 7.1, the target population is between 100 thousand and 1 million with a 5% margin error. Therefore, the sample should be at least 384 Jordanian engineers. In this research, the sample was 402 engineers, so this was sufficient. They included a site engineer, civil engineer, project managers, risk managers etc. In addition, the adopted technique has the benefit of being able to generalise the conclusion of the research.

According to Saunders et al. (2019), testing and piloting the questionnaire guarantees that the participants can read and answer the questions easily without any problem, and this indicates participant satisfaction, which affects the reliability and validity of the data collection. In this research study, all the eight participants who tested and piloted the questionnaire stated that the questionnaire was sufficiently associated with the clarity of the research topic in terms of understanding the type of questions and the required information. Two of the participants recommended that instead of including all the 48 risks in one section, they should be separated into two sections regarding the events group. In addition, they suggested including the impact and probability in the same scale question. Therefore, all the suggestions were taken into consideration to edit the draft of the questionnaire, and produce the final version.

The final questionnaire was designed to be self-administered and it was distributed to the participants through the LinkedIn social platform and via email. Four sections and 55 questions were included in the questionnaire to explore which risks has the highest impact and probability. In the beginning, a description was given to explain the research topic, then the participants were asked to sign the consent form, confirming that they agreed to take part in this questionnaire and were aware that they were free to withdraw at any time. The first section contained five checklist questions about the respondents' demographic information such as years of experience, current job position, type and size of the organisation they worked for. The main topic of the questionnaire was about the respondents' experience of environmental risk management practices. Section two was designed to utilise a 5-point Likert scale, and the participants were asked to rate the impact and frequency of a hazardous event on natural resources, the ecosystem, and biodiversity groups. The impact level and score went from very low (1) to very high (5), whereas the probability score and level went from very rare (1) to highly possible (5). Moreover, the next section was also designed to rate the impact and frequency of a hazardous event in socio-economic terms, public and occupational health, waste management, chemical or hazardous materials, and managerial events. These questions were scored the same as the previous questions. The final section included one open question about the participants' comments on environmental hazardous events from their own experience and in their own words (see appendix 7).

Multiple data analysis techniques were adopted in this study to analyse the quantitative data. Collis and Hussey (2014) illustrated two ways to analyse the data: manually or through software such as Excel spreadsheets, or advanced analysis software such as Statistical Package for the Social Sciences (SPSS). The researcher used Excel and SPSS software to analyse the quantitative data.

In particular, the quantitative data can be analysed through descriptive statistics or/and inferential statistics (Saunders et al., 2019). Both techniques were used to analyse the data in this research. Firstly, descriptive statistics were used to describe the respondents' information at the first stage. In the second stage: (1) each group of the environmental hazardous events was summarised and displayed by calculating the mean and standard deviation; (2) each risk was described across the mean and standard deviation; and (3) the 48 risks were organised from highest to lowest. On the other hand, inferential statistics were deployed through simple linear regression and Pearson's correlation test (Saunders et al., 2019), which includes three tests: (1) correlation between each group and the total risk; (2) correlation between each group; and (3) correlation between each risk with its group. Each statistical technique will be discussed in detail in the data analysis and findings chapter.

4.8.3.3 Case Study

In order to answer the research questions and achieve the research objectives, the case study was the most suitable approach (Saunders et al., 2019). As previously explained in the research strategy, there are two types of case study: a single case study approach and a multiple case study approach. The single case is used if the nature of the case is critical or unique, while the multiple case study is mainly used to allow duplication to answer the research questions and achieve the objectives (Saunders et al., 2019).

In this research study, the case studies were not used for data collection, but for validating and checking the efficiency of the model, according to the data findings from the focus group and questionnaire. Three case studies from different projects and different companies were employed to achieve the goal of using this method. Each case study has its own type and position in the research. The first case study is a commercial building, the second is a road and infrastructure project, and the third is a landfill construction project. Consequently, the researcher introduced the model including the highest 32 risks, then the manager of each project provided the probability and the impact of each risk. The final results showed different rankings of the risks in each company, as each project had its own risks, type of environment, type of project, and position in general. After validating the developed model throughout the selected projects, the data was analysed to provide recommendations for the efficiency of the model, which will be discussed in detail in the validation of the model chapter.

Three general questions were asked of the participants within an interview: could you describe the situation of risk management in Jordan? What is the risk assessment process in your company? and Do you consider sustainability-related risk events in your risk assessment? The classification of the risks during the validation of the model differed from one project to another, depending on each project, the company risks, environment, type of project, and the position of the project.

4.8.4 Validity and Reliability

Two aspects of the research were formed to reflect the trustworthiness of the research, as it is important for every research to measure its quality and activities. The term 'validity' refers to the truthfulness and accuracy of the results of the research in terms of whether the research measures what it wants to measure (Bryman & Bell, 2007; Collis & Hussey, 2014). Reliability refers to the estimated consistency of the data collection and analysis during the research (Saunders et al., 2019). Both aspects were considered in this research within the data collection in the focus group and questionnaire.

Reliability was considered in this research by avoiding the four threats that affect it: participant errors, participant bias, observer error, and observer bias (Robson & McCartan, 2016). Reliability was also addressed through the research methods selected, and by establishing the pilot study to measure the reliability. Cronbach's alpha reliability test was used to estimate the internal consistency of the findings. The result of Cronbach's alpha test showed that the reliability was 0.7, an acceptable average value according to Field (2013) and Creswell (2012).

In addition, the strength of the reliability was ensured through the strong process and plan across all the research stages. This showed in the research as the researcher obtained a transcript through the focus group research method to illustrate the reliability of the findings.

Validity was encompassed in this research study through three types of validity: construct, content, and external validity. In general, validation is important in research within the qualitative and quantitative data. The validation of qualitative data refers to the honesty, triangulation, and truthfulness of data and objectives, while validation of quantitative research refers to measuring errors in data, statistics, and the sampling of the participants. Measuring the accuracy of the study concept is described as construct validity, while content validity refers to assessing the research method, analysis, and procedures (Collis & Hussey, 2014). On the other hand, Bryman and Bell, (2015) separated the types of validity into internal and external. Internal validity evaluates the strength and truth of the value, while external validity refers to the transferability and generalisability of the research findings. In this research study, validity was achieved in the following ways:

Construct validity was attained by providing evidence of multiple methods of data collection (focus group, questionnaire, and literature review) triangulation, and the consistency of the statistical analysis procedure (Creswell, 2014).

Content validity was established through the pilot study for the questionnaire, the appropriate connection between the research questions and research objectives, and a properly structured literature review (Saunders et al., 2016).

Internal validity was achieved mostly through the design of the questionnaire and the selection of participants, and the findings, which represent sustainability risk assessment in the Jordanian construction industry (Yin, 2018).

External validity was achieved through the researcher selecting the number of participants to represent the Jordanian construction industry. While it considered the generalisability of the research, external validity was also achieved while analysing the inferential statistics and the high responses rate in the questionnaire (Robson & McCartan, 2016).

4.8.5 Ethical Considerations

The researcher considered all the essential ethical issues throughout the gathering of the primary data from the participants through a focus group and questionnaire. It is essential to avoid research ethical issues such as privacy, data confidentiality, the anonymity of participants' information, and a misuse of the findings (Saunders et al., 2019). Multiple ethical matters were taken into consideration throughout this research study. Firstly, ethical approval was confirmed by the University of Salford. Secondly, a consent form was used while collecting the data that described to all the participants the research topic, the flexibility of choice to volunteer in this study, the type of questions, the time they would spend on each method, the fact that they could withdraw at any time, and an assurance of the privacy of their information. In the focus group research method, the researcher explained all of these ethical considerations in the consent form, asked for permission to record the meetings and assured the participants that this record and their personal details would be kept confidential. In addition, the participants in the focus group method were told that they would be able to check the research findings to check them and avoid any future risk. In the questionnaire research method, the researcher clarified the research topic, the time it would take, the flexibility to withdraw at any time, and the fact that the participants' personal information was not required in the questionnaire. A signature was required before taking part in the questionnaire. All the data were collected and kept confidentially on the researcher's computer via Google Drive. There were no personal details related to the participants' organisation, no pressure to answer any question, and certainly, no deceptive practices were included in the consent form. Regarding the tool used to collect the data, in the questionnaire the participants were informed through Google Sheet, which gave them the choice in the focus group to choose either the Zoom application or another that they preferred.

4.9 Conclusion

This chapter discussed the methodological choices and presented the justification for using each method, which connects with the research questions and objectives. This research adopted the onion model by Saunders et al. (2019), which illustrated the research philosophies, research approaches, methodological choices, research strategy, time horizon, and research techniques and procedures. With regard to the research philosophy, the pragmatism philosophy was adopted in this research due to its flexibility to combine qualitative and quantitative research methods, which reflect the research topic, questions, and objectives. This study adopted an abductive approach combining the inductive and deductive approaches, which are both associated with the nature of the research topic. A mixed-method approach was adopted, combining qualitative and quantitative research methods – a focus group and questionnaire respectively. The focus group was utilised to understand the participants' perceptions of the research topic, while the questionnaire was adopted to test their perceptions of the model developed in the research. Multiple research strategies were clarified and discussed, and their use justified. Probability sampling was used for the questionnaire and the participants in the focus group were selected according to their experience. Both quantitative and qualitative data analysis were adopted; quantitative data were analysed with descriptive statistics and/or inferential statistics visa Microsoft Excel and SPSS, while qualitative data were analysed using the thematic approach. Eight experts participated in the focus group, while 402 engineers participated in the questionnaire.

Chapter Five

Chapter Five: Diagnosis of Sustainability-related Risks in The Jordanian Construction Industry

5.1 Introduction

This chapter discusses the analysis of the findings from the data collection in two stages. The first stage analyses the qualitative data obtained from the focus group, and the second stage analyses the quantitative data gathered through the questionnaire. The chapter start with the meetings that were made with the members participating in the focus group, there will be no statistical results, but there will be a review of the mentioned risks and causes that collected from literature, and their confirmation or denial. Then, a questionnaire is distributed to people who are familiar with sustainability and risk management, in order to generate statistics that will prove or deny any of the risks and causes as well. Finally, the questionnaire hypothesis is developed on the basis of which the research questions and objectives were developed, besides reaching a final conclusion through which a risk model in this research can be developed in this research.

5.2 Qualitative Risk Analysis

In this section, qualitative data will be collected from the expert participants, and then, the risks that were previously listed will be reviewed in a dialogue form through which experts can provide their opinion about the existence of those risks in the context of the Jordanian construction industry or not. This information will be realistic and up-to-date because these experts are located in the Jordanian context and in the construction field in particular. Therefore, the information provided by them will be real, reliable, varied, authentic, and also, non-statistical. Through this section, the risks and causes of the risks will be filtered to relate to the Jordanian context in particular.

According to Saunders et al., (2019), the qualitative data conducted by the focus group contains the respondents' background and profile, and the data analysis of each discussion includes the initial risks in general and causes of the risks in the Jordanian construction industry. As mentioned in the previous chapter, the focus group aims to review the 89 initial sustainability-related risks that was collected from literature review and consider their applicability in the Jordanian Construction industry, then discuss the respondents' suggestions about the causes of these risks in the Jordanian Construction Industry.

5.2.1 Respondents Background

The focus group consisted of eight respondents who met twice to discuss the research topic. Each meeting lasted for approximately half an hour. The meetings were recorded, and notes were taken by the researcher to summarise the key points after the discussion. Each meeting covered two main questions. At the first meeting, all of the participants were asked about their job titles and their work experience, and then they were asked to review the 89 environmental and social risks and their applicability in the Jordanian construction industry. This discussion reduced the number of risks to 48. At the second meeting on the following day, the same participants were asked to suggest two or three causes of each of the 48 hazards that had been discussed the day before. Table 5-1 shows the eight participants' job titles and years of work experience.

Table 5-1: Respondents' Profiles

Participants	Job Title	Years of Work experience
1	A construction manager in a consultant company.	28
2	CEO of a construction company.	35
3	A risk manager in a construction company.	17
4	A risk manager in a consultant company.	15
5	Academic/lecturer at the University of Philadelphia – Civil Engineer Department – Environment specialist.	30
6	Academic/lecturer at the University of Philadelphia - Civil engineer - Environment specialist.	33
7	A construction manager in a construction company.	10
8	Senior site engineer - Civil Engineer.	8

5.2.2 Thematic Analysis

A thematic analysis approach was used as a technique to analyse the qualitative data from the focus group. This was done by reviewing the transcribed data from the focus group discussions. According to Saunders et al. (2019), there are different techniques for analysing qualitative data, such as thematic analysis, template analysis, explanation building and testing, grounded theory, narrative analysis, discourse analysis, content analysis, and data display and analysis. Transcript summaries are one of the aids that help researchers in qualitative data analysis, as they allow the researcher to briefly consider the key points from the transcribed interviews (Saunders et al., 2019). Therefore, the thematic analysis approach was adopted, and the transcript summaries from the two discussion meetings were analysed. Firstly, the participants' responses to the 89 environmental and social risks, and their applicability to the Jordanian construction industry, were analysed. The second analysis considered the key points from the respondents' suggestions for the causes of these risks.

5.2.2.1 Discussion of The Initial Risks in General

A considerable list of hazards was drawn up from the literature review, rating systems, UN sustainability goals and EIA, as stated in the literature review chapter. Therefore, 89 sustainability-related risks were presented within 8 category groups: risks that have an impact on natural resources; risks that affect socio-economic conditions; risks that pose a threat to public and occupational health; risks that have an impact on the ecosystem, including noise, air quality, soil and water; waste management risks; risks related to chemical materials; risks that have an impact on biodiversity; and managerial risks. Table 5-2 lists all of the risks that were obtained from the literature review and needed to be discussed. The participants were asked the following questions about the risks.

Q1: Could you review the 89 environmental and social risks in terms of their applicability to the Jordanian construction industry?

Reviewing the risks in their respective groups, **natural resources** contains three risks: excessive use of raw materials, excessive consumption of both renewable and non-renewable resources, and the depletion of natural resources. A discussion took place between participants 3 and 5 about combining the second and third risks as they are related to each other and both concern resources such as water, oil, timber, and soil. They all agreed to combine these two hazards.

In the second group of risks related to socio-economic conditions, comprising ten risks as shown in Table 5-2, participant 2 commented *"I would suggest editing the fourth risk from high demand to just demand"*, and participants 1 and 7 agreed that "*In risk number five, delete the social disruption and leave it to just the project causing"*. Moreover, six out of eight of the respondents believed that hazards 6 and 10 should be combined into one risk. Four of the participants suggested that *"Hazards 7 and 8 should be combined to just people relocation risk"*, and finally, four out of eight participants felt that hazard 9 (public satisfaction with the project is very low) should be rewritten again in a better way.

The five hazards in the third category group are about **public and occupational health**. Regarding risk 2 (poor site hygiene conditions), participants 3, 4, 5, 6, 7 and 8 suggested to *"delete this hazard number 2 because hazards number 3 and 4 gave better understanding and cover hazard number 2"*. The researcher asked the group to review hazard 5 (inadequate responsibility or commitment of the expert in HSE work) and whether it was in the right group. Seven out of the 8 participants agreed that *"this type of hazard supposed to be under managerial hazards as it describes and indicates the managerial hazards group better"*.

Regarding the **ecosystem**, six subgroups of the hazards that have an impact on the ecosystem were considered. The majority of participants agreed to *"delete the subgroups as there is no need for them"*. Referring to the **noise hazards**, participants 1 and 7 suggested to *"combine all the three noise hazards as they are more convenient to be all together"*. Three participants argued that *"the first two hazards in the air quality should be merged in a better way, in addition, to mention the indoor and outdoor"*. The following hazard (emissions from the combustion of fossil fuel from stationary and mobile sources) was removed as most of the participants agreed that the next hazard (emissions from construction activities and equipment) already mentioned the same point. When asked to review hazards 8, 9, and 13, there was a suggestion from participants 5,7 and 3 to *"remove CFCs from hazard number 8 and put it in the next hazard, but also combine hazards number 9, 13 and make some modifications"*. In **the air quality** hazard, there was a suggestion to *"delete hazard number 16 as it contains all possible toxins from previous hazards from construction activities which already covered before. Moreover, hazard 17 which is related to the HVAC construction is not considered within* *the construction phase as it is more with the operations phase"*. It was suggested that *"the first two hazards from the soil were deleted and consider other last three hazards with some modification"*. However, regarding the hazards of **water**, the majority of participants agreed to *"merge all the eleven hazards into three hazards that covered all of them and refer to the topic"*. In the case of the **waste management** hazards, a view was echoed by the participants to *"link them in one hazard which is the contamination of rainwater runoff and surface water"*. Waste management indicated five hazards under a subgroup in the **ecosystem,** and participants 1, 7, 3, 4 reported that: "*this group need to split in a separate group, to include the first two hazards in one hazard, while hazard number 39 which refers to chemical waste should be moved to chemical's hazard"*. Similarly to waste management, it was suggested that the chemical hazards should be in a separate group, not a subgroup. However, multiple comments were made here: *chemical pollution from hazardous is indicating more to causes than a hazard, so it will be remove","43 and 52 that related to spills were combined together"*, *"from hazard number 45 to hazard number 53 should be all together but do some changes"*.

Biodiversity hazards were reduced from 10 hazards to 7 by considering the participants` comments accordingly. These were to *"edit hazard number 2 to show it as hazard more than a cause"*, *"hazard number 3 which is about dams will divert water from freshwater habitats this hazard suggested to be removed from the list because there are no dams in Jordan and usually if it exists it will have EIA"*, "*hazard number 4 also was suggested to delete because the only place in Jordan that have marine organisms is located in Aqaba and it is a small place while no need to mention it*", and final comment was "*There is no need to hazard number 7 due to the small number of endangered species which they are already in nature reserves in Jordan*".

The **managerial** hazard event was changed according to two comments from the participants, and three of the participants pointed out that *"the second hazard should not be mentioned as it is already covered in the ecosystem"*, and five commented that *"hazard number 3 and 5 are mostly similar according to they are not environmental nor social hazards"*.

Table 5-2: The List of Initial Hazards

The list of Hazards
Category Group 1 - Natural Resources Risk
H1-Excessive use of raw materials.
H2-The depletion of natural resources, renewable and non-renewable resources. (i.e., water, oil, timber, soil, etc.)
Category Group 2 - Ecosystem Risk
H3- Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, piling, blasting, etc., and on and off site traffic and deliveries.
H4- Deterioration of air quality (indoor and outdoor).

H5- Emissions from construction activities and equipment.
H6- Emissions of VOC (volatile organic compounds).
H7- Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane, and ozone).
H8- Dust generation from construction activities, machinery, and equipment.
H9- Bad odour generation from handling of construction materials, waste, and sewage.
H10- High soil erosion and excavation.
H11- Land pollution (associated with construction activities, machinery, and equipment).
H12- The use of identified or unidentified contaminated soil during fill operations.
H13- Inadvertent transport and subsequent disposal of unknown contaminated soil.
H14- Contamination of rainwater runoff and surface water.
H15- Underground water pollution.
H16- Improper discharge of the workplace's wastewater.
H17- Change in or obstruction of river flow.
Category Group 3 - Biodiversity Risks
H18- Adverse effects on the wildlife and disrupting habitats.
H19- Impact on migration routes.
H20- Loss of agricultural lands and vegetation removal.
H21- Mountains and forest removal (Deforestation).
H22- Wetland habitats disruption.
H23- Roadside vegetation removal.
H24- Disruption of sensitive species of flora and fauna during breeding, nesting, foraging, residing overwintering migration.
Category Group 4 - Socio-economic Conditions
H25- Adverse visual impact.
H26- Landscape alteration.
H27- Disruption of business in the community.
H28- Demand or stress on the infrastructure and the road network.
H29- Adverse effect on local communities and disturbance of the demographic structure of local communities.
H30- People relocation risk.
H31- Public dissatisfaction with the project.
H32- Adverse effect on archaeology, cultural heritage, and sacred sites.
Category Group 5 - Public and Occupational Health
H33- Construction accidents and casualties.
H34- Adverse effect on public health and safety.
H35- Lack of attention to health issues in the workplace.
Category Group 6 - Waste Management

H36- Improper disposal of ordinary and domestic solid waste.
H37- Improper disposal of special waste.
H38- Improper disposal of the building debris (other than soil).
Category Group 7 - Chemicals or Hazardous Materials
H39- Improper use of materials containing a carcinogenic substance.
H40- Lead poisoning from paint and other material containing lead.
H41- Spills and releases during the application and transportation of asphalt.
H42- Pollution resulting from collisions with various structures like above-ground tanks, pole-mounted transformers.
H43- Contamination from spills of oils, fuels, lubricants from field equipment and improperly stored materials or due to vandalism.
H44- Failure of underground utility lines, pipes, and other underground structures.
Category Group 8 - Managerial Hazardous Events
H45- Insufficient on-site investigation resulting in improper adjustment measures to local conditions.
H46- Unclear allocation of roles and responsibilities.
H47- Lack of availability of green materials and equipment (limited availability of suppliers and import restrictions).
H48- Inadequate knowledge of workers about environmental concerns, green materials, and construction technologies.

5.2.2.2 Discussion the Causes of the Risks in the Jordanian Construction Industry

From the data discussed in the first meeting, as a final hazards list, 48 hazards were considered. In the second meeting, the researcher asked the participants about their suggestions for the causes of the 48 hazards. At least two to three causes were required from the participants for each hazard.

Q2: Can you suggest two to three causes for each of the 48 hazards that were discussed yesterday?

Overall, the researcher organised the risks then added three other columns to fill in the causes of each risk. Table 5-3 summarises the suggested causes of each risk.

Table 5-3: Causes of Hazards in the Jordanian Construction Industry

Category	Risk	Risk name	Cause 1	Cause 2	Cause 3
Natural resources	R1	Excessive use of raw materials.	Poor planning.	Poor handling.	Poor storage.
	R2	The depletion of natural resources, renewable and non-renewable resources. (i.e., water, oil, timber, soil, etc.)	Poor planning and handling.	The use of traditional energy sources.	Lack of reuse and recycle practices.
Ecosystem	R3	Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, pilling, blasting, etc., and on and off site traffic and deliveries.	Poor maintenance.	The use of inappropriate machines.	Not turning off the vehicles and machinery when not used.
	R4	Deterioration of air quality (indoor and outdoor).	Poor circulation, and poor ventilation during construction activities.	The use of non-environmentally friendly materials.	Leaks of volatile materials.
	R5	Emissions from construction activities and equipment.	Ageing of machinery.	Insufficient combustion.	Leaks.
	R6	Emissions of VOCs (volatile organic compounds).	Storage of opened containers of unused paint strippers and other solvents.	Poor ventilation when using products that emit VOCs.	Mixing household care products without noticing manufacturer's directions.
	R7	Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane, and ozone).	Poor quality of fuel (sulphur).	Incomplete combustion.	Leaks of gases.
	R8	Dust generation from construction activities, machinery, and equipment.	Improper handling.	Improper transfer of materials.	
	R9	Bad odour generation from handling of construction materials, waste, and sewage.	Improper handling and transfer.	Use of non-environmentally friendly materials.	

	R10	High soil erosion and excavation.	Cut and fill.	Poor soil excavation practices.	
	R11	Land pollution (associated with construction activities, machinery, and equipment).	Waste generation.	Poor storage of materials.	Poor handling of waste.
	R12	The use of identified or unidentified contaminated soil during fill operations.	Insufficient soil test.	Poor planning.	
	R13	Inadvertent transport and subsequent disposal of unknown contaminated soil.	Poor planning.	Insufficient soil test.	
	R14	Contamination of rainwater runoff and surface water.	Land pollution.	Leaks.	
	R15	Underground water pollution.	Leaks of oil and other harmful materials.	Poor planning of waste dumping.	
	R16	Improper discharge of the workplace's wastewater.	Poor handling of waste water.	Lack of monitoring.	
	R17	Change in or obstruction of river flow.	Unplanned urbanisation.	Illegal permission for the building.	
Biodiversity	R18	Adverse effects on wildlife and disruption of habitats.	Not respecting environmental laws.	Lack of strict policies from the management.	
	R19	Impact on migration routes.	Lack of strict policies from the management.	Illegal permission for the building.	
	R20	Loss of agricultural lands and vegetation removal.	Unplanned urbanisation.	Project location.	
	R21	Mountains and forest removal (deforestation).	Unplanned urbanisation.	Project location.	
	R22	Wetland habitats disruption.	Lack of strict policies from the management.	Illegal permission for the building.	
	R23	Roadside vegetation removal.	Unplanned urbanisation.	Project location.	
	R24	Disruption of sensitive species of flora and fauna during breeding, nesting,	Lack of strict policies from the management.	Illegal permission for the building.	

		foraging, residing overwintering migration.			
Socio-economic	R25	Adverse visual impact.	Poor handling and disposal of wastes.	The use of unsuitable scaffolding sheets and barriers to enclose the building.	Delay of the project.
	R26	Landscape alteration.	Poor handling and disposal of wastes.	Not replanting the area.	
	R27	Disrupt business in the community.	Road closure.	Not giving priority to local contractors or shops.	
	R28	Demand or stress on the infrastructure and the road network.	Poor existing infrastructures.	Poor planning and scheduling of construction activities.	
	R29	Adverse effect on local communities and disturbance of the demographic structure of local communities.	Unplanned urbanisation.	Road closure.	
	R30	People relocation risk.	Unplanned urbanisation.	Not enough space to meet the project requirements.	
	R31	Public dissatisfaction with the project.	Shops closing	Construction activities.	
	R32	Adverse effect on archaeology, cultural heritage and sacred sites.	Unplanned urbanisation.	Illegal permission for the building.	
Public and occupational health	R33	Construction accidents and casualties.	Not having or following safety signs where needed.	Failure to use personal protective equipment (PPE).	
	R34	Adverse effect on public health and safety.	The generation of dust, odour and emissions.	Poor handling of hazardous materials and waste.	
	R35	Lack of attention to health issues in the workplace.	Poor management and monitoring.	Lack of strict policies.	

Waste management	R36	Improper disposal of ordinary and domestic solid waste.	Poor disposal policies.	Poor monitoring.	
	R37	Improper disposal of special waste.	Poor disposal policies.	Poor monitoring.	
	R38	Improper disposal of building debris (other than soil).	Poor disposal policies.	Poor monitoring.	
Chemicals or Hazardous Materials Failures	R39	Improper use of materials containing a carcinogenic substance.	Poor monitoring.	Using hazardous materials.	
	R40	Lead poisoning from paint and other material containing lead.	Not following manufacturer's directions.	Poor monitoring.	
	R41	Spills and releases during the application and transportation of asphalt.	Poor monitoring.	Reckless workers.	
	R42	Pollution resulting from collisions with various structures like above-ground tanks, pole-mounted transformers.	Poor monitoring.	Reckless workers.	
	R43	Contamination from spills of oils, fuels, lubricants from field equipment and improperly stored materials or due to vandalism.	Poor monitoring.	Poor maintenance for the equipment.	
	R44	Failure of underground utility lines, sewage pipes, and other underground structures.	Poor planning.	Reckless workers.	
Managerial	R45	Insufficient on-site investigation resulted in improper adjustment measures to local conditions.	Not taking enough time for site investigation.	Not allocating funds for site investigation.	
	R46	Unclear allocation of roles and responsibilities.	Bad management.	Not knowing the appropriate roles.	
	R47	Lack of availability of green materials and equipment.	Limited availability of suppliers.	Import restrictions.	
	R48	Inadequate knowledge of workers about environmental concerns, green materials. and construction technologies.	Limited availability of skilled workers.	Lack of training.	

5.3 Quantitative Risk Analysis

This section presents and discusses the results from the primary data collected in this research from a questionnaire. The questionnaire was distributed in the Jordanian construction industry, mainly to civil engineers and architects working in different job positions from design engineers to project managers and engineers.

5.3.1 Questionnaire Hypotheses

Based on the aim, objectives and questions of the research, a main hypothesis for the questionnaire can be formulated.

The main hypothesis is as follows: "There is no statistically significant effect at the level of significance ($\alpha = 0.05$) for the elements of sustainable engineering management in the construction phase on the overall risks of the facility to the environment and human beings."

From this hypothesis, the questionnaire will check statistically the correlation between the risk categories, the risk categories themselves, and between each risk and its category. The questionnaire will rank the risks according to their probability and impact, in order to produce the list of the high and very high risks. These will be analysed quantitatively in the developed model.

The questionnaire had two sections; The first section asked for general information about the participants: their years of experience, their current job position, the type of organisation they work in, the size of their organisation, and their experience in environmental risk management practices. The second section asked the participants to rate the most hazardous events affecting the environment and humans during construction by rating their impact and probability from 1 to 5, suggesting other hazardous events if needed.

Tables 5-4, 5-5, 5-6 and 5-7 show the probability levels from 1 to 5 and their description, the impact levels and their descriptions, the final risk rank (weight) levels and their description after multiplying the probability by the impact, i.e., and finally the risk matrix.

Risk = Probability × Impact. (1)

Table 5-4: Probability Levels

Highly possible	Possible	Intermediate	Rare	Very rare
%99 - %81	%80 - %61	%60 - %41	%40 - %21	%20- %1
5	4	3	2	1
It occurred a lot during the construction project before.	It has a high possibility to occur in the construction project, and it occurred before.	It might occur during the construction project, and it occurred before.	It might occur during the project but rarely.	It is not predicted to occur during the construction project.

Table 5-5: Impact Levels

Very high	High	Intermediate	Low	Very low
5	4	3	2	1
It has a severe impact on the environment and humans during the construction project.	It has a significant impact on the environment and humans during the construction project.	It has a moderate impact on the environment and humans during the construction project.	It has a minimum impact on the environment and humans during the construction project.	It has a minimal (little or no) impact on the environment and humans during the construction project.

Table 5-6: Risk Rank

Very high	High	Intermediate	Low	Very low
25 - 16	15 - 9	8 - 4	4 - 3	2 -1
A severe risk on the environment and humans, and needed to be eliminated.	A significant risk on the environment and humans, and needed to be eliminated or reduced.	A moderate risk on the environment and humans, and needed to be eliminated or reduced, if it is cost effective.	A minimum risk on the environment and humans, no action is needed.	Minimal risk on the environment and humans, no action needed.

Table 5-7: Risk Matrix

Impact	Very high	5	10	15	20	25
	High	4	8	12	16	20
	Intermediate	3	6	9	12	15
	Low	2	4	6	8	10
	Very low	1	2	3	4	5
		Very rare	Rare	Intermediate	Possible	Very possible
	Probability					

5.3.2 Questionnaire Reliability

Reliability, in general, is related to consistency. Therefore, the reliability of a questionnaire examines its soundness and whether the questionnaire would obtain consistent answers at different times under different conditions (Saunders et al., 2009). The reliability of a questionnaire can be calculated using different methods, the most common of which is

Cronbach's Alpha. Its values range from 0 to 1, the higher the value the more consistent and reliable is the questionnaire, and the minimum value to be accepted is 0.7.

In this research, Cronbach's alpha analysis was applied using SPSS to check the reliability of the questions. Table 5-8 shows the result for every risk group; Natural resources, ecosystem, biodiversity, socio-economics conditions, public and occupational health, waste management, chemical and hazardous materials, and managerial risk. All the Cronbach's Alpha values were accepted and above the limit which indicates that the questionnaire is reliable.

Table 5-8: Cronbach's Alpha Reliability Values

Reliability Statistics		
Sections	Cronbach's Alpha	No. of Items
Natural resources	0.714	2
Ecosystem	0.882	15
Biodiversity	0.869	7
Socio-economic conditions	0.836	8
Public and occupational health	0.781	3
Waste management	0.858	3
Chemical materials	0.833	6
Managerial hazardous events	0.859	4

5.3.3 Respondents' General Information

The first section of the questionnaire asked about the respondents' general information: their years of experience, their current job position, the type of the organisation they work in, the size of their organisation, and their experience in environmental risk management practices. The results are shown in pie charts below.

5.3.2.1 Years of Experience

Figure 5-1 shows the respondents' years of experience. These varied from 11% to 53%. The majority of the respondents (53%) had less than 5 years of experience, while only 11% had 10 to 5 years of experience, 19% had worked in the construction industry for 5 to 10 years, followed by 17% with more than 15 years of experience. This shows that the respondents had a variety of years of experience.

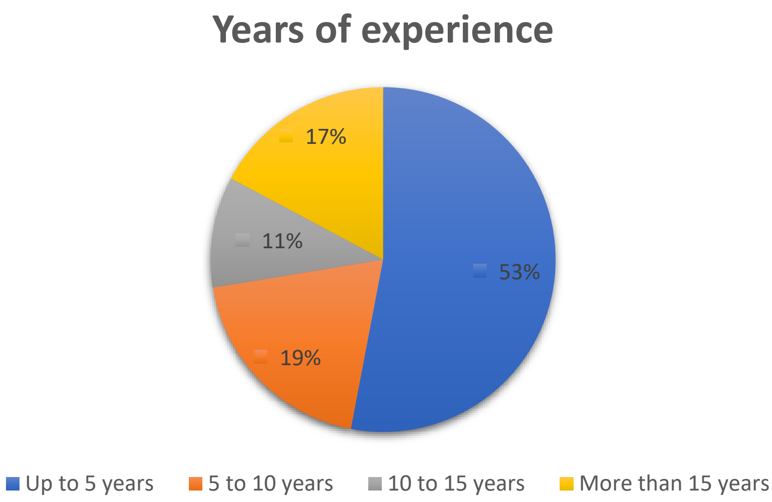

Figure 5-1: Respondents' Years of Experience

5.3.3.2 Current job Position

The second question about the respondents` background was their current job position. Figure 5-2 shows that most of the respondents were working as either site engineers or architects, with 36% and 29% respectively, followed by 13% who were working as project managers and 13% as structural engineers, while only 9% worked as researchers.

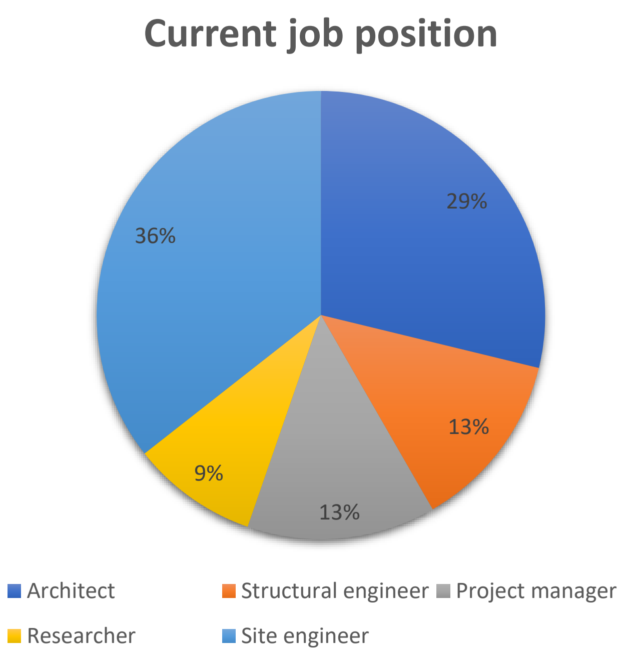

Figure 5-2: Respondents' Current Job Position

5.3.3.3 Type of Organisation

As can be seen from Figure 5-3, the largest group of respondents (41%) worked in construction companies (contractors), followed by 25% working in supervision and consultancy firms, 14% working in universities, and 10% working in both architectural design companies and structural design companies.

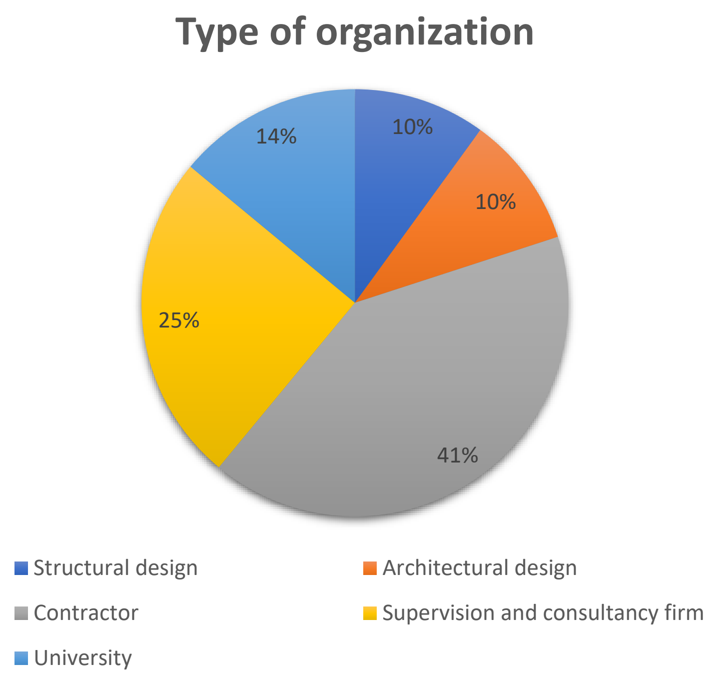

Figure 5-3: Respondents' Type of Organisation

5.3.3.4 Organisation Size

The questionnaire also asked the respondents about the size of the organisation they worked for. As can be seen in Figure 5-4, almost half of the respondents (49%) worked in a company or organisation with more than 100 employers, 28% worked in companies with less than 25 employees, 12% worked in organisations that had between 50 and 100 employees, and 11% worked in organisations with 25–50 employees.

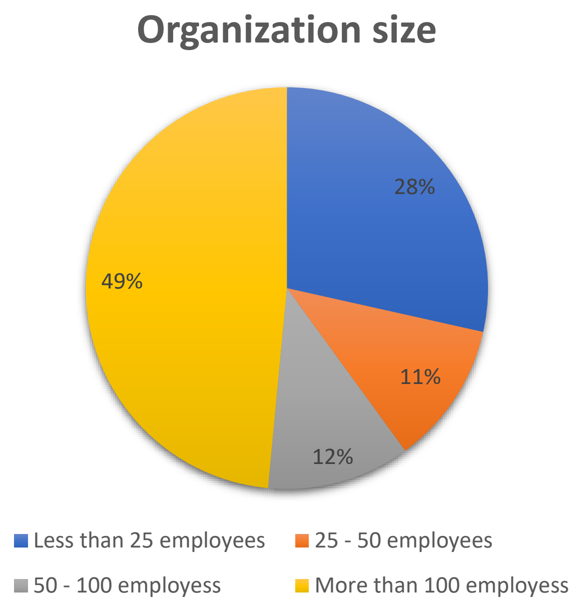

Figure 5-4 Respondents' Organisation Size

5.3.3.5 Experience in Environmental Risk Management Practices

The last question in the respondents' general information section asked about the respondents' experience in environmental risk management practices. The largest group of 42% of the respondents were familiar with environmental risk management practices but had not applied them before. Only 27% of the respondents had worked on projects that were considered to be environmentally risky before. Finally, 31% of the respondents were not familiar with these practices at all.

Figure 5-5: Respondents' Experience in Environmental Risk Management

From the first section it can be shown that the sample was drawn from different professionals in Jordanian construction and that they varied in their years of experience, their current job position, the type of organisation they worked in, the size of their organisation, and their knowledge and experience of environmental risk management practices. Also, it showed that the Jordanian construction industry is aware of environmental risk management practices but is not commonly applying them.

5.3.4 The Probability and Impact of Hazardous Events

This section presents the descriptive and inferential analysis of the rated hazardous events. It includes the mean and standard deviation as well as theory testing using a simple linear regression test and Pearson's correlation coefficient test R^2.

5.3.4.1 Descriptive Data Analysis

The second section of the questionnaire asked the respondents to rate the impact and frequency of hazardous events using a Likert scale from 1 to 5. The product of the impact and frequency gives the risk rank or weight: $R = I \times P$.

The following tables show the mean and standard deviation of the results of the risk weighting for each event and group.

Table 5-9: The Mean and Std. Deviation for The Events Groups

Descriptive Statistics			
Risk Group	N	Mean	Standard Deviation
Natural resources	402	10.4701	5.45044
Ecosystem	402	10.0158	4.07707
Biodiversity	402	8.7942	5.02232
Socio-economics	402	9.2136	4.27188
Public and occupational	402	10.6692	5.23329
Waste management	402	9.0796	4.81187
Chemical materials	402	8.4306	4.90192
Managerial	402	10.6194	5.88216
Valid N (listwise)	402		

Table 5-9 shows the mean and the standard deviation for the eight hazard events groups. It can be seen that the mean results ranged from 8.4306 for the chemical and hazardous materials to 10.6692 for public and occupational health. All the groups were high risk except for biodiversity, chemicals and hazardous materials, which were intermediate. This means that all of the suggested events and groups are important but at the same time not having very high risks means that the Jordanian construction industry considers the environment and humans during the construction phase of a project.

1. Natural resources hazardous events:

Table 5-10: Natural Resources Risks Ranking

Natural Resources Risk	Mean	Std. Deviation
R1- Excessive use of raw materials.	10.00	5.986
R2- The depletion of natural resources, renewable and non-renewable resources. (i.e., water, oil, timber, soil, etc.).	10.94	6.820

Table 5-10 shows the mean and standard deviation for the risk ranking of the natural resources. Both of the hazardous events were considered to be high risk and important, so they should be considered during project planning. The risk response will be to eliminate them or at least reduce them.

2. Ecosystem hazardous events:

Table 5-11: Ecosystem Risks Ranking

Ecosystem Risk	Mean	Std. Deviation
R1- Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, piling, blasting, etc., and on and off site traffic and deliveries.	13.46	7.077
R2- Deterioration of air quality (indoor and outdoor).	11.51	7.106
R3- Emissions from construction activities and equipment.	11.54	6.840
R4- Emissions of VOCs (volatile organic compounds).	8.34	6.585

R5- Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane, and ozone).	9.16	7.073
R6- Dust generation from construction activities, machinery and equipment.	13.87	7.523
R7- Bad odour generation from handling of construction materials, waste, and sewage.	10.72	6.623
R8- High soil erosion and excavation.	10.93	6.915
R9- Land pollution (associated with construction activities, machinery, and equipment).	10.37	6.400
R10- The use of identified or unidentified contaminated soil during fill operations.	8.76	5.317
R11- Inadvertent transport and subsequent disposal of unknown contaminated soil.	8.07	6.462
R12- Contamination of rainwater runoff and surface water.	9.44	6.902
R13- Underground water pollution.	7.99	6.386
R14- Improper discharge of the workplace’s wastewater.	9.13	6.381
R15- Change or obstruction in river flow.	6.02	5.593

Table 5-11 shows the result for the ecosystems risks ranking. Only five hazards were less than 9, which is intermediate risk, with the highest risk being noise and vibration (13.46) and the lowest a risk change or obstruction in river flow, with 6.02.

3. Biodiversity hazardous events:

Table 5-12: Biodiversity Risks Ranking

Biodiversity Risks	Mean	Std. Deviation
R1- Adverse effects on wildlife and disrupting habitats.	7.66	6.330
R2- Impact on migration routes.	7.24	6.612

R3- Loss of agricultural lands and vegetation removal.	12.53	8.201
R4- forest removal (deforestation).	9.67	7.472
R5- Wetland habitat disruption.	7.01	5.489
R6- Roadside vegetation removal.	9.80	6.507
R7- Disruption of sensitive species of flora and fauna during breeding, nesting, foraging, residing and overwintering migration.	7.66	6.001

Table 5-12 shows the risk ranking results for the biodiversity group with four out of seven risks being intermediate while the remaining three risks were high.

