On Impacts of Using Prefabrication on Mitigating the Economic Risk in the Construction Industry

Master Thesis

International Master of Science in Construction and Real Estate Management

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Author,

Ehsan Bodaghi

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Topic: On impacts of using prefabrication on mitigating the economic risk in the construction industry

Introduction

The construction industry is one of the largest sectors in the world economy by spending about $10 trillion on goods and services per year (McKinsey Global Institute). It is reported that 13,000 building is expected to build per day until 2050 of about 7 billion citizenships (BERTOLLINI, 2019).
Previous research result shows that construction is one of the riskiest industries which exposed too many internal and external risks. Financial Hazards and economic risks such as bankruptcy, inflation, interest rates, fluctuation of prices and currency rates are the most important factors which can influence on the construction industry (Hasani, 2018). The most internal risk factors in construction projects are considered the cost, the time and the quality of the projects (Antonio J. Monroy Antón, 2011).
Some previous researchers indicated that the economic consequences essentially are results of poor scheduling and forecasting in construction projects (Ellis, 2019). The risk of cost overruns and delays can directly impact on the profit margin of construction projects such as final sell price or return on investment period. Hence, identification, analysing and responding to the financial risk factors to control and reduce the negative economic impacts of those, on the construction projects is needed (Hong Xian Li, 2013).
Recent studies illustrated that the development of prefabrication as a modern technology can improve accuracy in planning and minimize construction risks (Lei Jiang, 2018). Prefabrication is a process of manufacturing offsite in the factory, shipping to the project and onsite assembly. The mentioned method has been used by the 19th century and become modified, useful, and developed in recent years. Prefabrication is widely proposed as an innovative approach in the construction industry and has been proven as a safety and environmentally friendly (Lei Jiang, 2018). Prefabrication has appeared as an alternative and effective method of construction and an example of flexible design (Andriel Evandro Fenner, 2017). Currently, using prefabrication as a sustainable method has increased substantially (Ji, et al., 2018). For example in 2018, Germany had imported 553.3 million Euros worth of prefabricated buildings. This was an increase compared to the previous year, at 512.6 million Euros (Department, 2020).

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One of the important positive propriety of Prefabrication technology is accuracy in planning and control the quality in the manufacturing process which provide dynamic and reliability-driven scheduling for the parallel activities. Prefabrication is an innovative idea which enables time and cost-saving and avoid projects facing significant delays and improve profitability (Hong Xue, 2017). The main idea of this research is to consider using prefabrication in construction projects and evaluate its effects on the projects economics risks. Previous research results show that using prefabrication might be effective on the project costs and time, while this research will focus on the effects of applying prefabrication on real projects economic risks.

Research question:

Fewer researches have addressed the relation of prefabrication and financial risk management. Therefore, the question is to evaluate the role of prefabrication technology effects in financial risk reduction or increase in comparison with other traditional construction methods.
Consequently, this research will be an attempt to answer the following questions.

1- How prefabrication can mitigate the risk of construction cost overrun?

2- How prefabrication can reduce the risk factors of financial issues of project delays?

3- How would be directly and indirectly the positive impact of prefabrication on construction profit margin?

Research method:

To find the answer to current research's questions about the potential risks of economics in construction projects, the qualitative and quantitative study method using a questionnaire form and considering previous research results will be used. Such methods considered the different real projects experiences in both factors costs and time which affected by using prefabrication. In addition, the achieved result will compare with the previews research or real projects experiences.

For this aim the following steps will be used in this study:

1. **1-** Preparing a standard questionnaire form with an emphasis on projects costs and time considering the effects of using prefabrication in construction projects.
2. **2-** Making different oral or online interview with construction experts which have had experience to use prefabrication method in their previous real construction projects and filling the questionnaire form.
3. **3-** Collecting the data achieved by questionnaire form and converting the qualitative data to quantitative data using standard methods. The main aim is converting the qualitative data to a digital data source.

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4- Applying statistical analysis on quantitative data using correlations, standard errors, normalization, and interpolations method (using SPSS software) to find data coherence and correlations.

5- Making a professional comparison between achieved statistical result and previous research result to verify the result of current research.

6- Drawing graphs, tables and arrange the data on different graphical output.

7- Explaining the graphs, tables, and analyzing all the mentioned data

8- Making a professional conclusion for all the analysis due to data comparison and current research results.

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Abstract

This research tries to describe the risk management process in the construction industry and aims to identify and analyze the potential risks which can, directly and indirectly, affect project objectives focused on economic impacts of construction risks and introduce the prefabricated and modular construction (PMC) method as an innovative and alternative method which can mitigate the economic risks in the construction industry as well as the critical success factors and the barriers of applying the PMC method.