4. Socio-economic hazardous events:

Table 5-13: Socio-Economic Risks Ranking

Socio-economic Conditions	Mean	Std. Deviation
R1- Adverse visual impact.	9.06	5.798
R2- Landscape alteration.	9.72	6.025
R3- Disruption of business in the community.	9.58	6.355
R4- Demand or stress on the infrastructure and the road network.	11.90	7.256
R5- An adverse effect on local communities and disturbing the demographic structure of local communities.	8.67	5.837
R6- People relocation risk.	7.90	6.129
R7- Public dissatisfaction with the project.	9.81	6.465
R8- Adverse effect on archaeology, cultural heritage, and sacred sites.	7.07	5.453

Table 5-13 presents the risk ranking for the socio-economic hazards, with only two of them in the intermediate-risk range and the remainder seen as high risks.

5. Public and Occupational Health hazardous events:

Table 5-14: Public and Occupational Health Hazardous Events Ranking

Public and Occupational Health	Mean	Std. Deviation
R1- Construction accidents and casualties.	9.84	5.940
R2- Adverse effect on public health and safety.	9.49	5.783
R3- Lack of attention to health issues in the workplace.	10.88	7.094

As can be seen in Table 5-14, all three Public and Occupational Health risks were in the high-risk range.

6. waste management hazardous events

Table 5-15: Waste Management Hazardous Events Ranking

Waste Management	Mean	Std. Deviation
R1- Improper disposal of ordinary and domestic solid waste.	10.07	6.370
R2- Improper disposal of special waste.	90.1	6.281
R3- Improper disposal of building debris (other than soil).	9.56	6.156

Table 5-15 shows that all of the waste management risks were ranked as being in the high-risk range.

7. Chemical or Hazardous Materials hazardous events

Table 5-16: Chemicals or Hazardous Materials Hazardous Events Ranking

Chemicals or Hazardous Materials	Mean	Std. Deviation
R1- Improper use of materials containing a carcinogenic substance.	7.86	6.416

R2-Lead poisoning from paint and other material containing lead.	8.60	6.268
R3- Spills and releases during the application and transportation of asphalt.	8.96	6.206
R4- Pollution resulting from collisions with various structures like above-ground tanks, pole-mounted transformers.	7.44	5.241
R5- Contamination from spills of oils, fuels, lubricants from field equipment and improperly stored materials or due to vandalism.	9.06	5.638
R6- Failure of underground utility lines, pipes, and other underground structures.	9.54	6.594

Table 5-16 shows that only two of the chemical or hazardous materials risks fall within the high-risk range, while the rest are intermediate.

8. Managerial hazardous events

Table 5-17: Managerial Hazardous Events Ranking

Managerial Hazardous Events	Mean	Std. Deviation
R1- Insufficient on-site investigation resulted in improper adjustment measures to local conditions.	9.01	6.168
R2- Unclear allocation of roles and responsibilities.	10.98	7.087
R3- Lack of availability of green materials and equipment (limited availability of suppliers and import restrictions).	10.35	6.830
R4- Inadequate knowledge of workers about environmental concerns, green materials, and construction technologies.	12.14	7.888

Table 5-17 shows the ranking results for managerial risks, with all of them being high risk and inadequate knowledge of workers about environmental concerns, green materials, and construction technologies seen as the highest risk with a mean score of 12.14.

Table 5-18 shows the ranking of all the suggested risks together, in order of their ranking, with dust generation from construction activities, machinery and equipment the highest, and a change in or obstruction of river flow the lowest – most likely because Jordan has few rivers and you cannot find rivers in the cities.

Table 5-18: Sustainability-Related Hazardous Events Total Rank

Descriptive Statistics			
Risk	Sustainability-related hazardous events.	Mean	Std. Deviation
R1	Dust generation from construction activities, machinery and equipment.	13.87	7.523
R2	Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, piling, blasting, etc., and on and off site traffic and deliveries.	13.46	7.077
R3	Loss of agricultural lands and vegetation removal.	12.53	8.201
R4	Inadequate knowledge of workers about environmental concerns, green materials, and construction technologies.	12.14	7.888
R5	Demand or stress on the infrastructure and the road network risk.	11.9	7.256
R6	Emissions from construction activities and equipment.	11.54	6.84
R7	Deterioration of air quality (indoor and outdoor).	11.51	7.106
R8	Unclear allocation of roles and responsibilities.	10.98	7.087
R9	The depletion of natural resources, renewable and non-renewable resources. (i.e., water, oil, timber, soil, etc.)	10.94	6.82
R10	High soil erosion and excavation.	10.93	6.915

R11	Lack of attention to health issues in the workplace.	10.88	7.094
R12	Bad odour generation from handling of construction materials, waste, and sewage	10.72	6.623
R13	Land pollution (associated with construction activities, machinery and equipment).	10.37	6.4
R14	Lack of availability of green materials and equipment (limited availability of suppliers and import restrictions).	10.35	6.83
R15	Improper disposal of ordinary and domestic solid waste.	10.07	6.37
R16	Excessive use of raw materials.	10	5.986
R17	Construction accidents and casualties.	9.84	5.94
R18	Public dissatisfaction with the project risk.	9.81	6.465
R19	Roadside vegetation removal.	9.8	6.507
R20	Landscape alteration.	9.72	6.025
R21	Mountains and forest removal (deforestation).	9.67	7.472
R22	Disruption of business in the community.	9.58	6.355
R23	Improper disposal of building debris (other than soil).	9.56	6.156
R24	Failure of underground utility lines, pipes, and other underground structures.	9.54	6.594
R25	Adverse effect on public health and safety.	9.49	5.783
R26	Contamination of rainwater runoff and surface water.	9.44	6.902

R27	Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane, and ozone).	9.16	7.073
R28	Improper discharge of the workplace's wastewater.	9.13	6.381
R29	Adverse visual impact.	9.06	5.798
R30	Inadvertent transport and subsequent disposal of unknown contaminated soil.	9.04	6.462
R31	Improper disposal of special waste.	9.01	6.281
R32	Insufficient on-site investigation resulting in improper adjustment measures to local conditions.	9.01	6.168
R33	Spills and releases during the application and transportation of asphalt.	8.96	6.206
R34	The use of identified or unidentified contaminated soil during fill operations.	8.76	5.317
R35	Adverse effect on local communities and disturbance of the demographic structure of local communities.	8.67	5.837
R36	Contamination from spills of oils, fuels, lubricants from field equipment and improperly stored materials or due to vandalism.	8.62	5.638
R37	Lead poisoning from paint and other material containing lead.	8.6	6.268
R38	Emissions of VOCs (volatile organic compounds).	8.34	6.585
R39	Underground water pollution.	7.99	6.386
R40	People relocation risk.	7.9	6.129

R41	Improper use of materials containing a carcinogenic substance.	7.86	6.416
R42	Adverse effect on wildlife and disrupting habitats.	7.66	6.33
R43	Disruption of sensitive species of flora and fauna during breeding, nesting, foraging, residing overwintering migration.	7.66	6.001
R44	Pollution resulting from collisions with various structures like above-ground tanks, pole-mounted transformers.	7.44	5.241
R45	Impact on migration routes.	7.24	6.612
R46	Adverse effect on archaeology, cultural heritage, and sacred sites.	7.07	5.453
R47	Wetland habitat disruption.	7.01	5.489
R48	Change or obstruction in river flow.	6.02	5.593

5.3.4.2 Inferential Data Analysis

After finishing the descriptive analysis and choosing the highest ranking risks from the 48 hazards, inferential data analysis will show the static correlation between the risk groups, the risk groups themselves, and between each risk and its group.

5.3.4.2.1 Simple Linear Regression and Pearson's Correlation Coefficient

Both simple linear regression and Pearson's correlation coefficient are statistical analysis tests that examine the possible relationships between variables or how variables affect other variables. Pearson's correlation coefficient tests the strength of a relationship between two variables. It shows the appearance or the absence of a relationship between two variables, and its strength and direction. The value of Pearson's correlation coefficient (r) ranges from -1 to 1, with zero indicating no relationship and 1 the strongest linear relationship. If the value is positive, that means there is a positive correlation, where when one variable increases (decreases), the other increases (decreases) as well. If the value is negative, this is a negative correlation, meaning that the two variables move in opposite directions, e.g., as one variable increases, the other decreases (Saunders et al., 2019).

Simple linear regression demonstrates the relationship between dependent and independent variables, by finding the slope and the intercept of the linear equation between them, The correlation coefficient (R) shows that there is a positive or negative correlation between them and the coefficient of determination (R Square) show how strong the correlation is and how much the dependent variable can be explained by the independent value (Saunders et al., 2019).

In this research, simple linear regression and Pearson's correlation coefficient were employed to test the relationship between each risk group and the total risk, between risk groups themselves, and between each risk and its own risk group. This confirms whether all the sustainability-related risks are indeed significant and affect the total risk of a project with regard to the environment and humans.

5.3.4.2.2 Test Analysis

1. Correlations between each group and the total risk of the construction project for the environment and humans:

1.1 Natural resources:

The Table 5-19 shows the result of the linear simple regression and the person correlation test between the natural resources group and the total risk on the environment and humans using SPSS. The correlation coefficient (R) 0.703 show that there is a positive and strong correlation between them and the coefficient of determination (R Square) show there is a strong correlation and that 49 percent of the variation can be explained by the independent value (Natural resource), while the value of sig. and sig. F change shows how statistically significant the relation is, and since the value is less than (p =0.05) then the relation is statistically significant and it is unlikely to have occurred by chance.

Table 5-19: Model Summary & Coefficients for The Natural Resource with The Total Risk

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig. F Change	Sig.
		B	Std. Error	Beta					
1	(Constant)	4.459	.297		15.037	.703	.494	.000	.000
	Natural resource	.497	.025	.703	19.737				.000

1.2 Ecosystems

Table 5-20 shows the result of the linear simple regression and the Pearson correlation test between the natural resources group and the total risk for the environment and humans. The value of the correlation coefficient (R) is 0.911, demonstrating a positive and strong correlation between them. Also, the coefficient of determination (R Square) shows that 83 percent of the variation in the dependent value can be explained by the independent value, demonstrating a very strong correlation. Finally, it can be seen that the relationship is statistically significant since the value of sig. is less than 0.05.

Table 5-20: Model Summary & Coefficients for The Ecosystem with The Total Risk

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig. F Change	Sig.
		B	Std. Error	Beta					
1	(Constant)	1.037	.211		4.924	.911	.830	.000	.000
	Ecosystem	.860	.019	.911	44.155				.000

1.3 Biodiversity:

It can be seen from Table 5-21 that the biodiversity risk group has a significant effect on the total risk (0.000 < 0.05), and the correlation between them is positive and strong (R = 0.807). Also, 65.1% of the change in the total risk can be explained by the independent variable (R^2= 0.651).

Table 5-21: Model Summary & Coefficients for the Biodiversity and The Total Risk

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig. F Change	Sig.
		B	Std. Error	Beta					
1	(Constant)	4.220	.229		18.410	.807	.651	.000	.000
	biodiversity	.618	.023	.807	27.284				.000

1.4 Socio-economic:

Table 5-22 shows that the socio-economic conditions risk group has a significant effect on the total risk (0.000 < 0.05), and that the correlation between them is positive and strong (R = 0.723). Also, 52.2% of the change in the total risk can be explained by the independent variable (R^2 = 0.522).

Table 5-22: Model Summary & Coefficients for The Socio-Economics and The Total Risk

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig. F Change	Sig.
		B	Std. Error	Beta					
1	(Constant)	3.650	.317		11.529	.723	.522	.000	.000
	Socio-economics	.653	.031	.723	20.887				.000

1.5 Public and occupational health:

Table 5-23 explains the relationship between the public and occupational health risk group and the total risk. The value of the correlation coefficient, R, is 0.739, showing that the correlation is positive and strong. In addition, the value of the coefficient of determination, R^2, is 0.546, meaning that 54.6% of the change in the total risk (the dependent variable) can be explained by the independent variable. Finally, it can be seen that the relation is significant (0.000 < 0.05).

Table 5-23: Model Summary & Coefficients for The Public and Occupational Health and The Total Risk

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig. F Change	Sig.
		B	Std. Error	Beta					
1	(Constant)	3.861	.295		13.107	.739	.546	.000	.000
	Public and occupational health	.543	.025	.739	21.897				.000

1.6 Waste management:

Table: 5-24 below explains the relationship between the public and occupational health risk group and the total risk, from the value of the correlation coefficient: R = 0.782. It shows that the correlation is positive and strong. In addition, the value of the coefficient of determination (R^2 = 0.612) shows that 61.2% of the change in the total risk (the dependent variable) can be explained by the independent variable. The relationship is significant (0.000 < 0.05).

Table 5-24: Model Summary & Coefficients for The Waste Management and The Total Risk

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig. F Change	Sig.
		B	Std. Error	Beta					
1	(Constant)	3.979	.256		15.534	.782	.612	.000	.000
	Waste management	.626	.025	.782	25.064				.000

1.7 Chemical and hazardous materials:

Table 5-25 shows that the relationship between chemical and hazardous materials and the total risk is statistically significant (.000 < 0.05). Also, it shows that the relationship is positive and strong (R = 0.871). In addition, it shows that the variation in the dependent variable can be explained by the change in the independent variable by 75.9%.

Table 5-25: Model Summary & Coefficients for The Chemical Materials and The Total Risk

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig. F Change	Sig.
		B	Std. Error	Beta					
1	(Constant)	3.886	.188		20.642	.871	.759	.000	.000
	Chemical materials	.684	.019	.871	35.418				.000

1.8 Managerial Events

Table 5-26 shows that the relationship between managerial events and the total risk is statistically significant (.000 < 0.05). Also, it shows that the relation is positive and strong (R = 0.719). In addition, 51.7% of the variation in the dependent variable can be explained by the change in the independent variable.

Table 5-26: Model Summary & Coefficients for Managerial Events and The Total Risk

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig. F Change	Sig.
		B	Std. Error	Beta					
1	(Constant)	4.646	.277		16.790	.719	.517	.000	.000
	Managerial	.473	.023	.719	20.664				.000

2. Correlations between each group:

Table 5-27 shows the Pearson's correlations between the groups and it indicates that all the relationships are positive, strong, and significant.

Table 5-27: Correlations between The Risk Groups

		Managerial risk	Chemical materials risk	Waste management risk	Public and occupational risk	Socio-economic risk	Biodiversity risk	Ecosystem risk	Natural resources risk
Managerial risk	Pearson Correlation	1	.527**	.516**	.350**	.520**	.505**	.531**	.456**
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000
Chemical material risk	Pearson Correlation	.527**	1	.640**	.517**	.575**	.881**	.791**	.541**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.000
Waste management risk	Pearson Correlation	.516**	.640**	1	.588**	.446**	.509**	.777**	.445**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000
Public and occupational risk	Pearson Correlation	.350**	.517**	.588**	1	.457**	.487**	.789**	.449**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.000
Socio-economic risk	Pearson Correlation	.520**	.575**	.446**	.457**	1	.587**	.572**	.429**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000
Biodiversity risk	Pearson Correlation	.505**	.881**	.509**	.487**	.587**	1	.669**	.418**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.000
Ecosystem risk	Pearson Correlation	.531**	.791**	.777**	.789**	.572**	.669**	1	.609**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000
Natural resources risk	Pearson Correlation	.456**	.541**	.445**	.449**	.429**	.418**	.609**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

3. Correlations between each risk with its group:

This section shows the simple linear regression and Pearson's correlation tests for each of the group's test with its own risk.

3.1 Natural resources risks:

3.1.1 Excessive use of raw materials

Table 5-28 shows that the relationship between excessive use of raw materials and the natural resources group is significant ($0.00 < 0.05$). Also, $R = 0.829$, clarifying that the correlation is very strong and positive. $R^2 = 0.687$, indicating that the change in the dependent variable can be explained by the independent variable by 68.7%, which is strong. These results confirm the mean result that the risk is in the high-risk range.

Table 5-28: Model Summary & Coefficients for the 1st risk with the Total Risk of the 1st Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	2.925	.297		9.853	.829	.687	.000
	Excessive use of raw materials	.754	.025	.829	29.608			.000

3.1.2 The depletion of natural resources, renewable and non-renewable resources. (i.e., water, oil, timber, soil, etc.)

Table 5-29 shows that the relationship between the excessive use of raw materials and natural resources is significant (0.00 < 0.05). Also, the R = 0.871, clarifying that the correlation is very strong and positive, and the $R^2 = 0.759$, indicating that the change in the dependent variable can be explained by the independent variable by 75.9%, which is strong. These results confirm the mean result that the risk is high.

Table 5-29: Model Summary & Coefficients for the 2nd Risk with the Total Risk of the 1st Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	2.855	.253		11.285	.871	.759	.000
	The depletion of natural resources, renewable and non-renewable resources. (i.e., water, oil, timber, soil, etc.)	.696	.020	.871	35.456			.000

3.2 Ecosystem group:

3.2.1 Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, piling, blasting, etc., and on and off site traffic and deliveries.

The results of the simple regression and Pearson’s correlation are presented in Table 5-30. It can be seen that the correlation is statistically significant (0.000 < 0.05) and that there is a strong correlation (R = 0.571). In addition, the variation in the dependent variable ecosystem group can be explained by the independent variable noise and vibrations by 32.6% ($R^2 = 0.326$).

Table 5-30: Model Summary & Coefficients for the 1st Risk with the Total Risk of the 2nd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant).	5.594	.359		15.567			.000
	Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, pilling, blasting, etc. and on and off site traffic and deliveries.	.329	.024	.571	13.906	.571	.326	.000

3.2.2 Deterioration of air quality (indoor and outdoor)

The result of the simple regression and Pearson's correlation is presented in Table 5-31. The correlation is statistically significant (0.000 < 0.05), and strong (R = 0.608). Also, the variation in the dependent variable ecosystem group can be explained by the independent variable deterioration of air quality by 37% ($R^2 = 0.370$).

Table 5-31: Model Summary & Coefficients for the 2nd Risk with the Total Risk of the 2nd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	5.998	.308		19.452	.608	.370	.000
	Deterioration of air quality (indoor and outdoor)	.349	.023	.608	15.304			.000

3.2.3 Emissions from construction activities and equipment

Table 5-32 illustrates the correlation between the 3rd risk of this group and the group itself. The value of R = 0.752 and the value of significance = 0.000 < 0.05, indicating that the correlation is significant, positive, and strong. Furthermore, the value of R^2 = 0.566, indicating that 56.6% of the change in the dependent variable can be explained by the independent variable.

Table 5-32: Model Summary & Coefficients for the 3rd Risk with the Total Risk of the 2nd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	4.850	.263		18.425			.000
	Emissions from construction activities and equipment	.448	.020	.752	22.816	.752	.566	.000

3.2.4 Emissions of VOCs

Table 5-33 illustrates the correlation between the 4th risk of this group with the group itself. The value of R = 0.587 and value of significance = 0.000 < 0.05, indicating that the correlation is significant, positive, and strong. The value of R^2 = 0.345 , indicating that 35.5% of the change in the dependent variable can be explained by the independent variable.

Table 5-33: Model Summary & Coefficients for the 4th Risk with the Total Risk of the 2nd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	6.987	.266		26.253	.587	.345	.000
	Emissions of VOCs	.363	.025	.587	14.500			.000

3.2.5 Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane, and ozone)

Table 5-34 shows that there is a significant, strong, and positive correlation between the 5th risk and its group. It also shows that the variation in the dependent variable can be explained by the independent variable by 36.4%.

Table 5-34: Model Summary & Coefficients for the 5th Risk with the Total Risk of the 2nd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	6.833	.266		25.667			.000
	Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane and ozone)	.347	.023	.603	15.103	.603	.364	.000

3.2.6 Dust generation from construction activities, machineries and equipment

As can be seen from Table 5-35 below, the correlation between dust generation from construction activities, machinery, and equipment and the ecosystem group is strong, positive, and statistically significant based on the R and significance values. Furthermore, 36% of the variation in the dependent variable can be explained by the independent variable.

Table 5-35: Model Summary & Coefficients for the 6th Risk with the Total Risk of the 2nd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	5.514	.342		16.116	.600	.360	.000
	Dust generation from construction activities, machineries and equipment	.325	.022	.600	14.967			.000

3.2.7 Bad odour generation from handling construction materials, waste and sewage

From Table 5-36, it can be observed that the correlation between bad odour generation from the handling of construction materials, waste, and sewage and the ecosystem group, is strong, positive, and statistically significant based on the R and significance values. Furthermore, 44.3% of the variation in the dependent variable can be explained by the independent variable.

Table 5-36: Model Summary & Coefficients for the 7th Risk with the Total Risk of the 2nd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	5.630	.289		19.464			.000
	Bad odour generation from the handling of construction materials, waste and sewage	.409	.023	.666	17.829	.666	.443	.000

3.2.8 High soil erosion and excavation

Table 5-37 demonstrates the result for the regression and Pearson's correlation between the 8th risk and the ecosystem group. It illustrates a strong, positive, and statistically significant correlation between them. Also, 30.3% of the variation in the dependent variable can be explained by the independent variable.

Table 5-37: Model Summary & Coefficients for the 8th Risk with the Total Risk of the 2nd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	6.470	.318		20.321	.551	.303	.000
	High soil erosion and excavation	.324	.025	.551	13.179			.000

3.2.9 Land pollution (associated with construction activities, machineries and equipment)

Table 5-38 presents the result for the regression and Pearson's correlation between the 8th risk and the ecosystem group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 42.3% of the variation in the dependent variable can be explained by the independent variable.

Table 5-38: Model Summary & Coefficients for the 9th Risk with the Total Risk of the 2nd Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	5.724	.295		19.426	.651	.423	.000
Land pollution (associated with construction activities, machineries and equipment)	.414	.024	.651	17.116			.000

3.2.10 The use of identified or unidentified contaminated soil during fill operations

From Table 5-39 it can be seen that the correlation between the risk and its own group is statistically significant, positive, and strong. Furthermore, 28.4% of the variation in the dependent variable can be explained by the independent variable.

Table 5-39: Model Summary & Coefficients for the 10th Risk with the Total Risk of the 2nd Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	6.437	.332		19.361			.000
The use of identified or unidentified contaminated soil during fill operations	.408	.032	.533	12.588	.533	.284	.000

3.2.11 Inadvertent transport and subsequent disposal of unknown contaminated soil

Table 5-40 shows that the correlation between the risk and its own group is statistically significant, positive, and strong. Furthermore, 32.8% of the variation in the dependent variable can be explained by the independent variable.

Table 5-40: Model Summary & Coefficients for the 11th Risk with the Total Risk of the 2nd Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	6.756	.287		23.523			.000
Inadvertent transport and subsequent disposal of unknown contaminated soil	.361	.026	.573	13.952	.573	.328	.000

3.2.12 Contamination of rainwater runoff and surface water

The results of the simple regression and Pearson's correlation are presented in Table 5-41. It can be seen that the correlation is statistically significant (0.000 < 0.05). Also, it shows that there is strong relationship based on the R value, which is 0.678. In addition, 46% of the variation in the dependent value can be explained by the independent variable ($R^2 = 0.460$).

Table 5-41: Model Summary & Coefficients for the 12th Risk with the Total Risk of the 2nd Group

Model	Unstandardised Coefficients		Standardised Coefficients	T	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	6.238	.254		24.572	.678	.460	.000
Contamination of rainwater runoff and surface water	.401	.022	.678	18.432			.000

3.2.13 Underground water pollution

Table 5-42 demonstrates the result for the regression and Pearson's correlation between the 13th risk and the ecosystem group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 47.2% of the variation in the dependent variable can be explained by the independent variable.

Table 5-42: Model Summary & Coefficients for the 13th Risk with the Total Risk of the 2nd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	6.514	.237		27.453	.687	.472	.000
	Underground water pollution	.438	.023	.687	18.889			.000

3.2.14 Improper discharge of the workplace's wastewater

As can be seen from Table 5-43, the correlation between the improper discharge of the workplace's wastewater and the ecosystem group is strong, positive, and statistically significant based on the R and significance values. Furthermore, 45.6% of the variation in the dependent variable can be explained by the independent variable.

Table 5-43: Model Summary & Coefficients for the 14th Risk with the Total Risk of the 2nd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	6.077	.263		23.132	.675	.456	.000
	Improper discharge of the workplace's wastewater	.431	.024	.675	18.286			.000

3.2.15 Change or obstruct of river flow

Table 5-44 shows that the relationship between change or obstruct of river flow and the ecosystem is significant (0.00 < 0.05). Also, the R = 0.475 clarifying that the correlation is strong and positive, and the $R^2 = 0.226$, indicating that 22.6% of the change in the dependent variable can be explained by the independent variable.

Table 5-44: Model Summary & Coefficients for the 15th Risk with the Total Risk of the 2nd Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	7.930	.264		30.069	.475	.226	.000
Change or obstruction of river flow	.346	.032	.475	10.788			.000

3.3 Biodiversity

3.3.1 Adverse effect on wildlife and disruption of habitats

As can be seen from Table 5-45, the correlation between the adverse effect on wildlife and disrupting habitats and the biodiversity group is strong, positive, and statistically significant based on the R and significance values. Furthermore, 62.6% of the variation in the dependent variable can be explained by the independent variable.

Table 5-45: Model Summary & Coefficients for the 1st Risk with the Total Risk of the 3rd Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	3.989	.241		16.553			.000
Adverse effect on wildlife and disrupting habitats	.628	.024	.791	25.863	.791	.626	.000

3.3.2 Impact on migration routes

Table 5-46 shows that the relationship between impact on migration routes and the biodiversity group is significant (0.00 < 0.05). Also, the R = 0.741 clarifying that the correlation is strong and positive, and the $R^2 = 0.549$, indicating that 54.9% of the change in the dependent variable can be explained by the independent variable.

Table 5-46: Model Summary & Coefficients for the 2nd Risk with the Total Risk of the 3rd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant).	4.719	.250		18.891			.000
	Impact on migration routes.	.563	.025	.741	22.081	.741	.549	.000

3.3.3 Loss of agricultural lands and vegetation removal

Table 5-47 demonstrates the result for the regression and Pearson's correlation between the third risk and the biodiversity group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 56.1% of the variation in the dependent variable can be explained by the independent variable.

Table 5-47: Model Summary & Coefficients for the 3rd Risk with the Total Risk of the 3rd Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	3.049	.304		10.034			.000
	Loss of agricultural lands and vegetation removal.	.459	.020	.749	22.593	.749	.561	.000

3.3.4 Mountains and forest removal (deforestation).

The results of the simple regression and Pearson's correlation are presented in Table 5-48. It can be seen that the correlation is statistically significant (0.000 < 0.05). Also, it shows that there is strong relationship based on the R = 0.813 and that 66/1% of the variation in the dependent value can be explained by the independent variable (R^2 = 0.661).

Table 5-48: Model Summary & Coefficients for the 4th Risk with the Total Risk of the 3rd Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	3.510	.239		14.680			.000
Mountains and forest removal (Deforestation).	.546	.020	.813	27.915	.813	.661	.000

3.3.5 Wetland habitats disruption

Table 5-49 shows that the correlation between the risk and its own group is statistically significant, positive, and strong. Furthermore, 78.7% of the variation in the dependent variable can be explained by the independent variable.

Table 5-49: Model Summary & Coefficients for the 5th Risk with the Total Risk of the 3rd Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	3.748	.251		14.925			.000
Wetland habitats disruption.	.720	.028	.787	25.510	.787	.619	.000

3.3.6 Roadside vegetation removal

From Table 5-50, it can be observed that the correlation between roadside vegetation removal and the biodiversity group is strong, positive, and statistically significant based on the R and significance values. Furthermore, 48.3% of the variation in the dependent variable can be explained by the independent variable.

Table 5-50: Model Summary & Coefficients for the 6th Risk with the Total Risk of the 3rd Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	3.537	.326		10.843			.000
Roadside vegetation removal.	.537	.028	.695	19.340	.695	.483	.000

3.3.7 Disruption of sensitive species of flora and fauna during breeding, nesting, foraging, residing and overwintering migration

Table 5-51 demonstrates the result for the regression and Pearson's correlation between the 7th risk and the biodiversity group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 48.7% of the variation in the dependent variable can be explained by the independent variable.

Table 5-51: Model Summary & Coefficients for the 7th Risk with the Total Risk of the 3rd Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	4.320	.291		14.833			.000
Disruption of sensitive species of flora and fauna during breeding, nesting, foraging, residing overwintering migration.	.584	.030	.698	19.506	.698	.487	.000

3.4 Socio-economic conditions

The next eight tables show the result for the regression and Pearson's correlation for all the risks in the socio-economics conditions with the group itself.

3.4.1 Adverse visual impact

Table 5-52 lists the result for the regression and Pearson's correlation between the first risk and the socio-economic conditions group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 58.3% of the variation in the dependent variable can be explained by the independent variable.

Table 5-52: Model Summary & Coefficients for the 1st Risk with the Total Risk of the 4th Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	4.116	.256		16.096			.000
	Adverse visual impact.	.563	.024	.764	23.660	.764	.583	.000

3.4.2 Landscape alteration

From Table 5-53, it can be observed that the correlation between landscape alteration and the socio-economic conditions group is strong, positive, and statistically significant based on the R and significance values. Furthermore, 50.2% of the variation in the dependent variable can be explained by the independent variable.

Table 5-53: Model Summary & Coefficients for the 2nd Risk with the Total Risk of the 4th Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	4.329	.286		15.133			.000
	Landscape alteration.	.502	.025	.709	20.084	.709	.502	.000

3.4.3 Disruption of business in the community

Table 5-54 shows that the correlation between disrupting business in the community risk and its own group is statistically significant, positive, and strong. Furthermore, 57.8% of the variation in the dependent variable can be explained by the independent variable.

Table 5-54: Model Summary & Coefficients for the 3rd Risk with the Total Risk of the 4th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	4.318	.251		17.201			.000
Disrupting business in the community	.511	.022	.760	23.390	.760	.578	.000

3.4.4 Demand or stress on the infrastructure and the road network

The results of the simple regression and Pearson's correlation are presented in Table 5-55. It can be seen that the correlation is statistically significant (0.000 < 0.05). Also, it shows that there is strong relationship, as R = 0.650. In addition, 42.3% of the variation in the dependent value can be explained by the independent variable ($R^2 = 0.423$).

Table 5-55: Model Summary & Coefficients for the 4th Risk with the Total Risk of the 4th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	4.658	.312		14.944			.000
Demand or stress on the infrastructure and the road network	.383	.022	.650	17.108	.650	.423	.000

3.4.5 The project caused an adverse effect on local communities and disturbed demographic structure of local communities.

Table 5-56 shows that the relationship between the 5th risk and the 4th group is significant (0.00 < 0.05). Also, the R = 0.690, clarifying that the correlation is strong and positive, and the $R^2 = 0.476$, indicating that 47.6% of the change in the dependent variable can be explained by the independent variable.

Table 5-56: Model Summary & Coefficients for the 5th Risk with the Total Risk of the 4th Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	4.833	.277		17.467			.000
	An adverse effect on local communities and disturbed demographic structure of local communities	.505	.026	.690	19.080	.690	.476	.000

3.4.6 People relocation

From Table 5-57, it can be observed that the correlation between people relocation and the socio-economics conditions group is strong, positive, and statistically significant based on the R and significance values. Furthermore, 39.3% of the variation in the dependent variable can be explained by the independent variable.

Table 5-57: Model Summary & Coefficients for the 6th Risk with the Total Risk of the 4th Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	5.765	.271		21.246	.627	.393	.000
	People relocation	.437	.027	.627	16.080			.000

3.4.7 Public dissatisfaction with the project

Table: 5-58 shows the result for the regression and Pearson's correlation between the 7th risk and the socio-economic conditions group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 51.2% of the variation in the dependent variable can be explained by the independent variable.

Table 5-58: Model Summary & Coefficients for the 7th Risk with the Total Risk of the 4th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	4.577	.271		16.892			.000
Public dissatisfaction with the project	.473	.023	.716	20.491	.716	.512	.000

3.4.8 Adverse effect on archaeology, cultural heritage and sacred sites

Table 5-59 presents the result for the regression and Pearson's correlation between the 8th risk and the socio-economic conditions group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 39.7% of the variation in the dependent variable can be explained by the independent variable.

Table 5-59: Model Summary & Coefficients for the 8th Risk with the Total Risk of the 4th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	5.726	.271		21.096			.000
Adverse effect on archaeology, cultural heritage and sacred sites.	.494	.030	.630	16.223	.630	.397	.000

3.5 Public and occupational health

The following three tables show the result of the regression and correlation for the risk in the public and occupational health group.

3.5.1 Construction accidents and casualties

From Table 5-60 it can be observed that the correlation between construction accidents and casualties and the public and occupational health group is strong, positive, and statistically significant based on the R and significance values. Furthermore, 10.7% of the variation in the dependent variable can be explained by the independent variable.

Table 5-60: Model Summary & Coefficients for the 1st Risk with the Total Risk of the 5th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	7.832	.478		16.382			.000
Construction accidents and casualties.	.288	.042	.327	6.930	.327	.107	.000

3.5.2 Adverse effect on public health and safety

Table 5-61 shows the result for the regression and Pearson's correlation between the 2nd risk and the public and occupational health group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 11.9% of the variation in the dependent variable can be explained by the independent variable.

Table 5-61: Model Summary & Coefficients for the 2nd Risk with the Total Risk of the 5th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	7.714	.472		16.350			.000
Adverse effect on public health and safety.	.312	.042	.344	7.333	.344	.119	.000

3.5.3 Lack of attention to health issues in the workplace

Table 5-62 shows that the relationship between the 3rd risk and the 5th group is significant (0.00 < 0.05). Also, the R = 0.690, clarifying that the correlation is strong and positive. The R^2 = 0.476 , indicating that 47.6% of the change in the dependent variable can be explained by the independent variable.

Table 5-62: Model Summary & Coefficients for the 3rd Risk with the Total Risk of the 5th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	8.453	.460		18.364			.000
Lack of attention to health issues in the workplace	.204	.035	.276	5.744	.276	.076	.000

3.6 Waste management group

The three tables below illustrate the result for the correlation between the waste management group and its risks. All the correlations were positive, strong, and statistically significant.

3.6.1 Improper disposal of ordinary and domestic solid waste

Table 5-63 demonstrates the result for the regression and Pearson's correlation between the 1st risk and the waste management group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 24.2% of the variation in the dependent variable can be explained by the independent variable.

Table 5-63: Model Summary & Coefficients for the 1st Risk with the Total Risk of the 6th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	5.335	.391		13.628			.000
Improper disposal of ordinary and domestic solid waste	.372	.033	.492	11.315	.492	.242	.000

3.6.2 Improper disposal of special waste

Table 5-64 shows that the relationship between the 2nd risk and the 6th group is significant (0.00 < 0.05). Also, the R = 0.506, clarifying that the correlation is strong and positive, and the R^2 = 0.256 , indicating that 25.6% of the change in the dependent variable can be explained by the independent variable.

Table 5-64: Model Summary & Coefficients for the 2nd Risk with the Total Risk of the 6th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	5.586	.363		15.406			.000
Improper disposal of special waste.	.388	.033	.506	11.739	.506	.256	.000

3.6.3 Improper disposal of building debris (other than soil)

From Table 5-65, it can be observed that the correlation between improper disposal of building debris (other than soil) and the waste management group is strong, positive, and statistically significant based on the R and significance values. Furthermore, 23.7% of the variation in the dependent variable can be explained by the independent variable.

Table 5-65: Model Summary & Coefficients for the 3rd Risk with the Total Risk of the 6th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	5.444	.388		14.026			.000
Improper disposal of the building's debris (other than soil)	.380	.034	.487	11.138	.487	.237	.000

3.7 Chemical and hazardous materials

The next six tables show the result for the regression and Pearson's correlation for all the risks in the chemical and hazardous materials with the group itself.

3.7.1 Improper use of materials containing a carcinogenic substance

Table: 5-66 shows the result for the regression and Pearson's correlation between the 1st risk and the chemical and hazardous materials group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 28.8% of the variation in the dependent variable can be explained by the independent variable.

Table 5-66: Model Summary & Coefficients for the 1st Risk with the Total Risk of the 7th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	5.212	.327		15.929			.000
Improper use of materials containing a carcinogenic substance	.411	.032	.536	12.697	.536	.288	.000

3.7.2 Lead poisoning from paint and other material containing lead

The result of the simple regression and Pearson's correlation is presented in Table 5-67. This table shows that the correlation is statistically significant (0.000 < 0.05), and that there is a strong correlation (R = 0.547). Also, 29.9% of the variation in the dependent value ecosystem group can be explained by the independent variable deterioration of air quality (R^2 = 0.299).

Table 5-67: Model Summary & Coefficients for the 2nd Risk with the Total Risk of the 7th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	4.750	.349		13.626			.000
Lead poisoning from paint and other material containing lead	.429	.033	.547	13.059	.547	.299	.000

3.7.3 Spills and releases during the application and transportation of asphalt

Table 5-68 shows the result for the regression and Pearson's correlation between the 2nd risk and the chemical and hazardous materials group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 34.3% of the variation in the dependent variable can be explained by the independent variable.

Table 5-68: Model Summary & Coefficients for the 3rd Risk with the Total Risk of the 7th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	4.293	.349		12.316			.000
Spills and releases during the application and transportation of asphalt	.463	.032	.586	14.442	.586	.343	.000

3.7.4 Pollution resulting from collisions with various structures like above-ground tanks, pole-mounted transformers

From Table 5-69, it can be observed that the correlation between 4th risk and the chemical and hazardous materials is strong, positive, and statistically significant based on the R and significance values. Furthermore, 27.9% of the variation in the dependent variable can be explained by the independent variable.

Table 5-69: Model Summary & Coefficients for the 4th Risk with the Total Risk of the 7th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	4.760	.361		13.169			.000
Pollution resulting from collisions with various structures like above-ground tanks, pole-mounted transformers	.495	.040	.528	12.420	.528	.279	.000

3.7.5 Contamination from spills of oils, fuels and lubricants from field equipment and improperly stored materials or due to vandalism

Table 5-70 shows that the relationship between the 5th risk and the 7th group is significant (0.00 < 0.05). Also, R = 0.458, clarifying that the correlation is strong and positive, and the R^2 =

0.210, indicating that 21% of the change in the dependent variable can be explained by the independent variable.

Table 5-70: Model Summary & Coefficients for the 5th Risk with the Total Risk of the 7th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	5.005	.398		12.580			.000
Contamination from spills of oils, fuels, lubricants from field equipment and improperly stored materials or due to vandalism	.398	.039	.458	10.290	.458	.210	.000

3.7.6 Failure of underground utility lines, pipes and other underground structures

Table 5-71 shows that the correlation between the 6th risk and its own group is statistically significant, positive, and strong. Furthermore, 23% of the variation in the dependent variable can be explained by the independent variable.

Table 5-71: Model Summary & Coefficients for the 6th Risk with the Total Risk of the 7th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	5.029	.378		13.287			.000
Failure of underground utility lines, pipes and other underground structures.	.356	.033	.480	10.922	.480	.230	.000

3.8 Managerial group

The last four tables show the result of the regression and correlation for the risk in the public and occupational health group. It shows a statistically significant and positive correlation between them. Also, it explains the variation between them by the result of the R^2 value.

3.8.1 Insufficient on-site investigation results in improper adjustment measures to local conditions

As can be seen from Table 5-72, the correlation between the 1st risk and the managerial group is strong, positive, and statistically significant based on the R and significance values. Furthermore, 60.3% of the variation in the dependent variable can be explained by the independent variable.

Table 5-72: Model Summary & Coefficients for the 1st Risk with the Total Risk of the 8th Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	3.951	.328		12.045			.000
	Insufficient on-site investigation results in improper adjustment measures to local conditions.	.740	.030	.776	24.626	.776	.603	.000

3.8.2 Unclear allocation of roles and responsibilities

Table 5-73 shows that the relationship between the unclear allocation of roles and responsibilities risk and the managerial group is significant ($0.00 < 0.05$). Also, R = 0.879, clarifying that the correlation is strong and positive, and the $R^2 = 0.772$, indicating that 77.2% of the change in the dependent variable can be explained by the independent variable.

Table 5-73: Model Summary & Coefficients for the 2nd Risk with the Total Risk of the 8th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	2.613	.259		10.098			.000
Unclear allocation of roles and responsibilities	.729	.020	.879	36.816	.879	.772	.000

3.8.3 Lack of availability of green materials and equipment

Table 5-74 shows that the correlation between the 3rd risk and its own group is statistically significant, positive, and strong. Furthermore, 79% of the variation in the dependent variable can be explained by the independent variable.

Table 5-74: Model Summary & Coefficients for the 3rd Risk with the Total Risk of the 8th Group

Model	Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
	B	Std. Error	Beta				
1 (Constant)	2.696	.245		11.019			.000
Lack of availability of green materials and equipment	.766	.020	.889	38.789	.889	.790	.000

3.8.4 Inadequate knowledge of workers about environmental concerns, green materials and construction technologies

Table 5-75 shows the result for the regression and Pearson's correlation between the 3rd risk and the chemical and hazardous materials group. It illustrates a strong, positive, and statistically significant correlation between them. Furthermore, 66.7% of the variation in the dependent variable can be explained by the independent variable.

Table 5-75: Model Summary & Coefficients for the 4th Risk with Total Risk of the 8th Group

Model		Unstandardised Coefficients		Standardised Coefficients	t	R	R Square	Sig.
		B	Std. Error	Beta				
1	(Constant)	3.223	.311		10.354			.000
	Inadequate knowledge of workers about environmental concerns, green materials and construction technologies.	.609	.022	.817	28.327	.817	.667	.000

5.4 Conclusion

This chapter concluded the process of data and information collection and analysis. In the focus group stage, the expert participants were interviewed to identify the extent of sustainability-related risks in Jordan. Then, after completing the data collection in the focus group, the number of sustainability-related risks was reduced and some of them were combined, resulting in a list of 46 applicable risks. As a second step, a questionnaire was conducted with experts, enquiring about the significance of these 46 risks. The questionnaire was based on assumptions and objectives related to sustainability-related risks in the construction industry in Jordan. The data analysis was conducted by utilising SPSS to calculate the final results. The aforementioned two steps provided the researcher with a broader understanding of the situation and problems in the Jordanian construction industry due to the paucity of information available on this subject in the literature. The results from the focus group and the questionnaire developed a set of data that in turn contributed to understanding the most important sustainability-related risks associated with the construction industry in Jordan. By identifying the most important classifications of risks, and the extent of their potential impact on the environment and people in Jordan, the researcher was able to develop his model, as explained in the following chapter.

Chapter Six

Chapter Six: Risk Assessment Model Development

6.1 Introduction

This chapter illustrates the work carried out on the development of the proposed sustainable risk assessment model. As was explained in Chapter Two, it is a bottom-up risk assessment process that is divided into five major steps: problem identification; data and information collection and analysis; risk identification; risk assessment; and risk response. This proposed model provides a systemic approach to identifying and controlling sustainability-related risks. Figure 6-1 illustrates the proposed model for this research.

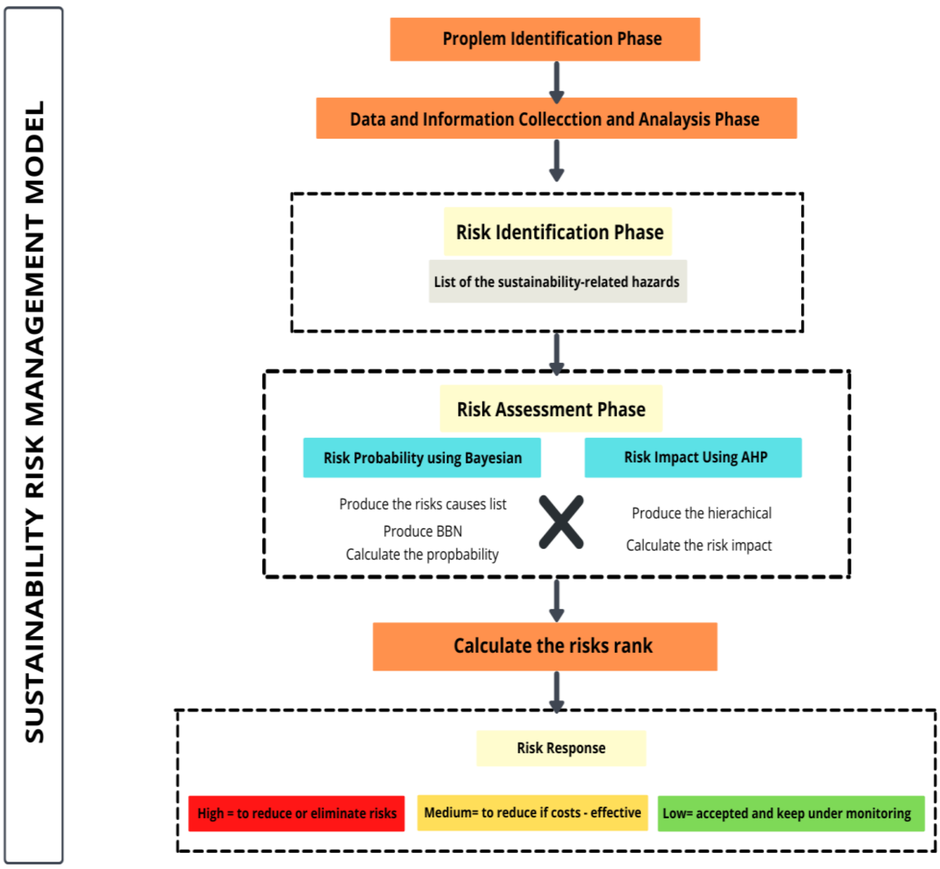

Figure 6-1: Model Development

6.2 Problem Identification

The construction field is experiencing a period of rapid growth and development, with the desire to incorporate new technologies into design and construction processes. The human impacts on the environment are generally so long-term that they are not appreciated directly. However, the belief that the available resources are unlimited, and excessive demographic growth has resulted in an increased demand for sustainability. The truth is that, in Jordan, resources are limited; nature has limits for materials and the production of services, not to mention limitations in absorption of the waste that may be generated from the construction industry (Hassan, 2011). Climate change and sustainable development are challenges in Jordan that present mutual synergies and interdependencies. Several factors are regarded as pivotal to well-being and development: human health, social and economic systems, terrestrial and aquatic ecology. These, in turn, are sensitive and vulnerable to changes in the local climate in Jordan or the global climate (Nassar, 2016). The construction field in Jordan adds significantly to global warming and climate change, as well as affecting the environment and society. According to Abbasi and Jaber (2005), the construction industry in Jordan fails to apply risk management in general as well as environmental risk management. According to Assaf (2017), the government and the Jordanian engineering association do not require the adoption of risk management or sustainability rules. This shows the problem in the Jordanian construction industry as well as the need for the model. Likewise, Jordanian measures aiming to introduce sustainability into the construction industry positively impact mitigation and adaptation to climate change (Assaf, 2017). All this means that a new model of social and environmental development must be proposed, one that incorporates sustainable development in Jordan's construction industry. This model was developed to identify, assess, and control sustainability-related risks in the Jordanian construction industry, especially human and environmental risks.

This model was developed in order to solve the research problem, which is finding a way to implement the dimensions of sustainability in the risk management process of the Jordanian construction industry. The aim is to decrease the negative impacts of construction on the society and the environment in Jordan during the construction phase of a project.

6.3 Data and Information Collection and Analysis

After the need for the model has been identified, the process moves to data and information collection and analysis. This step aims to shape an understanding of the situation and problems and to develop a body of information (An et al., 2007). In this research, the developed model will facilitate our understanding of the situation and problems that occur during the construction of a building in Jordan that affect the environment and humans. Unfortunately, this type of data is hard to find or it may even not exist in the construction industry. Nutter (2007) indicated that there is a lack of knowledge and experience related to sustainability and green buildings, which prevents professionals from identifying all the related risks. Jordan has a significant lack of knowledge and experience in sustainability-related risk as only a few projects are constructed as green buildings. In fact, according to Lacave (2021), only 10 projects are considered sustainable in Jordan. Hence, it is difficult to address the uncertainties and subjectivities associated with sustainable construction activities. It is clearly essential to develop a new risk model to identify and assess all the sustainable and environmental construction risks.

To generate the body of information for this model and achieve triangulation in the information resources, the literature review was conducted to review all the available literature related to environmental and sustainability-related problems during a construction project in general and in Jordan in particular. Using books, journal articles, published papers, and analysis of other established sustainability and environmental standards, such as rating systems (LEED, BREEAM, GSAS, and ESTIDAMA), EIA reports and the key principles of the UN SDGs, a list of 89 hazardous events was created, as illustrated at the end of the sustainability chapter in

Tables 2-2 and 2-3. This body of information is part of the model development, so it will be used for all the case studies.

6.4 Risk Identification

The aim of this step is to systematically distinguish all the potential risk events related to sustainable construction. Plenty of risk identification techniques are available, according to the PMBOK® Guide specifies the most common techniques used for this step: brainstorming, focus groups, interviews and checklists (PMI, 2017). Which can be used separately or combined. Moreover, the PMBOK® Guide, defined risk identification step as the step of defining all the individual project risks along with their sources and documenting their specification. This step ensures the success of the project.

In this model, the risk identification phase will be based on the collected data in the step before and it will produce the list of sustainability-related risks. This step can be found in the qualitative analysis of the data collection (see Chapter 5). A focus group was carried out with seven experts on the original 89 risk list to identify the major environmental and sustainability-related risks and their applicability in the Jordanian construction industry. The original list was edited, some risks were removed and others were combined to create a new list consisting of 48 risk events based on the opinion of the 7 environmental experts in the Jordanian construction industry.

Also, the causes of each of the identified risks were identified through a focus group (the same group), following the same steps as described earlier in the thesis. Table 6-1 shows the 48 identified sustainability-related risks with their identified causes.

Table 6-1: The 48 sustainable risks in Jordan and their causes

Category	Risk	Risk name	Cause 1	Cause 2	Cause 3
Natural resources	R1	Excessive use of raw materials.	Poor planning.	Poor handling.	Poor storage.
	R2	The depletion of natural resources, renewable and non-renewable resources. (i.e., water, oil, timber, soil, etc.)	Poor planning and handling.	The use of traditional energy sources.	Lack of reuse and recycle practices.
	R3	Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, pilling, blasting, etc., and on and off site traffic and deliveries.	Poor maintenance.	The use of inappropriate machines.	Not turning off the vehicles and machinery when not used.
	R4	Deterioration of air quality (indoor and outdoor).	Poor circulation, poor ventilation during construction activities.	The use of non-environmentally friendly materials.	Leaks of volatile materials.
	R5	Emissions from construction activities and equipment.	Ageing of machinery.	Insufficient combustion.	Leaks.
	R6	Emissions of VOCs.	Storage of opened containers of	Poor ventilation when using	Mixing household care products without noticing

Ecosystem			unused paints strippers and other solvents.	products that emit VOCs.	manufacturer's directions.
	R7	Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane, and ozone).	Poor quality of fuel (sulphur).	Incomplete combustion.	Leaks of gases.
	R8	Dust generation from construction activities, machinery, and equipment.	Improper handling.	Improper transfer of materials.	
	R9	Bad odour generation from handling of construction materials, waste, and sewage.	Improper handling and transfer.	Use of non-environmentally friendly materials.	
	R10	High soil erosion and excavation.	Cut and fill.	Poor soil excavation practices.	
	R11	Land pollution (associated with construction activities, machinery, and equipment).	Waste generation.	Poor storage of materials.	Poor handling of waste.
	R12	The use of identified or unidentified contaminated soil during fill operations.	Insufficient soil test.	Poor planning.	
	R13	Inadvertent transport and subsequent disposal of unknown contaminated soil.	Poor planning.	Insufficient soil test.	
	R14	Contamination of rainwater runoff and surface water.	Land pollution.	Leaks.	
	R15	Underground water pollution.	Leaks of oil and other harmful materials.	Poor planning of waste dumping.	
	R16	Improper discharge of the workplace's wastewater.	Poor handling of waste water.	Lack of monitoring.	
	R17	Change or obstruction of river flow.	Unplanned urbanisation.	Illegal permission for the building.	
Biodiversity	R18	Adverse effects on wildlife and disruption of habitats.	Not respecting environmental laws.	Lack of strict policies from the management.	
	R19	Impact on migration routes.	Lack of strict policies from the management.	Illegal permission for the building.	
	R20	Loss of agricultural lands and vegetation removal.	Unplanned urbanisation.	Project location.	
	R21	Mountains and forest removal (deforestation).	Unplanned urbanisation.	Project location.	
	R22	Wetland habitat disruption.	Lack of strict policies from the management.	Illegal permission for the building.	
	R23	Roadside vegetation removal.	Unplanned urbanisation.	Project location.	
	R24	Disruption of sensitive species of flora and fauna during breeding, nesting, foraging, and residing overwintering migration.	Lack of strict policies from the management.	Illegal permission for the building.	
Socio-economic	R25	Adverse visual impact.	Poor handling and disposal of wastes.	The use of unsuitable scaffolding sheets and barriers to	Delay of the project.

				enclose the building.	
	R26	Landscape alteration.	Poor handling and disposal of wastes.	Not replanting the area.	
	R27	Disruption of business in the community.	Road closure.	Not giving priority to local contractors and shops.	
	R28	Demand or stress on the infrastructure and the road network.	Poor existing infrastructures.	Poor planning and scheduling of construction activities.	
	R29	An adverse effect on local communities and disturbing the demographic structure of local communities.	Unplanned urbanisation.	Road closure.	
	R30	People relocation risk.	Unplanned urbanisation.	No enough space to meet the project requirements.	
	R31	Public dissatisfaction with the project.	Shops closed	Construction activities.	
	R32	Adverse effect on archaeology, cultural heritage and sacred sites.	Unplanned urbanisation.	Illegal permission for the building.	
Public and occupational health	R33	Construction accidents and casualties.	Not having or following safety signs where needed.	Not using personal protective equipment (PPE).	
	R34	Adverse effect on public health and safety.	The generation of dust, odour and emissions.	Poor handling of hazardous materials and waste.	
	R35	Lack of attention to health issues in the workplace.	Poor management and monitoring.	Lack of strict policies.	
Waste management	R36	Improper disposal of ordinary and domestic solid waste.	Poor disposal policies.	Poor monitoring.	
	R37	Improper disposal of special waste.	Poor disposal policies.	Poor monitoring.	
	R38	Improper disposal of building debris (other than soil).	Poor disposal policies.	Poor monitoring.	
Chemicals or Hazardous Materials Failures	R39	Improper use of materials containing a carcinogenic substance.	Poor monitoring.	Using hazardous materials.	
	R40	Lead poisoning from paint and other material containing lead.	Not following manufacturer's directions.	Poor monitoring.	
	R41	Spills and releases during the application and transportation of asphalt.	Poor monitoring.	Reckless workers.	
	R42	Pollution resulting from collisions with various structures like above-ground tanks, pole-mounted transformers.	Poor monitoring.	Reckless workers.	
	R43	Contamination from spills of oils, fuels or lubricants from field equipment and improperly stored materials or due to vandalism.	Poor monitoring.	Poor maintenance for the equipment.	

	R44	Failure of underground utility lines, sewage pipes, and other underground structures.	Poor planning.	Reckless workers.	
Managerial	R45	Insufficient on-site investigation resulting in improper adjustment measures to local conditions.	Not taking enough time for site investigation.	Not allocating funds for site investigation.	
	R46	Unclear allocation of roles and responsibilities.	Bad management.	Not knowing the appropriate roles.	
	R47	Lack of availability of green materials and equipment.	Limited availability of suppliers.	Import restrictions.	
	R48	Inadequate knowledge of workers about environmental concerns, green materials. and construction technologies.	Limited availability of skilled workers.	Lack of training.	

Since this list was approved by the focus-group experts, it will be used as the basis of risk identification in the three case studies as discussed in Chapter 7. The next phase of the model is the risk assessment phase which consist of two steps.

6.5 Risk Assessment

Once the sustainability-related risks are identified, the next phase is risk assessment. The purpose of this phase is to assess the rank or level of the identified risks. As it was mentioned before in chapter two, the risk assessment phase has two types: qualitative and quantitative. For both types, there are various risk analysis methods currently available and have been used in the industry like Monte Carlo simulation analysis, fault tree analysis, event tree analysis, FMEA, programme evaluation, and review technique. Although these methods were well-known and used before, this proposed model has to cope well with the uncertainty and the lack of available information about the sustainability-related risks. This requires expert knowledge and experience or engineering judgement. In this model, the risk assessment phase was done in two steps, using a probability and impact matrix for the qualitative analysis step with a questionnaire distributed in the Jordanian construction industry. In addition, The Analytic Hierarchy Process (AHP) was used to calculate risk consequences while the Bayesian Belief Network (BBN) was used to calculate risk probability for the quantitative analysis step of the model.

As it has been mentioned before in the risk management chapter, the BBN was used for its ability to calculate the probability of a variable (risk) by the change in other dependent values (causes). In this model, the probability of the sustainability-related risks was calculated by the probability of their causes. While the impact of the risk was done using AHP because it is a convenient, flexible, and straightforward decision-making method, it can work with uncertainties for its ability to decompose the decision or the problem into basic elements and create hierarchies, then displays the importance of each element by pairwise comparisons. It also can work with accurate data or scale data depending on the availability of the data. These properties assist in calculating the impact of the sustainability-related risks while having this much of uncertainty.

6.5.1 Qualitative Risk Assessment (Questionnaire)

The qualitative risk assessment part was done using a questionnaire distributed to the Jordanian construction industry, the target sample was the engineers in Jordan especially the civil engineers in their different majors and the architecture engineers. According to the Jordanian Engineers Association (JEA reports, 2019), the total number of engineers in Jordan is 17389, and the questionnaire sample was 402 which achieve the minimum number for sample for the population, according to Saunders et al. (2019).

The questionnaire used the Probability-Impact-Matrix (PIM) to categorise the risks. A Likert scale from 1 to 5 was used for both the probability and the impact, as shown in the quantitative part of Chapter 5. Based on their answers, the high and very high risks were considered for the next step of the model – these 32 risks are listed in Table 6-2.

Table 6-2: The high and very high risks

Category	Risk	Risk name
1-Natural resources	R1	Excessive use of raw materials.
	R2	The depletion of natural resources, renewable and non-renewable resources (i.e., water, oil, timber, soil, etc.)
2-Ecosystem	R3	Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.), site activities, construction, demolition, piling, blasting, etc. and on and off site traffic and deliveries.
	R4	Deterioration of air quality (indoor and outdoor).
	R5	Emissions from construction activities and equipment.
	R6	Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane and ozone).
	R7	Dust generation from construction activities, machinery and equipment.
	R8	Bad odour generation from handling of construction materials, waste and sewage.
	R9	High soil erosion and excavation.
	R10	Land pollution (associated with construction activities, machinery and equipment).
	R11	Contamination of rainwater runoff and surface water.
	R12	Improper discharge of the workplace's wastewater.
3-Biodiversity	R13	Loss of agricultural lands and vegetation removal.
	R14	Mountains and forest removal (deforestation).
	R15	Roadside vegetation removal.
4-Socio-economic	R16	Adverse visual impact.
	R17	Landscape alteration.
	R18	Disruption of business in the community.
	R19	Demand or stress on the infrastructure and the road network.
	R20	Public dissatisfaction with the project.
	R21	Construction accidents and casualties.

5-Public and occupational health	R22	Adverse effect on public health and safety.
	R23	Lack of attention to health issues in the workplace.
6-Waste management	R24	Improper disposal of ordinary and domestic solid waste.
	R25	Improper disposal of special waste.
	R26	Improper disposal of the building debris (other than soil).
7- Hazardous Materials Failures	R27	Contamination from spills of oils, fuels and lubricants from field equipment and improperly stored materials or due to vandalism.
	R28	Failure of underground utility lines, pipes and other underground structures.
8-Managerial	R29	Insufficient on-site investigation resulting in improper adjustment measures to local conditions.
	R30	Unclear allocation of roles and responsibilities.
	R31	Lack of availability of green materials and equipment.
	R32	Inadequate knowledge of workers about environmental concerns, green materials and construction technologies.

This list contains only the high and very high risks that have been assessed and ranked based on the qualitative risk assessment. These high and very high risks will be examined further by using the proposed quantitative risk assessment model.

6.5.2 Quantitative Risk Assessment (BBN & AHP Method)

1. Risk Probability Using Bayesian belief Network (BBN)

The Bayesian Belief Network (BBN) is one of the graphical models that describes causal relationships by probabilities. Thomas Bayes established this theory in the 16th century (1701–1761). Although Bayes' theory was developed for the subject of statistics and mathematics, it has been applied in various domains for data analysis, risk management, and reliability analysis (Podofillini & Dang, 2013). In spite of the fact that many other methods were developed after BBN, in the nineties, it began to regain popularity due to its numerous advantages. In his 1763 publication, Thomas Bayes referred to his theorem as "the doctrine of chances." Several centuries later, the significance of the 'Bayesian Method' has not waned. In fact, several of the world's premier universities now teach it in considerable depth.

Nowadays, Bayes' theorem is widely used to compute probabilities in a broad range of circumstances, including but not limited to medicine and genetics. As stated in the literature review chapter, the BBN is a versatile and adjustable method that may provide extremely accurate findings in the most extreme risk analysis measures. BBN uses conditional dependencies to depict the joint probability distribution of a problem area. BBN can naturally and efficiently collect knowledge on a specific domain. A BBN constructs an "acyclic" network in which nodes represent feature variables and links indicate direct probabilistic interactions between the variables. Thus, it expresses complex causal inferences through a directed acyclic graph structure and conditional probabilities of individual variable relationships (Gaag, 1996). What BBN provides is a structure that allows risk analysis specialists to obtain a greater knowledge of risk factors and how to reduce risks (Rechenthin, 2004; Mosleh 1992). The occurrence of a factor in BBN can be determined by the occurrence of a change in other associated factors, which greatly assists with determining the risks and mitigating them (Onisko et al., 2001).

The Bayesian method (BM) appears to have piqued the interest of scholars in recent years owing to its potential to solve complex model systems, as it is premised on the factorisation of variables' joint distributions based on conditional dependencies. BM's major goal is to compute the distribution probabilities in a group of variables based on observations of some variables and prior knowledge of others (Weber et al., 2012).

The BM is applied in a variety of applications, several of which are mentioned here. The first example is the Bayesian analysis of measurement error models using integrated nested Laplace approximations (Muff et al., 2015). Another example is the robust fit of Bayesian mixed-effects regression models in tuberculosis research, which can be applied to colony-forming unit counts (Burger et al., 2018). In econometric models with reduced rank, Bayesian analysis is also employed for boundary and near-border evidence (Baştürk et al., 2017). Because it is founded on frequentist statistics, the Bayesian statistical method is also suitable for the analysis and design of clinical trials. It provides a formal mathematical approach for merging past and current information during the design, trial, and analysis stages. It can also be used in post-marketing surveillance and meta-analysis (Gupta, 2012).

Bayesian analysis has many advantages, particularly in terms of risk probability as it follows the likelihood principle. **First**, it generates more intuitive and relevant conclusions. Bayesian approaches can provide clear, precise, and interpretable answers to complex questions. **Second,** Bayesian approaches make use of all the available information and they can also work in the absence of data. This demonstrates that they incorporate previous knowledge. Within a sound decision theory framework, BM offers a natural and logical approach to merge prior information with data. In a Bayesian analysis, no significant information is missed because the prior information should reflect all the accessible knowledge, separate from the data itself. **Third,** since it adopts the nature of probability and parameters, Bayesian approaches are specifically tailored for decision making; uncertainty makes decisions difficult, and Bayesian approaches can quantify such uncertainties considering personal probability. **Fourth,** BM provides a convenient framework for diverse models, including hierarchical models and missing data issues.

There are three ways in which the BM might be employed in risk analysis for scientific or regulatory purposes. Ferson (2005) described these three methods. The first way is to take over the assessment and decision process entirely. The Bayesian approach would be used to frame scientific or regulatory decision problems. On the other hand, the BM could be used merely to estimate risk distributions. This use of these methods puts Bayesian analysts at the centre of the issue, although not in charge of the entire process. Finally, the BM could be used as a tool to select or parameterise input distributions for a risk model. This use relegates the roles of Bayesian analysts to those of technicians and support analysts because the form of the risk model and the overarching decision process are developed without appealing to the BM. In practice, it appears that BMs are invading risk analysis in a gradual way, starting with this technical level. In such uses, the methods are applied to estimation problems too, but in these cases, one is estimating the inputs to models rather than estimating the answers directly.

In this model, the BM was used as a tool or method in its network form (BBN) to calculate the risk probability part of the entire model. This made use of its ability to calculate the probability of the sustainability-related risks based on changes in the causes of these risks.

The mechanism used in a BBN to compute the probability of an effect on any variable in the model from the probability of a given cause is the Bayes theorem (Vick, 2002). Bayes theorem was derived from the conditional probability theory, and the basic expression of an event A given event B is presented as follow:

$$P(A|B) = \frac{P(A,B)}{P(B)} \qquad (6.1)$$

When the joint probability of P (A, B) is considered, then from the cumulative property of logic, it follows that (A,B) = (B,A). Therefore, they must have the same probability no matter what the state of knowledge is. Hence P(A,B) = P(B,A). Applying this relationship to the conditional probabilities results in Bayes' formula:

PosteriorαLikelihood × Prior Or $P(B|A) = \frac{P(A|B) \times P(B)}{P(A)}$ (6.2)

P(B) is the initial belief that event B will occur, also called the prior probability.
P(A|B) is the belief that event A will be found once event B has actually occurred.
P(A) is the belief that event A will be found to be true under general circumstances and
P(B|A) is the belief that event B will occur after evidence of event A is known to support or deny event B, also called posterior probability.

The BBN is a unicycle framework. Graphs consist of nodes, which symbolise random variables, and arcs, which symbolise direct dependency between variables. The way these nodes are connected represents the type of connection they have: whether a connection is serial, diverging or converging depends on how these main events and dependent events affect each other.

Figure 6-2 represents a simple BBN in a converging connection, where node C is affected by changes in the causes A and B.

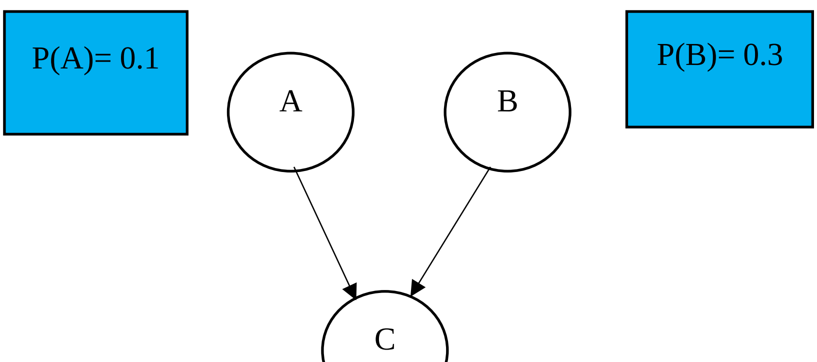

Figure 6-2: Bayesian Network

Table 6-3: Conditional probability table

A		B	P(C|A,B)
T		T	0.95
T		F	0.8
F		T	0.4
F		F	0.05

In each node, there is a conditional probability table or a node probability table, which represents the conditional probability of a single variable with respect to the other variables affecting that node. The general equation represents the probability of occurrence of variable C conditioned to the occurrence of variables A and B, and it is derived from equation 6.2.

$$P(C) = \mathrm{P(C|A,B)P(A)P(B)} \quad (6.3)$$

$$P(C) = \mathrm{P(C|A,B)P(A)P(B)} + \mathrm{P(C|A,-B)P(A)P(-B)} + \mathrm{P(C|-A,B)P(-A)P(B)} + \mathrm{P(C|-A,-B)P(-A)P(-B)} \quad (6.4)$$

The probability of the causes and posterior probability will follow the range below

Table 6-4: Risk Probability Rating Levels

Probability level	Probability
Very low	Below 0.11
Low	0.11-0.3
Moderate	0.31-0.6
High	0.61-0.8
Very high	More than 0.81

From this general equation, the probability of event C in Figure 6-2 and Table 6-3 can be found as:

P(C) = (0.95*0.1*0.3) + (0.8*0.1*0.7) + (0.4*0.9*0.3) + (0.05*0.9*0.7) = 0.162

For the proposed model, the main node will be the sustainability-related risk and the other nodes that affect the main node are the causes of this sustainability-related risk. The same equation will be used to find the probability of the sustainability-related risk depending on the changes that occur in the probability of its causes.

In this model development, the BBN was based on the qualitative analysis result – only the high and very high risks were analysed with the Bayes network, a total of 32 sustainability risks. The network consists of the main node (the project's effects on the environment and humans) at the first level, the second level is the risk categories, followed by the sustainability-related risk, and the final level of the network is the causes of these risks as discussed by the focus group during the data collection. The network of Figure 6-3 shows the full BBN in the proposed model.

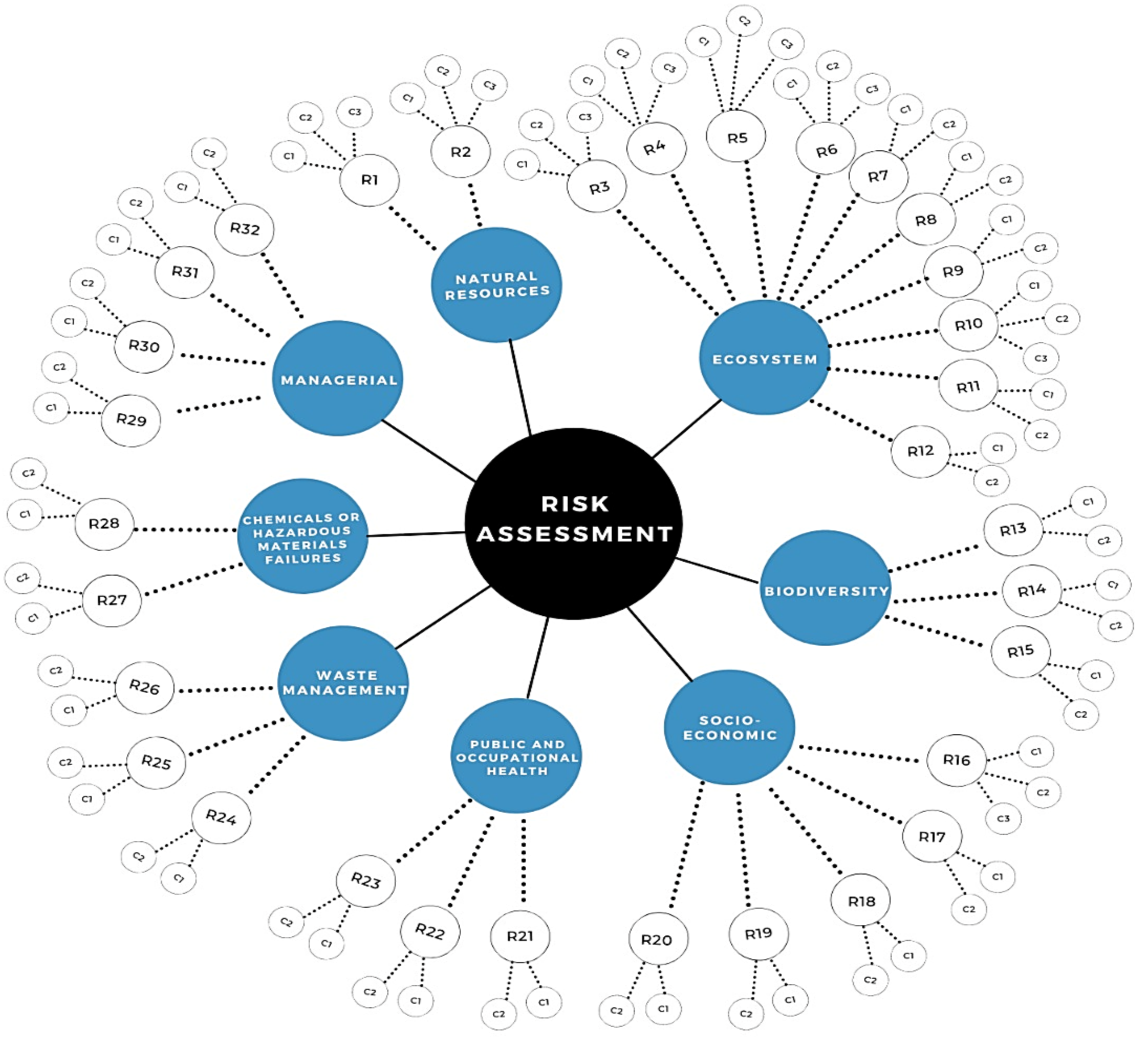

Figure 6-3: The full Bayesian network for the developed model

Before starting to calculate the probability and filling in the conditional probability tables, the weight factor method is used. Each expert is assigned a weight for their judgement, based on their experience, knowledge and expertise. The total weight equals one, and then the final answer can be calculated as the summation of the weighted judgements. This step can be skipped if only one expert is using the model.

Table 6-5: Weights assigned to experts

Experts	Background	Weight
E1	Project manager	0.35
E2	Construction manager	0.3
E3	Site engineer for 10 yrs	0.2
E4	Site engineer for 7 yrs	0.15
Total	W1+W2+W3+W4	1

The probability of the sustainability-related risk is calculated by the change in the probability of the causes. The network above shows just one category of the full BBN to calculate the probability of these risks.

Based on the derivation of the Bayes theorem and equation 6.4, the probability of the sustainability-related risk for two causes can be calculated:

$$P(C) = \mathrm{P(C|A,B)P(A)P(B)} + \mathrm{P(C|A,-B)P(A)P(-B)} + \mathrm{P(C|-A,B)P(-A)P(B)} + \mathrm{P(C|-A,-B)P(-A)P(-B)}$$

While for three causes it can be calculated as below:

$$P(D) = \mathrm{P(D|A,B,C)P(A)P(B)}P(C) + P(D|A,B,-C)P(A)P(B)P(-C) + \mathrm{P(D|A,-B,C)P(A)P(-B)}P(C) + \mathrm{P(D|-A,B,C)P(-A)P(B)P(C)} + \mathrm{P(D|A,-B,-C)P(A)P(-B)P(-C)} + \mathrm{P(D|-A,B,-C)P(-A)}P(B)\mathrm{P(-C)} + \mathrm{P(D|-A,-B,C)P(-A)P(-B)P(C)} + \mathrm{P(C|-A,-B,-C)P(-A)P(-B)P(-C)}$$

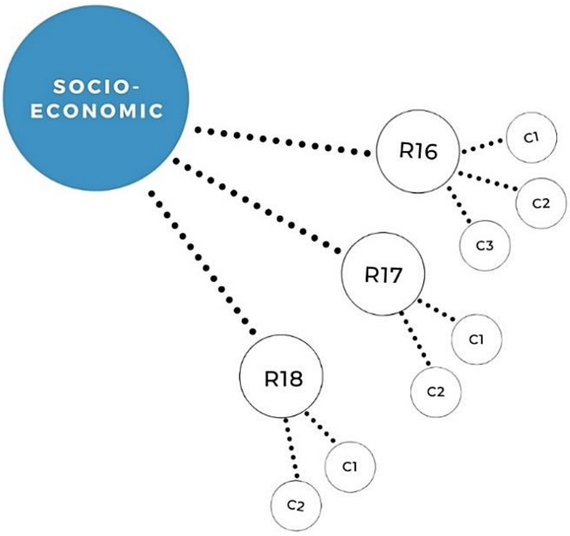

Figure 6-4: Part of the Socio-economic group

Figure 6-4 shows part of the socio-economic category (R16, R17 and R18). To calculate the risks, the following equations are used:

$$\begin{aligned} P(R16) = {} & P(R16|C1, C2, C3)P(C3)P(C2)P(C3) \\ & + P(R16|C1, C2, -C3)P(C1)P(C2)P(-C3) \\ & + P(R16|C1, -C2, C3)P(C1)P(-C2)P(C3) \\ & + P(R16|-C1, C2, C3)P(-C1)P(C2)P(C3) \\ & + P(R16|C1, -C2, -C3)P(C1)P(-C2)P(-C3) \\ & + P(R16|-C1, C2, -C3)P(-C1)P(C2)P(-C3) \\ & + P(R16|-C1, -C2, C3)P(-C1)P(-C2)P(C3) \\ & + P(R16|-C1, -C2, -C3)P(-C1)P(-C2)P(-C3) \end{aligned}$$

$$\begin{aligned} P(R17) = {} & \mathrm{P(R17|C1, C2)P(AC1)P(C2) + P(R17|C1, -C2)P(C1)P(-C2)} \\ & + \mathrm{P(R17|-C1, C2)P(-C1)P(C2) + P(R17|-C1, -C2)P(-C1)P(-C2)} \end{aligned}$$

$$\begin{aligned} P(R18) = {} & \mathrm{P(R18|C1, C2)P(C1)P(C2) + P(R18|C1, -C2)P(C1)P(-C2)} \\ & + \mathrm{P(R18|-C1, C2)P(-C1)P(C2) + P(R18|-C1, -C2)P(-C1)P(-C2)} \end{aligned}$$

Each of the three risk nodes above will have a conditional probability table. These conditional probability tables will have the probability of the causes P(C) and the posterior probability of the risk with these causes P(R|C1, C2,…..). Table 6-6 shows the conditional probability table for each risk.

Table 6-6: Conditional Probability Table for R16

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R16|C1,C2,C3)
R16	C1	0.3	0.7	T	T	T	0.9
Adverse visual impact	C2	0.2	0.8	T	T	F	0.7
	C3	0.25	0.75	T	F	T	0.6
				F	T	T	0.65
P(R16) =	0.29			T	F	F	0.35
				F	T	F	0.4
				F	F	T	0.3
				F	F	F	0.1

Table 6-7: Conditional Probability Table for R17

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R17|C1,C2)
R17	C1	0.7	0.3	T	T	0.95
Landscape alteration	C2	0.6	0.4	T	F	0.75
	0.66			F	T	0.25
P(R17) =				F	F	0.05

Table 6-8: Conditional Probability Table for R18

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R18|C1,C2)
R18	C1	0.1	0.9	T	T	0.9
Disrupt business in the community	C2	0.15	0.85	T	F	0.75
	0.18			F	T	0.25
P(R18) =				F	F	0.1

Based on the equations and the data from the tables above, the probability of the risk are:

$P(R16) = (0.9 * 0. * 0.2 * 0.25) + (0.7 * 0.3 * 0.2 * 0.75 + (0.6 * 0.3 * 0.8 * 0.25) + (0.65 * 0.7 * 0.2 * 0.25) + (0.35 * 0.3 * 0.8 * 0.75) + (0.4 * 0.7 * 0.2 * 0.75) + (0.3 * 0.7 * 0.8 * 0.25) + (0.1 * 0.7 * 0.8 * 0.75)$ = 0.29

$P(R17) = (0.95 * 0.7 * 0.6) + (0.75 * 0.7 * 0.4) + (0.25 * 0.3 * 0.6) + (0.05 * 0.4 * 0.3)$ = 0.66

$$P(R18) = (0.9 * 0.1 * 0.15) + (0.75 * 0.1 * 0.85) + (0.25 * 0.9 * 0.15) + (0.1 * 0.9 * 0.85) = 0.18$$

Finally, using Microsoft Excel software and filling in all the data in the conditional probability tables for all the networks, the result will show the probability of all 32 sustainability-related risks and sort them by their probability of occurrence.

The next step is calculating the risk impacts using the Analytical Hierarchical Process (AHP).

2. Calculating Risk Consequence Using the Analytic Hierarchy Process (AHP)

The AHP is a multi-criteria decision-making method invented by mathematician Thomas L. Saaty in the 1970s (Iberraken, 2013). Using AHP, it becomes possible to arrange information about a decision problem in an effective and graphical form by employing a hierarchical model comprised of a general aim, criteria, and options. The approach has been used to tackle complicated choice issues in a variety of areas (Saaty, 1980). In order to rank hierarchically, the AHP technique breaks a complex problem into small parts. As a result, the relative relevance of options is weighted appropriately. The procedure is divided into various steps, starting with the framing of the decision problem, and implementing (binary comparisons/pairwise comparison matrix) in which the AHP compares subjective values 'in pairs' based on both quantitative (tangible aspects) and qualitative factors (non-tangible aspects) using its own measurement scale (Saaty, 1980). The prioritisation and synthesis phase follows, in which we can calculate the priority of each element and understand this priority. The final stage of this process is the so-called sensitivity analysis. Using support software and expert choice, it allows the decision problem to be solved quickly and it facilitates the analysis of the sensitivity of the results (decision) to the different possible changes, thus, allowing the problem to be analysed in different scenarios (Bhushan & Raj, 2004).

Therefore, the AHP is useful and it may be used to create the model and make decisions to prioritise and choose projects in a portfolio. For example, Thanki et al. (2016) applied AHP to investigate lean-green implementation techniques in small and medium-sized businesses. Other examples are its application in delineating groundwater potential zones in a watershed (Pinto et al., 2017), in a building refurbishment assessment (Kamaruzzaman et al., 2018) and in military analysis (Teknomo, 2006).

AHP has plenty of advantages, which is why it was chosen for this model. According to Emrouznejad and Marra (2017), **first,** AHP is flexible, straightforward, convenient, usable, and instinctive for decision makers. **Second,** it has the ability to check inconsistencies and it decomposes the decision problems into their basic components, and builds hierarchies of criteria, which shows the importance of each component by pairwise comparisons. **Third,** it disentangles a difficult issue by breaking it down into little parts; it does not necessitate real data sets. **Forth,** it decreases the bias of the decision-making process by checking the consistency of the alternatives. **Fifth,** AHP's framework results in a straightforward approach for dealing with complicated situations; it is helpful for models where there are uncertainty and risk.

Generally, using AHP for a decision-making model consists of six major steps, starting with making a model for decision making by breaking down the process into a hierarchy model that contains the goal, criteria, and alternatives. Figure 6-5 below shows an example of a hierarchy model.

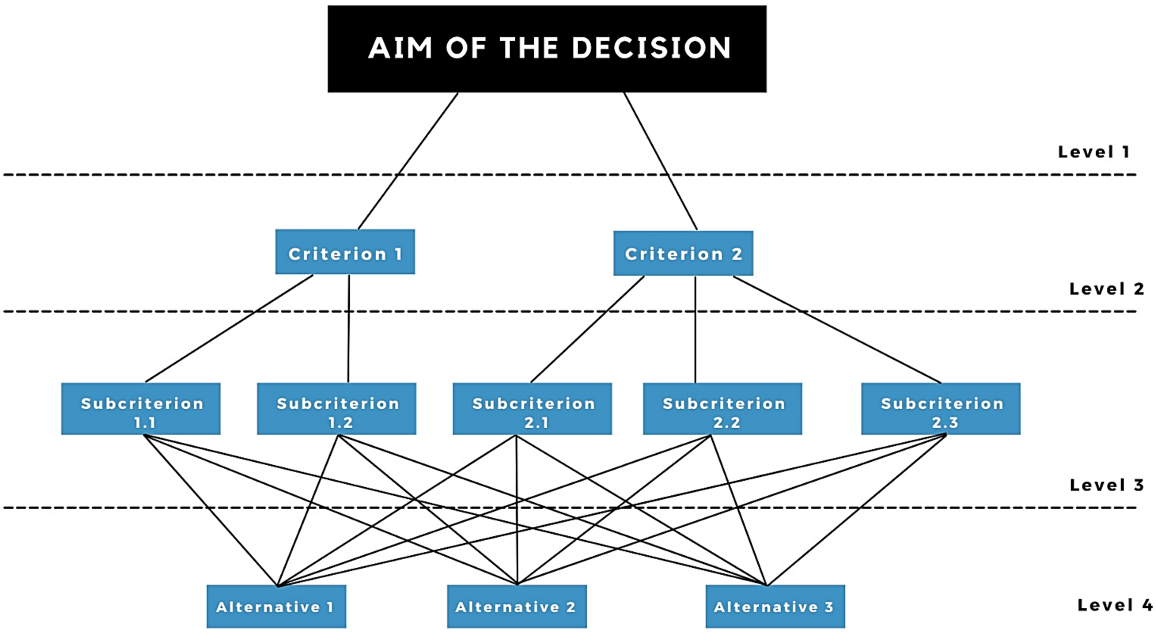

Figure 6-5: AHP hierarchical model

The second step is to give priorities or weight to the criteria by pairwise comparing them with respect to the goal. That is done by making a comparison matrix, using a relative importance scale for the criteria and checking the consistency of the decision by calculating the consistency ratio (CR=CI/RI).

The matrix *A* as shown below represents a pairwise comparison matrix where each element $\boldsymbol{a_{ij}}$ shows the relative importance of the compared elements (*i* and *j*). The higher its value, the stronger the preference of the first element (*i*) over the second (*j*).

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}, \quad a_{ii} = 1, \quad a_{ji} = \frac{1}{a_{ij}}, \quad a_{ij} \neq 0 \tag{6.5}$$

Thereafter, the priority weights of each criterion can be calculated using the following equation:

$$w_i = \frac{1}{n}\left(\sum_{j=1}^{n} a_{ij}\right) \Big/ \left(\sum_{k=1}^{n} a_{kj}\right) \tag{6.6}$$

The next step in the AHP method is to ensure the consistency of the data. According to Saaty (1986), the equation to control and check whether the comparison pairwise matrix is consistent is called the consistency index (CI). CI can be calculated as follows:

$$CI = (\lambda_{\max} - n)/(n-1) \tag{6.7}$$

Where n is the order of the matrix *A* and λ_{max} is its dominant Eigenvector, which satisfies the following equation:

$$\sum_{j=1}^{n} a_{ij} w_j = \lambda_{\max} w_i \tag{6.8}$$

A consistency ratio (CR) calculation is then needed to specify reasonable consistency. The CR value can be calculated by equation 6.9. The CR value must be equal to or smaller than 0.10, and it it is not, the expert judgement is revised to obtain a consistent result. In the equation, RCI stands for random consistency index, introduced by Saaty (1994).

$$CR = CI / RCI \tag{6.9}$$

As highlighted by Dong and Saaty (2014), to find the values of RCI, Saaty (1980) compared the estimated CI with the same index derived from a randomly generated square matrix. The values were found as shown in Table 6-9 below.

Table 6-9: Random Consistency Index (Dong & Saaty, 2014)

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

After that, the next step is to pairwise compare the alternatives with respect to each criterion, following the same steps as those used for the pairwise comparison carried out on the criteria with respect to the goal. A comparison matrix for all the alternatives of every criterion is created and the consistency checked. The fourth step is to designate an overall weight to each alternative through a weighted sum of every alternative from the previous step and the highest alternative is the chosen one.

The model is then analysed by changing the weight for the criteria and finding how the final result will change (De FSM Russo & Camanho, 2015).