This present research also tries to answer how the PMC method can reduce the risk of cost overruns, time overruns and increase the profit margins in construction projects and the motivation of this research is to promote the PMC method and attract the construction investor to apply the PMC as an alternative, reliable and more efficient method.

In risk management, risk identification and awareness of unexpected events during the construction phase play the main role of project success, therefore the importance of risk management and the consequences of failure in risk identification in the early stage in the construction industry has discussed and to find the potential construction risks, literature review, brainstorming, checklist and questionnaire survey are seen as the main method.

At the end in the result and discussion section, qualitative and quantitative Analyzing method is used to rank and weight the results of experts from the questionnaire survey about the critical success factors and barrios of PMC implementation and by probability and impact method, the proximity of potential construction risks are compared in excel sheets and graphs in both conventional and PMC method to show the quantity of risk reduction in PMC method.

Keywords: Construction Risk Management, Prefabricated and Modular Construction (PMC), Cost Overruns, Time Overruns

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List of Abbreviations

AIPM	Australian Institute of Project Management
APMBoK	APM Body of Knowledge
BIM	Building Information Modelling
BS	British Standard
CRFs	Critical Risk Factors
CSFs	Critical Success Factors
DIN	Deutsches Institut für Normung
HSE	Health, Safety and Environment
IMPA	International Project Management Association
ISO	International Organization for Standardization
MCS	Monte Carlo Simulation
PERT	Program Evaluation and Review Technique
PMBOK	Project Management Body of Knowledge
PMC	Prefabricated and modular construction
PMI	Project Management Institute
PRINCE	Projects IN Controlled Environments
PRM	Project Risk Management
RBS	Risk Breakdown Structure
SLR	Systematic Literature Review
SWOT	Strengths, Weaknesses, Opportunities, and Threats

1 Introduction

The construction industry is one of the largest sectors in the world economy by spending about $10 trillion on goods and services per year(McKinsey Global Institute)and as reported, 13,000 building is expected to build per day until 2050 of about 7 billion citizenships(BERTOLLINI, 2019).

The results show that construction is one of the riskiest industries which exposed to many internal and external risks. Financial Hazards and economic risks such as bankruptcy, inflation, interest rates, fluctuation of prices and currency rates are the most important factors which can influence on construction industry (Hasani, 2018). The most internal risk factors are considered for the Cost, Time and Quality as the main objectives of construction projects (Antón, 2011)

For any construction company the financial aspects of the construction projects, in particular in evolving economies, have always been a major challenge. The construction sector is vulnerable to recession, associated with lack of funds, fluctuating the exchange rates and political uncertainty due to high project capital expenditures, low-cost flexibility and high competition that restricts the final prices. (Purnuş and Bodea, 2015)

Despite the fact that exceeding budget on construction projects is not an unusual issue and has become an industry-wide norm, Economic consequences essentially resulted in poor scheduling and forecasting (Ellis, 2020). The risk of cost overruns and delays can directly impact on the profit margin of construction projects such as final sell price or return on investment period. Hence, identification, analysing and responding to the financial risk factors to control and reduce the negative economic impacts of those, on the construction project is needed (Li *et al.*, 2013).

Recent surveys show that the Development of prefabrication technology can improve accuracy in planning and minimize construction risks. Prefabrication is a process of manufacturing offsite in the factory, shipping to the project and onsite assembly. From the 19th century, prefabrication is widely proposed as an effective approach in the construction industry and has been proven as safety and environmentally friendly method. (R. Jin *et al.*, 2018) Prefabrication has appeared as an alternative method of construction and an example of flexible design (Fenner *et al.*, 2017). In recent years,

The use of prefabrication as a sustainable method has increased substantially (Ji *et al.*, 2018). Besides, Prefabrication and modularization can boost reliability in scheduling which avoids projects facing significant delays and improve the profitability (Li *et al.*, 2013).

1.1 Problem Statement

Promoting new and modern construction methods, despite the advantages and high speed of implementation, has always been associated with concerns and uncertainty for investors in the construction industry.

To find the great value that modern methods can bring in the construction process, it is necessary to assess and evaluate the aspects of applying these methods on the project objectives and compare with conventional methods.

thus, the problem is to what extend the prefabricated and modular construction (PMC) method is reliable and can reduce financial risks and investment's concerns in the construction industry?

1.2 Research Aims and Objectives

The main idea of this research is to consider the impact of using prefabrication methods in construction projects and evaluate its effects on the projects economics risks. Previous research result shows that using prefabrication might be effective on the project costs, time and quality while this research will focus on the effects of applying the prefabrication method on project financial risks.