In the development of this model, the first step is the development of the AHP hierarchical model. The top of a hierarchical model is the goal to be achieved by AHP – in this case, the impact of the sustainability-related risks of a project. The second layer (criteria layer) refers to the proposed 8 major categories of sustainability-related risks: impact on natural resources, the ecosystem, biodiversity, socio-economic conditions, public and occupational health, waste management, chemical or hazardous materials, and managerial. The third layer (alternatives) is the sustainability-related risks that were identified in the previous steps, as shown in Figure 6-6 below.

Before starting to calculate the probability and filling in the conditional probability tables, the weight factor method is used. See Table 6-5 for the weights assigned to each expert. This step can be skipped if only one expert is using the model.

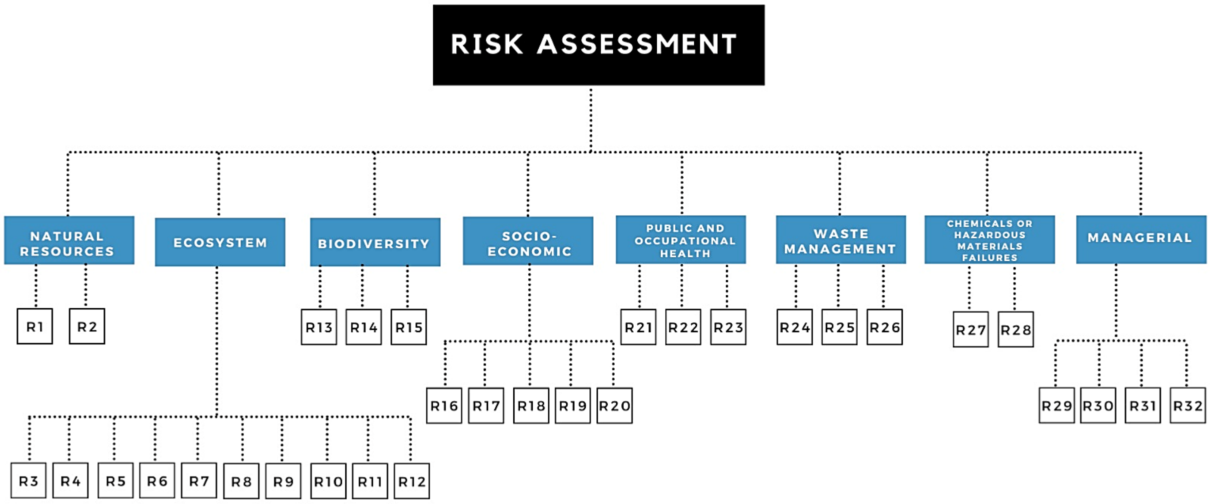

Figure 6-6: the AHP hierarchical model

The next step of the AHP method is to create a pairwise comparison matrix (Table 6-11) for the risk categories by using the relative importance scale shown in Table 6-10 to weight each risk.

Table 6-10: Relative Impact Scale

Impact score	Impact level
1	Very low
3	Low
5	Moderate
7	high
9	Very high
2,4,6,8	Intermediate values

Table 6-11: The Pairwise Comparison Matrix for the Risk Categories

	CAT 1	CAT 2	CAT 3	CAT 4	CAT 5	CAT 6	CAT 7	CAT 8
CAT 1	1.00	0.20	1.00	0.11	0.14	0.20	0.33	0.11
CAT 2	5.00	1.00	5.00	0.20	0.33	1.00	3.00	0.20
CAT 3	1.00	0.20	1.00	0.11	0.14	0.20	0.33	0.11
CAT 4	9.00	5.00	9.00	1.00	3.00	5.00	7.00	1.00
CAT 5	7.00	3.00	7.00	0.33	1.00	3.00	5.00	0.33

CAT 6	5.00	1.00	5.00	0.20	0.33	1.00	3.00	0.20
CAT 7	3.00	0.33	3.00	0.14	0.20	0.33	1.00	0.14
CAT 8	9.00	5.00	9.00	1.00	3.00	5.00	7.00	1.00
TOTAL	40.00	15.73	40.00	3.10	8.15	15.73	26.67	3.10

The matrix uses the data on the case studies with the experts, who were asked to pairwise compare the risk categories. Based on the completed pairwise comparative matrix, the weight values (impact) of categories can be quantitatively calculated using the Eigenvector corresponding to the maximum Eigenvalue of the pairwise comparative matrices as the weighted values. As mentioned previously, the dominant Eigenvector can be computed through equation 5.

Now by dividing each element by the sum of its column, we can find the normalised relative

Table 6-12: The normalised Pairwise Comparison Matrix for the Risk Categories

	CAT 1	CAT 2	CAT 3	CAT 4	CAT 5	CAT 6	CAT 7	CAT 8	TOTAL	AVG.		Consistency Measure	
CAT 1	0.03	0.01	0.03	0.04	0.02	0.01	0.01	0.04	0.18	0.02	CAT 1	8.116792155	
CAT 2	0.13	0.06	0.13	0.06	0.04	0.06	0.11	0.06	0.66	0.08	CAT 2	8.329645511	
CAT 3	0.03	0.01	0.03	0.04	0.02	0.01	0.01	0.04	0.18	0.02	CAT 3	8.116792155	
CAT 4	0.23	0.32	0.23	0.32	0.37	0.32	0.26	0.32	2.36	0.30	CAT 4	8.767287276	
CAT 5	0.18	0.19	0.18	0.11	0.12	0.19	0.19	0.11	1.26	0.16	CAT 5	8.754907859	
CAT 6	0.13	0.06	0.13	0.06	0.04	0.06	0.11	0.06	0.66	0.08	CAT 6	8.329645511	
CAT 7	0.08	0.02	0.08	0.05	0.02	0.02	0.04	0.05	0.35	0.04	CAT 7	8.007179779	
CAT 8	0.23	0.32	0.23	0.32	0.37	0.32	0.26	0.32	2.36	0.30	CAT 8	8.767287276	
											CI	0.056956027	
											RI	1.41	
											CR	0.040394346	1

weight pairwise matrix, and then the normalised principal Eigen vector. We have to average across the normalised relative weight pairwise matrix, and the Eigen vector shows the relative weights among the compared elements.

In order to check the consistency, we need to find the CR. To do that, we need the Principal Eigen value. This is obtained from the summation of products between each element of the Eigen vector and the sum of the columns of the reciprocal matrix. Using equation 4 we calculate the CI value, and finally, from equation 6, we can find the CR, and from table 11 we calculate the RCI. Since the CR value was less than 0.10, our values are consistent.

After relative weights of the risk categories were calculated and the consistency was checked, the sustainability-related risks of each category were pairwise compared with respect to their category. Eight pairwise comparison matrices were created based on the hierarchical model.

Table 6-13: The Pairwise Comparison Matrix for the Socio-Economic Risks

SOCIO-ECONOMIC	R 16	R 17	R 18	R 19	R 20
R 16	1	1.00	5.00	1.00	9.00

R 17	1	1	5.00	1.00	9.00
R 18	0.2	0.2	1	0.20	5.00
R 19	1	1	5	1	9.00
R 20	0.111111	0.111111	0.2	0.111111	1
TOTAL	3.311111	3.311111	16.2	3.311111	33

In this model, based on the hierarchical model, nine matrices were created in total. The first was developed to compare the categories and the remaining eight matrices were developed to compare the risks in each group. Only two matrices are displayed here as examples to illustrate the model: the categories matrix and the socio-economic conditions matrix.

Table 6-14: The normalised Pairwise Comparison Matrix for the Socio-Economic Risks

SOCIO-ECONOMIC	R16	R17	R18	R19	R20	TOTAL	AVG		CM	
R16	0.302013	0.302013	0.308642	0.302013	0.272727	1.48741	0.297482	R16	5.193166	
R17	0.302013	0.302013	0.308642	0.302013	0.272727	1.48741	0.297482	R17	5.193166	
R18	0.060403	0.060403	0.061728	0.060403	0.151515	0.394452	0.07889	R18	5.079195	
R19	0.302013	0.302013	0.308642	0.302013	0.272727	1.48741	0.297482	R19	5.193166	
R20	0.033557	0.033557	0.012346	0.033557	0.030303	0.14332	0.028664	R20	5.009867	
								CI	0.033428	
								RI	1.12	
								CR	0	1

The same steps were used in this matrix to find the normalised relative weight pairwise matrix, we then averaged across it, and found the normalised principal Eigen vector, to show the relative weights among the socio-economic risks. Finally, the consistency was checked and achieved since the CR was less than 0.1.

The tables below show the final relative weight of each matrix. The final relative weight of the sustainability-related risks are calculated by multiplying the weight of the sustainability-related risk by the weight of its category.

Table 6-15: The Final Weights of the Risks categories

CAT	AVG
CAT 1	0.022146
CAT 2	0.082451
CAT 3	0.022146

CAT 4	0.295197
CAT 5	0.157085
CAT 6	0.082451
CAT 7	0.043327
CAT 8	0.295197

Table 6-16: The Final Weights of the Socio-Economic Risks

SOCIO-ECONOMIC	AVG
R16	0.297482
R17	0.297482
R18	0.07889
R19	0.297482
R20	0.028664

The calculation of the impact of the sustainability-related risks 16,17 and 18:

R16 = 0.297482*0.295197 = 0.087815753

R17 = 0.297482*0.295197 = 0.087815753

R18 = 0.07889*0.295197 = 0.023288183

6.6 Calculate the Risk Ranking

The value of the risk ranking can be calculated by using equation 6.10:

$$RR = Risk\ probability\ \times Risk\ impact \qquad (6.10)$$

To multiply the impact by the probability, it is important to ensure that the two numbers have the same scale, and that the results of the impact are scaled out of 100%, while the impact shows the weight of each risk with a total of one.

The risk impact results were scaled using standardisation. In this case study, the final results were divided by the highest value, after checking if there were any outliers values. Then the results were divided into the original five interval scale from 1 to 9 with the intermediate values 2, 4 ,6, 8 and 10, to give more accurate results. The tables below show the risk relative weight levels.

For the probability, as the value is already a probability value (rate) out of 100%, the scale will contain five intervals from 1 to 9 with intermediate values (2, 4, 6, 8, 10) to give more accurate results, as shown in the table presenting the risk probability levels.

Table 6-17: Risk probability Levels

Probability score	Probability level	Probability
1	Very low	0 – 20%
3	Low	20% – 40%
5	Moderate	40% – 60%
7	High	60% – 80%
9	Very high	Above 80%

Table 6-18: Risk Impact Relative Weight Levels

Impact score	Impact level	Relative weight
1	Very low	Below 0.2
3	low	0.2 - 0.4
5	Moderate	0.4 – 0.6
7	high	0.6 – 0.8
9	Very high	Above 0.8

The RR of the sustainability-related risks can be calculated from equation 6 and based on the scale above as follows:

$RR(R16) = 3 \times 9 = 27$

$RR(R17) = 7 \times 9 = 63$

$RR(R18) = 1 \times 3 = 3$

So, from the answer above it can be seen that R17 ≥ R16 ≥ R18.

6.7 Risk Response

After calculating the risk levels and ranking them, the results were used in the risk response phase to assist the managers in developing the right operation and maintenance policies (An et al., 2007). In this model, the risk levels were categorised into three groups: high, medium, and low.

When the risk ranking is high, the risk needs to be reduced or the construction of the project has to be reassessed to reduce the risk’s impact or its probability. When the risk is low or negligible, no further action is needed; nevertheless, the information has to be recorded and the risk has to be monitored. When the risk level is medium, the risk falls in a transition region where it needs to be reduced as low as is reasonably practicable (ALARP) (An et al., 2011).

High = reduce or eliminate risks.

Medium = reduce if cost-effective.

Low = accept and keep under monitoring.

6.8 Conclusion

This chapter demonstrated the steps involved in the development of the proposed sustainable risk assessment model. In this chapter, the problem identification was clearly discussed; Jordan needs a green and sustainable environment to decrease harm to its people and environment. In addition, it needs a sustainable construction industry that bonds with the risk management process. The data and information collection were illustrated in this chapter, as well as the analysis frame. Risk identification was manifest and the risk assessment response was clarified. All of these steps are the initial phases that our model will be based on. This chapter provided the reader with sufficient information to be able to develop a model, accompanied by a systemic approach, for the purpose of identifying and controlling sustainability-related risk in Jordan's construction industry.

Chapter Seven

Chapter Seven: Validation of The Model

7.1 Introduction

This chapter includes three case studies that have been investigated by using the developed model for check and validation. The three case studies are different types of projects, i.e., a building construction project, a road and infrastructure project, and a waste landfill rehabilitation project, all from the Jordanian construction industry. Each case starts with an overview introduction to the background of the company, then it moves on to the case study data and information collection, the application of the proposed risk assessment model and the results of the case study. A discussion of the results and the validation of the proposed model are presented at the end of this chapter.

7.2 Case Study 1: The construction of a commercial building project

7.2.1 Overview of the Company and the Project

The first case study is the construction of a commercial building project (small shopping centre) by a private client in the capital city of Jordan, Amman.

The total duration of the project is 52 weeks and it involves the building and fitting of a seven-storey commercial building with a total area of 3500 m^2 and an initial project budget of 1.2 million JD (£1.2 million), around 400 JD per m^2. The construction site is in an old car parking plot. The building has been designed and supervised by an architectural and engineering firm, while the construction work is undertaken by a private contractor (construction company) from the start to the handover. The construction company is specialised in commercial and private villas, it is ranked number one in the Jordanian construction association. The project involves the construction and fitting of the shopping centre.

At the time of the case study and collecting data, the project had passed the week 40 mark. However, the project manager clarified that considering the work done and the work left to finish, the building still needed 20 weeks, which means that the project is delayed by eight weeks. Also, he explained that the project will be 200,000 JD over the budget. The reasons for these delays and being over budget, according to the project manager, were the excessive number of changing orders and shortages in materials as a result of problems in the supply chain due to the COVID-19 pandemic.

This project does not have an engineer who is responsible for managing and assessing risks, but the construction company's project manager was the person in charge of managing the project, and assuring that it was completed within its schedule and budget, with high-quality work. The project manager confirmed that no risk assessment had been done for this project, and that generally, Jordanian companies do not perform risk management or assess sustainability-related risks; however, he was interested in the concept.

7.2.2 Data and Information Collection

As discussed previously, the first three steps of the case studies, through to the quantitative risk analysis, were completed during the research and the development of the model. The first was done by critically reviewing the available resources, i.e., rating systems (LEED, BREEAM, GSAS, and ESTIDAMA), EIA reports, and finally, the key principles of the UN SDGs. Using these sources, a list consisting of 89 hazardous events was created, then this list was reviewed for its applicability to the Jordanian construction industry through qualitative data collection (focus group) with eight experts from the industry in Jordan. Finally, the risks were ranked by a questionnaire distributed to employees in the Jordanian construction industry; 402 engineers completed the questionnaire. Only the high and very high risks will be assessed in the quantitative part.

As for the collected data for this study, it starts in the quantitative part of the risk assessment risk model. Data were collected from the project manager only in a meeting, due to time limitations. The manager was asked to fill in the model with all the relevant data. He used Microsoft Excel software to fill in the model. For the risk probability part, the manager filled in all the probabilities for the causes of the risks and the conditional probability between the risks and their causes. Finally, for the risk impact part, the project manager was asked to use the model to fill in the pairwise comparison tables. The next section presents the risk analysis, which was done using BBN and AHP.

7.2.3 Data Analysis

7.2.3.1 Probability Analysis Using BBN

This section shows the calculation used to find the probability using a BBN. It starts by presenting the BBN network adopted for this model, then it moves to the conditional probability tables for every node (risk) in the network that was filled in by the project manager. Finally, it displays the final probability result for the first case study.

1- The first step in the BM is the development of the belief network. Figure 7-1 shows the network developed and used in the model for the first case study.

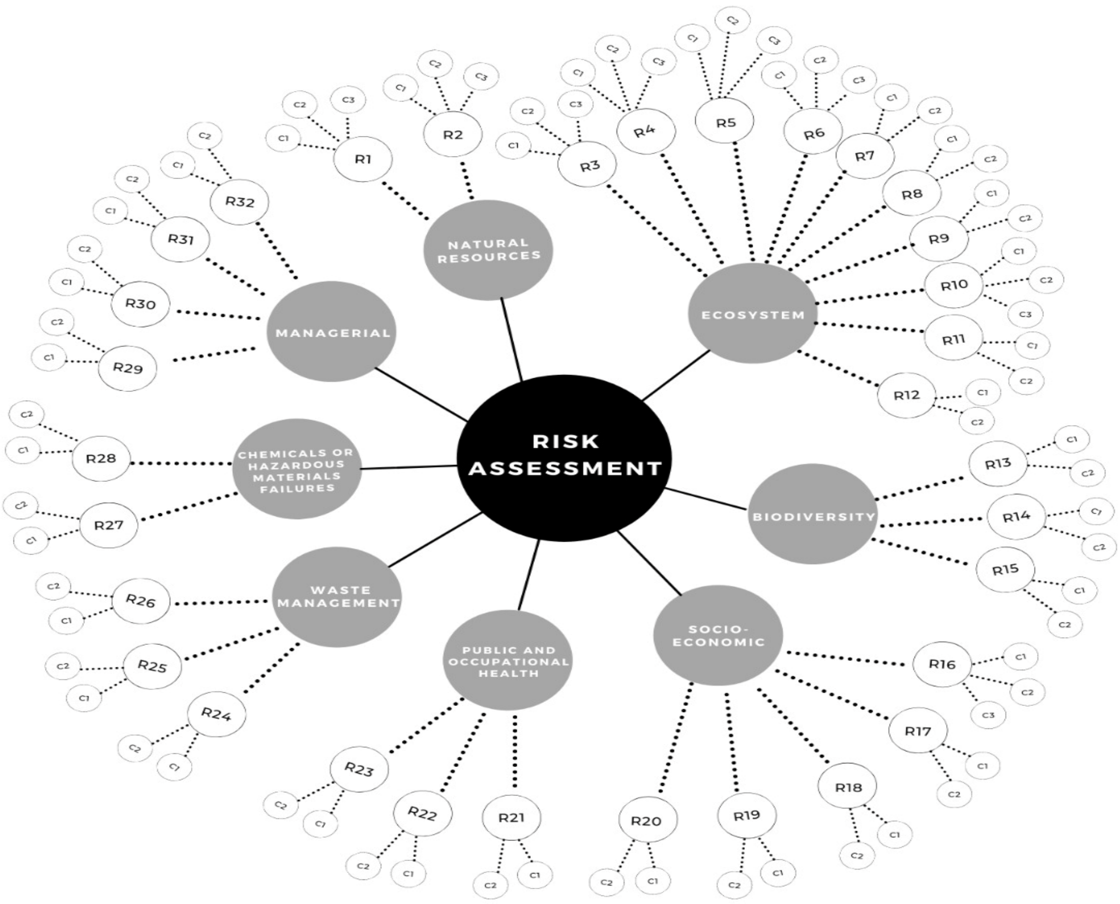

Figure 7-1: Bayesian Belief Network for the developed model

After the network is developed for this project, the next step should be the weight factor method. However, in this case study, the data came from the project manager alone, therefore the weight factor method is omitted.

2- Bayesian Belief Network Conditional Probability Tables

This part of the case study shows the conditional probability tables for each node (sustainability-related risk). These table were filled in by the project manager of this case study based on the network above and the characteristics of the project. Each table contains the probability of the causes (two or three), plus the posterior probability between the risk and its causes (P(R1|C1, C2,C3). The final probability of the risk P(Ri) will be calculated with equations 5 and 6, discussed in the model development chapter (Chapter 6). These equations were put into the Microsoft Excel software.

(1) Conditional Probability Table for node 1 (R1)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R1|C1,C2,C3)
R1	C1	0.15	0.85	T	T	T	0.9
Excessive use of raw materials	C2	0.1	0.9	T	T	F	0.7
	C3	0.15	0.85	T	F	T	0.7
				F	T	T	0.7
P(R1) =	0.1896			T	F	F	0.3
				F	T	F	0.3
				F	F	T	0.3
				F	F	F	0.1

(2) Conditional Probability Table for node 2 (R2)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R2|C1,C2,C3)
R2	C1	0.3	0.7	T	T	T	0.85
The depletion of natural resources, renewable and non-renewable resources	C2	0.55	0.45	T	T	F	0.6
	C3	0.15	0.85	T	F	T	0.65
				F	T	T	0.6
P(R2) =	0.3725			T	F	F	0.4
				F	T	F	0.35
				F	F	T	0.4
				F	F	F	0.15

(3) Conditional Probability Table for node 3 (R3)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R3|C1,C2,C3)
R3	C1	0.9	0.1	T	T	T	0.9
Noise and vibrations from construction machinery and equipment	C2	0.85	0.15	T	T	F	0.75
	C3	0.8	0.2	T	F	T	0.65
				F	T	T	0.7
P(R3) =	0.8007			T	F	F	0.3
				F	T	F	0.35
				F	F	T	0.25
				F	F	F	0.1

(4) Conditional Probability Table for node 4 (R4)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R4|C1,C2,C3)
R4	C1	0.1	0.9	T	T	T	0.95
Deterioration of air quality (indoor and outdoor)	C2	0.2	0.8	T	T	F	0.55
	C3	0.15	0.85	T	F	T	0.7
				F	T	T	0.55
P(R4) =	0.19115			T	F	F	0.45
				F	T	F	0.3
				F	F	T	0.45
				F	F	F	0.05

(5) Conditional Probability Table for node 5 (R5)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R5|C1,C2,C3)
R5	C1	0.3	0.7	T	T	T	0.9
Emissions from construction activities and equipment	C2	0.4	0.6	T	T	F	0.65
	C3	0.25	0.75	T	F	T	0.7
				F	T	T	0.6
P(R5) =	0.34425			T	F	F	0.4
				F	T	F	0.3
				F	F	T	0.35
				F	F	F	0.1

(6) Conditional Probability Table for node 6 (R6)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R6|C1,C2,C3)
R6	C1	0.5	0.5	T	T	T	0.95
Emissions of harmful gases	C2	0.55	0.45	T	T	F	0.7
	C3	0.6	0.4	T	F	T	0.75
				F	T	T	0.55
P(R6) =	0.53875			T	F	F	0.45
				F	T	F	0.25
				F	F	T	0.3
				F	F	F	0.05

(7) Conditional Probability Table for node 7 (R7)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R7|C1,C2,C3)
R7	C1	0.95	0.05	T	T	0.98
Dust generation from construction activities, machineries and equipment	C2	0.85	0.15	T	F	0.95
	0.929			F	T	0.05
P(R7) =				F	F	0.02

(8) Conditional Probability Table for node 8 (R8)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R8|C1,C2,C3)
R8	C1	0.9	0.1	T	T	0.9
Bad odour generation from handling of construction materials, waste and sewage	C2	0.85	0.15	T	F	0.55
	0.8025			F	T	0.45
P(R8) =				F	F	0.1

(9) Conditional Probability Table for node 9 (R9)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R9|C1,C2,C3)
R9	C1	0.1	0.9	T	T	0.9
High soil erosion and excavation	C2	0.15	0.85	T	F	0.73
	0.1885			F	T	0.27
P(R9) =				F	F	0.1

(10) Conditional Probability Table for node 10 (R10)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R10|C1,C2,C3)
R10	C1	0.85	0.15	T	T	T	0.85
Land pollution (associated with construction activities, machineries and equipment)	C2	0.9	0.1	T	T	F	0.6
	C3	0.8	0.2	T	F	T	0.65
				F	T	T	0.6
				T	F	F	0.4
P(R10) =	0.7425			F	T	F	0.35
				F	F	T	0.4
				F	F	F	0.15

(11) Conditional Probability Table for node11 (R11)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R11|C1,C2,C3)
R11	C1	0.15	0.85	T	T	0.87
Contamination of rainwater runoff and surface water	C2	0.15	0.85	T	F	0.66
	0.241			F	T	0.34
P(R11) =				F	F	0.13

(12) Conditional Probability Table for node 12 (R12)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R12|C1,C2,C3)
R12	C1	0.98	0.02	T	T	0.99
Improper discharge of the workplace’s wastewater	C2	0.9	0.1	T	F	0.75
	0.9512			F	T	0.25
P(R12) =				F	F	0.01

(13) Conditional Probability Table for node 13 (R13)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R13|C1,C2,C3)
R13	C1	0.95	0.05	T	T	0.9
Loss of agricultural lands and vegetation removal	C2	0.9	0.1	T	F	0.6
	0.845			F	T	0.4
P(R13) =				F	F	0.1

(14) Conditional Probability Table for node 14 (R14)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R14|C1,C2,C3)
R14	C1	0.25	0.7	T	T	0.85
Mountains and forest removal (deforestation)	C2	0.2	0.8	T	F	0.55
	0.2995			F	T	0.45
P(R14) =				F	F	0.15

(15) Conditional Probability Table for node 15 (R15)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R15|C1,C2,C3)
R15	C1	0.35	0.65	T	T	0.85
Roadside vegetation removal	C2	0.25	0.75	T	F	0.5
				F	T	0.5
P(R15) =	0.36			F	F	0.15

(16) Conditional Probability Table for node 16 (R16)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R16|C1,C2,C3)
R16	C1	0.9	0.1	T	T	0.99
Adverse visual impact	C2	0.85	0.15	T	F	0.75
				F	T	0.25
P(R16) =	0.88			F	F	0.01

(17) Conditional Probability Table for node 17 (R17)

SUSTAINABLE RISK	CAUSE	PROBABILITY		C1	C2	C3	P(R17|C1,C2,C3)
R17	C1	0.85	0.15	T	T	T	0.98
Landscape alteration	C2	0.9	0.1	T	T	F	0.8
	C3	0.95	0.05	T	F	T	0.75
				F	T	T	0.65
				T	F	F	0.35
P(R17) =	0.83619			F	T	F	0.25
				F	F	T	0.2
				F	F	F	0.02

(18) Conditional Probability Table for node 18 (R18)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R18|C1,C2,C3)
R18	C1	0.9	0.1	T	T	0.95
Disruption of business in the community	C2	0.85	0.15	T	F	0.65
				F	T	0.35
P(R18) =	0.845			F	F	0.05

(19) Conditional Probability Table for node 19 (R19)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R19|C1,C2,C3)
R19	C1	0.85	0.15	T	T	0.85
Demand or stress on the infrastructure and the road network	C2	0.75	0.25	T	F	0.6
				F	T	0.4
P(R19) =	0.72			F	F	0.15

(20) Conditional Probability Table for node 20 (R20)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R20|C1,C2,C3)
R20	C1	0.1	0.9	T	T	0.99
Public dissatisfaction with the project	C2	0.15	0.85	T	F	0.9
	0.1125			F	T	0.1
P(R20) =				F	F	0.01

(21) Conditional Probability Table for node 21 (R21)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R21|C1,C2,C3)
R21	C1	0.3	0.7	T	T	0.95
Construction accidents and casualties	C2	0.25	0.75	T	F	0.75
	0.31			F	T	0.25
P(R21) =				F	F	0.05

(22) Conditional Probability Table for node 22 (R22)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R22|C1,C2,C3)
R22	C1	0.65	0.35	T	T	0.9
Adverse effect on public health and safety	C2	0.4	0.6	T	F	0.65
	0.5575			F	T	0.35
P(R22) =				F	F	0.1

(23) Conditional Probability Table for node 23 (R23)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R23|C1,C2,C3)
R23	C1	0.95	0.05	T	T	0.85
Lack of attention to health issues in the workplace	C2	0.75	0.25	T	F	0.55
	0.755			F	T	0.45
P(R23) =				F	F	0.15

(24) Conditional Probability Table for node 24 (R24)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R24|C1,C2,C3)
R24	C1	0.6	0.4	T	T	0.95
Improper disposal of ordinary and domestic solid waste	C2	0.45	0.55	T	F	0.5
	0.5225			F	T	0.5
P(R24) =				F	F	0.05

(25) Conditional Probability Table for node 25 (R25)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R25|C1,C2,C3)
R25	C1	0.45	0.55	T	T	0.83
Improper disposal of special waste	C2	0.3	0.7	T	F	0.7
	0.4475			F	T	0.3
P(R25) =				F	F	0.17

(26) Conditional Probability Table for node 26 (R26)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R26|C1,C2,C3)
R26	C1	0.65	0.35	T	T	0.87
Improper disposal of building debris	C2	0.5	0.5	T	F	0.5
	0.5555			F	T	0.5
P(R26) =				F	F	0.13

(27) Conditional Probability Table for node 27 (R27)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R27|C1,C2,C3)
R27	C1	0.7	0.3	T	T	0.95
Contamination from spills of oils, fuels, and lubricants from field equipment and improperly stored materials or due to vandalism.	C2	0.65	0.35	T	F	0.75
	0.67			F	T	0.25
P(R27) =				F	F	0.05

(28) Conditional Probability Table for node 28 (R28)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R28|C1,C2,C3)
R28	C1	0.8	0.2	T	T	0.85
Failure of underground utility lines, pipes and other underground structures.	C2	0.65	0.35	T	F	0.45
	0.624			F	T	0.35
P(R28) =				F	F	0.15

(29) Conditional Probability Table for node 29 (R29)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R29|C1,C2,C3)
R29	C1	0.35	0.65	T	T	0.95
Insufficient on-site investigation resulted in improper adjustment measures to local conditions.	C2	0.15	0.85	T	F	0.75
	0.325			F	T	0.25
P(R29) =				F	F	0.05

(30) Conditional Probability Table for node 30 (R30)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R30|C1,C2,C3)
R30	C1	0.3	0.7	T	T	0.88
Unclear allocation of roles and responsibilities.	C2	0.25	0.75	T	F	0.6
	0.334			F	T	0.4
P(R30) =				F	F	0.12

(31) Conditional Probability Table for node 31 (R31)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R31|C1,C2,C3)
R31	C1	0.98	0.02	T	T	0.95
Lack of availability of green materials and equipment	C2	0.95	0.05	T	F	0.45
	0.917			F	T	0.55
P(R31) =				F	F	0.05

(32) Conditional Probability Table for node 32 (R32)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R32|C1,C2,C3)
R32	C1	0.8	0.2	T	T	0.9
Inadequate knowledge of workers about environmental concerns, green materials and construction technologies.	C2	0.9	0.1	T	F	0.45
	0.785			F	T	0.55
P(R32) =				F	F	0.1

3- Final Probability Result

Table 7-1 shows the final result for the risk probability for this case study.

Table 7-1: Case Study One – Risk Probability

FACTORS	PROBABILITY	PROBABILITY (%)	scale
R1	0.1896	19	2
R2	0.3725	37	4
R3	0.8007	80	9
R4	0.19115	19	2
R5	0.34425	34	4
R6	0.53875	54	6
R7	0.929	93	10
R8	0.8025	80	9
R9	0.1885	19	2
R10	0.7425	74	8
R11	0.241	24	3
R12	0.9512	95	10
R13	0.845	85	9
R14	0.2995	30	3
R15	0.36	36	4
R16	0.88	88	9
R17	0.83619	84	9
R18	0.845	85	9
R19	0.72	72	8
R20	0.1125	11	2
R21	0.31	31	4
R22	0.5575	56	6
R23	0.755	76	8
R24	0.5225	52	6
R25	0.4475	45	5
R26	0.5555	56	6
R27	0.67	67	7
R28	0.624	62	7
R29	0.325	33	4
R30	0.334	33	4
R31	0.917	92	10
R32	0.785	79	8

7.2.3.2 Impact Analysis Using AHP

This section shows the calculation used to find the impact using Analytic Hierarchy Process (AHP). It starts by presenting the hierarchy model adopted for this model, then it moves on to the pairwise comparison table for the categories and the risks of each category. These tables were filled in by the project manager. The comparison matrices are then presented, followed by the final impact results for this case study.

Figure 7-2: The Hierarchy Model

After the network is developed for this project, the next step should be the weight factor method. However, in this case study, the data came from the project manager alone, therefore the weight factor method is omitted.

Pairwise comparison tables

The next nine tables are the comparison tables for the first case study, as the project manager filled them in. The first table shows the comparison between the categories, while the next eight show the comparison between the risks of each category.

1- Categories pairwise comparison table

	1---9			1---9	
C1	0.20	C2	C3	0.11	C8
C1	1.00	C3	C4	3	C5
C1	0.11	C4	C4	5	C6
C1	0.14	C5	C4	7	C7
C1	0.20	C6	C4	1	C8
C1	0.33	C7	C5	3	C6
C1	0.11	C8	C5	5	C7
C2	5.00	C3	C5	0.33	C8
C2	0.20	C4	C6	3.00	C7
C2	0.33	C5	C6	0.20	C8
C2	1.00	C6	C7	0.14	C8
C2	3.00	C7			
C2	0.20	C8			
C3	0.11	C4			
C3	0.14	C5			
C3	0.20	C6			
C3	0.33	C7			

2- First category pairwise comparison table

	1--9	
R1	9	R2

3- Second category comparison table

	1--9			1--9	
R3	5.00	R4	R6	1.00	R7
R3	5.00	R5	R6	0.33	R8
R3	3.00	R6	R6	3.00	R9
R3	3.00	R7	R6	0.33	R10
R3	1.00	R8	R6	3.00	R11
R3	5.00	R9	R6	0.33	R12
R3	1.00	R10	R7	0.33	R8
R3	5.00	R11	R7	3.00	R9
R3	1.00	R12	R7	0.33	R10
R4	1.00	R5	R7	3.00	R11
R4	0.33	R6	R7	0.33	R12
R4	0.33	R7	R8	3.00	R9
R4	0.20	R8	R8	0.33	R10
R4	1.00	R9	R8	3.00	R11
R4	0.20	R10	R8	0.33	R12
R4	1.00	R11	R9	0.20	R10
R4	0.20	R12	R9	1.00	R11
R5	0.33	R6	R9	0.20	R12
R5	0.33	R7	R10	5.00	R11
R5	0.20	R8	R10	1.00	R12
R5	1.00	R9	R11	0.20	R12
R5	0.20	R10			
R5	1.00	R11			
R5	0.20	R12			

4- Third category table

	1--9	
R13	1.00	R14
R13	5.00	R15
R14	5.00	R15

5- Fourth category table

	1--9	
R16	1.00	R17
R16	5.00	R18
R16	1.00	R19
R16	9.00	R20
R17	5.00	R18
R17	1.00	R19
R17	9.00	R20
R18	0.20	R19
R18	5.00	R20
R19	9.00	R20

6- Fifth category comparison table

R21	5.00	R22
R21	1.00	R23
R22	0.20	R23

7- Sixth category comparison table

R24	1.00	R25
R24	0.33	R26
R25	0.33	R26

8- Seventh category comparison table

R27	0.33	R28

9- Eighth category comparison table

R29	0.33	R30
R29	0.33	R31
R29	0.33	R32
R30	1.00	R31
R30	1.00	R32
R31	1.00	R32

The nine categories pairwise comparison tables above were used to create the comparison matrix for the next step. Each of the nine tables produced a matrix; the first matrix is between the categories, while the remaining eight matrices show the comparison between the risk of each category. Below each matrix the calculation for the dominant Eigenvector is presented, to find the relative weight of the risk and the CR.

Pairwise comparison matrix:

1- Categories pairwise comparison matrix

	CAT 1	CAT 2	CAT 3	CAT 4	CAT 5	CAT 6	CAT 7	CAT 8
CAT 1	1.00	0.20	1.00	0.11	0.14	0.20	0.33	0.11
CAT 2	5.00	1.00	5.00	0.20	0.33	1.00	3.00	0.20
CAT 3	1.00	0.20	1.00	0.11	0.14	0.20	0.33	0.11
CAT 4	9.00	5.00	9.00	1.00	3.00	5.00	7.00	1.00
CAT 5	7.00	3.00	7.00	0.33	1.00	3.00	5.00	0.33
CAT 6	5.00	1.00	5.00	0.20	0.33	1.00	3.00	0.20
CAT 7	3.00	0.33	3.00	0.14	0.20	0.33	1.00	0.14
CAT 8	9.00	5.00	9.00	1.00	3.00	5.00	7.00	1.00
TOTAL	40.00	15.73	40.00	3.10	8.15	15.73	26.67	3.10

	CAT 1	CAT 2	CAT 3	CAT 4	CAT 5	CAT 6	CAT 7	CAT 8	TOTAL	AVG.		Consistency Measure	
CAT 1	0.03	0.01	0.03	0.04	0.02	0.01	0.01	0.04	0.18	0.02	CAT 1	8.116792155	
CAT 2	0.13	0.06	0.13	0.06	0.04	0.06	0.11	0.06	0.66	0.08	CAT 2	8.329645511	
CAT 3	0.03	0.01	0.03	0.04	0.02	0.01	0.01	0.04	0.18	0.02	CAT 3	8.116792155	
CAT 4	0.23	0.32	0.23	0.32	0.37	0.32	0.26	0.32	2.36	0.30	CAT 4	8.767287276	
CAT 5	0.18	0.19	0.18	0.11	0.12	0.19	0.19	0.11	1.26	0.16	CAT 5	8.754907859	
CAT 6	0.13	0.06	0.13	0.06	0.04	0.06	0.11	0.06	0.66	0.08	CAT 6	8.329645511	
CAT 7	0.08	0.02	0.08	0.05	0.02	0.02	0.04	0.05	0.35	0.04	CAT 7	8.007179779	
CAT 8	0.23	0.32	0.23	0.32	0.37	0.32	0.26	0.32	2.36	0.30	CAT 8	8.767287276	
											CI	0.056956027	
											RI	1.41	
											CR	0.040394346	1

2- First categories pairwise comparison matrix

NATURAL	R1	R2
R1	1	9
R2	0.111111	1
total	1.111111	10

NATURAL	R1	R2	TOTAL	AVG		CM	
R1	0.9	0.9	1.8	0.9	R1	2	
R2	0.1	0.1	0.2	0.1	R2	2	
					CI	0	
					RI	0	
					CR	0	1

3- Second categories pairwise comparison matrix

ECOSYSTEM	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12
R 3	1	5.00	5.00	3.00	3.00	1.00	5.00	1.00	5.00	1.00
R 4	0.2	1	1.00	0.33	0.33	0.20	1.00	0.20	1.00	0.20
R 5	0.2	1	1	0.33	0.33	0.20	1.00	0.20	1.00	0.20
R 6	0.333333	3	3	1	1.00	0.33	3.00	0.33	3.00	0.33
R 7	0.333333	3	3	1	1	0.33	3.00	0.33	3.00	0.33
R 8	1	5	5	3.030303	3.030303	1	3.00	0.33	3.00	0.33
R 9	0.2	1	1	0.333333	0.333333	0.333333	1	0.20	1.00	0.20
R 10	1	5	5	3	3	3	5	1	5.00	1.00
R 11	0.2	1	1	0.333333	0.333333	0.333333	1	0.2	1	0.20
R 12	1	5	5	3	3	3	5	1	5	1
TOTAL	5.466667	30	30	15.36364	15.36364	9.726667	28	4.8	28	4.8

ECOSYSTEM	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	TOTAL	AVG	CM
R3	0.182927	0.17	0.17	0.20	0.20	0.10	0.18	0.21	0.18	0.21	1.78	0.18	10.30282185
R4	0.036585	0.033333	0.03	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.32	0.03	10.12449019
R5	0.036585	0.033333	0.033333	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.32	0.03	10.12449019
R6	0.060976	0.1	0.1	0.065089	0.07	0.03	0.11	0.07	0.11	0.07	0.78	0.08	10.11736521
R7	0.060976	0.1	0.1	0.065089	0.065089	0.03	0.11	0.07	0.11	0.07	0.78	0.08	10.11736521
R8	0.182927	0.166667	0.166667	0.197239	0.197239	0.10281	0.11	0.07	0.11	0.07	1.37	0.14	10.55561779
R9	0.036585	0.033333	0.033333	0.021696	0.021696	0.03427	0.035714	0.04	0.04	0.04	0.34	0.03	10.25390921
R10	0.182927	0.166667	0.166667	0.195266	0.195266	0.30843	0.178571	0.208333	0.18	0.21	1.99	0.20	10.61200494
R11	0.036585	0.033333	0.033333	0.021696	0.021696	0.03427	0.035714	0.041667	0.035714	0.04	0.34	0.03	10.25390921
R12	0.182927	0.166667	0.166667	0.195266	0.195266	0.30843	0.178571	0.208333	0.178571	0.208333	1.99	0.20	10.61200494
												CI	0.034155319
												RI	1.49
												CR	0.022923033

4- Third categories pairwise comparison matrix

BIODAIVERSITY	R 13	R 14	R 15
R 13	1	1.00	5.00
R 14	1	1	5.00
R 15	0.2	0.2	1
TOTAL	2.2	2.2	11

BIODAIVERSITY	R13	R14	R15	TOTAL	AVG		CM	
R13	0.454545	0.454545	0.454545	1.363636	0.454545	R13	3	
R14	0.454545	0.454545	0.454545	1.363636	0.454545	R14	3	
R15	0.090909	0.090909	0.090909	0.272727	0.090909	R15	3	
						CI	0	
						RI	0.58	
						CR	0	1

5- Fourth categories pairwise comparison matrix

SOCIO-ECONOMIC	R 16	R 17	R 18	R 19	R 20
R 16	1	1.00	5.00	1.00	9.00
R 17	1	1	5.00	1.00	9.00
R 18	0.2	0.2	1	0.20	5.00
R 19	1	1	5	1	9.00
R 20	0.111111	0.111111	0.2	0.111111	1
TOTAL	3.311111	3.311111	16.2	3.311111	33

SOCIO-ECONOMIC	R16	R17	R18	R19	R20	TOTAL	AVG		CM	
R16	0.302013	0.302013	0.308642	0.302013	0.272727	1.48741	0.297482	R16	5.193166	
R17	0.302013	0.302013	0.308642	0.302013	0.272727	1.48741	0.297482	R17	5.193166	
R18	0.060403	0.060403	0.061728	0.060403	0.151515	0.394452	0.07889	R18	5.079195	
R19	0.302013	0.302013	0.308642	0.302013	0.272727	1.48741	0.297482	R19	5.193166	
R20	0.033557	0.033557	0.012346	0.033557	0.030303	0.14332	0.028664	R20	5.009867	
								CI	0.033428	
								RI	1.12	
								CR	0	1

6- Fifth categories pairwise comparison matrix

PUBLIC	R 21	R 22	R 23
R 21	1	5.00	1.00
R 22	0.2	1	0.20
R 23	1	5	1
TOTAL	2.2	11	2.2

PUBLIC	R21	R22	R23	TOTAL	AVG		CM	
R21	0.454545	0.454545	0.454545	1.363636	0.454545	R21	3	
R22	0.090909	0.090909	0.090909	0.272727	0.090909	R22	3	
R23	0.454545	0.454545	0.454545	1.363636	0.454545	R23	3	
						CI	0	
						RI	0.58	
						CR	0	1

7- Sixth categories pairwise comparison matrix

WASTE	R 24	R 25	R 26
R 24	1	1.00	0.33
R 25	1	1	0.33
R 26	3	3	1
TOTAL	5	5	1.666667

WASTE	R24	R25	R26	TOTAL	AVG		CM	
R24	0.2	0.2	0.2	0.6	0.2	R24	3	
R25	0.2	0.2	0.2	0.6	0.2	R25	3	
R26	0.6	0.6	0.6	1.8	0.6	R26	3	
						CI	0	
						RI	0.58	
						CR	0	1

8- Seventh categories pairwise comparison matrix

CHEMICALS	R 27	R 28
R 27	1	0.33
R 28	3	1
TOTAL	4	1.333333

CHEMICALS	R27	R28	TOTAL	AVG		CM	
R27	0.25	0.25	0.5	0.25	R27	2	
R28	0.75	0.75	1.5	0.75	R28	2	
					CI	0	
					RI	0	
					CR	0	1

9- Eighth categories pairwise comparison matrix

MANEGIRIAL	R 29	R 30	R 31	R 32
R 29	1	0.33	0.33	0.33
R 30	3	1	1.00	1.00
R 31	3	1	1	1.00
R 32	3	1	1	1
TOTAL	10	3.333333	3.333333	3.333333

MANEGIRIAL	R29	R30	R31	R32	TOTAL	AVG		CM
R29	0.1	0.1	0.1	0.1	0.4	0.1	R29	3.5
R30	0.3	0.3	0.3	0.3	1.2	0.3	R30	3.5
R31	0.3	0.3	0.3	0	0.9	0.225	R31	4.666666667
R32	0.3	0.3	0.3	0	0.9	0.225	R32	4.666666667
							CI	0.027777778
							RI	0.9

AHP final result

The table below (7-2) shows the final results of the impacts of the risks, using the AHP method for Case Study 1.

Table 7-2: Case Study One's Risk Impact

RISKS	CAT	CAT IMPACT	R IMPACT	TOTAL IMPACT	Standardisation scale	Out of 9	RISKS
R1	CAT1	0.022146051	0.9	0.019931446	0.225063808	3	R1
R2		0.022146051	0.1	0.002214605	0.02500709	1	R2
R3	CAT2	0.082450607	0.178341237	0.014704343	0.166039913	2	R3
R4		0.082450607	0.032196847	0.00265465	0.029976027	1	R4
R5		0.082450607	0.032196847	0.00265465	0.029976027	1	R5
R6		0.082450607	0.077825508	0.00641676	0.07245739	1	R6
R7		0.082450607	0.077825508	0.00641676	0.07245739	1	R7
R8		0.082450607	0.136672223	0.011268708	0.127245074	2	R8
R9		0.082450607	0.033567649	0.002767673	0.031252276	1	R9
R10		0.082450607	0.198903266	0.016399695	0.185183649	2	R10
R11		0.082450607	0.033567649	0.002767673	0.031252276	1	R11
R12		0.082450607	0.198903266	0.016399695	0.185183649	2	R12
R13	CAT3	0.022146051	0.454545455	0.010066387	0.11366859	2	R13
R14		0.022146051	0.454545455	0.010066387	0.11366859	2	R14
R15		0.022146051	0.090909091	0.002013277	0.022733718	1	R15
R16	CAT4	0.29519696	0.297481903	0.087815753	0.991606344	10	R16
R17		0.29519696	0.297481903	0.087815753	0.991606344	10	R17
R18		0.29519696	0.07889032	0.023288183	0.262967734	3	R18
R19		0.29519696	0.297481903	0.087815753	0.991606344	10	R19
R20		0.29519696	0.02866397	0.008461517	0.095546567	1	R20
R21	CAT5	0.157085427	0.454545455	0.071402467	0.806269222	9	R21
R22		0.157085427	0.090909091	0.014280493	0.161253844	2	R22
R23		0.157085427	0.454545455	0.071402467	0.806269222	9	R23

R24	CAT6	0.082450607	0.2	0.016490121	0.186204734	2	R24
R25		0.082450607	0.2	0.016490121	0.186204734	2	R25
R26		0.082450607	0.6	0.049470364	0.558614201	6	R26
R27	CAT7	0.043327338	0.25	0.010831835	0.122311948	2	R27
R28		0.043327338	0.75	0.032495504	0.366935845	4	R28
R29	CAT8	0.29519696	0.1	0.029519696	0.333333333	4	R29
R30		0.29519696	0.3	0.088559088	1	10	R30
R31		0.29519696	0.225	0.066419316	0.75	8	R31
R32		0.29519696	0.225	0.066419316	0.75	8	R32

7.2.4 Risk Assessment Results

This section presents the risk rankings for Case Study 1 by using the developed risk assessment model on a seven-story commercial building, showing how it has been calculated.

As discussed earlier in this thesis, the equation to calculate the risk ranking is:

$$RR = Risk\ probability\ \times Risk\ impact$$

To multiply the impact by its probability, it is important to ensure that the two numbers have the same scale. The results of the impact are scaled out of 100%, while the impact shows the weight of each risk with a total of one.

The risk impact results are scaled using standardisation. In this case study, the final results were divided by the highest value, after checking to see if there are any outlying values. Then the results were divided into the original five interval scale from 1 to 9 with intermediate values (2, 4, 6, 8, 10) to give more accurate results. The tables below show the risk relative weight levels.

For the probability, as the value is already a probability value (rate) out of 100%, the scale will be from five intervals from 1 to 9 with intermediate values (2, 4, 6, 8, 10) to give more accurate results, as shown in the table for risk probability levels below.

Table 7-3: Risk relative weight Levels

Impact	out of 9	scale
Very high	10	above 0.9
	9	above 0.8 to0.9
High	8	above 0.7to 0.8
	7	above 0.6 to0.7
Moderate	6	above 0.5 to0.6
	5	above 0.4 to0.5
Low	4	above 0.3 to 0.4
	3	above 0.2 to0.3
Very low	2	above 0.1 to0.2
	1	below 0.1

Table 7-4: Risk probability Levels

Probability	out of 9	scale
Very high	10	above 0.9
	9	above 80 to90%
High	8	above 70 to80%
	7	above 60 to70%
Moderate	6	above 50 to60%
	5	above 40 to50%
Low	4	above 30 to 40%
	3	above 20 to30%
Very low	2	above 10 to20%
	1	below 10%

The risk matrix below shows the final risk rank levels from very high in dark red to very low in white.

Table 7-5: Risks Levels

Very high	9	27	45	63	81
High	7	21	35	49	63
Intermediate	5	15	25	35	45
Low	3	9	15	21	27
Very low	1	3	5	7	9
	Very rare	Rare	Intermediate	Possible	Very possible

The final results can be seen in Table 7-6 after the impact and probability have been scaled and multiplied.

Table 7-6: The Final Risk Ranking

Risk	Risk Probability	probability	impact	Risk Impact	Risk	Risk Rank
R1	0.1896	2	0.019931	3	R17	90
R2	0.3725	4	0.002215	1	R16	90
R3	0.8007	9	0.014704	2	R31	80
R4	0.19115	2	0.002655	1	R19	80
R5	0.34425	4	0.002655	1	R23	72
R6	0.53875	6	0.006417	1	R32	64
R7	0.929	10	0.006417	1	R30	40
R8	0.8025	9	0.011269	2	R26	36
R9	0.1885	2	0.002768	1	R21	36
R10	0.7425	8	0.0164	2	R28	28
R11	0.241	3	0.002768	1	R18	27
R12	0.9512	10	0.0164	2	R12	20
R13	0.845	9	0.010066	2	R8	18
R14	0.2995	3	0.010066	2	R3	18
R15	0.36	4	0.002013	1	R13	18
R16	0.88	9	0.087816	10	R29	16
R17	0.83619	9	0.087816	10	R10	16
R18	0.845	9	0.023288	3	R27	14
R19	0.72	8	0.087816	10	R24	12
R20	0.1125	2	0.008462	1	R22	12
R21	0.31	4	0.071402	9	R7	10
R22	0.5575	6	0.01428	2	R25	10
R23	0.755	8	0.071402	9	R6	6
R24	0.5225	6	0.01649	2	R14	6
R25	0.4475	5	0.01649	2	R1	6
R26	0.5555	6	0.04947	6	R5	4
R27	0.67	7	0.010832	2	R2	4
R28	0.624	7	0.032496	4	R15	4
R29	0.325	4	0.02952	4	R11	3
R30	0.334	4	0.088559	10	R9	2
R31	0.917	10	0.066419	8	R4	2
R32	0.785	8	0.066419	8	R20	2

7.2.5 Results Summary

After finalising the case study, the researcher and the project manager had a discussion about the result to check and confirm whether the result reflected what happened in real life or not. Six risks were considered very high, seven risks were high, eleven risks were intermediate, three risks were considered low risks and seven risks were very low.

- The very high risk group:

The first risk in the very high group is **"R17 Landscape alteration"**. The manager explained that usually, there is no law controlling this issue. In Jordan, nothing controls the landscape of the project or the area around it; usually, each project has its own landscape, that is why the probability and the impact are high.

The second risk in the very high range is **"R16 Adverse visual impact"**. It has a high impact on the neighbours around the project but there is no law considering this issue so its probability or frequency is high as well. In Jordan, buildings are not enclosed with the last layer of scaffolding that cover building to reduce the bad visual impact, only fences and the scaffolding for safety purposes only, even if the project was in the capital. So yes, the construction of a building will cause an adverse visual impact.

Regarding **"R31 Lack of availability of green materials and equipment"**. Until now, the idea of green buildings and sustainable buildings is not widely disseminated, so the availability of green materials is low. There is some use of green materials during the operation of the building but not during the construction phase.

"R19 Demand or stress on the infrastructure and the road network". There are no laws to control the time or the maximum number of vehicles entering and exiting the site, so its probability is high and its impact on the infrastructure is high as well.

"R23 Lack of attention to health issues in the workplace". Health and safety, in general, is a huge problem in Jordan. Neither project managers, engineers nor labourers care that much about health and safety. Even if the management staff try to implement health and safety laws, the employees consider them as just something restricts their motion and delays the work.

"R32 Inadequate knowledge of workers about environmental concerns, green materials and construction technologies". As mentioned in the last risk, the building culture in Jordan is still unfamiliar with the green process, so it is obvious that there will be a lack of knowledge among the labourers and engineers in general.

- The high risk group:

The first risk in this group is **"R30 Unclear allocation of roles and responsibilities"**. It is a common problem in the industry in Jordan due to cost reductions. One site engineer is usually responsible for everything on the site; this distracts him and leads to mistakes. We need more engineers.

“R26 Improper disposal of building debris (other than soil)”. This happens a lot in Jordan, where the debris is thrown anywhere or given to a contractor who will usually dump it in areas where streets and infrastructure projects will be constructed, since taking the debris to a special landfill will be expensive.

“R21 Construction accidents and casualties”. Of course this has a high impact, and as previously mentioned, labourers and sometimes engineers do not apply health and safety measures and consider them as time and cost consuming even if they are the law. The workers do not care and we do not have special safety engineers in every project. However, the probability of construction accidents and casualties is low in Jordan, with only small accidents and injuries.

“R28 Failure of underground utility lines, pipes and other underground structures”. This happens a lot, especially in old areas where the planning is bad or not available, but the impact is controllable.

“R18 Disruption of business in the community”. This frequently occurs during the construction phase, especially in densely populated areas. However, the disruption does not last for a long time or for the whole project, it only occurs in short periods during the project.

- The intermediate risk group:

After discussing the very high and high risks the discussion moves on to the intermediate risks. These intermediate risks need to be mitigated if it is cost effective to do so, otherwise they can be monitored. The intermediate risks are:

“R12 Improper discharge of the workplace’s wastewater”. The project manager explained that usually, the toilets are either made from blocks and the drainage is just a hole in the ground or they come with the offices’ caravan but the drainage is also a hole in the ground. After the project is completed, the hole is covered. However, since this project is in the heart of the capital, and the Greater Amman Municipality monitors construction projects in Amman, wastewater had to be pumped away, or the company would have been fined. If that was not the case, said the project manager, wastewater is just thrown anywhere or the hole is just covered.

“R8 Bad odour generation from handling of construction materials, waste, and sewage”. Usually, companies do not care much about cleaning during the construction phase, especially when the project is outside the capital.

“R3 Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, piling, blasting, etc. and on and off site traffic and deliveries”. While this has a high impact and high frequency, the law states that construction cannot take place on a Friday or after 6 o’clock during the week, so it has a minimum impact on the project’s neighbours.

“R13 Loss of agricultural lands and vegetation removal”. This can happen a lot when projects are located in villages where the Ministry of the Environment has little control and the lands are private. However, any public agricultural land or vegetation needs approval from the Ministry of the Environment to be removed, and the rest of the country is desert.

“R29 Insufficient on-site investigation resulting in improper adjustment measures to local conditions”. This has medium impact and probability of occurrence because Jordanians care a lot about cultural factors and their neighbours; also, it is important to check groundwater, the archaeology, and the presence of gold from Romans times.

“R10 Land pollution (associated with construction activities, machinery, and equipment)”. This has a high probability but low impact. As described for the dumping of construction waste, It is usually dumped in areas where streets and infrastructure projects will be constructed. But not in special landfill due to the high cost.

“R27 Contamination from spills of oils, fuels, lubricants from field equipment and improperly stored materials or due to vandalism”. Usually every site has security, so there is little vandalism; improper storage is more frequent.

“R24 Improper disposal of ordinary and domestic solid waste”. Usually, the waste is compiled until there is a huge amount, as it is then cheaper to get taken away.

“R22 Adverse effect on public health and safety”. As mentioned previously, health and safety are a big problem in Jordan but all the projects in Jordan are close to the public with fences and scaffoldings, so little effect on the public health.

“R7 Dust generation from construction activities, machinery, and equipment”. This is common, as a lot of materials are used when cutting and crushing things like stone, blocks and tiles, and cleaning the stones from outside generates a lot of dust. Water is not used to minimise the dust.

“R25 Improper disposal of special waste”. There is not a lot of special waste and if special materials like chemical admixtures are used, they are expensive so we care about them.

- The low risk group:

With regard to the low risk group, no reaction or mitigation plan is required.

“R6 Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane, and ozone)”. In the construction of buildings, few materials are used that emit harmful gases, but if they are, usually masks are used.

“R14 Mountains and forest removal (deforestation)”. There are not many forests and Jordan and they are highly controlled. If there is a project in the forest it is a tourist project that needs the wood.

“R1 Excessive use of raw materials”. Of course, this has a high impact on the environment (Jordanians do not recycle or reuse materials) but its probability of occurrence is low since contractors and owners of a project always try to control the expenses to reduce costs. The reason is more economic than environmental.

- The very low risk group:

The last group is the very low risk group. These risks can be accepted and do not need any reaction.

"R5 Emissions from construction activities and equipment". As with excessive use of raw materials, this has a high impact on the environment but its probability of occurrence is low since project stakeholders always try to control the expenses and reduce costs. The reason is more economic than environmental.

"R2 the depletion of natural resources, renewable and non-renewable resources. (i.e., water, oil, timber, soil, etc.)". Of course, this has a high impact on the environment (Jordanians do not recycle or reuse materials) but its probability of occurrence is low since contractors and owners of a project always try to control the expenses to reduce costs. The reason is more economic than environmental.

"R15 Roadside vegetation removal" has a low probability since there is not a lot of vegetation by the side of the road, and building projects do not usually remove the plants near the project.

"R11 Contamination of rainwater runoff and surface water". It has a high impact but the probability of occurrence is very low since Jordan is poor in surface water and the areas where there is surface water are highly controlled by the Minister of the Environment. Furthermore, the rainfall is low and it only rains during winter.

"R9 High soil erosion and excavation" has low impact and probability of occurrence because usually the cut and fill are exact in order to minimise the cost.

"R4 Deterioration of air quality (indoor and outdoor)" does have a high impact but the frequency is low since most equipment is electrical.

"R20 Public dissatisfaction with the project". This has a low probability of occurrence and impact because there is good planning, and areas are categorised as commercial or residential, so the public usually knows what the project is.

7.3 Case Study 2: The construction of a road infrastructure project.

7.3.1 Overview of the Company and the Project

The second case study is the construction of a road infrastructure project. The project has been financed by the Jordanian public sector, along with foreign loans and aid, and it has been implemented by the Ministry of Public Works and Housing (MPWH) in the second largest city of Jordan, Irbid. The project aims to improve land transportation services on the road network in Irbid's greater city and the surrounding areas. Also, it aims to accommodate and divert part of the increasing traffic travelling within and through the city of Irbid. The project was designed as a main road in semi-urban areas. The road included four lanes: two lanes in each direction with a width of 3.6 metres each. There is also a central island with concrete barriers for protection and a hard shoulder with a width of 3 metres in each direction and a total length of 43 km. The budget is 49.5 million JD and it is planned to be finished in three phases.

The first phase of the project was completed in two parts through two tenders; the first part is finished, but the second part suffered some delays due to issues with land ownership. This case study was carried out on the second part of the first phase, which was for a total length of 9 km.

At the time of the case study and data collection, the project had already faced delays and it had stopped. However, the rest of the project is on schedule to be finished by the new deadline and within the budget.

In this project there was no an engineer responsible for managing and assessing the risks. The construction company's project manager was the person in charge of managing the project and ensuring that it was completed within its schedule, on budget, and to a high quality. A risk assessment was carried out for the project by an independent company because it was requested by the loan body, and this risk assessment covered different areas like design risk, external risk, organisational risk, health and safety, etc. but not sustainability-related risks. The project manager confirmed that his company did not do risk assessments in general, or assessments of sustainability-related risks; nevertheless, he was interested in the concept.

7.3.2 Data and Information Collection

As discussed previously, the first three steps of the case studies, through to the quantitative risk analysis, were completed during the research and the development of the model. The first was done by critically reviewing the available resources, i.e., rating systems (LEED, BREEAM, GSAS, and ESTIDAMA), EIA reports, and finally, the key principles of the UN SDGs. Using these sources, a list consisting of 89 hazardous events was created, then this list was reviewed for its applicability to the Jordanian construction industry through qualitative data collection (focus group) with eight experts from the industry in Jordan. Finally, the risks were ranked by a questionnaire distributed to employees in the Jordanian construction industry; 402 engineers completed the questionnaire. Only the high and very high risks will be assessed in the quantitative part.

As for the collected data for this study, it starts in the quantitative part of the risk assessment risk model. Data were collected from the project manager only in a meeting, due to time limitations. The manager was asked to fill in the model with all the relevant data. He used Microsoft Excel software to fill in the model. For the risk probability part, the manager filled in all the probabilities for the causes of the risks and the conditional probability between the risks and their causes. Finally, for the risk impact part, the project manager was asked to use the model to fill in the pairwise comparison tables. The next section presents the risk analysis, which was done using BBN and AHP.

7.3.3 Data Analysis

7.3.3.1 Probability Analysis Using BBN

This section shows the calculation used to find the probability using a BBN. It starts by presenting the BBN network adopted for this model, then it moves to the conditional probability tables for every node (risk) in the network that was filled in by the project manager. Finally, it displays the final probability result for the first case study.

1- The first step in the BM is the development of the belief network. Figure 7-3 shows the network developed and used in the model for the second case study.

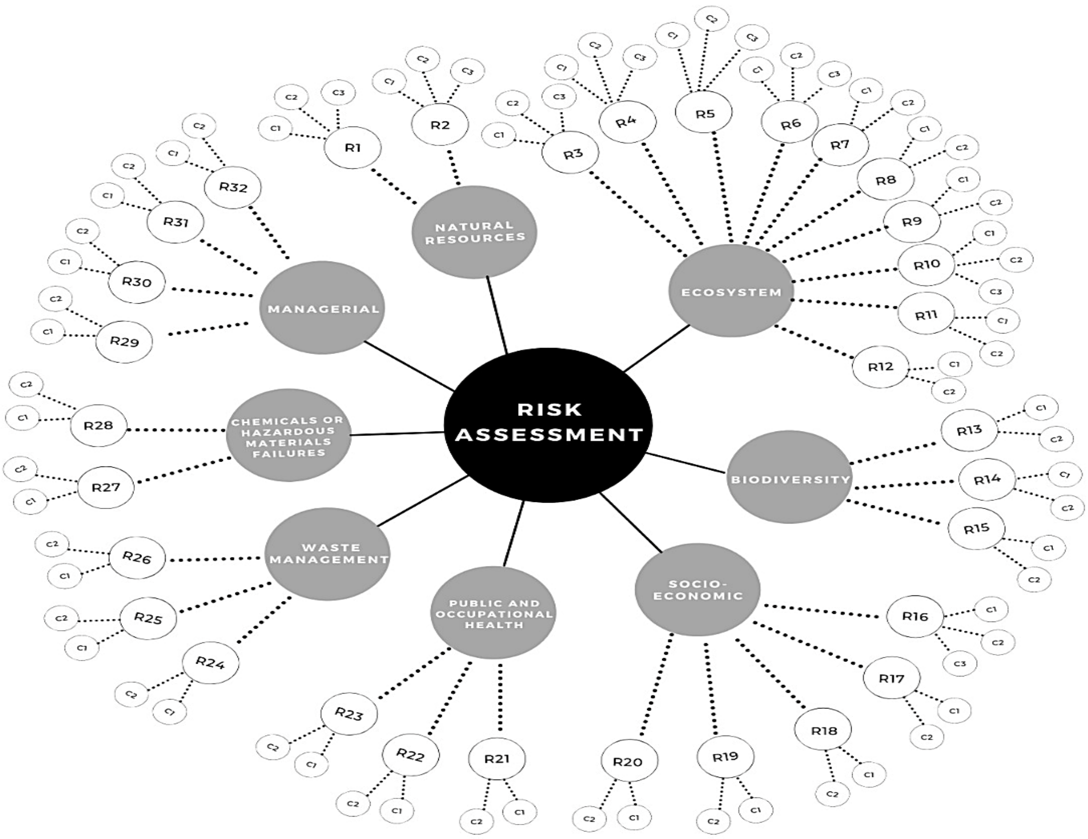

Figure 7-3 Bayesian Belief Network for the developed model

After the network is developed for this project, the next step should be the weight factor method. However, in this case study, the data came from the project manager alone, therefore the weight factor method is omitted.

2- Bayesian Belief Network Conditional Probability Tables

This part of the case study presents the conditional probability tables for each node (sustainability-related risk). These tables were filled in by the project manager of this case study based on the network above and the characteristics of the project. Each table contains the probability of the causes (two or three) plus the posterior probability between the risk and its causes (P(R1|C1, C2,C3). The final probability of the risk P(Ri) will be calculated with equations 5 and 6, discussed in the Model Development Chapter (Chapter 6). These equations were put in Microsoft Excel software.

(1) Conditional Probability Tables for node 1 (R1)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R1|C1,C2,C3)
R1	C1	0.3	0.7	T	T	T	0.9
Excessive use of raw materials	C2	0.4	0.6	T	T	F	0.7
	C3	0.25	0.75	T	F	T	0.6
				F	T	T	0.65
P(R1) =	0.35675			T	F	F	0.35
				F	T	F	0.4
				F	F	T	0.3
				F	F	F	0.1

(2) Conditional Probability Tables for node 2 (R2)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R2|C1,C2,C3)
R2	C1	0.25	0.75	T	T	T	0.85
The depletion of natural resources, renewable and non-renewable resources	C2	0.35	0.65	T	T	F	0.6
	C3	0.4	0.6	T	F	T	0.65
				F	T	T	0.6
P(R2) =	0.3825			T	F	F	0.4
				F	T	F	0.35
				F	F	T	0.4
				F	F	F	0.15

(3) Conditional Probability Tables for node 3 (R3)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R3|C1,C2,C3)
R3	C1	0.85	0.15	T	T	T	0.9
Noise and vibrations from construction machinery and equipment	C2	0.8	0.2	T	T	F	0.75
	C3	0.75	0.25	T	F	T	0.65
				F	T	T	0.7
P(R3) =	0.762			T	F	F	0.3
				F	T	F	0.35
				F	F	T	0.25
				F	F	F	0.1

(4) Conditional Probability Tables for node 4 (R4)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R4|C1,C2,C3)
R4	C1	0.6	0.4	T	T	T	0.95
Deterioration of air quality (indoor and outdoor)	C2	0.55	0.45	T	T	F	0.55
	C3	0.4	0.6	T	F	T	0.7
P(R4) =	0.5086			F	T	T	0.55
				T	F	F	0.45
				F	T	F	0.3
				F	F	T	0.45
				F	F	F	0.05

(5) Conditional Probability Tables for node 5 (R5)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R5|C1,C2,C3)
R5	C1	0.95	0.05	T	T	T	0.9
Emissions from construction activities and equipment	C2	0.85	0.15	T	T	F	0.7
	C3	0.9	0.1	T	F	T	0.65
P(R5)=	0.8262			F	T	T	0.6
				T	F	F	0.4
				F	T	F	0.35
				F	F	T	0.3
				F	F	F	0.1

(6) Conditional Probability Tables for node 6 (R6)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R6|C1,C2,C3)
R6	C1	0.95	0.05	T	T	T	0.95
Emissions of harmful gases	C2	0.9	0.1	T	T	F	0.85
	C3	0.85	0.15	T	F	T	0.85
P(R6) =	0.9032			F	T	T	0.8
				T	F	F	0.2
				F	T	F	0.15
				F	F	T	0.15
				F	F	F	0.05

(7) Conditional Probability Tables for node 7 (R7)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R7|C1,C2,C3)
R7	C1	0.95	0.05	T	T	0.95
Dust generation from construction activities, machineries and equipment	C2	0.8	0.2	T	F	0.85
	0.89			F	T	0.15
P(R7) =				F	F	0.05

(8) Conditional Probability Tables for node 8 (R8)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R8|C1,C2,C3)

R8	C1	0.9	0.1	T	T	0.9
Bad odour generation from handling of construction materials, waste and sewage	C2	0.8	0.2	T	F	0.55
	0.785			F	T	0.45
P(R8) =				F	F	0.1

(9) Conditional Probability Tables for node 9 (R9)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R9|C1,C2,C3)
R9	C1	0.95	0.05	T	T	0.95
High soil erosion and excavation	C2	0.9	0.1	T	F	0.85
	0.9315			F	T	0.85
P(R9) =				F	F	0.05

(10) Conditional Probability Tables for node 10 (R10)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R10|C1,C2,C3)
R10	C1	0.8	0.2	T	T	T	0.99
Land pollution (associated with construction activities, machineries and equipment)	C2	0.85	0.15	T	T	F	0.95
	C3	0.7	0.3	T	F	T	0.9
P(R10)=	0.86173			F	T	T	0.95
				T	F	F	0.05
				F	T	F	0.1
				F	F	T	0.05
				F	F	F	0.01

(11) Conditional Probability Tables for node 11 (R11)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R11|C1,C2,C3)
R11	C1	0.95	0.05	T	T	0.95
Contamination of rainwater runoff and surface water	C2	0.9	0.1	T	F	0.7
	0.90825			F	T	0.65
P(R11) =				F	F	0.05

(12) Conditional Probability Tables for node 12 (R12)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R12|C1,C2,C3)
R12	C1	0.7	0.3	T	T	0.99
Improper discharge of the workplace's wastewater	C2	0.8	0.2	T	F	0.75
	0.72			F	T	0.25
P(R12) =				F	F	0.01

(13) Conditional Probability Tables for node 13 (R13)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R13|C1,C2,C3)
R13	C1	0.9	0.1	T	T	0.9
Loss of agricultural lands and vegetation removal	C2	0.8	0.2	T	F	0.6
	0.79			F	T	0.4
P(R13) =				F	F	0.1

(14) Conditional Probability Tables for node 14 (R14)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R14|C1,C2,C3)
R14	C1	0.5	0.5	T	T	0.85
Mountains and forest removal (deforestation)	C2	0.3	0.7	T	F	0.55
	0.44			F	T	0.45
P(R14) =				F	F	0.15

(15) Conditional Probability Tables for node 15 (R15)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R15|C1,C2,C3)
R15	C1	0.15	0.85	T	T	0.9
Roadside vegetation removal	C2	0.05	0.95	T	F	0.5
	0.18			F	T	0.5
P(R15)=				F	F	0.1

(16) Conditional Probability Tables for node 16 (R16)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R16|C1,C2,C3)
R16	C1	0.35	0.65	T	T	0.99
Adverse visual impact	C2	0.25	0.75	T	F	0.75
	0.329			F	T	0.25
P(R16) =				F	F	0.01

(17) Conditional Probability Tables for node 17 (R17)

SUSTAINABLE RISK	CAUSE	PROBABILITY		C1	C2	C3	P(R17|C1,C2,C3)
R17	C1	0.9	0.1	T	T	T	0.98
Landscape alteration	C2	0.7	0.3	T	T	F	0.8
	C3	0.6	0.4	T	F	T	0.75
				F	T	T	0.65
P(R17) =	0.69604			T	F	F	0.35
				F	T	F	0.25
				F	F	T	0.2
				F	F	F	0.02

(18) Conditional Probability Tables for node 18 (R18)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R18|C1,C2,C3)
R18	C1	0.9	0.1	T	T	0.95
Disruption of business in the community	C2	0.85	0.15	T	F	0.65
	0.845			F	T	0.35
P(R18) =				F	F	0.05

(19) Conditional Probability Tables for node 19 (R19)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R19|C1,C2,C3)
R19	C1	0.95	0.05	T	T	0.99

Demand or stress on the infrastructure and the road network	C2	0.9	0.1	T	F	0.85
	0.9655			F	T	0.85
P(R19) =				F	F	0.01

(20) Conditional Probability Tables for node 20 (R20)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R20|C1,C2,C3)
R20	C1	0.45	0.55	T	T	0.99
Public dissatisfaction with the project	C2	0.3	0.7	T	F	0.55
	0.385			F	T	0.45
P(R20)=				F	F	0.01

(21) Conditional Probability Tables for node 21 (R21)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R21|C1,C2,C3)
R21	C1	0.9	0.1	T	T	0.95
Construction accidents and casualties	C2	0.85	0.15	T	F	0.75
	0.85			F	T	0.25
P(R21)=				F	F	0.05

(22) Conditional Probability Tables for node 22 (R22)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R22|C1,C2,C3)
R22	C1	0.85	0.15	T	T	0.9
Adverse effect on public health and safety	C2	0.75	0.25	T	F	0.65
	0.755			F	T	0.35
P(R22) =				F	F	0.1

(23) Conditional Probability Tables for node 23 (R23)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R23|C1,C2,C3)
R23	C1	0.9	0.1	T	T	0.85
Lack of attention to health issues in the workplace	C2	0.8	0.2	T	F	0.55
	0.75			F	T	0.45
P(R23) =				F	F	0.15

(24) Conditional Probability Tables for node 24 (R24)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R24|C1,C2,C3)
R24	C1	0.65	0.35	T	T	0.95
Improper disposal of ordinary and domestic solid waste	C2	0.6	0.4	T	F	0.5
	0.6125			F	T	0.5
P(R24)=				F	F	0.05

(25) Conditional Probability Tables for node 25 (R25)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R25|C1,C2,C3)
R25	C1	0.45	0.55	T	T	0.83

Improper disposal of special waste	C2	0.4	0.6	T	F	0.7
	0.4605			F	T	0.3
P(R25) =				F	F	0.17

(26) Conditional Probability Tables for node 26 (R26)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R26|C1,C2,C3)
R26	C1	0.09	0.91	T	T	0.95
Improper disposal of building debris	C2	0.05	0.95	T	F	0.5
	0.113			F	T	0.5
P(R26)=				F	F	0.05

(27) Conditional Probability Tables for node 27 (R27)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R27|C1,C2,C3)
R27	C1	0.1	0.9	T	T	0.95
Contamination from spills of oils, fuels, lubricants from field equipment and improperly stored materials or due to vandalism.	C2	0.15	0.85	T	F	0.75
	0.15			F	T	0.25
P(R27)=				F	F	0.05

(28) Conditional Probability Tables for node 28 (R28)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R28|C1,C2,C3)
R28	C1	0.3	0.7	T	T	0.8
Failure of underground utility lines, pipes and other underground structures.	C2	0.25	0.75	T	F	0.65
	0.3725			F	T	0.35
P(R28)=				F	F	0.2

(29) Conditional Probability Tables for node 29 (R29)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R29|C1,C2,C3)
R29	C1	0.35	0.65	T	T	0.95
Insufficient on-site investigation resulting in improper adjustment measures to local conditions.	C2	0.45	0.55	T	F	0.75
	0.385			F	T	0.25
P(R29)=				F	F	0.05

(30) Conditional Probability Tables for node 30 (R30)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R30|C1,C2,C3)
R30	C1	0.45	0.55	T	T	0.88
Unclear allocation of roles and responsibilities.	C2	0.3	0.7	T	F	0.6
	0.42			F	T	0.4
P(R30)=				F	F	0.12

(31) Conditional Probability Tables for node 31 (R31)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R31|C1,C2,C3)
R31	C1	0.65	0.35	T	T	0.95

Lack of availability of green materials and equipment.	C2	0.4	0.6	T	F	0.45
	0.51			F	T	0.55
P(R31)=				F	F	0.05

(32) Conditional Probability Tables for node 32 (R32)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R32|C1,C2,C3)
R32	C1	0.65	0.35	T	T	0.9
Inadequate knowledge of workers about environmental concerns, green materials and construction technologies.	C2	0.55	0.45	T	F	0.45
	0.575			F	T	0.55
P(R32)=				F	F	0.1

3- Final Probability Result

Table 7-8 shows the final result for the risk probability for this case study.

Table 7-7: Case Study Two – Risk Probability

FACTORS	PROBABILITY	PROBABILITY (%)	PROBABILITY (out of 9)
R1	0.35675	36	4
R2	0.3825	38	4
R3	0.762	76	8
R4	0.5086	51	6
R5	0.8262	83	9
R6	0.9032	90	10
R7	0.89	89	9
R8	0.785	79	8
R9	0.9315	93	10
R10	0.86173	86	9
R11	0.90825	91	10
R12	0.72	72	8
R13	0.79	79	8
R14	0.44	44	5
R15	0.18	18	2
R16	0.329	33	4
R17	0.69604	70	7
R18	0.845	85	9
R19	0.9655	97	10
R20	0.385	39	4
R21	0.85	85	9
R22	0.755	76	8
R23	0.75	75	8
R24	0.6125	61	7
R25	0.4605	46	5
R26	0.113	11	2
R27	0.15	15	2
R28	0.3725	37	4
R29	0.385	39	4
R30	0.42	42	5
R31	0.51	51	6
R32	0.575	58	6

7.3.3.2 Impact Analysis Using AHP

This section shows the calculation used to find the impact using Analytic Hierarchy Process (AHP). It starts by presenting the hierarchy model adopted for this model, then it moves on to the pairwise comparison tables for the categories and the risks of each category. These tables were filled in by the project manager. The section then presents the comparison matrices, and finally displays the final impact results for this case study.

Figure 7-4 The Hierarchy Model

After the network is developed for this project, the next step should be the weight factor method. However, in this case study, the data came from the project manager alone, therefore the weight factor method is omitted.

Pairwise comparison tables

The next nine tables are the comparison tables for the second case study, as the project manager filled them in. The first table shows the comparison between the categories, while the next eight show the comparison between the risks of each category.

1- **Categories pairwise comparison table** **2- First category pairwise comparison table**

	1--9			1--9	
C1	0.14	C2	C3	0.11	C8
C1	3.00	C3	C4	1.00	C5
C1	0.33	C4	C4	0.33	C6
C1	0.33	C5	C4	0.33	C7
C1	0.20	C6	C4	0.20	C8
C1	0.20	C7	C5	0.33	C6
C1	0.14	C8	C5	0.33	C7
C2	9.00	C3	C5	0.20	C8
C2	5.00	C4	C6	1.00	C7
C2	5.00	C5	C6	0.33	C8
C2	3.00	C6	C7	0.33	C8
C2	3.00	C7			
C2	1.00	C8			
C3	0.20	C4			
C3	0.20	C5			
C3	0.14	C6			
C3	0.14	C7			

R1	1	R2

3- Second category pairwise comparison table **4- Third category comparison table**

R3	9.00	R4	R6	0.20	R7
R3	3.00	R5	R6	3.00	R8
R3	5.00	R6	R6	1.00	R9
R3	1.00	R7	R6	0.20	R10
R3	7.00	R8	R6	1.00	R11
R3	5.00	R9	R6	0.20	R12
R3	1.00	R10	R7	7.00	R8
R3	5.00	R11	R7	5.00	R9
R3	1.00	R12	R7	1.00	R10
R4	0.14	R5	R7	5.00	R11
R4	0.20	R6	R7	1.00	R12
R4	0.11	R7	R8	0.33	R9
R4	0.33	R8	R8	0.14	R10
R4	0.20	R9	R8	0.33	R11
R4	0.11	R10	R8	0.14	R12
R4	0.20	R11	R9	0.20	R10
R4	0.11	R12	R9	1.00	R11
R5	3.00	R6	R9	0.20	R12
R5	0.33	R7	R10	5.00	R11
R5	5.00	R8	R10	1.00	R12
R5	3.00	R9	R11	0.20	R12
R5	0.33	R10			
R5	3.00	R11			
R5	0.33	R12			

R13	7.00	R14
R13	7.00	R15
R14	1.00	R15

5- Fourth category comparison table

R16	0.14	R17
R16	0.20	R18
R16	0.11	R19
R16	1.00	R20
R17	3.00	R18
R17	0.33	R19
R17	7.00	R20
R18	0.20	R19
R18	5.00	R20
R19	9.00	R20

6- Fifth category pairwise table

R21	5.00	R22
R21	3.00	R23
R22	0.33	R23

7- Sixth category comparison table

R24	0.33	R25
R24	7.00	R26
R25	9.00	R26

8- Seventh category comparison table

R27	0.11	R28

9- Eighth category pairwise comparison table

R29	0.33	R30
R29	0.33	R31
R29	0.20	R32
R30	1.00	R31
R30	0.33	R32
R31	0.33	R32

The nine categories pairwise comparison tables above were used to create the comparison matrix for the next step. Each of the nine tables produced a matrix; the first matrix is between the categories, while the remaining eight matrices show the comparison between the risk of each category. Each of the below matrices presents the calculation for the dominant Eigenvector to find the relative weight of the risk and the CR.

Pairwise comparison matrices:

1- Categories pairwise comparison matrix

	CAT 1	CAT 2	CAT 3	CAT 4	CAT 5	CAT 6	CAT 7	CAT 8
CAT 1	1.00	0.14	3.00	0.33	0.33	0.20	0.20	0.14
CAT 2	7.00	1.00	9.00	5.00	5.00	3.00	3.00	1.00
CAT 3	0.33	0.11	1.00	0.20	0.20	0.14	0.14	0.11
CAT 4	3.00	0.20	5.00	1.00	1.00	0.33	0.33	0.20
CAT 5	3.00	0.20	5.00	1.00	1.00	0.33	0.33	0.20
CAT 6	5.00	0.33	7.00	3.00	3.00	1.00	1.00	0.33
CAT 7	5.00	0.33	7.00	3.00	3.00	1.00	1.00	0.33
CAT 8	7.00	1.00	9.00	5.00	5.00	3.00	3.00	1.00
TOTAL	31.33	3.32	46.00	18.53	18.53	9.01	9.01	3.32

	CAT 1	CAT 2	CAT 3	CAT 4	CAT 5	CAT 6	CAT 7	CAT 8	TOTAL	AVG.
CAT 1	0.03	0.04	0.07	0.02	0.02	0.02	0.02	0.04	0.26	0.03
CAT 2	0.22	0.30	0.20	0.27	0.27	0.33	0.33	0.30	2.23	0.28
CAT 3	0.01	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.15	0.02
CAT 4	0.10	0.06	0.11	0.05	0.05	0.04	0.04	0.06	0.51	0.06
CAT 5	0.10	0.06	0.11	0.05	0.05	0.04	0.04	0.06	0.51	0.06
CAT 6	0.16	0.10	0.15	0.16	0.16	0.11	0.11	0.10	1.06	0.13
CAT 7	0.16	0.10	0.15	0.16	0.16	0.11	0.11	0.10	1.06	0.13
CAT 8	0.22	0.30	0.20	0.27	0.27	0.33	0.33	0.30	2.23	0.28

	Consistency Measure	
CAT 1	8.039470934	
CAT 2	8.572279371	
CAT 3	8.128633003	
CAT 4	8.215061725	
CAT 5	8.215061725	
CAT 6	8.530942294	
CAT 7	8.530942294	
CAT 8	8.572279371	
CI	0.050083406	
RI	1.41	
CR	0.035520146	1

2- First category pairwise comparison matrix

NATURAL	R1	R2
R1	1	1
R2	1	1
total	2	2

NATURAL	R1	R2	TOTAL	AVG
R1	0.5	0.5	1	0.5
R2	0.5	0.5	1	0.5

	CM	
R1	2	
R2	2	
CI	0	
RI	0	
CR	0	1

3- Second category pairwise comparison matrix

ECOSYSTEM	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12
R 3	1	9.00	3.00	5.00	1.00	7.00	5.00	1.00	5.00	1.00
R 4	0.111111	1	0.14	0.20	0.11	0.33	0.20	0.11	0.20	0.11
R 5	0.333333	7	1	3.00	0.33	5.00	3.00	0.33	3.00	0.33
R 6	0.2	5	0.333333	1	0.20	3.00	1.00	0.20	1.00	0.20
R 7	1	9	3	5	1	7.00	5.00	1.00	5.00	1.00
R 8	0.142857	3	0.2	0.333333	0.142857	1	0.33	0.14	0.33	0.14
R 9	0.2	5	0.333333	1	0.2	3	1	0.20	1.00	0.20
R 10	1	9.090909	3.030303	5	1	7.142857	5	1	5.00	1.00
R 11	0.2	5	0.333333	1	0.2	3	1	0.2	1	0.20
R 12	1	9	3	5	1	7	5	1	5	1
TOTAL	5.187302	62.09091	14.37316	26.53333	5.187302	43.47619	26.53333	5.18	26.53333	5.187302

ECOSYSTEM	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	TOTAL	AVG	CM
R3	0.192778	0.14	0.21	0.19	0.19	0.16	0.19	0.19	0.19	0.19	1.85	0.19	10.58486659
R4	0.02142	0.016105	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.14	0.01	10.10078059
R5	0.064259	0.112738	0.069574	0.11	0.06	0.12	0.11	0.06	0.11	0.06	0.89	0.09	10.60893372
R6	0.038556	0.080527	0.023191	0.037688	0.04	0.07	0.04	0.04	0.04	0.04	0.44	0.04	10.24201167
R7	0.192778	0.144949	0.208722	0.188442	0.192778	0.16	0.19	0.19	0.19	0.19	1.85	0.19	10.58486659
R8	0.02754	0.048316	0.013915	0.012563	0.02754	0.023001	0.01	0.03	0.01	0.03	0.23	0.02	10.01990093
R9	0.038556	0.080527	0.023191	0.037688	0.038556	0.069003	0.037688	0.04	0.04	0.04	0.44	0.04	10.24201167
R10	0.192778	0.146413	0.210831	0.188442	0.192778	0.164294	0.188442	0.19305	0.19	0.19	1.86	0.19	10.58518025
R11	0.038556	0.080527	0.023191	0.037688	0.038556	0.069003	0.037688	0.03861	0.037688	0.04	0.44	0.04	10.24201167
R12	0.192778	0.144949	0.208722	0.188442	0.192778	0.161008	0.188442	0.19305	0.188442	0.192778	1.85	0.19	10.58486659
												CI	0.042171447
												RI	1.49
												CR	0.028302985

4- Third category pairwise comparison matrix

BIODAIVERSITY	R 13	R 14	R 15
R 13	1	7.00	7.00
R 14	0.142857	1	1.00
R 15	0.142857	1	1
TOTAL	1.285714	9	9

BIODAIVERSITY	R13	R14	R15	TOTAL	AVG		CM	
R13	0.777778	0.777778	0.777778	2.333333	0.777778	R13	3	
R14	0.111111	0.111111	0.111111	0.333333	0.111111	R14	3	
R15	0.111111	0.111111	0.111111	0.333333	0.111111	R15	3	
						CI	0	
						RI	0.58	
						CR	0	1

5- Fourth category pairwise comparison matrix

SOCIO-ECONOMIC	R 16	R 17	R 18	R 19	R 20
R 16	1	0.14	0.20	0.11	1.00
R 17	7	1	3.00	0.33	7.00
R 18	5	0.333333	1	0.20	5.00
R 19	9	3	5	1	9.00
R 20	1	0.142857	0.2	0.111111	1
TOTAL	23	4.619048	9.4	1.755556	23

SOCIO-ECONOMIC	R16	R17	R18	R19	R20	TOTAL	AVG		CM	
R16	0.043478	0.030928	0.021277	0.063291	0.043478	0.202452	0.04049	R16	5.050435	
R17	0.304348	0.216495	0.319149	0.189873	0.304348	1.334213	0.266843	R17	5.392579	
R18	0.217391	0.072165	0.106383	0.113924	0.217391	0.727255	0.145451	R18	5.09208	
R19	0.391304	0.649485	0.531915	0.56962	0.391304	2.533628	0.506726	R19	5.453317	
R20	0.043478	0.030928	0.021277	0.063291	0.043478	0.202452	0.04049	R20	5.050435	
								CI	0.051942	
								RI	1.12	
								CR	0	1

6- Fifth category pairwise comparison matrix

PUBLIC	R 21	R 22	R 23
R 21	1	5.00	3.00
R 22	0.2	1	0.33
R 23	0.333333	3	1
TOTAL	1.533333	9	4.333333

PUBLIC	R21	R22	R23	TOTAL	AVG		CM	
R21	0.652174	0.555556	0.692308	1.900037	0.633346	R21	3.071973	
R22	0.130435	0.111111	0.076923	0.318469	0.106156	R22	3.011202	
R23	0.217391	0.333333	0.230769	0.781494	0.260498	R23	3.032969	
						CI	0.019357	
						RI	0.58	
						CR	0	1

7- Sixth category pairwise comparison matrix

WASTE	R 24	R 25	R 26
R 24	1	0.33	7.00
R 25	3	1	9.00
R 26	0.142857	0.111111	1
TOTAL	4.142857	1.444444	17

WASTE	R24	R25	R26	TOTAL	AVG		CM	
R24	0.241379	0.230769	0.411765	0.883913	0.294638	R24	3.081906	
R25	0.724138	0.692308	0.529412	1.945857	0.648619	R25	3.150108	
R26	0.034483	0.076923	0.058824	0.170229	0.056743	R26	3.011872	
						CI	0.040648	
						RI	0.58	
						CR	0	1

8- Seventh category pairwise comparison matrix

CHEMICALS	R 27	R 28
R 27	1	0.11
R 28	9	1
TOTAL	10	1.111111

CHEMICALS	R27	R28	TOTAL	AVG		CM	
R27	0.1	0.1	0.2	0.1	R27	2	
R28	0.9	0.9	1.8	0.9	R28	2	
					CI	0	
					RI	0	
					CR	0	1

9- Eighth category pairwise comparison matrix

MANEGIRIAL	R 29	R 30	R 31	R 32
R 29	1	0.33	0.33	0.20
R 30	3	1	1.00	0.33
R 31	3	1	1	0.33
R 32	5	3	3	1
TOTAL	12	5.333333	5.333333	1.866667

MANAGERIAL	R29	R30	R31	R32	TOTAL	AVG		CM	
R29	0.083333	0.0625	0.0625	0.107143	0.315476	0.078869	R29	3.486792453	
R30	0.25	0.1875	0.1875	0.178571	0.803571	0.200893	R30	3.595061728	
R31	0.25	0.1875	0.1875	0	0.625	0.15625	R31	4.622222222	
R32	0.416667	0.5625	0.5625	0	1.541667	0.385417	R32	4.803088803	
							CI	0.042263767	
							RI	0.9	
							CR	0.046959741	1

AHP final result

Table 7-8 shows the final result for the impact using the AHP method for this case study.