This research uses a Systematic Literature Review (SLR) and questionnaire survey by specialists in the construction industry to identify, analyze and classify the most important financial risk factors with their potential to have a major effect on the cost of construction projects continuum. The actual aim of prefabricated construction method proposed is to mitigate the most significant factors of financial risk, compare the critical risk and success factors with the conventional construction methods, also the advantages and barriers is considered and objective of this research is introduce the prefabricated and modular construction (PMC) as an alternative strategic method which mitigates the economic concerns and financial risks in the construction industry.

1.3 Research Questions

The research questions are to evaluate the role of prefabrication technology effects in financial risk reduction in comparison with other conventional construction methods.

Consequently, this research will be an attempt to answer the following questions.

1- How prefabrication can mitigate the risk of construction cost overrun?

2- How prefabrication can reduce the risk factors of financial issues of project delays?

3- How would be directly and indirectly the positive impact of prefabrication on construction profit margin?

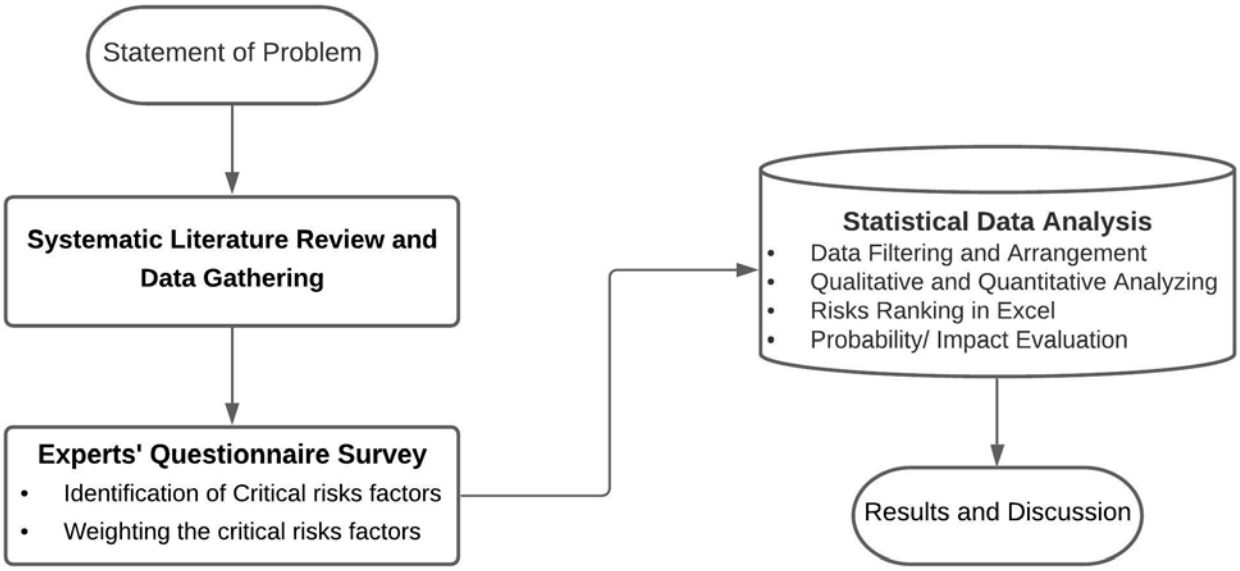
1.4 Limitation of the Study

This study is focused on the impact of prefabrication method on economic risks and the other construction risks are not considered.

The questionnaire is designed by critical Risks and success factors of prefabrication construction method and the number of Risks is limited to significant risks factors which are directly and indirectly effect on financial objectives and other objectives of the construction project are not considered.

Because of the realistic survey, all the construction risks factors were not possible to design in one questionnaire. To be successful in inviting the construction's experts in a scientific questionnaire, the number of questions must be limited and it is not possible to include all questions in one questionnaire. Therefore, an attempt has been made to collect important questions about financial factors, and other factors of prefabrication method have not been considered.