Table 7-8: Case Study Two's Risk Impact

RISKS	CAT	CAT IMPACT	R IMPACT	TOTAL IMPACT	Standardisation scale	out of 9	RISKS
R1	CAT1	0.032942879	0.5	0.01647144	0.191976026	2	R1
R2		0.032942879	0.5	0.01647144	0.191976026	2	R2
R3	CAT2	0.278360147	0.185139099	0.051535347	0.600648834	7	R3
R4		0.278360147	0.014181968	0.003947695	0.046010717	1	R4
R5		0.278360147	0.089299852	0.02485752	0.289716502	3	R5
R6		0.278360147	0.044006419	0.012249633	0.142770513	2	R6
R7		0.278360147	0.185139099	0.051535347	0.600648834	7	R7
R8		0.278360147	0.023256698	0.006473738	0.075451964	1	R8
R9		0.278360147	0.044006419	0.012249633	0.142770513	2	R9
R10		0.278360147	0.185824929	0.051726255	0.602873882	7	R10
R11		0.278360147	0.044006419	0.012249633	0.142770513	2	R11
R12		0.278360147	0.185139099	0.051535347	0.600648834	7	R12
R13	CAT3	0.01907428	0.777777778	0.014835551	0.172909608	2	R13
R14		0.01907428	0.111111111	0.002119364	0.024701373	1	R14
R15		0.01907428	0.111111111	0.002119364	0.024701373	1	R15
R16	CAT4	0.063351083	0.040490418	0.002565112	0.029896596	1	R16
R17		0.063351083	0.26684257	0.016904766	0.197026479	2	R17
R18		0.063351083	0.145450917	0.009214473	0.107395466	2	R18
R19		0.063351083	0.506725676	0.03210162	0.374147107	4	R19
R20		0.063351083	0.040490418	0.002565112	0.029896596	1	R20
R21	CAT5	0.063351083	0.63334572	0.040123137	0.467638567	5	R21
R22		0.063351083	0.106156324	0.006725118	0.078381821	1	R22
R23		0.063351083	0.260497956	0.016502828	0.192341855	2	R23
R24	CAT6	0.13228019	0.294637749	0.038974737	0.454253869	5	R24
R25		0.13228019	0.648619129	0.085799462	1	10	R25
R26		0.13228019	0.056743122	0.007505991	0.08748296	1	R26
R27	CAT7	0.13228019	0.1	0.013228019	0.154173683	2	R27
R28		0.13228019	0.9	0.119052171	1.387563146	10	R28
R29	CAT8	0.278360147	0.078869048	0.021954	0.255875727	3	R29
R30		0.278360147	0.200892857	0.055920565	0.651758928	7	R30
R31		0.278360147	0.15625	0.043493773	0.50692361	6	R31
R32		0.278360147	0.385416667	0.10728464	1.250411572	10	R32

7.3.4 Risk Assessment Results

This section presents the final risk ranking for the second case study using the developed model on a road infrastructure project, showing how it has been calculated.

Similarly, the equation to calculate the risk ranking is:

$$RR = Risk\ probability\ \times Risk\ impact$$

To multiply the impact by its probability, it is important to ensure that the two numbers have the same scale. The results of the impact are scaled out of 100%, while the impact shows the weight of each risk with a total of one.

The risk impact results are scaled using standardisation. In this case study, the final results were divided by the highest value, after checking to see if there are any outlying values. Then the results were divided into the original five interval scale from 1 to 9 with intermediate values (2, 4, 6, 8, 10) to give more accurate results. The tables below show the risk relative weight levels.

For the probability, as the value is already a probability value (rate) out of 100%, the scale will be from five intervals from 1 to 9 with intermediate values (2, 4, 6, 8, 10) to give more accurate results, as shown in the table for risk probability levels below.

Table 7-9: Risk Relative Weight Levels

Impact	out of 9	scale
Very high	10	above 0.9
	9	0.8-0.9
High	8	0.7-0.8
	7	0.6-.07
Moderate	6	0.5-0.6
	5	0.4-0.5
Low	4	0.3-0.4
	3	0.2-0.3
Very low	2	0.1-0.2
	1	below 0.1

Table 7-10: Risk probability Levels

Probability	out of 9	scale
Very high	10	above 0.9
	9	80-90%
High	8	70-80%
	7	60-70%
Moderate	6	50-60%
	5	40-50%
Low	4	30-40%
	3	20-30%
Very low	2	10-20%
	1	below 10%

The risk matrix below shows the final risk ranking levels from very high in dark red to very low in white.

Table 7-11: Risks Levels

Very high	9	27	45	63	81
High	7	21	35	49	63
Intermediate	5	15	25	35	45
Low	3	9	15	21	27
Very low	1	3	5	7	9
	Very rare	Rare	Intermediate	Possible	Very possible

The final result can be seen below after the impact and probability have been scaled and multiplied.

Table 7-12: The Final Risk Rank Result

risk	probability	probability	impact impact	impact	risk	final risk rank
R1	0.35675	4	0.016471	2	R7	63
R2	0.3825	4	0.016471	2	R10	63
R3	0.762	8	0.051535	7	R32	60
R4	0.5086	6	0.003948	1	R3	56
R5	0.8262	9	0.024858	3	R12	56
R6	0.9032	10	0.01225	2	R25	50
R7	0.89	9	0.051535	7	R21	45
R8	0.785	8	0.006474	1	R28	40
R9	0.9315	10	0.01225	2	R19	40
R10	0.86173	9	0.051726	7	R31	36
R11	0.90825	10	0.01225	2	R30	35
R12	0.72	8	0.051535	7	R24	35
R13	0.79	8	0.014836	2	R5	27
R14	0.44	5	0.002119	1	R9	20
R15	0.18	2	0.002119	1	R6	20
R16	0.329	4	0.002565	1	R11	20
R17	0.69604	7	0.016905	2	R18	18
R18	0.845	9	0.009214	2	R23	16
R19	0.9655	10	0.032102	4	R13	16
R20	0.385	4	0.002565	1	R17	14
R21	0.85	9	0.040123	5	R29	12
R22	0.755	8	0.006725	1	R8	8
R23	0.75	8	0.016503	2	R22	8
R24	0.6125	7	0.038975	5	R2	8
R25	0.4605	5	0.085799	10	R1	8
R26	0.113	2	0.007506	1	R4	6
R27	0.15	2	0.013228	2	R14	5
R28	0.3725	4	0.119052	10	R27	4
R29	0.385	4	0.021954	3	R20	4
R30	0.42	5	0.055921	7	R16	4
R31	0.51	6	0.043494	6	R26	2
R32	0.575	6	0.107285	10	R15	2

7.3.5 Results Summary

After obtaining the final result from the model, a discussion between the researcher and the project manager was carried out to check and confirm whether the results reflect what happens in real life. Six risks were considered very high, seven risks were high, eight risks were intermediate, six risks were considered low and five risks were very low.

- The very high risk group:

"R7 Dust generation from construction activities, machinery, and equipment". In the field of roads and infrastructure, dust generation is very common and it has a huge impact on the health and the environment. Furthermore, no tools are used to minimise the generated dust.

"R10 Land pollution (associated with construction activities, machinery, and equipment)". As mentioned before, this occurs due to the improper disposal of all types of waste. Land pollution is a big problem and it happens a lot.

"R32 Inadequate knowledge of workers about environmental concerns, green materials, and construction technologies". In Jordan, the concept of a green building is still new and therefore labourers and even engineers still have no experience of it.

"R3 Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, piling, blasting, etc. and on and off site traffic and deliveries". Most of our work results in noise and vibration, which is why its probability is high and its impact on health and the environment is high too.

"R12 Improper discharge of the workplace's wastewater". It has high impact because it pollutes the land and environment around, and it has high frequency because usually labourers and even the project stakeholders do not care about the environment and it costs less to just throw it anywhere.

"R25 Improper disposal of special waste". Most of the waste generated in the construction of roads and their infrastructure is considered special waste – asphalt, oils, etc. – and they are not disposed of properly at a special landfill.

- The high risk group:

The first risk is **"R21 Construction accidents and casualties"**. Health and safety are a big concern in Jordan. There are laws about health and safety procedures but no one follows them and there is no control over these laws.

"R28 Failure of underground utility lines, pipes and other underground structures". The impact of this is high and it happens frequently when the plans provided to the construction team are wrong.

"R19 Demand or stress on the infrastructure and the road network". The machinery is heavy and it has a negative impact on the roads. There are no laws that controls how and when machines or materials are moved.

"R31 Lack of availability of green materials and equipment". Since the concept of green building is new the availability of the materials is low as well.

"R30 Unclear allocation of roles and responsibilities". This is a common problem in the Jordanian construction industry, as the roles and responsibilities of the engineers are always not clear. They do everything and sometimes one engineer does work that should be done by two or more engineers, all to reduce the cost.

"R24 Improper disposal of ordinary and domestic solid waste". It happened a lot and it has a big impact on the environment.

"R5 Emissions from construction activities and equipment". This has high probability and impact as the activities associated with roads and infrastructure construction projects release a lot of emissions.

- The intermediate risks group:

"R9 High soil erosion and excavation". This has a high probability since all road construction work is based on cut and fill, but its impact is not that high.

"R6 Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane, and ozone)". Its probability and impact are relatively high since there is a lot of burning and releasing of gases and odour.

"R11 Contamination of rainwater runoff and surface water". This has a low impact since there is not much surface water in Jordan, but it happens a lot because all of the construction work is outside and sometimes streams cross the constructed roads in the winter.

"R18 Disruption of business in the community". This happens when the road is going through a town or city but the impact is usually temporary and any disruption is announced in advance. The infrastructure project is usually welcomed by the communities.

"R23 Lack of attention to health issues in the workplace". As has been said before, this is a common problem in the Jordanian construction industry.

"R13 Loss of agricultural lands and vegetation removal". In rural areas, opening new roads will for sure cause loss of agricultural lands.

"R17 Landscape alteration". Usually, when opening new roads, all the landscape will be changed but the company tries to keep the change minimal.

"R29 Insufficient on-site investigation resulted in improper adjustment measures to local conditions". The company cares about the local conditions around projects in Jordan, about cultural factors, and what the neighbours think about the project. Also, it is important to check about groundwater and archaeology around the project's location. That is why it has an intermediate impact and probability of occurrence because the company cares a lot about avoiding this issue.

- The low risk group:

"R8 Bad odour generation from handling of construction materials, waste, and sewage". Some of the materials used have a bad odour but the building work does not involve sewage since the project's facilities are always moving; that is why it is ranked intermediate.

"R22 Adverse effect on public health and safety". Health and safety are common issues in the Jordanian construction industry, but adverse effects on the public are not that common.

"R1 Excessive use of raw materials" and **"R2 the depletion of natural resources, renewable and non-renewable resources. (i.e., water, oil, timber, soil, etc.)".** Both of them have an impact on the environment if they happen but their probability of occurrence is relatively low since all the project stakeholders are concerned about the cost and losing money.

"R4 Deterioration of air quality (indoor and outdoor)" is considered a low risk as road projects are always outdoors.

"R14 Mountains and forest removal (deforestation)". First of all, there are few forests in Jordan, and few infrastructure projects in forests. Furthermore, if they occurred they would be highly controlled and monitored by the Ministry of the Environment.

- The very low risk group:

"R27 Contamination from spills of oils, fuels, and lubricants from field equipment and improperly stored materials or due to vandalism". Usually every site has security, so vandalism has a low impact, but improper storage is more frequent.

"R16 Adverse visual impact", and **"R20 Public dissatisfaction with the project".** Both are usually temporary if they occur during the construction. Road projects involve a lot of road closures, but usually the public are happy with the finished project.

"R26 Improper disposal of building debris (other than soil)." This does not happen in infrastructure projects and if it happened the debris would be reused in the fill operation in the same project.

"R15 Roadside vegetation removal". During the project, any vegetation removed will be planted back after the project is finished, by either the contractor or the Ministry of the Environment.

7.4 Case Study 3: The rehabilitation of a waste landfill project

7.4.1 Overview of the Company and the Project

This case study was the rehabilitation of a waste landfill project, financed by the Ministry of Environment along with foreign loans and aids. It was implemented by the MPWH. The project aims to expand the landfill and create recycling units and electricity generation units using methane gas. The landfill is one of the biggest landfills in the north of Jordan, and it has had major environmental problems in the last 20 years. The project budget is around 32 million JDs.

The case study was carried out on the construction phase of the project's structure, while the fitting and the machines for the recycling and electricity generation units were done by different companies. At the time of the case study and data collection, the project was in the final part of the construction phase.

In this project there was no an engineer responsible for managing and assessing the risks. The construction company's project manager was the person in charge of managing the project and ensuring that it was completed within its schedule, on budget, and to a high quality. A risk assessment was carried out for the project by an independent company because it was requested by the loan body, and this risk assessment covered different areas like design risk, external risk, organisational risk, health and safety, etc. but not sustainability-related risks. The project manager confirmed that his company did not do risk assessments in general, or assessments of sustainability-related risks; nevertheless, he was interested in the concept.

7.4.2 Data and Information Collection

As discussed previously, the first three steps of the case studies, through to the quantitative risk analysis, were completed during the research and the development of the model. The first was done by critically reviewing the available resources, i.e., rating systems (LEED, BREEAM, GSAS, and ESTIDAMA), EIA reports, and finally, the key principles of the UN SDGs. Using these sources, a list consisting of 89 hazardous events was created, then this list was reviewed for its applicability to the Jordanian construction industry through qualitative data collection (focus group) with eight experts from the industry in Jordan. Finally, the risks were ranked by a questionnaire distributed to employees in the Jordanian construction industry; 402 engineers completed the questionnaire. Only the high and very high risks will be assessed in the quantitative part.

As for the collected data for this study, it starts in the quantitative part of the risk assessment risk model. Data were collected from the project manager only in a meeting, due to time limitations. The manager was asked to fill in the model with all the relevant data. He used Microsoft Excel software to fill in the model. For the risk probability part, the manager filled in all the probabilities for the causes of the risks and the conditional probability between the risks and their causes. Finally, for the risk impact part, the project manager was asked to use the model to fill in the pairwise comparison tables. The next section presents the risk analysis, which was done using BBN and AHP.

7.4.3 Data Analysis

7.4.3.1 Probability Analysis Using BBN

This section shows the calculation used to find the probability using a BBN. It starts by presenting the BBN network adopted for this model, then it moves to the conditional probability tables for every node (risk) in the network that was filled in by the project manager. Finally, it displays the final probability result for the third case study.

1- The first step in the BM is the development of the belief network. Figure 7-3 shows the network developed and used in the model for the third case study.

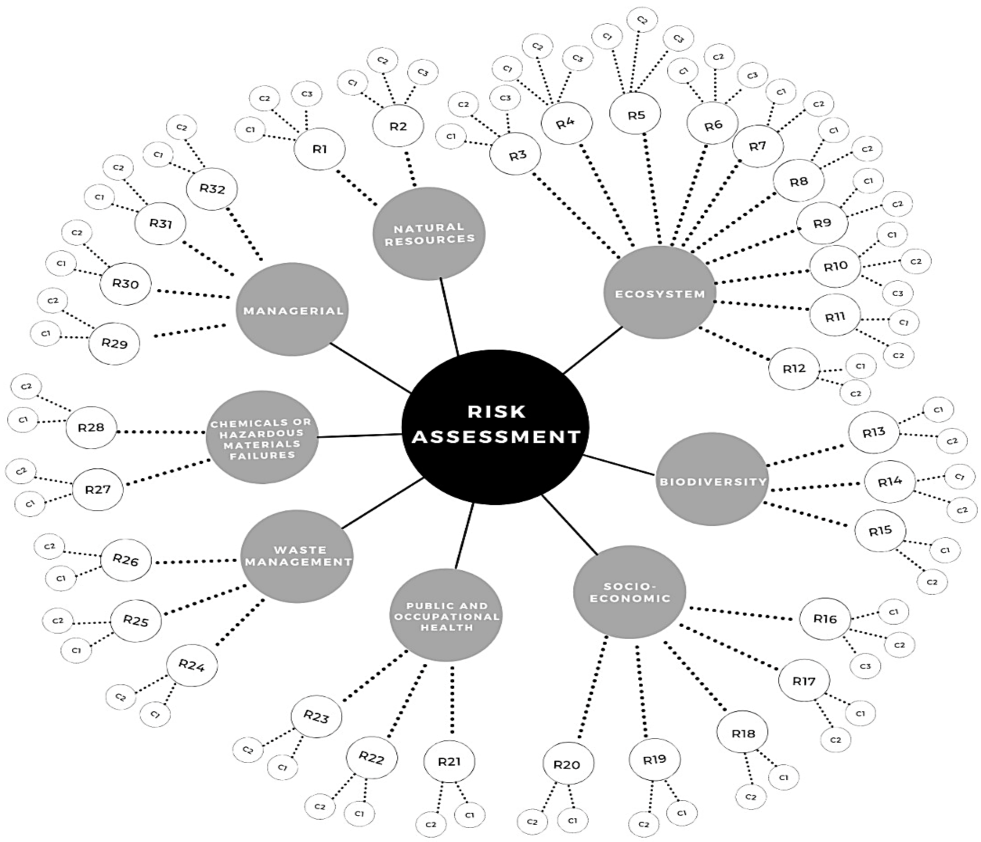

Figure 7-5 Bayesian Belief Network for the developed model

After the network is developed for this project, the next step should be the weight factor method. However, in this case study, the data came from the project manager alone, therefore the weight factor method is omitted.

2- Bayesian Belief Network Conditional Probability Tables

This part of the case study presents the conditional probability tables for each node (sustainability-related risk). These tables were filled in by the project manager of this case study based on the network above and the characteristics of the project. Each table contains the probability of the causes (two or three) plus the posterior probability between the risk and its causes (P(R1|C1, C2,C3). The final probability of the risk P(Ri) will be calculated with equations 5 and 6, discussed in the Model Development Chapter (Chapter 6). These equations were put in Microsoft Excel software.

(1) Conditional Probability Tables for node 1 (R1)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R1|C1,C2,C3)
R1	C1	0.1	0.9	T	T	T	0.95
Excessive use of raw materials	C2	0.1	0.9	T	T	F	0.8
	C3	0.1	0.9	T	F	T	0.8
				F	T	T	0.8
P(R1)=	0.1076			T	F	F	0.2
				F	T	F	0.2
				F	F	T	0.2
				F	F	F	0.05

(2) Conditional Probability Tables for node 2 (R2)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R2|C1,C2,C3)
R2	C1	0.3	0.7	T	T	T	0.95
The depletion of natural resources, renewable and non-renewable resources	C2	0.45	0.55	T	T	F	0.8
	C3	0.4	0.6	T	F	T	0.85
				F	T	T	0.8
P(R2) =	0.3635			T	F	F	0.2
				F	T	F	0.15
				F	F	T	0.2
				F	F	F	0.05

(3) Conditional Probability Tables for node 3 (R3)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R3|C1,C2,C3)
R3	C1	0.1	0.9	T	T	T	0.99
Noise and vibrations from construction machinery and equipment	C2	0.15	0.85	T	T	F	0.75
	C3	0.15	0.85	T	F	T	0.65
				F	T	T	0.7
P(R3) =	0.13128			T	F	F	0.3
				F	T	F	0.35
				F	F	T	0.25
				F	F	F	0.01

(4) Conditional Probability Tables for node 4 (R4)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R4|C1,C2,C3)
R4	C1	0.7	0.3	T	T	T	0.95
Deterioration of air quality (indoor and outdoor)	C2	0.65	0.35	T	T	F	0.8
	C3	0.5	0.5	T	F	T	0.7
				F	T	T	0.7
P(R4) =	0.63125			T	F	F	0.3
				F	T	F	0.3
				F	F	T	0.2
				F	F	F	0.05

(5) Conditional Probability Tables for node 5 (R5)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R5|C1,C2,C3)
R5	C1	0.15	0.85	T	T	T	0.99
Emissions from construction activities and equipment	C2	0.15	0.85	T	T	F	0.65
	C3	0.1	0.9	T	F	T	0.7
				F	T	T	0.6
P(R5) =	0.14408			T	F	F	0.4
				F	T	F	0.3
				F	F	T	0.35
				F	F	F	0.01

(6) Conditional Probability Tables for node 6 (R6)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R6|C1,C2,C3)
R6	C1	0.85	0.15	T	T	T	0.95
Emissions of harmful gases	C2	0.8	0.2	T	T	F	0.9
	C3	0.9	0.1	T	F	T	0.85
				F	T	T	0.8
P(R6) =	0.8671			T	F	F	0.2
				F	T	F	0.15
				F	F	T	0.1
				F	F	F	0.05

(7) Conditional Probability Tables for node 7 (R7)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R7|C1,C2,C3)
R7	C1	0.35	0.65	T	T	0.99
Dust generation from construction activities, machineries and equipment	C2	0.25	0.75	T	F	0.7
	0.324			F	T	0.3
P(R7) =				F	F	0.01

(8) Conditional Probability Tables for node 8 (R8)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R8|C1,C2,C3)
R8	C1	0.1	0.9	T	T	0.99
Bad odour generation from handling of construction materials, waste and sewage	C2	0.1	0.9	T	F	0.55
	0.108			F	T	0.45
P(R8) =				F	F	0.01

(9) Conditional Probability Tables for node 9 (R9)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R9|C1,C2,C3)
R9	C1	0.9	0.1	T	T	0.95
High soil erosion and excavation	C2	0.85	0.15	T	F	0.6
	0.8425			F	T	0.4
P(R9) =				F	F	0.05

(10) Conditional Probability Tables for node 10 (R10)

SUSTAINABLE RISK	CAUSE	PROBABILITY (T)	F(1-P)	C1	C2	C3	P(R10|C1,C2,C3)
R10	C1	0.9	0.1	T	T	T	0.9
Land pollution (associated with construction activities, machineries and equipment)	C2	0.85	0.15	T	T	F	0.85
	C3	0.75	0.25	T	F	T	0.75
				F	T	T	0.8
P(R10) =				T	F	F	0.2
	0.82			F	T	F	0.25
				F	F	T	0.15
				F	F	F	0.1

(11) Conditional Probability Tables for node R11

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R11|C1,C2,C3)
R11	C1	0.95	0.05	T	T	0.95
Contamination of rainwater runoff and surface water	C2	0.85	0.15	T	F	0.66
	0.876			F	T	0.34
P(R11) =				F	F	0.05

(12) Conditional Probability Tables for node 12 (R12)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R12|C1,C2,C3)
R12	C1	0.9	0.1	T	T	0.99
Improper discharge of the workplace's wastewater	C2	0.8	0.2	T	F	0.8
	0.917			F	T	0.75
P(R12) =				F	F	0.01

(13) Conditional Probability Tables for node 13 (R13)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R13|C1,C2,C3)
R13	C1	0.7	0.3	T	T	0.85
Loss of agricultural lands and vegetation removal	C2	0.5	0.5	T	F	0.7
	0.61			F	T	0.3
P(R13) =				F	F	0.15

(14) Conditional Probability Tables for node 14 (R14)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R14|C1,C2,C3)
R14	C1	0.15	0.85	T	T	0.9
Mountains and forest removal (deforestation)	C2	0.01	0.99	T	F	0.55
	0.171			F	T	0.45
P(R14) =				F	F	0.1

(15) Conditional Probability Tables for node 15 (R15)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R15|C1,C2,C3)
R15	C1	0.15	0.85	T	T	0.95
Roadside vegetation removal	C2	0.1	0.9	T	F	0.3
	0.1525			F	T	0.7
P(R15) =				F	F	0.05

(16) Conditional Probability Tables for node 16 (R16)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R16|C1,C2,C3)
R16	C1	0.1	0.9	T	T	0.99
Adverse visual impact	C2	0.15	0.85	T	F	0.75
	0.12			F	T	0.25
P(R16) =				F	F	0.01

(17) Conditional Probability Tables for node 17 (R17)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	C3	P(R17|C1,C2,C3)
R17	C1	0.6	0.4	T	T	T	0.9
Landscape alteration	C2	0.5	0.5	T	T	F	0.7
	C3	0.25	0.75	T	F	T	0.65
	0.45875			F	T	T	0.7
P(R17) =				T	F	F	0.3
				F	T	F	0.35
				F	F	T	0.3
				F	F	F	0.1

(18) Conditional Probability Tables for node 18 (R18)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R18|C1,C2,C3)
R18	C1	0.25	0.75	T	T	0.95
Disruption of business in the community	C2	0.15	0.85	T	F	0.65
	0.245			F	T	0.35
P(R18) =				F	F	0.05

(19) Conditional Probability Tables for node 19 (R19)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R19|C1,C2,C3)
R19	C1	0.75	0.25	T	T	0.95
Demand or stress on the infrastructure and the road network	C2	0.7	0.3	T	F	0.6
	0.7075			F	T	0.4
P(R19) =				F	F	0.05

(20) Conditional Probability Tables for node 20 (R20)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R20|C1,C2,C3)
R20	C1	0.9	0.1	T	T	0.99
Public dissatisfaction with the project	C2	0.8	0.2	T	F	0.8
	0.921			F	T	0.8
P(R20) =				F	F	0.01

(21) Conditional Probability Tables for node 21 (R21)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R21|C1,C2,C3)
R21	C1	0.4	0.6	T	T	0.95
Construction accidents and casualties	C2	0.5	0.5	T	F	0.75
	0.43			F	T	0.25
P(R21) =				F	F	0.05

(22) Conditional Probability Tables for node 22 (R22)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R22|C1,C2,C3)
R22	C1	0.7	0.3	T	T	0.9
Adverse effect on public health and safety	C2	0.6	0.4	T	F	0.8
	0.749			F	T	0.75
P(R22) =				F	F	0.1

(23) Conditional Probability Tables for node 23 (R23)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R23|C1,C2,C3)
R23	C1	0.5	0.5	T	T	0.85
Lack of attention to health issues in the workplace	C2	0.35	0.65	T	F	0.55
	0.455			F	T	0.45
P(R23) =				F	F	0.15

(24) Conditional Probability Tables for node 24 (R24)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R24|C1,C2,C3)
R24	C1	0.8	0.2	T	T	0.95
Improper disposal of ordinary and domestic solid waste	C2	0.7	0.3	T	F	0.5
	0.725			F	T	0.5
P(R24) =				F	F	0.05

(25) Conditional Probability Tables for node 25 (R25)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R25|C1,C2,C3)
R25	C1	0.6	0.4	T	T	0.95
Improper disposal of special waste	C2	0.55	0.45	T	F	0.65
	0.575			F	T	0.35
P(R25) =				F	F	0.05

(26) Conditional Probability Tables for node 26 (R26)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R26|C1,C2,C3)
R26	C1	0.7	0.3	T	T	0.9
Improper disposal of building debris	C2	0.85	0.15	T	F	0.5
	0.72			F	T	0.5
P(R26) =				F	F	0.1

(27) Conditional Probability Tables for node 27 (R27)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R27|C1,C2,C3)
R27	C1	0.3	0.7	T	T	0.95
Contamination from spills of oils, fuels, and lubricants from field equipment and improperly stored materials or due to vandalism.	C2	0.35	0.65	T	F	0.75
	0.33			F	T	0.25
P(R27) =				F	F	0.05

(28) Conditional Probability Tables for node 28 (R28)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R28|C1,C2,C3)
R28	C1	0.1	0.9	T	T	0.9
Failure of underground utility lines, pipes and other underground structures.	C2	0.15	0.85	T	F	0.65
	0.1925			F	T	0.35
P(R28) =				F	F	0.1

(29) Conditional Probability Tables for node 29 (R29)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R29|C1,C2,C3)
R29	C1	0.35	0.65	T	T	0.95
Insufficient on-site investigation resulted in improper adjustment measures to local conditions.	C2	0.2	0.8	T	F	0.75
	0.335			F	T	0.25
P(R29) =				F	F	0.05

(30) Conditional Probability Tables for node 30 (R30)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R30|C1,C2,C3)
R30	C1	0.05	0.95	T	T	0.88
Unclear allocation of roles and responsibilities.	C2	0.1	0.9	T	F	0.6
	0.172			F	T	0.4
P(R30) =				F	F	0.12

(31) Conditional Probability Tables for node 31 (R31)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R31|C1,C2,C3)
R31	C1	0.25	0.75	T	T	0.95
Lack of availability of green materials and equipment.	C2	0.3	0.7	T	F	0.45
	0.3			F	T	0.55
P(R31) =				F	F	0.05

(32) Conditional Probability Tables for node 32 (R32)

SUSTAINABLE RISK	CAUSE	PROBABILITY	(1-P)	C1	C2	P(R32|C1,C2,C3)
R32	C1	0.9	0.1	T	T	0.9
Inadequate knowledge of workers about environmental concerns, green materials and construction technologies.	C2	0.95	0.05	T	F	0.5
	0.84			F	T	0.5
P(R32) =				F	F	0.1

3- Probability Result

Table 7-13 shows the final results for risk probability for this case study.

Table 7-13: Case Study Three – Risk Probability

FACTORS	PROBABILITY	PROBABILITY (%)	PROBABILITY (out of 9)
R1	0.1076	11	2
R2	0.3635	36	4
R3	0.13128	13	2
R4	0.63125	63	7
R5	0.14408	14	2
R6	0.8671	87	9
R7	0.324	32	4
R8	0.108	11	2
R9	0.8425	84	9
R10	0.82	82	9
R11	0.876	88	9
R12	0.917	92	10
R13	0.61	61	7
R14	0.171	17	2
R15	0.1525	15	2
R16	0.12	12	2
R17	0.45875	46	5
R18	0.245	25	3
R19	0.7075	71	8
R20	0.921	92	10
R21	0.43	43	5
R22	0.749	75	8
R23	0.455	46	5
R24	0.725	73	8
R25	0.575	58	6
R26	0.72	72	8
R27	0.33	33	4
R28	0.1925	19	2
R29	0.335	34	4
R30	0.172	17	2
R31	0.3	30	3
R32	0.84	84	9

7.4.3.2 Impact Analysis Using AHP

This section shows the calculation used to find the impact using Analytic Hierarchy Process (AHP). It starts by presenting the hierarchy model adopted for this model, then it moves on to the pairwise comparison table for the categories and the risks of each category. These tables were filled in by the project manager. The comparison matrices are then presented, followed by the final impact results for this case study.

Figure 7-6 The Hierarchy Model

After the network is developed for this project, the next step should be the weight factor method. However, in this case study, the data came from the project manager alone, therefore the weight factor method is omitted.

Pairwise comparison table:

The next nine tables show the comparison table for the third case study as the project manager filled them in. The first table shows the comparison between the categories, while the next eight tables show the comparison between the risks of each category.

1- Categories pairwise comparison table

	1---9			1---9	
C1	0.33	C2	C3	3.00	C8
C1	5.00	C3	C4	0.20	C5
C1	3.00	C4	C4	0.33	C6
C1	0.33	C5	C4	5.00	C7
C1	1.00	C6	C4	5.00	C8
C1	7.00	C7	C5	3.00	C6
C1	7.00	C8	C5	9.00	C7
C2	7.00	C3	C5	9.00	C8
C2	5.00	C4	C6	7.00	C7
C2	1.00	C5	C6	7.00	C8
C2	3.00	C6	C7	1.00	C8
C2	9.00	C7			
C2	9.00	C8			
C3	0.33	C4			
C3	0.14	C5			
C3	0.20	C6			
C3	3.00	C7			

2- First categories pairwise comparison table

R1	1.00	R2

3- Second categories pairwise comparison table

R3	0.11	R4	R6	3.00	R7
R3	1.00	R5	R6	5.00	R8
R3	0.20	R6	R6	1.00	R9
R3	0.33	R7	R6	1.00	R10
R3	1.00	R8	R6	0.20	R11
R3	0.20	R9	R6	0.33	R12
R3	0.20	R10	R7	3.00	R8
R3	0.11	R11	R7	0.33	R9
R3	0.14	R12	R7	0.33	R10
R4	9.00	R5	R7	0.14	R11
R4	5.00	R6	R7	0.20	R12
R4	7.00	R7	R8	0.20	R9
R4	9.00	R8	R8	0.20	R10
R4	5.00	R9	R8	0.11	R11
R4	5.00	R10	R8	0.14	R12
R4	1.00	R11	R9	1.00	R10
R4	3.00	R12	R9	0.20	R11
R5	0.20	R6	R9	0.33	R12
R5	0.33	R7	R10	0.20	R11
R5	1.00	R8	R10	0.33	R12
R5	0.20	R9	R11	3.00	R12
R5	0.20	R10			
R5	0.11	R11			
R5	0.14	R12			

4- Third categories comparison table

R13	7.00	R14
R13	7.00	R15
R14	1.00	R15

5- Fourth categories comparison table

R16	0.20	R17
R16	1.00	R18
R16	0.20	R19
R16	0.14	R20
R17	5.00	R18
R17	1.00	R19
R17	0.20	R20
R18	0.20	R19
R18	0.11	R20
R19	0.20	R20

6- Fifth categories comparison table

R21	0.33	R22
R21	1.00	R23
R22	3.00	R23

7- Sixth categories comparison table

R24	0.20	R25
R24	1.00	R26
R25	5.00	R26

8- Seventh categories comparison table

R27	5.00	R28

9- Eighth categories comparison table

R29	0.33	R30
R29	1.00	R31
R29	0.20	R32
R30	3.00	R31
R30	0.33	R32
R31	0.20	R32

The nine categories pairwise comparison tables above will be used to create the comparison matrix for the next step. Each of the nine tables produced a matrix. The first matrix is between the categories, while the remaining eight matrices show the comparison between the risk of each category. Below, each matrix will present the calculation for the dominant Eigenvector to find the relative weight of the risk and the CR.

Pairwise comparison matrix:

1- Categories Pairwise comparison matrix

	CAT 1	CAT 2	CAT 3	CAT 4	CAT 5	CAT 6	CAT 7	CAT 8
CAT 1	1.00	0.33	5.00	3.00	0.33	1.00	7.00	7.00
CAT 2	3.00	1.00	7.00	5.00	1.00	3.00	9.00	9.00
CAT 3	0.20	0.14	1.00	0.33	0.14	0.20	3.00	3.00
CAT 4	0.33	0.20	3.00	1.00	0.20	0.33	5.00	5.00
CAT 5	3.00	1.00	7.00	5.00	1.00	3.00	9.00	9.00
CAT 6	1.00	0.33	5.00	3.00	0.33	1.00	7.00	7.00
CAT 7	0.14	0.11	0.33	0.20	0.11	0.14	1.00	1.00
CAT 8	0.14	0.11	0.33	0.20	0.11	0.14	1.00	1.00

TOTAL	8.82	3.23	28.67	17.73	3.23	8.82	42.00	42.00				
	CAT 1	CAT 2	CAT 3	CAT 4	CAT 5	CAT 6	CAT 7	CAT 8	TOTAL	AVG.		Consistency Measure
CAT 1	0.11	0.10	0.17	0.17	0.10	0.11	0.17	0.17	1.11	0.14	CAT 1	8.624565144
CAT 2	0.34	0.31	0.24	0.28	0.31	0.34	0.21	0.21	2.25	0.28	CAT 2	8.679445638
CAT 3	0.02	0.04	0.03	0.02	0.04	0.02	0.07	0.07	0.33	0.04	CAT 3	8.016542961
CAT 4	0.04	0.06	0.10	0.06	0.06	0.04	0.12	0.12	0.60	0.07	CAT 4	8.266992698
CAT 5	0.34	0.31	0.24	0.28	0.31	0.34	0.21	0.21	2.25	0.28	CAT 5	8.679445638
CAT 6	0.11	0.10	0.17	0.17	0.10	0.11	0.17	0.17	1.11	0.14	CAT 6	8.624565144
CAT 7	0.02	0.03	0.01	0.01	0.03	0.02	0.02	0.02	0.17	0.02	CAT 7	8.103121538
CAT 8	0.02	0.03	0.01	0.01	0.03	0.02	0.02	0.02	0.17	0.02	CAT 8	8.103121538
											CI	0.055317862
											RI	1.41
											CR	0.039232527	1

2- First category pairwise comparison matrix

NATURAL	R1	R2
R1	1	1
R2	1	1
total	2	2

NATURAL	R1	R2	TOTAL	AVG		CM	
R1	0.5	0.5	1	0.5	R1	2	
R2	0.5	0.5	1	0.5	R2	2	
					CI	0	
					RI	0	
					CR	0	1

3- Second category pairwise comparison matrix

ECOSYSTEM	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12
R 3	1	0.11	1.00	0.20	0.33	1.00	0.20	0.20	0.11	0.14
R 4	9	1	9.00	5.00	7.00	9.00	5.00	5.00	1.00	3.00
R 5	1	0.111111	1	0.20	0.33	1.00	0.20	0.20	0.11	0.14
R 6	5	0.2	5	1	3.00	5.00	1.00	1.00	0.20	0.33
R 7	3	0.142857	3	0.333333	1	3.00	0.33	0.33	0.14	0.20
R 8	1	0.111111	1	0.2	0.333333	1	0.20	0.20	0.11	0.14
R 9	5	0.2	5	1	3	5	1	1.00	0.20	0.33
R 10	5	0.2	5	1	3	5	1	1	0.20	0.33
R 11	9	1	9	5	7	9	5	5	1	3.00
R 12	7	0.333333	7	3	5	7	3	3	0.333333	1
TOTAL	46	3.409524	46	16.93333	30	46	16.93333	16.93333	3.409524	8.628571

ECOSYSTEM	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	TOTAL	AVG	CM
R3	0.021739	0.03	0.02	0.01	0.01	0.02	0.01	0.01	0.03	0.02	0.19	0.02	10.14950445
R4	0.195652	0.293296	0.20	0.30	0.23	0.20	0.30	0.30	0.29	0.35	2.64	0.26	11.00466896
R5	0.021739	0.032588	0.021739	0.01	0.01	0.02	0.01	0.01	0.03	0.02	0.19	0.02	10.14950445
R6	0.108696	0.058659	0.108696	0.059055	0.10	0.11	0.06	0.06	0.06	0.04	0.76	0.08	10.4187572
R7	0.065217	0.041899	0.065217	0.019685	0.033333	0.07	0.02	0.02	0.04	0.02	0.40	0.04	9.982556414
R8	0.021739	0.032588	0.021739	0.011811	0.011111	0.021739	0.01	0.01	0.03	0.02	0.19	0.02	10.14950445
R9	0.108696	0.058659	0.108696	0.059055	0.1	0.108696	0.059055	0.06	0.06	0.04	0.76	0.08	10.4187572
R10	0.108696	0.058659	0.108696	0.059055	0.1	0.108696	0.059055	0.059055	0.06	0.04	0.76	0.08	10.4187572
R11	0.195652	0.293296	0.195652	0.295276	0.233333	0.195652	0.295276	0.295276	0.293296	0.35	2.64	0.26	11.00466896
R12	0.152174	0.097765	0.152174	0.177165	0.166667	0.152174	0.177165	0.177165	0.097765	0.115894	1.47	0.15	10.97985752
												CI	0.05196152
												RI	1.49
												CR	0.034873503

4- Third category pairwise comparison matrix

BIODAIVERSITY	R 13	R 14	R 15
R 13	1	7.00	7.00
R 14	0.142857	1	1.00
R 15	0.142857	1	1
TOTAL	1.285714	9	9

BIODAIVERSITY	R13	R14	R15	TOTAL	AVG		CM	
R13	0.777778	0.777778	0.777778	2.333333	0.777778	R13	3	
R14	0.111111	0.111111	0.111111	0.333333	0.111111	R14	3	
R15	0.111111	0.111111	0.111111	0.333333	0.111111	R15	3	
						CI	0	
						RI	0.58	
						CR	0	1

5- Fourth category pairwise comparison matrix

SOCIO-ECONOMIC	R 16	R 17	R 18	R 19	R 20
R 16	1	0.20	1.00	0.20	0.14
R 17	5	1	5.00	1.00	0.20
R 18	1	0.2	1	0.20	0.11
R 19	5	1	5	1	0.20
R 20	7	5	9	5	1
TOTAL	19	7.4	21	7.4	1.653968

SOCIO-ECONOMIC	R16	R17	R18	R19	R20	TOTAL	AVG		CM	
R16	0.052632	0.027027	0.047619	0.027027	0.086372	0.240677	0.048135	R16	5.037525	
R17	0.263158	0.135135	0.238095	0.135135	0.120921	0.892445	0.178489	R17	5.206239	
R18	0.052632	0.027027	0.047619	0.027027	0.067179	0.221483	0.044297	R18	5.079489	
R19	0.263158	0.135135	0.238095	0.135135	0.120921	0.892445	0.178489	R19	5.206239	
R20	0.368421	0.675676	0.428571	0.675676	0.604607	2.75295	0.55059	R20	5.577829	
								CI	0.055366	
								RI	1.12	
								CR	0	1

6- Fifth category pairwise comparison matrix

PUBLIC	R 21	R 22	R 23
R 21	1	0.33	1.00
R 22	3	1	3.00
R 23	1	0.333333	1
TOTAL	5	1.666667	5

PUBLIC	R21	R22	R23	TOTAL	AVG		CM	
R21	0.2	0.2	0.2	0.6	0.2	R21	3	
R22	0.6	0.6	0.6	1.8	0.6	R22	3	
R23	0.2	0.2	0.2	0.6	0.2	R23	3	
						CI	0	
						RI	0.58	
						CR	0	1

7- Sixth category pairwise comparison matrix

WASTE	R 24	R 25	R 26
R 24	1	0.20	1.00
R 25	5	1	5.00
R 26	1	0.2	1
TOTAL	7	1.4	7

WASTE	R24	R25	R26	TOTAL	AVG		CM	
R24	0.142857	0.142857	0.142857	0.428571	0.142857	R24	3	
R25	0.714286	0.714286	0.714286	2.142857	0.714286	R25	3	
R26	0.142857	0.142857	0.142857	0.428571	0.142857	R26	3	
						CI	0	
						RI	0.58	
						CR	0	1

8- Seventh category pairwise comparison matrix

CHEMICALS	R 27	R 28
R 27	1	5.00
R 28	0.2	1
TOTAL	1.2	6

CHEMICALS	R27	R28	TOTAL	AVG		CM	
R27	0.833333	0.833333	1.666667	0.833333	R27	2	
R28	0.166667	0.166667	0.333333	0.166667	R28	2	
					CI	0	
					RI	0	
					CR	0	1

9- Eighth category pairwise comparison matrix

MANEGIRIAL	R 29	R 30	R 31	R 32
R 29	1	0.33	1.00	0.20
R 30	3	1	3.00	0.33
R 31	1	0.333333	1	0.20
R 32	5	3	5	1
TOTAL	10	4.666667	10	1.733333

MANEGIRIAL	R29	R30	R31	R32	TOTAL	AVG		CM	
R29	0.1	0.071429	0.1	0.115385	0.386813	0.096703	R29	3.418560606	
R30	0.3	0.214286	0.3	0.192308	1.006593	0.251648	R30	3.505822416	
R31	0.1	0.071429	0.1	0	0.271429	0.067857	R31	4.871794872	
R32	0.5	0.642857	0.5	0	1.642857	0.410714	R32	4.841471572	
							CI	0.053137456	
							RI	0.9	
							CR	0.059041617	1

AHP final result

Table 7-14 shows the final result for the impact using the AHP method for this case study.

Table 7-14: Case Study Three's Risk Impact

RISKS	CAT	CAT IMPACT	R IMPACT	TOTAL IMPACT	Standardisation scale	out of 9	RISKS
R1	CAT1	0.138749196	0.5	0.069374598	0.7	7	R1
R2		0.138749196	0.5	0.069374598	0.7	7	R2
R3	CAT2	0.281739806	0.019349477	0.005451518	0.055006627	1	R3
R4		0.281739806	0.264039092	0.074390323	0.750609409	8	R4
R5		0.281739806	0.019349477	0.005451518	0.055006627	1	R5
R6		0.281739806	0.075920209	0.021389745	0.215825706	3	R6
R7		0.281739806	0.039501832	0.011129238	0.112295669	2	R7
R8		0.281739806	0.019349477	0.005451518	0.055006627	1	R8
R9		0.281739806	0.075920209	0.021389745	0.215825706	3	R9
R10		0.281739806	0.075920209	0.021389745	0.215825706	3	R10
R11		0.281739806	0.264039092	0.074390323	0.750609409	8	R11
R12		0.281739806	0.146610923	0.041306133	0.416785021	5	R12
R13	CAT3	0.041287859	0.777777778	0.032112779	0.324022714	4	R13
R14		0.041287859	0.111111111	0.00458754	0.046288959	1	R14
R15		0.041287859	0.111111111	0.00458754	0.046288959	1	R15
R16	CAT4	0.074812929	0.048135408	0.003601151	0.036336148	1	R16
R17		0.074812929	0.178488942	0.013353281	0.134736585	2	R17
R18		0.074812929	0.044296637	0.003313961	0.03343836	1	R18
R19		0.074812929	0.178488942	0.013353281	0.134736585	2	R19
R20		0.074812929	0.550590072	0.041191256	0.415625894	5	R20
R21	CAT5	0.281739806	0.2	0.056347961	0.568559301	6	R21
R22		0.281739806	0.6	0.169043883	1.705677902	10	R22
R23		0.281739806	0.2	0.056347961	0.568559301	6	R23
R24	CAT6	0.138749196	0.142857143	0.019821314	0.2	2	R24
R25		0.138749196	0.714285714	0.099106568	1	10	R25
R26		0.138749196	0.142857143	0.019821314	0.2	2	R26
R27	CAT7	0.021460605	0.833333333	0.017883837	0.180450575	2	R27
R28		0.021460605	0.166666667	0.003576767	0.036090115	1	R28
R29	CAT8	0.021460605	0.096703297	0.002075311	0.020940199	1	R29
R30		0.021460605	0.251648352	0.005400526	0.054492108	1	R30
R31		0.021460605	0.067857143	0.001456255	0.014693833	1	R31
R32		0.021460605	0.410714286	0.008814177	0.088936355	1	R32

7.4.4 Risk Assessment Result

This section presents the final risk ranking for the third case study using the developed model on the rehabilitation of a waste landfill project, showing how it has been calculated.

As discussed previously, the equation to calculate the risk ranking is:

$$RR = Risk\ probability\ \times Risk\ impact$$

To multiply the impact by its probability, it is important to ensure that the two numbers have the same scale. The results of the impact are scaled out of 100%, while the impact shows the weight of each risk with a total of one.

The risk impact results are scaled using standardisation. In this case study, the final results were divided by the highest value, after checking to see if there are any outlying values. Then the results were divided into the original five interval scale from 1 to 9 with intermediate values (2, 4, 6, 8, 10) to give more accurate results. The tables below show the risk relative weight levels.

For the probability, as the value is already a probability value (rate) out of 100%, the scale will be from five intervals from 1 to 9 with intermediate values (2, 4, 6, 8, 10) to give more accurate results, as shown in the table for risk probability levels below.

Table 7-15: Risk Relative Weight Levels

Impact	out of 9	scale
Very high	10	above 0.9
	9	0.8-0.9
High	8	0.7-0.8
	7	0.6-.07
Moderate	6	0.5-0.6
	5	0.4-0.5
Low	4	0.3-0.4
	3	0.2-0.3
Very low	2	0.1-0.2
	1	below 0.1

Table 7-16: Risk Probability Levels

Probability	out of 9	scale
Very high	10	above 0.9
	9	80-90%
High	8	70-80%
	7	60-70%
Moderate	6	50-60%
	5	40-50%
Low	4	30-40%
	3	20-30%
Very low	2	10-20%
	1	below 10%

The risk matrix below shows the final risk ranking levels from very high in the dark red to very low in white.

Table 7-17: Risk Probability Levels

Very high	9	27	45	63	81
High	7	21	35	49	63
Intermediate	5	15	25	35	45
Low	3	9	15	21	27
Very low	1	3	5	7	9
	Very rare	Rare	Intermediate	Possible	Very possible

The final result can be seen below after the impact and probability have been scaled and multiplied.

Table 7-18: The Final Risk Rank Result

risk	probability	probability	impact	impact	risk	Final risk rank
R1	0.1076	2	0.069375	7	R22	80
R2	0.3635	4	0.069375	7	R11	72
R3	0.13128	2	0.005452	1	R25	60
R4	0.63125	7	0.07439	8	R4	56
R5	0.14408	2	0.005452	1	R20	50
R6	0.8671	9	0.02139	3	R12	50
R7	0.324	4	0.011129	2	R23	30
R8	0.108	2	0.005452	1	R21	30
R9	0.8425	9	0.02139	3	R2	28
R10	0.82	9	0.02139	3	R13	28
R11	0.876	9	0.07439	8	R9	27
R12	0.917	10	0.041306	5	R6	27
R13	0.61	7	0.032113	4	R10	27
R14	0.171	2	0.004588	1	R26	16
R15	0.1525	2	0.004588	1	R24	16
R16	0.12	2	0.003601	1	R19	16
R17	0.45875	5	0.013353	2	R1	14
R18	0.245	3	0.003314	1	R17	10
R19	0.7075	8	0.013353	2	R32	9
R20	0.921	10	0.041191	5	R7	8
R21	0.43	5	0.056348	6	R27	8
R22	0.749	8	0.169044	10	R29	4
R23	0.455	5	0.056348	6	R31	3
R24	0.725	8	0.019821	2	R18	3
R25	0.575	6	0.099107	10	R8	2
R26	0.72	8	0.019821	2	R5	2
R27	0.33	4	0.017884	2	R30	2
R28	0.1925	2	0.003577	1	R3	2
R29	0.335	4	0.002075	1	R28	2
R30	0.172	2	0.005401	1	R16	2
R31	0.3	3	0.001456	1	R15	2
R32	0.84	9	0.008814	1	R14	2

7.4.5 Results Summary

A discussion on the final results of the model took place between the researcher and the project manager to check and confirm whether the results reflects what happens in real life. Six risks were considered very high, seven risks were high, six risks were intermediate, two risks were considered low risks and eleven risks were very low.

- The very high risk group:

"R22 Adverse effect on public health and safety". Health and safety are important and common issues in the Jordanian construction industry and they need to be fixed.

"R11 Contamination of rainwater runoff and surface water" was the first risk in the very high risk group. It is important and has priority. It has a huge impact on the environment because already there is a shortage of water in Jordan and we have to save what we have.

"R25 Improper disposal of special waste". Special and hazardous waste has a big impact on the environment and this risk frequently occurs.

"R4 Deterioration of air quality (indoor and outdoor)". It has a high impact on the environment and health, and its probability of occurrence is intermediate.

"R20 Public dissatisfaction with the project". Public approval of the project is important for the social pillar, however, the dissatisfaction of the public happens frequently.

"R12 Improper discharge of the workplace's wastewater". As mentioned previously, this has a huge impact on the environment because already there is a shortage of water in Jordan and we have to save what we have.

- The high risk group:

"R23 Lack of attention to health issues in the workplace important". This is a big problem in Jordan.

"R21 Construction accidents and casualties". These are an important problem for the health of the workers and engineers and they happen a lot.

"R2 the depletion of natural resources, renewable and non-renewable resources (i.e., water, oil, timber, soil, etc.)". This has a huge impact on the environment but its probability of occurrence is relatively low due to cost control.

"R13 Loss of agricultural lands and vegetation removal". It has a high impact on the environment and it happens frequently in Jordan.

"R9 High soil erosion and excavation". It has an intermediate impact but it happens frequently.

“R6 Emissions of harmful gases (i.e., CFCs, carbon dioxide, nitrous oxide, sulphur oxide, methane, and ozone)”. It can be controlled or managed; however, it has a high impact on the environment as it pollutes it.

“R10 Land pollution (associated with construction activities, machinery, and equipment)”. Pollution, in general, has a huge impact on the environment and land pollution happens frequently.

- The intermediate risks group:

“R26 Improper disposal of building debris (other than soil)”. Building debris has a lower impact on the environment than special waste.

“R24 Improper disposal of ordinary and domestic solid waste”. It has the lowest impact on the environment among all the types of waste but it is the most frequent one.

“R19 Demand or stress on the infrastructure and the road network”. It is important but this project is far away from major cities and roads.

“R1 Excessive use of raw materials”. Its impact is huge on the environment but its probability of occurrence is low because all the project stakeholders care a lot about minimising the cost.

“R17 Landscape alteration”. It has an impact on the environment and the public but it is temporary.

“R32 Inadequate knowledge of workers about environmental concerns, green materials, and construction technologies”. It is a common issue in Jordan since we do not use green buildings.

- The low risk group:

“R7 Dust generation from construction activities, machinery, and equipment”. It can be managed and it does not happen that much.

“R27 Contamination from spills of oils, fuels, lubricants from field equipment and improperly stored materials or due to vandalism”. Usually every site has security, so vandalism has a low impact. Improper storage is more frequent.

- The very low risk group:

“R29 Insufficient on-site investigation resulted in improper adjustment measures to local conditions”. In Jordan, we care about local conditions and we check them.

“R31 Lack of availability of green materials and equipment”. It is a problem but we do not use green materials in our project.

“R18 Disruption of business in the community”. It has a low impact since it is a temporary problem and usually these types of projects are far away from local communities.

“R8 Bad odour generation from handling of construction materials, waste and sewage” and **“R5 Emissions from construction activities and equipment”.** Both of the above risks can be managed and controlled.

“R30 Unclear allocation of roles and responsibilities”. It is a common problem in Jordan but it does not have a huge impact.

“R3 Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, piling, blasting, etc. and on and off site traffic and deliveries”. It depends on the project and this type of project is far away from everything and usually this risk can be controlled.

“R28 Failure of underground utility lines, pipes, and other underground structures not that high impact and do not happen that much”. This project is far away from everything and there are good plans for the area.

“R16 Adverse visual impact”. It does not have a big impact and usually it is a temporary problem.

“R15 Roadside vegetation removal”. It has low impact and it does not happen with this type of project.

“R14 Mountains and forest removal (deforestation)”. There are few forests in Jordan and our project will not be near forests.

7.5 The Discussion of Results and Validation of the Proposed Model

7.5.1 Discussion of Results

The developed model has been validated through three case studies based on three different projects from the Jordanian construction industry. The three projects were of different types, and had different conditions and characteristics, which resulted in different outcomes for the risk assessment. These have proven that the proposed model can be applied to different construction projects for risk analysis.

In Case Study 1, the construction of a commercial building, six risks were classified as very high, with the highest risk being **“R17 Landscape alteration”**. Comparing this with the second and the third case studies, both ranked this risk as intermediate. This would suggest that it was important in the first case study as the project was in the middle of a city, while it is an intermediate risk when the projects were outside a city. The second highest risk was **“R16 adverse visual impact”**. Comparing this with the second and third case studies, both classified it as a very low risk where, again, this is probably due to the different characteristics of the projects as both latter case studies were projects far away from a large population. The third-ranked risk was **“R31 lack of availability of green materials and equipment”**, which was highly ranked in the second case study (fourth highest) but was the second risk in the group of very low risks in the third case study. The next highest risk in Case Study 1 was **“R19 demand**

or stress on the infrastructure and the road network". It was ranked third highest in the second case study due to the high stress on infrastructure and traffic caused by the machinery used in the project, while it was classified as an intermediate risk in the third case study since the project had a lower impact on the infrastructure. The fifth highest risk in Case Study 1 was **"R23 lack of attention to health issues in the workplace"**. Comparing this with the second case study, it was ranked the fifth risk in the intermediate risk group, while in the third case study it was the first of the high risk group. The last very high risk in the first case study was **"R32 inadequate knowledge of workers about environmental concerns, green materials, and construction technologies"**, while in the second and third case studies it was ranked the third highest overall and last in the intermediate risk group, respectively.

In the second case study, the construction of a road infrastructure project, six risks were classified as very high, with the highest being **"R7 dust generation from construction activities, machinery, and equipment"**. Compared to the other case studies, it was classified as an intermediate risk in the first case study and low risk in the third case study since only infrastructure projects caused this much dust. The second highest risk was **"R10 land pollution (associated with construction activities, machinery, and equipment)"**. In the first case study, it was classified as an intermediate risk and ranked sixth, while in the third case study it was the last of the high risks. The third risk was **"R32 inadequate knowledge of workers about environmental concerns, green materials, and construction technologies"**. This was also classified as a very high risk in the first case study, although ranked sixth, while it was classified as an intermediate risk in the third case study. Fourth highest in Case Study 2 was **"R3 noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, piling, blasting, etc. and on and off site traffic and deliveries"**. This was classified as an intermediate risk in the first case study, ranked third, while in the third case study it was classified as a very low risk as the project was located far away from the public. The fifth most significant risk for the second case study was **"R12 improper discharge of the workplace's wastewater"**. It was ranked the first risk of the intermediate risk group in the first case study, while it was classified as the sixth highest risk in the third case study. The final risk was **"R25 improper disposal of special waste"**. In the first case study, it was classified as an intermediate risk and ranked eleventh, while in the third case study it was classified as a very high risk and ranked third.

In the third case study, the rehabilitation of a waste landfill project, six risks were classified as very high risks, the first being "**R22 Adverse effect on public health and safety"**. It was ranked ninth of the intermediate risks in the first case study, while it was ranked second of the low risks in the second case study. In both cases, the probability of this risk was low and multiple problems would occur on the site. The second highest risk is **"R11 contamination of rainwater runoff and surface water"**. This was higher than the first and second case studies, as it was ranked the fourth of the very low risks in the first case study and third of the intermediate risks in the second case study. As previously mentioned, this is not a significant problem as Jordan is suffering from a shortage of water in general. The next risk was **"R25 improper disposal of special waste"**. It was ranked eleventh of the intermediate risks in the first case study since special waste was not used that much in buildings, and even if it were used, it would be handled carefully because it was expensive. However, in the second case study it was also ranked high, the sixth of the very high risks, since work on road infrastructure involves a lot of special material and waste. The fourth highest risk was **"R4 deterioration of air quality (indoor and outdoor)"**, which was ranked sixth of the very low risks in the first case study, due to the use of electrical tools over diesel ones, while in the second case study it was ranked fifth of the low risks. The next risk was **"R20 public dissatisfaction with the project"**. In the first case study, it was ranked the last of the very low risks, and it was ranked second of the very low risks in the second case study. This is because in Jordan, the planning for areas is known and the public will know what the project will be. The sixth highest risk was **"R12 improper discharge of the workplace's wastewater"** which was ranked the first of the intermediate risks in the first case study and the fifth of the very high risks in the second case study, showing that this is a common problem in Jordan.

7.5.2 The Validation of The Model

It can be seen that the developed model can be successfully used to analyse the risks associated with projects in the construction industry, based on our experience in the three cases studied in Jordan. This validation can be justified by the results collected from the previous three case studies. The same model was used for each case, and through this, the model stages were developed, beginning with the problem identification phase. Through this we identified the problems related to construction projects. In the data and information collection and analysis phase, all the information about the construction project was collected and analysed, and its possible effects were analysed. The next phase was risk identification. At this stage, this model helped the researcher to determine the risks and their risk levels from low, or medium, to high. Utilising this model, the researcher was able to list the sustainable risk events. At this stage, the researcher was also able to identify the sustainability-related risks, particularly in construction projects in Jordan. In the risk assessment phase, this model helps the researcher as an engineer to assess the risks and give them the probabilities of occurrence using the Bayesian model. The researcher was then able to produce a BBN for the risk factors and events and calculate their probability. The researcher used the AHP to determine the risk impact. Through this, the researcher examined the impact that each risk may have on the environment and society. The hierarchical model was produced and the risk impact and rank were calculated. The researcher found that each case study produced different results because of the different characteristics of the projects. The model proved its validation and success as it showed its ability to identify, classify and evaluate the most important risks and evaluate their impact based on the surroundings and the type of construction work being undertaken. All project phases can be applied to any construction project in and outside Jordan, whether they are sustainable or unsustainable projects. The organised and hierarchical structure gives this model the ability to detect general risks, and sustainability-related risks in particular. This is achieved by implementing the model's steps in a descending sequence, which will inevitably help reduce or eliminate those risks that are likely to occur or that actually occur in construction. To sum up, the differences in the result show that the model is valid and works in different types of projects in the Jordanian construction industry. The next step in validating the model was done with the three project managers after concluding the case studies, to verify the need, content, structure and applicability of the developed model.

7.5.2.1 verification of the need to apply sustainability:

Working on the case study included having discussion and the help of the project manager of each case, providing direct feedback on each point that needed a verification. The first point, which is the need to apply sustainability in construction sites,

- *As professionals where do you stand and what is your opinion on the need of sustainability in construction site and in general in Jordan?*

In all three cases, the project managers agreed and talked about the importance of applying sustainability while working on such projects and highlighted how this research serve and takes in consider this point. Also, the need of sustainability in Jordan and especially in the construction industry was confirmed, as the Jordanian construction industry lacks the application of sustainability and risk management.

7.5.2.2 verification of content (sustainability related risk):

in order to get the verification of the content in this research, and for the model, the three professionals where asked the following question:

- *After going over the model and part of the research, do you think the research covered enough content to create a successful risk assessment model?*

All the three project managers agreed on how the research discusses and covers the sustainability aspect regarding such model, as it discusses the three pillars of sustainability and how it helps in increasing the success of the model, the relation between the risk in construction industry and sustainability, and the connection between each pillar and the risk in construction sites. With this content, the model would achieve more than other models that have been applied in similar projects.

7.5.2.2 verification of structure and applicability:

the last feedback asked from the project managers was regarding the structure and applicability of the model, the question asked was:

- *As professionals, and people that work in the field, what is your opinion regarding the structure and the applicability of the model in Jordan?*

All agreed that the structure of the model was clear enough and covered enough to make it applicable, and the possibility of applying it in Jordan is high especially if Jordan started taking in consider the risk management aspect and the sustainability aspect together in the construction industry.

7.6 Conclusion

This chapter presented the three case studies carried out in the Jordanian construction industry, to check and validate the developed model. The first case study was a commercial building, while the second was an infrastructure project for the construction of a road. The final project was the construction and rehabilitation of a waste landfill. Afterward, the results were presented and compared for the three case studies, confirming that the model is valid and gave different rankings for sustainability-related risks, depending on the projects characteristics. Finally, it showed the discussions with the three project managers validating the need, content, structure, and applicability of the developed model.

Chapter Eight

Chapter Eight: Conclusion, Limitation and Recommendations

8.1 Introduction

This chapter summarises the thesis's main ideas. It starts by reviewing the aim and objectives we well as the methods used to achieve them. It then presents the most important findings of the study and their compatibility with and disagreement with the literature review. In addition, the final perspective of the developed model is stated, acknowledging the most important limitations faced by the study. Finally, it concludes the thesis work by providing several recommendations to help apply sustainability risk management in the construction industry, with the aim of reducing its effect on the environment.

8.2 Research Objectives:

This section clarifies the objectives that were set for the research and the approached used in order to achieve each objective.

First objective: To undertake a literature review and identify sustainability, sustainable construction and sustainable rating systems, and compare these rating systems with the UN SDGs and EIA reports to produce the list of sustainability-related hazards for the proposed model.

In order to achieve the first objective, the research started by collecting secondary data in the literature review discussing and defining sustainability, sustainable construction and the best practises in applying sustainability concept in the construction industry. In order to produce the initial potential sustainability-related risks and achieve triangulation throughout the process, the researcher derived insights from the resemblance that common sustainable construction risks had with a number of leading sustainability standards, such as LEED, BREEAM, GSAS and ESTIDAMA. Further reference was made to the key principles of the UN SDGs, EIA reports and other publications in that area. Finally, risk management was proposed as a tool to apply for sustainable construction.

Second objective: To investigate the current risk management frameworks and methods in the construction industry and analyse and compare these methods in order to develop a theoretical basis for the new model.

The literature review proceeded further into risk management processes and best practices in the industry, comparing the available methods to develop the theoretical basis for the development of a new model. In this research, a four-step risk management process framework was adopted: risk identification, risk analysis, risk response, and risk monitoring. Afterwards, the literature review continued to compare the current risk analysis methods. Although most of the methods were mature and had been used in the industry before, due to the uncertainties and the unavailability or absent of data and risks, i.e., the relatively new sustainability-related risks, the Bayesian Belief Network (BBN) and the Analytic Hierarchy Process (AHP) were chosen as a combined method for the risk analysis and assessment in the proposed model.

Third objective: To conduct a focus group to check and modify the initial sustainability-related hazards and their applicability in the Jordanian construction industry.

the primary data collection began with a focus group conducted with eight experts from the Jordanian construction industry. This discussion identified the sustainability-related risks that affect the Jordanian construction industry, as well as the causes of these risks.

Fourth objective: To conduct a questionnaire survey to find the highest sustainability-related risks in the Jordanian construction industry, for use in the final proposed model.

In the second part of the primary data collection, a questionnaire was distributed to experts, engineers and managers working in the construction industry in Jordan. The questionnaire asked the participants to rate sustainability-related risks based on their impact and frequency, thus producing the final list of sustainability-related risks.

Fifth objective: To develop a new risk model for sustainability risk analysis and assessment using the Analytic Hierarchy Process and Bayesian Belief Network for managing and assessing these sustainability-related risks.

The development of the model started early in the research, firstly, by identifying the initial list of sustainability-related risks in the literature review. After that, the theoretical basis for the development of a new model were set in the risk management chapter. Later in the primary data collection, the researcher was able to generate the final list of sustainability-related risk that would be used in the final model by identifying the risks applicable in the Jordanian construction industry and their cause from the initial list then rate them according to their impact and probability by using focus groups and questionnaire, respectively. The risk assessment development model chapter concluded with developing the risk analysis method by combining the Analytic Hierarchy Process (AHP) and Bayesian Belief Network (BBN) to produce the final sustainability risk assessment model.

Sixth objective: To conduct three case studies to validate the proposed model.

Three case studies were carried out on three different projects in the Jordanian construction industry to check and validate the model. The first case study was a commercial building, while the second was an infrastructure project for the construction of a road. The final case was the construction and rehabilitation of a waste landfill. The results were presented and compared for the three case studies, confirming that the validity of the model and giving different rankings for sustainability-related risks, depending on the projects' characteristics. Finally, it showed the discussions with the three project managers validating the need, content, structure and applicability of the developed model.

Seventh objective: To produce recommendations for the improvement of risk management and sustainability in Jordanian construction projects.

A list of recommendations for the improvement of risk management and sustainability in construction projects were drawn up in order to help the industry move further towards sustainable practices.

8.3 Research Findings

The results of this study indicated a strong relationship between risk management in the construction industry and sustainability. The results of this study agreed with the WCED's (1987) definition of sustainability or sustainable building, which is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The study demonstrated the importance of sustainability at the local and global levels, as it worked to reduce long-term risks associated with resource and energy depletion, pollution, waste management, and product obligations, risks stated previously by Shrivastava (1995). The study concluded that sustainability consisted of three basic dimensions, which were social, environmental, and economic dimensions, in agreement with Talbot and Venkataraman (2011). According to these authors, what linked these dimensions in the construction industry was their social and environmental aspects, as the management of sustainable construction positively affected individuals and the environment in which they live. In agreement with Munasinghe (1993), the study results indicated that neglecting sustainability would negatively affect the biological and physical systems in the surrounding environment, and this would lead to inequality between generations and different living organisms.

Previous research, such as that by Bello et al. (2020) focused on countries and how they establish rules for regulating their construction industries. As stated in HLPF-Jordan (2017), Jordan is in its infancy in terms of developing a sustainable building industry in line with the green buildings that sustainability founders aspire to popularise. This is due to the lack of resources and the unprosperous economic situation in Jordan. There are buildings, rating systems, and tools that show whether the building is sustainable or not. Our results, in accordance with Kibert, (2013), acknowledged LEED, BREEAM, PEARL, RATING, GSAS, among other of certification systems for sustainable constructions. In Jordan, only ten buildings are LEED certified (Lacave, 2021). This shows the beginning of an interest in linking sustainability to the construction industry, but the country seems unable to accelerate sustainable development as desired. The concept of sustainability is directly related in this research to risk management. In view of the research hypotheses, the results of the study agreed with the first research hypothesis, which states that the construction industry in Jordan contains risks that fall under six categories, namely, risks that have an impact on natural resources, socio-economic conditions, public and occupational health, the ecosystem, and biodiversity, and managerial risks, similar to the findings of Saaty (1986).

Wang et al.'s (2000) research showed that in our fast-moving world, humans and the environment may be exposed to several risks that can have high, medium, or low impacts on them. Hence, the concept of risk management has appeared (Flanagan & Norman, 1993). The researcher recognised that risk management is the process by which risks are identified or predicted in a way to enable decisions with a higher degree of certainty (Clark et al., 1990). In line with Tsiga et al. (2017), the researcher found that risk management in the construction industry helps to implement a good project that is free from risks and has a higher degree of certainty of success. Through risk management, any negative impacts on the environment or on the community surrounding the construction industry can be mitigated (Tsiga et al., 2017). This is one of the most important principles of sustainability that Mensah (2019) listed, along with ensuring justice, human rights, equality, and continuity so that people can live in a dignified atmosphere without endangering their lives directly or indirectly.

After identifying the risks, their classifications, and their impacts on the environment in Jordan, the results of the study indicated that the model that has been developed is valid. This is due to the fact that this model understands the management of sustainability-related risks exclusively to help the realtors and their projects to implement risk management related to sustainability, thus creating sustainable buildings. This was assessed through three case studies that contributed to clarifying the model's validity. With this model, the problems associated with risk management in the Jordanian construction industry can be identified. A model has been created through which each building project is taken separately, a problem is identified in it, and then the information is collected and analysed. Sustainability-related risks are then identified so that they can be managed and the events that may lead to or be affected by these risks can be assessed. Then, the risks are assessed, their ratings calculated, and finally, they can be quantified and managed efficiently through the use of this valid model. Despite its validation, future research must be conducted to improve its effectiveness and increase its implications.

The results of the three case studies showed that the construction industry in Jordan is very familiar with the concepts of risk management and sustainability, albeit failing to apply them. It seems that there is a great deal of neglect on the part of the government and private bodies responsible for the construction industry and the application of sustainability.

8.3 Recommendations

In the construction industry, contractors and engineers must control the impacts of the work in each stage during the development of the project. It is possible to incorporate elements aimed at reducing, mitigating, correcting, or compensating for the negative impacts on the environment, as well as enhancing the positive ones. Through the analysis of the relationship between the construction project and the environment, it would be possible to identify the activities and risks that require more careful management and the most important programmes to reduce the significant impacts. The application of the following recommendations will make it possible to assess the environmental impacts, define the priorities in the sustainability-related risks management process and create mitigation plans in the construction industry to reduce its effects on the environment:

- When initiating a new construction project, timely identification of the restrictions process would be helpful in achieving a construction design in accordance with the conditions of the terrain, reducing possible impacts. When studying the terrain on which the construction project work takes place, the responsible engineers must identify the relationships between the terrain's stability, hydrological dynamics, topography, and vegetation. They must observe the area during heavy rain events and also identify the state of the existing urban infrastructure.

- ❖ It is essential to consider the environmental aspects of a project in order to reduce its impacts. The construction project design must consider having the least impact on natural resources. The project planners and engineers must minimise the felling of trees, conserve withdrawals to water sources (where possible, exceed the existing standard), reduce earth movements, maintain the largest possible green area, use materials with low environmental impact, etc. They must bear in their mind that the best environmental management strategy consists of designing a construction project according to the reality of the terrain. Instead of compensating for or mitigating negative environmental impacts, these must be eliminated from the design's core work. The design of the internal spaces must also contemplate a maximum use of natural lighting and ventilation in order to minimise energy consumption during the operation of the building. Engineers must contemplate the opportunity to use rainwater and reuse grey water.

- ❖ The construction project executors must process all the authorisations and approvals from the different entities. They must ensure the project's compatibility with the municipality, the planning and management plans for watersheds and micro-watersheds, sustainable development projects, partial plans, etc.

- ❖ The timely development of the construction project procedures would allow the work to be executed in the estimated times. The construction project executors should carry out this type of management so that it does not leave open the possibility of stopping the construction project once it has started. In this way, its impact on the environment and the neighbouring community will be reduced over time.

- ❖ Engineers must consider that proper space management can allow them to reduce transportation needs inside the construction site and make the handling of materials more efficient. Engineers and project executers must keep internal roads in good condition and carry out adequate drainage works. They must keep as much distance as possible from water sources and other environmental resources, and where possible arrange for the storage of rainwater collected on roofs. They must organise their construction sites so that they can use this resource. They must design the necessary infrastructure for a comfortable and efficient separation of waste.

- ❖ Engineers have to avoid the movement of materials or debris in residential areas and during rush hours.

- ❖ Engineers, project executors, and workers must consider the adequate sites to store buildings materials, whether temporarily or permanently. They must focus on the excavation residues and seek quick covers that prevent fugitive emissions of particulate material and arrange drainage so that erosive processes are prevented.

- Engineers, project executors, and the workers must provide the infrastructure and elements necessary for the proper handling of lubricants and fuels. They have to carry out works for the assembly of the machinery in a way that prevents soil contamination. In addition, installing noise barriers is a must.

- The engineers must design a programme for waste management. The solid waste generated during the construction process is of various types. Proper classification of the same will allow the materials to be recycled or reused, thus minimising the amount of unusable waste. In this way, final disposal costs are reduced, the use of materials is optimised, and a lower environmental impact is achieved.

8.4 Limitations

In conclusion, the researcher cannot deny that there were limitations to the study in the lack of literature related to risk management and sustainability in Jordan and their relationship to each other. These limitations were overcome by utilising a mixed methodology through a questionnaire, a focus group, and also case studies. The other limitation was in convincing the experts to attend and participate in the focus group meetings, where some experts in the focus group refused to attend the meetings. The initial focus group was made up of ten experts, but two apologised and the group was reduced accordingly to eight experts, none of which accepted that the sessions be recorded. It was a challenge for the researcher to convince them to attend the meetings, but this challenge was overcome by reframing the focus group and making it consist of eight people in a way that fitted the study. The study reflected very important findings. The significance of this research and its expanded methodology lies in its contribution to enriching the literature on the topic of sustainability-related risk management in Jordan and across the world.

8.5 Conclusions

The links between climate change, global warming, sustainability-related risk management, national and global development, and the management of the construction industry are evident. Technical knowledge and capacities in these areas are important. There are important strategies and frameworks for sustainability at the local level in Jordan and the international level. Yet it is still necessary to bring together all these assets in a coherent and rational way. This is done by garnering the lasting participation of all areas of expertise and all levels of responsibility, to achieve systematic sustainable-risk management and reduction of the risks locally and globally. Many challenges remain, evident in the continuing increase in sustainability vulnerabilities and the impacts of risks. Developing countries such as Jordan are the most vulnerable.

The sustainability-related risks management process requires the full commitment of the Jordanian construction industry to sustainable development. Engineers are indeed well placed because of their knowledge of sustainability and their relationships with the construction industry. Furthermore, they have essential capacities that allow them to understand both general hazards or risks and sustainability-related risks management, as well as long-term variations and changes in climate.

The actions that this research proposes to carry out are applying best practices through the proposed model concerning the forecasting and identification of the risks, which in turn lead to their analysis, thus, mitigating or eliminating them. International rating systems and methods can be used in Jordan such as LEED, BREEAM, PEARL RATING, GSAS with their various frameworks in order to build a sustainable construction industry. These systems and methods are important melting pots for the sustainability of new ideas, commitment, and coordination needed. These methods and the developed model obviously do not end in themselves but are essential means to develop and guide concrete measures where appropriate, namely to continuously contribute to the management of the sustainability-related risks in Jordan and other countries.

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Appendices

Appendix 1 Ethical approval

Research, Innovation and Academic Engagement Ethical Approval Panel

Doctoral & Research Support
Research and Knowledge Exchange,
Room 827, Maxwell Building
University of Salford
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M5 4WT

T +44(0)161 295 5278

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17 December 2019

Yazan Salem Al-Sheikh

Dear Yazan

RE: ETHICS APPLICATION STR1920-03 – The development of a sustainability risk assessment model for construction projects: A case study on the Jordanian construction industry.

Based on the information you provided, I am pleased to inform you that your application STR1920-03 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

Dr Devi Prasad Tumula
Deputy Chair of the Science & Technology Research Ethics Panel

Appendix 2 Participant Information Sheet (Focus Group)

Participant Information Sheet
(Focus Group)

What is the purpose of the study?
The aim of this research is to develop a risk assessment and analysis model to manage the sustainability-related risks in the Jordanian construction industry.

Why have I been invited?
You have been invited to participate in this research as you are an effective member of the Jordanian construction industry.

Do I have to take part?
It is up to you to decide. It is really appreciated if you participate and you are free to withdraw at any time without giving a reason*.

What will happen to me if I take part?

- Your identity remains anonymous.
- All collected data will be stored electronically on Salford University computer and accessed only by the researcher, then it will be destroyed when no longer value to this research.

What will I have to do?
You will be asked to sign a consent form to show that you agreed to take part. All what you have to do then is participating in the focus group.

What if there is a problem?
If you have a concern about any aspect of this study, you should ask to speak to me; I will do my best to answer your questions. If you remain unsatisfied and wish to complain formally you can do this through my supervisor:
Prof. Min An

(Email: m.an@salford.ac.uk).

* In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

Will my information in the study be kept anonymous?

- Procedures for handling, processing, storage and destruction of data match the general data protection regulation (GDPR) and The Salford Research code of Ethics, the data is not to be used for future studies
- All your information collected during the course of the research will be kept strictly anonymous.
- Collected data will be stored electronically on Salford University computer and accessed only by the researcher and will be destroyed when no longer value to this research.
- Collected data will be stored and archived. After that, data will be deleted after the completion of this research.

What will happen if I don't carry on with the study?
In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

What will happen to the results of the research study?
The results of the study in which you are involved in will be made available on your request. Furthermore, according to the general data protection regulation (GDPR) and The Salford Research code of Ethics, all data collected will be kept securely and will be erased completely after the results of the study are published.

Further information and contact details:

Yazan Alsheikh Salem
PhD Researcher
School of Built Environment
University of Salford
Maxwell Building
Mobile: +44 7459423893
E-mail: Y.alsheikhsalem@edu.salford.ac.uk

* In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

Appendix 3 Participant Invitation Letter (Focus Group)

Participant Invitation Letter (Focus Group)

Dear Participant,

I would like to invite you to take part in a research project entitled: The development of a sustainability risk assessment model for construction projects: A case study on the Jordanian construction industry

The aim of this research is to develop a risk assessment and analysis model to manage the sustainability-related risks in the Jordanian construction industry.

There are no identified risks from participating in this research and it is completely voluntary, and you may refuse to participate without consequence. Furthermore, according to the general data protection regulation (GDPR) and The Salford Research code of Ethics, all data collected will be kept securely and will be erased completely after the results of the study are published.

Attached to this invitation is a Participant Information Sheet. This will provide you with further information about the focus group and who to contact if you have any questions.

I hope you choose to take part in this focus group and to consider sharing your experience, which will help me identifying ways to improve Jordanian construction industry.

Sincerely,

Yazan Alsheikh Salem
PhD Researcher
School of Built Environment
University of Salford
Maxwell Building
Mobile: +44 7459423893
E-mail: Y.alsheikhsalem@edu.salford.ac.uk

Appendix 4 Participant Consent Form (Focus Group)

Participant Consent Form
(Focus Group)

The development of a sustainability risk assessment model for construction projects: A case study on the Jordanian construction industry

Name of the researcher: Yazan Alsheikh Salem

Name of the supervisor: Prof. Min An

The collected data will be used for:

A study aims to develop a risk assessment and analysis model to manage the sustainability-related risks in the Jordanian construction industry.

Please tick the appropriate boxes:

	Yes	No
• I have read and understand the project information sheet.	☐	☐
• I have been given the opportunity to ask questions about the project.	☐	☐
• I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part. *	☐	☐
• I agree to take part I n this interview.	☐	☐

Name of the participant: ………………………...

Signature: ………………………………………...

* In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

Appendix 5 Participant Information Sheet (Questionnaire)

Participant Information Sheet
(Questionnaire)

What is the purpose of the study?

The aim of this research is to develop a risk assessment and analysis model to manage the sustainability-related risks in the Jordanian construction industry.

Why have I been invited?
You have been invited to participate in this research as you are an effective member of the Jordanian construction industry.

Do I have to take part?
It is up to you to decide. It is really appreciated if you participate and you are free to withdraw at any time without giving a reason*.

What will happen to me if I take part?

- Your identity remains anonymous.
- All collected data will be stored electronically on Salford University computer and accessed only by the researcher, then it will be destroyed when no longer value to this research.

What will I have to do?
You will be asked to sign a consent form to show that you agreed to take part. All what you have to do then is answering the questionnaire questions.

What if there is a problem?
If you have a concern about any aspect of this study, you should ask to speak to me; I will do my best to answer your questions. If you remain unsatisfied and wish to complain formally you can do this through my supervisor: **Prof. Min An**

(Email: m.an@salford.ac.uk).

* In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

Will my information in the study be kept anonymous?

- Procedures for handling, processing, storage and destruction of data match the general data protection regulation (GDPR) and The Salford Research code of Ethics, the data is not to be used for future studies.
- All your information collected during the research will be kept strictly anonymous.
- Collected data will be stored electronically on Salford University computer and accessed only by the researcher and will be destroyed when no longer value to this research.
- Collected data will be stored and archived. After that, data will be deleted after the completion of this research.

What will happen if I don't carry on with the study?
In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

What will happen to the results of the research study?
The results of the study in which you are involved in will be made available on your request. Furthermore, according to the general data protection regulation (GDPR) and The Salford Research code of Ethics, all data collected will be kept securely on Salford university PC and will be erased completely after the results of the study are published.

Further information and contact details:

Yazan Alsheikh Salem
PhD Researcher
School of Built Environment
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Mobile: +44 7459423893
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Appendix 6 Participant Invitation Letter (Questionnaire)

Participant Invitation Letter (Questionnaire)

Dear Participant,

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The aim of this research is to develop a risk assessment and analysis model to manage the sustainability-related risks in the Jordanian construction industry.

There are no identified risks from participating in this research and it is completely voluntary, and you may refuse to participate without consequence. Furthermore, according to the general data protection regulation (GDPR) and The Salford Research code of Ethics, all data collected will be kept securely and will be erased completely after the results of the study are published.

Attached to this invitation is a Participant Information Sheet. This will provide you with further information about the interview and who to contact if you have any questions.

I hope you choose to take part in this questionnaire and to consider sharing your experience, which will help me identifying ways to improve Jordanian construction industry.

Sincerely,

Yazan Alsheikh Salem
PhD Researcher
School of Built Environment
University of Salford
Maxwell Building
Mobile: +44 7459423893
E-mail: Y.alsheikhsalem@edu.salford.ac.uk

Appendix 7 <u>Participant Consent Form (Questionnaire)</u>

Participant Consent Form (Questionnaire)

The development of a sustainability risk assessment model for construction projects: A case study on the Jordanian construction industry

Name of the researcher: Yazan Alsheikh Salem

Name of the supervisor: Prof. Min An

The collected data will be used for:

The aim of this research is to develop a risk assessment and analysis model to manage the sustainability-related risks in the Jordanian construction industry.

Please tick the appropriate boxes:

	Yes	No
• I have read and understand the project information sheet.	☐	☐
• I have been given the opportunity to ask questions about the project.	☐	☐
• I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part. *	☐	☐
• I agree to take part I n this questionnaire.	☐	☐

Name of the participant: ………………………………………………………………………

Signature: ……………………………………………………………………………………

* In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

Appendix 8 Participant Information Sheet (Interviews)

Participant Information Sheet (Interviews)

What is the purpose of the study?
The aim of this research is to develop a risk assessment and analysis model to manage the sustainability-related risks in the Jordanian construction industry.

Why have I been invited?
You have been invited to participate in this research as you are an effective member of the Jordanian construction industry.

Do I have to take part?
It is up to you to decide. It is really appreciated if you participate and you are free to withdraw at any time without giving a reason*.

What will happen to me if I take part?

- Your identity remains anonymous.
- All collected data will be stored electronically on Salford University computer and accessed only by the researcher, then it will be destroyed when no longer value to this research.

What will I have to do?
You will be asked to sign a consent form to show that you agreed to take part. All what you have to do then is answering the interview questions.

What if there is a problem?
If you have a concern about any aspect of this study, you should ask to speak to me; I will do my best to answer your questions. If you remain unsatisfied and wish to complain formally you can do this through my supervisor: **Prof. Min An**

(Email: m.an@salford.ac.uk).

* In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

Will my information in the study be kept anonymous?

- Procedures for handling, processing, storage and destruction of data match the general data protection regulation (GDPR) and The Salford Research code of Ethics, the data is not to be used for future studies
- All your information collected during the course of the research will be kept strictly anonymous.
- Collected data will be stored electronically on Salford University computer and accessed only by the researcher and will be destroyed when no longer value to this research.
- Collected data will be stored and archived. After that, data will be deleted after the completion of this research.

What will happen if I don't carry on with the study?

In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

What will happen to the results of the research study?

The results of the study in which you are involved in will be made available on your request. Furthermore, according to the general data protection regulation (GDPR) and The Salford Research code of Ethics, all data collected will be kept securely and will be erased completely after the results of the study are published.

Further information and contact details:

Yazan Alsheikh Salem

PhD Researcher
School of Built Environment
University of Salford
Maxwell Building
Mobile: +44 7459423893
E-mail: Y.alsheikhsalem@edu.salford.ac.uk

* In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

Appendix 9 Participant Invitation Letter (Interviews)

Participant Invitation Letter (Interviews)

Dear Participant,

I would like to invite you to take part in a research project entitled: The development of a sustainability risk assessment model for construction projects: A case study on the Jordanian construction industry

The aim of this research is to develop a risk assessment and analysis model to manage the sustainability-related risks in the Jordanian construction industry.

There are no identified risks from participating in this research and it is completely voluntary, and you may refuse to participate without consequence. Furthermore, according to the general data protection regulation (GDPR) and The Salford Research code of Ethics, all data collected will be kept securely and will be erased completely after the results of the study are published.

Attached to this invitation is a Participant Information Sheet. This will provide you with further information about the interview and who to contact if you have any questions.

I hope you choose to take part in this interview and to consider sharing your experience, which will help me identifying ways to improve Jordanian construction industry.

Sincerely,

Yazan Alsheikh Salem
PhD Researcher
School of Built Environment
University of Salford
Maxwell Building
Mobile: +44 7459423893
E-mail: Y.alsheikhsalem@edu.salford.ac.uk

Appendix 10 **Participant Consent Form (Interviews)**

Participant Consent Form (Interviews)

The development of a sustainability risk assessment model for construction projects: A case study on the Jordanian construction industry

Name of the researcher: Yazan Alsheikh Salem

Name of the supervisor: Prof. Min An

The collected data will be used for:

The aim of this research is to develop a risk assessment and analysis model to manage the sustainability-related risks in the Jordanian construction industry.

Please tick the appropriate boxes:

	Yes	No
• I have read and understand the project information sheet.	☐	☐
• I have been given the opportunity to ask questions about the project.	☐	☐
• I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part. *	☐	☐
• I agree to take part I n this interview.	☐	☐

Name of the participant: ………………………………………………………………………………

Signature: ……………………………………………………………………………………………

* In case the participant decided to withdraw after the data been analysed and anonymised, the collected data continue to be used anonymously. It is not able to delete the data due to the anonymity process.

Appendix 11 The Questionnaire

Sustainable Risk Management

I would like to invite you to take part in a research study. Before you decide you need to understand why this research is being done and what would it involve for you. Please take the time to read the following information carefully. Ask questions if anything is not clear or if you would like more information. Take time to decide whether or not to take part.

The aim of this research is to develop a model for sustainability risk assessment that is efficient and feasible in the Jordanian construction industry. Also, this research will focus on addressing the problems facing sustainable construction and its application in Jordan.

It is your choice to decide to participate in this survey. the study will be described through the information sheet, which will be given to you. then you will be asked to sign a consent form to show you agreed to take part. You are free to withdraw at any time, without even giving any reason.

The survey is designed to easily work with and not to waste a lot of your time, with rating questions for the impact and frequency of the hazardous events.

There will be no expense or cost by participating in this study; it is completely free. A thank you email will be sent to you after completing the questionnaire. I cannot promise the study will help you but the information I get from the study will be helpful for this research.

If you have a concern about any aspect of this study, please contact me, I will do my best to answer your questions:

Yazan Alsheikh Salem
00447459423893
Ysalem92@gmail.com

*Required

1. I confirm that I have read and understood the information sheet of the study above, and what my contribution will be. *

   Mark only one oval.

   ◯ Yes
   ◯ No

Respondent information

Questions 1-5

/

2. 1- Years of experience?

Mark only one oval.

- Less than 5 years
- 5 to 10 years
- 10 to 15 years
- More than 15 years

3. 2- What is your current job position?

Mark only one oval.

- Architect
- Structural engineer
- Project manager
- Researcher
- Site engineer
- Other: ______________________

4. 3- What is the type of your organisation?

Mark only one oval.

- Structural design
- Architectural design
- Contractor
- Supervision and consultancy firm
- University
- Other: ______________________

5. 4- What is the size of your organisation?

Mark only one oval.

- Less than 25 employees
- less than 50 employees
- 50 - 100 employees
- more than 100 employees
- Other: ____________________

6. 5- How can you describe your experience in environmental risk management practices? *

Mark only one oval.

- Worked on projects that are considered environmentally risky before.
- Familiar with environmental risk management practices but did not apply them before
- Not familiar at all

The impact and frequency of hazardous events

24 questions

Impact score	Impact level
1	Very low
2	low
3	Moderate
4	high
5	Very high

probability score	Probability level
1	Very rare
2	Rare
3	Intermediate
4	Possible
5	Highly possible

The impact and frequency of hazardous events on natural resources

Questions 1-2

7. 1- Excessive use of raw materials *

Mark only one oval per row.

	1	2	3	4	5
impact					
frequency					

/

8. 2- The depletion of natural resources, renewable and non-renewable resources. (i.e. water, oil, timber, soil, etc.) *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

The impact and frequency of hazardous events on the ecosystem

Noise

Question 3

9. 3- Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.) site activities construction, demolition, pilling, blasting, etc. and on and of site traffic and deliveries. *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

Air quality

Questions 4-9

10. 4- Deterioration of air quality (indoor and outdoor) *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

11. 5- Emissions from construction activities and equipment *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

12. 6- Emissions of VOC (Volatile organic compounds) *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

13. 7- Emissions of harmful gases (i.e. CFCs, Carbone dioxide, Nitrous oxide, Sulfur oxide, Methane and Ozone) *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

14. 8- Dust generation from construction activities, machineries and equipment *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

15. 9- Bad odour generation from handling of construction materials, waste and sewage *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

Soil

Questions 10-13

16. 10- High soil erosion and excavation *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

17. 11- Land pollution (associated with construction activities, machineries and equipment) *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

18. 12- The use of identified or unidentified contaminated soil during fill operations *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

/

19. 13- Inadvertent transport and subsequent disposal of unknown contaminated soil *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

Water

Questions 14-17

20. 14- Contamination of rainwater runoff and surface water *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

21. 15- Underground water pollution *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

22. 16- Improper discharge of the workplace's wastewater *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

/

23. 17- Change or obstruct of river flow *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

The impact and frequency of hazardous events on biodiversity

Questions 18-24

24. 18- Adverse effect on the wildlife and disrupting the habitats. *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

25. 19- Impact on migration routes. *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

26. 20- Loss of agricultural lands and vegetation removal. *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

27. 21- Mountains and forest removal (Deforestation). *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

28. 22- Wetland habitats disruption. *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

29. 23- Roadside plantation removal. *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

30. 24- Disruption of sensitive species of flora and fauna during breeding, nesting, foraging, residing overwintering migration. *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

The impact and frequency of hazardous events

24 Questions

The impact and frequency of hazardous events on socio-economic conditions

Questions 1-8

31. 1- Adverse visual impact. *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

32. 2- Landscape alteration. *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

33. 3- Disrupt business in the community *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

34. 4- Demand or stress on the infrastructure and the road network *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

/

35. 5- The project caused an adverse effect on local communities and disturbed demographic structure of local communities *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

36. 6- People relocation *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

37. 7- Public dissatisfaction with the project *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

38. 8- Adverse effect on archaeology, cultural heritage and sacred site. *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

The impact and frequency of hazardous events on public and occupational health

Questions 9-11

/

39. 9- Construction accidents and causalities *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

40. 10- Adverse effect on public health and safety *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

41. 11- Lack of attention to health issues in the workplace *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

Waste management

Questions 12-14

42. 12- Improper disposal of ordinary and domestic solid waste *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

43. 13- Improper disposal of special waste *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

44. 14- Improper disposal of the building's debris (other than soil) *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

Chemicals or hazardous materials

Questions 15-20

45. 15- Improper use of materials containing a carcinogen substance *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

46. 16-Lead poisoning from paint and other material containing lead *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

47. 17- Spills and releases during the application and transportation of asphalt *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

48. 18- Pollution resulting from collisions with various structures like above-ground tanks, pole-mounted transformers *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

49. 19- Contamination from spills of (oils, fuels, lubricants) from field equipment and improperly stored materials or due to vandalism *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

50. 20- Failure of underground utility lines, pipes and other underground structures. *

Mark only one oval per row.

	1	2	3	4	5
impact	◯	◯	◯	◯	◯
frequency	◯	◯	◯	◯	◯

The impact and frequency of managerial hazardous events

Questions 21-24

51. 21- Insufficient on-site investigation resulted in improper adjustment measures to local conditions. *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

52. 22- Unclear allocation of roles and responsibilities. *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

53. 23- Lack of availability of green materials and equipment (limited availability of suppliers and import restrictions). *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

54. 24- Inadequate knowledge of workers about environmental concerns, green materials and construction technologies. *

Mark only one oval per row.

	1	2	3	4	5
impact	⬭	⬭	⬭	⬭	⬭
frequency	⬭	⬭	⬭	⬭	⬭

Suggested environmental hazardous event

One question

/

55. 1- Could you please suggest an additional hazardous event (if any)

Appendix 12 The List of Hazards taken from Rating Systems and UN Goals

List of Hazards Impact on Natural Resources:		RATING SYSTEMS	UN GOALS
(1)	Excessive use of raw materials.	• LEED/Sourcing of Raw Materials – MRc3. • GSAS/[E.1] ENERGY USE - TEMPORARY BUILDINGS. • GSAS/[E.2] ENERGY USE – PLANT & EQUIPMENT. • BREEAM/ Ene 01 Reduction of energy use and carbon emissions standards.	• UN/7.1 By 2030, ensure universal access to affordable, reliable and modern energy services. • UN/7.3 By 2030, double the global rate of improvement in energy efficiency.
(2)	Excessive consumption of both renewable and non-renewable resources.	• LEED/Renewable Energy Production – EAc5. • LEED/Building Life-Cycle Impact Reduction – MRc1. • ESTIDAMA/PW-R1: Water Efficiency. • ESTIDAMA/RE-1: Renewable Energy. • GSAS/[E.1] ENERGY USE - TEMPORARY BUILDINGS. • GSAS/[E.2] ENERGY USE – PLANT & EQUIPMENT. • GSAS/[W.1] DOMESTIC WATER USE. • GSAS/[W.2] NON-DOMESTIC WATER USE. • BREEAM/ Wat 01 Water consumption. • BREEAM/ Ene 01 Reduction of energy use and carbon emissions standards.	• UN/12.2 By 2030, achieve the sustainable management and efficient use **of natural resources.** • 7.1 By 2030, ensure universal access to affordable, reliable and modern energy services. • 7.2 By 2030, increase substantially the share of renewable energy in the global energy mix. • 7.3 By 2030, double the global rate of improvement in energy efficiency. • 7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology. • 7.b By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed

			countries, small island developing states, and land-locked developing countries, in accordance with their respective programmes of support.
(3)	The depletion of natural resources.	• LEED/Building Life-Cycle Impact Reduction – MRc1. • ESTIDAMA/PW-R1: Water Efficiency. • BREEAM/ Wat 01 Water consumption.	• UN/12.2 By 2030, achieve the sustainable management and efficient use **of natural resources.** • UN/6.4 By 2030, substantially increase **water-use efficiency across all** sectors and ensure sustainable withdrawals and supply of fresh water to address water scarcity and substantially reduce the number of people suffering from water scarcity.
Socio-Economic Conditions:			
(4)	Adverse visual impact.	• LEED/Site Development: Protect and Restore Habitat – SSc2. • GSAS/[S.1] LAND PRESERVATION. • GSAS/[OE.3] LIGHT POLLUTION & VISUAL IMPACT CONTROL. • BREEAM/Hea 01 Visual comfort.	
(5)	Landscape alteration.	• LEED/Site. Development: Protect and Restore Habitat – SSc2. • ESTIDAMA/NS-3: Landscape Enhancement. • GSAS/[S.1] LAND PRESERVATION.	
(6)	Disrupt business in the community.	• GSAS/[SD.2] SOCIO-CULTURAL INTERACTION.	• UN/By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day. • UN/1.2 By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions

			according to national definitions. • UN/8.6 By 2020, substantially reduce the proportion of youth not in employment, education or training.
(7)	High demand or stress on the infrastructure and the road network.		• UN/1.4 By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance. • UN/11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons. • UN/9.2 Promote inclusive and sustainable industrialisation and, by 2030, significantly raise industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries.
(8)	Social disruption, the project causing an adverse effect on the local communities and disturb the demographic structure of the locals.	• GSAS/[SD.2] SOCIO-CULTURAL INTERACTION.	

(9)	Disturbance to a sacred site or other cultural values.	• LEED/High Priority Site – LTc3. • LEED/Building Life-Cycle Impact Reduction – MRc1. • GSAS/[S.1] LAND PRESERVATION. • GSAS/[SD.1] PROTECTION OF ARCHAEOLOGICAL REMAINS. • BREEAM/ LE 01 Site selection.	• UN/11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage.
10)	People relocation.	• GSAS/[S.2] BIODIVERSITY PRESERVATION. • GSAS/[SD.2] SOCIO-CULTURAL INTERACTION.	
11)	Poor habitability.	• GSAS/[S.2] BIODIVERSITY PRESERVATION. • GSAS/[SD.2] SOCIO-CULTURAL INTERACTION.	
12)	The public's satisfaction with the project is very low.	• GSAS/[SD.2] SOCIO-CULTURAL INTERACTION.	
13)	Adverse effect on archaeology and cultural heritage.	• LEED/High Priority Site – LTc3. • LEED/Building Life-Cycle Impact Reduction – MRc1. • GSAS/[S.1] LAND PRESERVATION. • GSAS/[SD.1] PROTECTION OF ARCHAEOLOGICAL REMAINS. • BREEAM/ LE 01 Site selection.	• UN/11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage.
Public and occupational Health:			
14)	Construction accidents and casualties.	• GSAS/[MO.3] CONSTRUCTION HEALTH & SAFETY.	• UN/8.8 Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment.

15)	Poor site hygiene conditions.	• GSAS/[MO.3] CONSTRUCTION HEALTH & SAFETY. • GSAS/[MO.2] WELFARE FACILITIES.	
16)	Adverse effect on public health and safety.	• GSAS/[MO.3] CONSTRUCTION HEALTH & SAFETY.	• UN/8.8 Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment.
17)	Lack of attention to health issues in the workplace.	• GSAS/[MO.3] CONSTRUCTION HEALTH & SAFETY.	
18)	Inadequate responsibility or commitment of the expert in HSE work.	• GSAS/[MO.3] CONSTRUCTION HEALTH & SAFETY.	
Impact on the ecosystem:			
	Noise		
19)	Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.).	• GSAS/[OE.2] NOISE & VIBRATION CONTROL. • BREEAM/ Pol 05 Reduction of noise pollution.	
20)	Noise and vibrations from site activities construction, demolition, piling, blasting, etc.	• GSAS/[OE.2] NOISE & VIBRATION CONTROL. • BREEAM/ Pol 05 Reduction of noise pollution.	
21)	Noise and vibrations from on and off site traffic and deliveries.	• GSAS/[OE.2] NOISE & VIBRATION CONTROL. • BREEAM/ Pol 05 Reduction of noise pollution.	
	Air quality		
22)	Air pollution.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • BREEAM/ Pol 02 Local air quality.	• UN/13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries. • UN/13.2 Integrate climate change measures into national policies, strategies and planning. • UN/11.6 By 2030, reduce the adverse per capita environmental impact of

			cities, including by paying special attention to air quality and municipal and other waste management. • UN/3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
23)	Bad air quality.	• LEED/Indoor Air Quality (IAQ). • LEED/Construction Indoor Air Quality Management – EQc3. • BREEAM/ Hea 02 Indoor air quality. • BREEAM/ Pol 02 Local air quality.	
24)	Emission from the combustion of fossil fuel from stationary and mobile sources.	• LEED/Construction Activity Pollution Prevention – SSp1. • LEED/Construction Indoor Air Quality Management – EQc3. • BREEAM/ Pol 02 Local air quality.	• UN/13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries. • UN/13.2 Integrate climate change measures into national policies, strategies and planning.
25)	Emissions from construction activities and equipment.	• LEED/Construction Activity Pollution Prevention – SSp1. • LEED/Construction Indoor Air Quality Management – EQc3. • BREEAM/ Pol 02 Local air quality.	
26)	Emissions of CFC, VOC (Volatile organic compounds).	• LEED/Building Life-Cycle Impact Reduction – MRc1. • LEED/Indoor Air Quality (IAQ). • LEED/Construction Indoor Air Quality Management – EQc3. • GSAS/[OE.4] ODOUR & VOC EMISSIONS CONTROL. • BREEAM/ Hea 02 Indoor air quality.	

		• BREEAM/ Pol 02 Local air quality.	
27)	Emissions of greenhouse gases.	• LEED/Building Life-Cycle Impact Reduction – MRc1. • LEED/Construction Indoor Air Quality Management – EQc3. • BREEAM/ Hea 02 Indoor air quality. • BREEAM/ Pol 02 Local air quality.	• UN/13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries. • UN/13.2 Integrate climate change measures into national policies, strategies and planning.
28)	Airborne house suspended particles.	• LEED/Construction Activity Pollution Prevention – SSp1. • LEED/Indoor Air Quality (IAQ). • LEED/Construction Indoor Air Quality Management – EQc3. • BREEAM/ Hea 02 Indoor air quality. • BREEAM/ Pol 02 Local air quality.	
29)	Photochemical smog.	• LEED/Construction Activity Pollution Prevention – SSp1. • LEED/Indoor Air Quality (IAQ). • LEED/Construction Indoor Air Quality Management – EQc3. • BREEAM/ Hea 02 Indoor air quality. • BREEAM/ Pol 02 Local air quality.	
30)	Ozone exhaustion or depletion.	• LEED/Building Life-Cycle Impact Reduction – MRc1. • Construction Indoor Air Quality. Management – EQc3. • BREEAM/ Pol 02 Local air quality.	• UN/13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries. • UN/13.2 Integrate climate change measures into national policies, strategies and planning.
31)	CO2, SO2, CO, NOx, emissions.	• LEED/Construction Activity Pollution Prevention – SSp1. • LEED/Building Life-Cycle Impact Reduction – MRc1.	

		• LEED/Construction Indoor Air Quality Management – EQc3. • BREEAM/ Pol 02 Local air quality.	
32)	Dust generation from construction activities, construction machinery and equipment.	• LEED/Construction Activity Pollution Prevention – SSp1. • LEED/Construction Indoor Air Quality Management – EQc3. • GSAS/[OE.1] DUST CONTROL. • BREEAM/ Hea 02 Indoor air quality. • BREEAM/ Pol 02 Local air quality.	
33)	Generation of bad odours from handling of construction materials, waste and sewage.	• LEED/Construction Indoor Air Quality Management – EQc3. • GSAS/[OE.4] ODOUR & VOC EMISSIONS CONTROL. • BREEAM/ Hea 02 Indoor air quality. • BREEAM/ Pol 02 Local air quality.	
34)	Toxic vapour from chemicals generated during construction activities.	• LEED/Construction Activity Pollution Prevention – SSp1. • LEED/Construction Indoor Air Quality. Management – EQc3. • BREEAM/ Hea 02 Indoor air quality. • BREEAM/ Pol 02 Local air quality.	
35)	HVAC construction errors causing the release of airborne bacteria, mould and other.	• LEED/Indoor Air Quality (IAQ). • LEED/Construction Indoor Air Quality. Management – EQc3. • BREEAM/ Hea 02 Indoor air quality. • BREEAM/ Pol 02 Local air quality.	
	Soil		
36)	Soil modification.	• LEED/Construction Activity Pollution Prevention – SSp1.	

		• ESTIDAMA/IDP-R4: Construction Environmental Management. • GSAS/[S.1] LAND PRESERVATION. • GSAS/[S.3] EROSION & SEDIMENT CONTROL. • GSAS/[S.4] EARTHWORKS CONTROL.	
37)	Soil/land movement and Slop land modification.	• LEED/Construction Activity Pollution Prevention – SSp1. • ESTIDAMA/IDP-R4: Construction Environmental Management. • GSAS/[S.1] LAND PRESERVATION. • GSAS/[S.3] EROSION & SEDIMENT CONTROL. • GSAS/[S.4] EARTHWORKS CONTROL.	
38)	High soil erosion and excavation.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • GSAS/[S.1] LAND PRESERVATION. • GSAS/[S.3] EROSION & SEDIMENT CONTROL.	
39)	Land pollution.	• LEED/Construction Activity Pollution Prevention – SSp1. • ESTIDAMA/IDP-R4: Construction Environmental Management. • GSAS/[S.1] LAND PRESERVATION. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	• UN/3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
40)	The use of contaminated soil during fill operations.	• GSAS/[S.1] LAND PRESERVATION. • GSAS/[S.4] EARTHWORKS CONTROL. • GSAS/[M.3] CUT & FILL OPTIMISATION.	
41)	Delivery of unidentified contaminated fill, inadvertent	• GSAS/[S.1] LAND PRESERVATION.	

	transport and subsequent disposal of unknown contaminated soil.	• GSAS/[S.4] EARTHWORKS CONTROL. • GSAS/[M.3] CUT & FILL OPTIMISATION.	
	Water		
42)	Water pollution.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • GSAS/[UC.3] WATERBODY CONTAMINATION.	• UN/14.1 By 2025, prevent and significantly **reduce marine pollution of all kinds**, in particular from land-based activities, including marine debris and nutrient pollution. • UN/6.3 By 2030, improve water quality by **reducing pollution, eliminating** dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally. • UN/6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes. • UN/3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
43)	Rainwater runoff pollution.	• LEED/Construction Activity Pollution Prevention – SSp1. • ESTIDAMA/IDP-R4: Construction Environmental Management. • GSAS/[UC.3] WATERBODY CONTAMINATION.	
44)	Surface runoff pollution.	• LEED/Construction Activity Pollution Prevention – SSp1.	

		• ESTIDAMA/IDP-R4: Construction Environmental Management. • GSAS/[UC.3] WATERBODY CONTAMINATION.	
45)	Waterborne suspended substances (lead, arsenic).	• LEED/Construction Activity Pollution Prevention – SSp1. • ESTIDAMA/IDP-R4: Construction Environmental Management. • GSAS/[UC.3] WATERBODY CONTAMINATION.	
46)	Waterborne chemical toxicities.	• GSAS/[UC.3] WATERBODY CONTAMINATION.	
47)	Inland water pollution.	• GSAS/[UC.3] WATERBODY CONTAMINATION.	• UN/14.1 By 2025, prevent and significantly **reduce marine pollution of all kinds**, in particular from land-based activities, including marine debris and nutrient pollution.
48)	Improper wastewater disposal.	• ESTIDAMA/PW-R1: Water Efficiency. • GSAS/[UC.3] WATERBODY CONTAMINATION.	
49)	Underground water pollution.	• GSAS/[UC.3] WATERBODY CONTAMINATION.	
50)	Surface water pollution.	• LEED/Construction Activity Pollution Prevention – SSp1. • ESTIDAMA/IDP-R4: Construction Environmental Management. • GSAS/[UC.3] WATERBODY CONTAMINATION.	• UN/14.1 By 2025, prevent and significantly **reduce marine pollution of all kinds**, in particular from land-based activities, including marine debris and nutrient pollution.
51)	Improper discharge of the workplace's wastewater.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/PW-R1: Water Efficiency. • GSAS/[UC.3] WATERBODY CONTAMINATION.	

52)	Change or obstruction of river flow.	• ESTIDAMA/IDP-R4: Construction Environmental Management.	
	Waste Management		
53)	Improper disposal of ordinary waste.	• LEED/Construction and Demolition Waste Management – MRp2 + MRc5. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/SM-R2: Basic Construction Waste Management. • ESTIDAMA/SM-4: Recycled Materials. • GSAS/[MO.1] WASTE MANAGEMENT. • BREEAM/Wst 01 Construction waste management.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment. • UN/12.5 By 2030, substantially reduce **waste generation through prevention**, reduction, recycling and reuse. • 11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.
54)	Improper disposal of domestic solid waste.	• LEED/Construction and Demolition Waste Management – MRp2 + MRc5. • ESTIDAMA/SM-R2: Basic Construction Waste Management. • ESTIDAMA/SM-4: Recycled Materials. • GSAS/[MO.1] WASTE MANAGEMENT. • BREEAM/Wst 01 Construction waste management.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment. • UN/12.5 By 2030, substantially reduce **waste generation through prevention**, reduction, recycling and reuse. • UN/11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying

			special attention to air quality and municipal and other waste management.
55)	Improper disposal of special waste.	• LEED/Construction and Demolition Waste Management – MRp2 + MRc5. • ESTIDAMA/SM-R2: Basic Construction Waste Management. • ESTIDAMA/SM-4: Recycled Materials. • GSAS/[MO.1] WASTE MANAGEMENT. • BREEAM/Wst 01 Construction waste management.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment. • UN/12.5 By 2030, substantially reduce **waste generation through prevention**, reduction, recycling and reuse. • UN/11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.
56)	Improper disposal of the debris building.	• LEED/Construction and Demolition Waste Management – MRp2 + MRc5. • ESTIDAMA/SM-R2: Basic Construction Waste Management. • ESTIDAMA/SM-4: Recycled Materials. • GSAS/[MO.1] WASTE MANAGEMENT. • BREEAM/Wst 01 Construction waste management.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment. • UN/12.5 By 2030, substantially reduce **waste generation through prevention**, reduction, recycling and reuse. • UN/11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air

			quality and municipal and other waste management.
57)	Improper disposal of chemical waste.	• LEED/Construction and Demolition Waste Management – MRp2 + MRc5. • ESTIDAMA/SM-R2: Basic Construction Waste Management. • ESTIDAMA/SM-4: Recycled Materials. • GSAS/[MO.1] WASTE MANAGEMENT. • BREEAM/Wst 01 Construction waste management.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment. • UN/12.5 By 2030, substantially reduce **waste generation through prevention**, reduction, recycling and reuse. • UN/11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.
	Chemicals or Hazardous Materials		
58)	Chemical pollution from hazardous materials and their poor storage (housekeeping).	• LEED/Material Ingredients – MRc4. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/SM-R1: Hazardous Materials Elimination.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment. • UN/3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
59)	Improper use of materials containing a cancerous substance.	• LEED/Material Ingredients – MRc4.	

		• ESTIDAMA/SM-R1: Hazardous Materials Elimination.	
60)	Lead poisoning from paint and other material containing lead.	• LEED/Material Ingredients – MRc4. • ESTIDAMA/SM-R1: Hazardous Materials Elimination.	
61)	Spills of asphaltic cement during transport.	• ESTIDAMA/SM-R1: Hazardous Materials Elimination.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment.
62)	Pollution resulting from collisions with various structures like above-ground tanks, pole-mounted transformers.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/SM-R1: Hazardous Materials Elimination.	
63)	Fuel/oils spill and leaks from vandalism.	• ESTIDAMA/SM-R1: Hazardous Materials Elimination.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment.
64)	Toxic leaking to underground/ above ground storage tanks.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/SM-R1: Hazardous Materials Elimination.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse

			impacts on human health and the environment.
65)	Residual contamination from minor spills of oils, fuels, lubricants, etc.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/SM-R1: Hazardous Materials Elimination.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment.
66)	Surface contamination from fuels and lubricants stored improperly.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/SM-R1: Hazardous Materials Elimination.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment.
67)	Disturbance of naturally occurring asbestos.	• ESTIDAMA/SM-R1: Hazardous Materials Elimination LEED/Material Ingredients – MRc4.	
68)	Lubricant oils and other spills from field equipment.	• ESTIDAMA/SM-R1: Hazardous Materials Elimination.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment.
69)	Disturbance of pre-existing contamination during site preparation/ excavation work (residual lead, petroleum contamination from fuels).	• ESTIDAMA/SM-R1: Hazardous Materials Elimination.	

70)	Spills and release from the application of asphalt.	• ESTIDAMA/SM-R1: Hazardous Materials Elimination.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment.
71)	Release from mobile fuel tanks.	• ESTIDAMA/SM-R1: Hazardous Materials Elimination.	• UN/12.4 By 2020, achieve the environmentally sound **management of chemicals and all wastes throughout** their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment.
72)	Impacting or breakage of underground utility lines, pipes and other underground structures.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/SM-R1: Hazardous Materials Elimination.	
Biodiversity:			
73)	Adverse effect on wildlife and disruption of habitats.	• UN. • LEED/Sensitive Land Protection – LTc2. • LEED/Site Development: Protect and Restore Habitat – SSc2. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/ NS-4: Habitat Creation & Restoration. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	• UN/15.9 By 2020, **integrate ecosystem and biodiversity** values into national and local planning, development processes, poverty reduction strategies and accounts. • UN/15.a Mobilise and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems.
74)	Roads in the forest will cut off migration routes.	• ESTIDAMA/IDP-R4: Construction Environmental Management.	• UN/15.9 By 2020, **integrate ecosystem and biodiversity** values into

		• ESTIDAMA/ NS-4: Habitat Creation & Restoration. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	national and local planning, development processes, poverty reduction strategies and accounts. • UN/15.a Mobilise and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems.
75)	Dams will divert water from freshwater habitats.	• LEED/ Sensitive Land Protection – LTc2. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/ NS-4: Habitat Creation & Restoration. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	• UN/15.9 By 2020**, integrate ecosystem and biodiversity** values into national and local planning, development processes, poverty reduction strategies and accounts. • UN/15. a Mobilise and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems.
76)	Spills from oil will kill marine organisms and pollute the shoreline and coastal zones.	• LEED/ Sensitive Land Protection – LTc2. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/ NS-4: Habitat Creation & Restoration. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	• 14.1 By 2025, prevent and significantly **reduce marine pollution of all kinds**, in particular from land-based activities, including marine debris and nutrient pollution. • 14.2 By 2020, sustainably manage and protect **marine and coastal ecosystem**s to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans. • 14.5 By 2020, **conserve at least 10 per cent of coastal and marine areas, consistent** with national and international law and based on the best available scientific information.
77)	Loss of agricultural lands and vegetation removal.	• LEED/ Sensitive Land Protection – LTc2.	• 15.3 By 2030, combat **desertification, restore degraded land and soil**, including land affected by

		• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/NS-3: Landscape Enhancement. • GSAS/[S.1] LAND PRESERVATION. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	desertification, drought and floods, and strive to achieve a land degradation-neutral world.
78)	Mountains and forest removal (deforestation).	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/NS-3: Landscape Enhancement. • GSAS/[S.1] LAND PRESERVATION. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	• UN/15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally. • UN/15.4 By 2030**, ensure the conservation of mountain ecosystems, including their biodiversity**, in order to enhance their capacity to provide benefits that are essential for sustainable development. • UN/15.b Mobilise significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation.
79)	Extinction of different species.	• LEED/ Sensitive Land Protection – LTc2. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/ NS-4: Habitat Creation & Restoration. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	• UN/15.5 Take urgent and significant action to reduce the **degradation of natural habitats**, halt the loss of biodiversity and, by 2020, protect and **prevent the extinction of threatened species.** • UN/15.c Enhance global support for efforts to **combat poaching and trafficking of protected species**, including by

			increasing the capacity of local communities to pursue sustainable livelihood opportunities. • UN/15.7 Take urgent action to **end poaching and trafficking of protected species of flora and fauna** and address both demand and supply of illegal wildlife products.
80)	Wetland habitats disruption.	• LEED/Sensitive Land Protection – LTc2. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/ NS-4: Habitat Creation & Restoration. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	• UN/15.9 By 2020**, integrate ecosystem and biodiversity** values into national and local planning, development processes, poverty reduction strategies and accounts. • UN/15.a Mobilise and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems.
81)	Roadside vegetation removal.	• LEED/Site Development: Protect and LEED/Restore Habitat – SSc2. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/NS-3: Landscape Enhancement. • GSAS/[S.1] LAND PRESERVATION. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	• 15.3 By 2030, combat **desertification, restore degraded land and soil**, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.
82)	Disruption of sensitive species of flora and fauna during breeding, nesting, foraging, residing and overwintering migration.	• UN. • LEED/ Sensitive Land Protection – LTc2. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/ NS-4: Habitat Creation & Restoration. • GSAS/[S.2] BIODIVERSITY PRESERVATION.	• 14.4 By 2020, effectively **regulate harvesting and end overfishing, illegal**, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as

			determined by their biological characteristics. • 14.6 By 2020, **prohibit certain forms of fisheries subsidies which contribute** to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognising that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation. • UN/15.7 Take urgent action to **end poaching and trafficking of protected species of flora and fauna** and address both demand and supply of illegal wildlife products.
Managerial:			
83)	Insufficient on-site investigation, meaning there are no adjustment measures to adapt to local conditions.	• LEED/Site Assessment – SSc1. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/NS-R1: Natural Systems Assessment. • BREEAM/ Man 03 Responsible construction.	
84)	Neglect the topography of the region and its adverse effect on the ecosystem.	• LEED/Site Assessment – SSc1. • ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/NS-R1: Natural Systems Assessment. • BREEAM/ Man 03 Responsible construction.	

85)	Green building energy efficiency has not reached the expected levels.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/NS-R1: Natural Systems Assessment. • BREEAM/ Man 01 Project brief and design. • BREEAM/ Man 03 Responsible construction.	
86)	Unclear allocation of roles and responsibilities.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/NS-R1: Natural Systems Assessment. • BREEAM/ Man 01 Project brief and design.	
87)	Being fined for failing to achieve green mark standards or disregarding green standards.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/NS-R1: Natural Systems Assessment. • BREEAM/ Man 01 Project brief and design. • BREEAM/ Man 03 Responsible construction.	
88)	Lack of availability of green materials and equipment (limited availability of suppliers and import restrictions).	• ESTIDAMA/RE-1: Renewable Energy. • BREEAM/ Man 01 Project brief and design. • BREEAM/ Wst 02 Use of recycled and sustainably sourced aggregates.	
89)	Inadequate knowledge of workers about environmental concerns, green materials and construction technologies.	• ESTIDAMA/IDP-R4: Construction Environmental Management. • ESTIDAMA/NS-R1: Natural Systems Assessment. • BREEAM/ Man 01 Project brief and design. • BREEAM/ Wst 02 Use of recycled and sustainably sourced aggregates.	

Appendix 13 The List of Hazards According to Previous Studies & EIA Reports

List of Hazards		Different EIA reports	Xiaodong Li et al. (2010)	Enshassi, A. et al. (2015)	Bassi, A., et al.(2012)	Selvakumar, S. et al. (2015)	Mora-Barrantes et al. (2018)	Islam, M. et al. (2017) *EIA*	Tao, X. et al. (2018)	Zolfagharian, S. et al. (2012)	Muhwezi, L. et al. (2012)
Impact on the Natural Resources:											
(1)	Excessive use of raw materials.	*	*	*						*	*
(2)	Excessive consumption of both renewable and non-renewable resources.	*	*	*	*		*			*	*
(3)	The depletion of natural resources.	*	*	*			*			*	*
Socio-Economic Conditions:											
(4)	Adverse visual impact.	*			*						
(5)	Landscape alteration.	*		*	*		*	*		*	
(6)	Disrupting business in the community.	*			*	*	*	*			
(7)	High demand or stress on the infrastructure and the road network.	*		*	*		*	*			
(8)	Social disruption, the project causing an adverse effect on the local communities and disturbing the demographic structure of the locals.	*		*		*	*	*	*	*	*
(9)	Disturbance of a sacred site or other cultural values.	*		*	*	*	*				
10)	People relocation.	*					*				
11)	Poor habitability.	*							*		
12)	The public satisfaction with the project is very low.	*				*			*		
13)	Adverse effect on archaeology and cultural heritage.	*		*	*	*	*				*
Public and occupational Health:											
14)	Construction accidents and casualties.	*		*					*	*	
15)	Poor site hygiene conditions.	*		*						*	
16)	Adverse effect on public health and safety.	*		*	*					*	

17)	Lack of attention to health issues in the workplace.	*									
18)	Inadequate responsibility or commitment of the expert in HSE work.	*									
Impact on the ecosystem:											
	Noise										
19)	Noise and vibrations from construction machinery and equipment (crushers, pumps, etc.)	*		*	*	*	*	*		*	*
20)	Noise and vibrations from site activities, construction, demolition, piling, blasting, etc.	*		*	*	*	*	*		*	*
21)	Noise and vibrations from onsite and offsite traffic and deliveries.	*		*	*	*	*	*		*	*
	Air quality										
22)	Air pollution.	*		*				*		*	
23)	Bad air quality.	*			*						
24)	Emissions from the combustion of fossil fuel from stationary and mobile sources.	*				*	*				
25)	Emissions from construction activities and equipment.	*		*		*	*				
26)	Emissions of CFCs and VOCs (volatile organic compounds).	*		*						*	*
27)	Emissions of greenhouse gases.	*	*	*						*	*
28)	Airborne house suspended particles.	*	*	*							
29)	Photochemical smog.	*	*	*							
30)	Ozone exhaustion or depletion.	*	*	*							
31)	CO2, SO2, CO, NOx, emissions.	*	*	*							
32)	Generation of dust from construction activities, construction machinery and equipment.	*	*	*		*		*		*	*
33)	Generation of bad odours from the handling of construction materials, waste and sewage.	*		*		*	*				
34)	Toxic vapours from chemicals generated during construction activities.	*		*						*	

35)	HVAC construction errors causing the release of airborne bacteria, mould and other.	*									
	Soil										
36)	Soil modification.	*		*	*		*				
37)	Soil/land movement and slop land modification.	*		*	*		*				
38)	High soil erosion and excavation.	*		*	*			*		*	*
39)	Land pollution.	*		*	*			*		*	
40)	The use of contaminated soil during fill operations.	*			*			*			
41)	Delivery of unidentified contaminated fill, inadvertent transport and subsequent disposal of unknown contaminated soil.	*			*			*			
	Water										
42)	Water pollution.	*		*	*			*		*	
43)	Rainwater run-off pollution.	*									
44)	Surface run-off pollution.	*			*		*				
45)	Waterborne suspended substances (lead, arsenic).	*	*	*	*					*	
46)	Waterborne chemical toxicities.	*	*		*					*	
47)	Inland water pollution.	*		*	*						
48)	Improper wastewater disposal.	*			*		*				
49)	Underground water pollution.	*		*	*						
50)	Surface water pollution.	*			*						
51)	Improper discharge of the workplace’s wastewater.	*		*	*		*				
52)	Change or obstruction of river flow.	*						*			
	Waste Management										
53)	Improper disposal of ordinary waste.	*		*	*	*	*	*		*	*
54)	Improper disposal of domestic solid waste.	*	*		*	*	*	*		*	*
55)	Improper disposal of special waste.	*			*	*	*	*		*	*
56)	Improper disposal of the debris from buildings.	*	*	*	*	*	*	*		*	*
57)	Improper disposal of chemical waste.	*			*	*	*	*		*	
	Chemicals or Hazardous Materials										

58)	Chemical pollution from hazardous materials and their poor storage (housekeeping).	*		*		*	*			*	*
59)	Improper use of materials containing a cancerous substance.	*					*				
60)	Lead poisoning from paint and other material containing lead.	*				*					*
61)	Spills of asphaltic cement during transport.	*				*					
62)	Pollution resulting from collisions with various structures like above-ground tanks and pole-mounted transformers.	*				*				*	
63)	Fuel/oil spill and leaks from vandalism.	*	*			*					
64)	Toxic leaking to underground/above ground storage tanks.	*				*					*
65)	Residual contamination from minor spills of oils, fuels, lubricants, etc.	*				*					
66)	Surface contamination from fuels and lubricants stored improperly.	*				*					
67)	Disturbance of naturally occurring asbestos.	*									
68)	Lubricant oils and other spills from field equipment.	*				*					
69)	Disturbance of pre-existing contamination during site preparation/excavation work (residual lead, petroleum contamination from fuels).	*									
70)	Spills and release from the application of asphalt.	*				*					
71)	Release from mobile fuel tanks.	*				*					
72)	Impacting or breaking underground utility lines, pipes and other underground structures.	*		*							*
Biodiversity:											
73)	Adverse effect on wildlife and disrupting habitats.	*				*	*	*			
74)	Roads in the forest will cut off migration routes.	*				*	*				

75)	Dams will divert water from freshwater habitats.	*				*	*	*			
76)	Spills from oil will kill marine organisms and pollute the shoreline and coastal zones.	*				*	*				
77)	Loss of agricultural lands and vegetation removal.	*		*	*	*	*	*		*	*
78)	Mountains and forest removal (deforestation).	*				*	*	*			*
79)	Extinction of different species.	*				*	*	*			
80)	Wetland habitats disruption.	*				*	*	*			
81)	Roadside vegetation removal.	*					*	*			
82)	Disruption of sensitive species of flora and fauna during breeding, nesting, foraging, and residing overwintering migration.	*			*	*	*	*			
Managerial:											
83)	Insufficient on-site investigation means that there are no adjustment measures to local conditions.				*				*		
84)	Neglect the topography of the region and any adverse effect on the ecosystem.				*				*		
85)	Green building energy efficiency has not reached the expected levels.								*		
86)	Unclear allocation of roles and responsibilities.								*		
87)	Being fined for failing to achieve green mark standards or disregard of green standards.								*		
88)	Lack of availability of green materials and equipment (limited availability of suppliers and import restrictions).								*		
89)	Inadequate knowledge of workers about environmental concerns, green materials and construction technologies.								*		