1.5 Structure of Research



2 Project Risk Management and prefabrication background

2.1 Project Risk Management (PRM)

It is not possible to avoid risk completely in the advanced globalization area which is an essential part of everybody lifestyle. Today the presence of risk is visible in all aspects of human life. The construction industry is one of the aspects of our life and the construction industry is the environment where the risk is an inherent component of this industry. It doesn't mean the effective risk management can remove the risk, which it seems that the cheapest way. In economic terms, this alternative makes little sense because what is potentially more profitable is riskier and each project which doesn't make risk is not interesting in economic terms and therefore doesn’t bring acceptable benefits. (Szymański, 2017a)

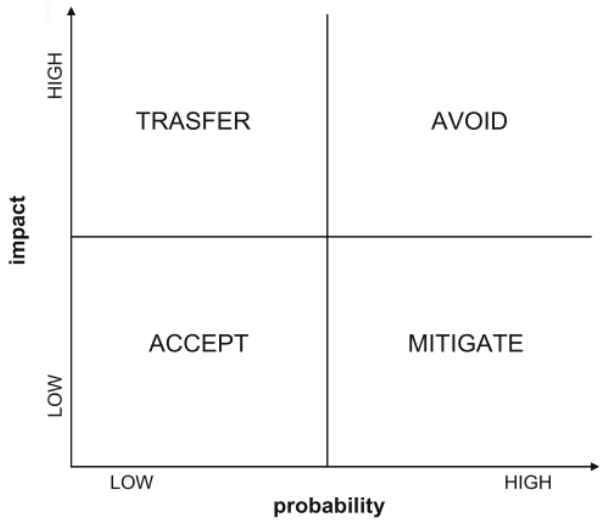


Figure 1: Control chart of Risk strategy(De Marco, 2018)

In the field of the construction industry, the risk factor is great since project objects are peculiar and they are built just a one time. The lifespan of construction objects is replete with different kinds of risks. There are several sources for project risk including temporary employees that are brought together from the different construction site and companies. Besides, complexity and the size of the project can increase the possible risks of construction objects. Furthermore, the social, economic and political circumstances can have an impact on the project. An uncertain event or state, if occurred, during the project is an object risk which has favourable or unfavourable influences on one or all project objectives for instance on cost, time and quality. In

construction projects, the presence of risk causes time and cost overruns. (Project Management Institute, 2004)

In project failure cases, the main reason is the lack of risk management practice or less quality of training in this field. (Algahtany, Alhammadi and Kashiwagi, 2016)

There are many project management processes within which Project Risk Management proposes a new approach to detect and manage risks which are not taken into consideration by the previous ones. In the presence of unmanaged risks, the main plan could be damaged and impaired, as a consequence, it is possible to miss the desired objectives of the project. Thus, PRM efficiency is strongly associated with project success. (PMI, 2017)

There are two levels of risks in each project which are addressed by Project Risk Management processes; one of them is individual risks which influence the attainment of project objectives. The other one appears when individual project risks are mingled with other incertitude elements. They are more elucidated as follows:

Individual project risks: Are the risks identified in the project as an uncertain occurrence or state that can have favourable or unfavourable impacts on project objectives.

Overall project risks: Are engendering from every source of uncertainty for the project as a unit containing individual risks as well. Overall project risk expresses the stakeholder's exposure to the significance of variation in the project final result (both benefits and losses).

Base on the project size, complexity, importance and development approach of each unique project it is essential to customize the way of the project management process, The adaptation to these attentions of the risk management process is part of the risk management process and subsequent decisions will be reported in the risk planning. (PMI, 2017)

Risk is an inseparable part of every work; it is more notable in construction processes. Project Risk Management methods and procedures attempt to convert the project random uncertainty to a measurable one founded on previous experience and practices along with statistical employment of historical data. (De Marco, 2018)

Risk which is an uncertainty capable of being measured is a window to deviate from the required standard. That is why consideration should be given to the positive and

negative deviations, which represent an opportunity and failure respectively. (Dziadosz, 2015)

Risk is an uncertain case with undesirable effects. So, it is inevitable for the Construction industry to be exposed to these risks which can be complicated and various. (Zhao et al, 2013)(Serpell *et al.*, 2014)

According to the definition of The British Standard Institute (Wiley, 1991), the risk is a compound of the possibility of an event of delineated riskiness and the extent of their impacts.

The likelihood of something wrong in the future; an event that could be harmful or that could have a bad consequence (Oxford Advanced Learner's Dictionary 2020).

The steps of Risk Management consist of the recognition, assessment and handling at most financial running costs of the risks which may jeopardize life, possessions, belongings, incomes of a company(Edwards, 1995).

Risks in the field of construction industry could be expressed as the likelihood of an occurrence which weakens the project practicality. This possibility may be greater in this industry compared to others. (Antón, 2011)

Risk is defined as an upcoming probable occurrence, in project management, that would produce a change in the project; it can be a favourable or unfavourable change. (Robert K. Wysocki, 2014).

Specific risks are defined in Macro, Mezzo and micro level.

Specific Risk Level		
Macro	***Mezzo***	***Micro***
Country	Construction Project	Project Management

Table 1: Level of specific risks in construction industry. Adapted from(Sanchez-Cazorla, Alfalla-Luque and Irimia-Dieguez, 2016) (Tamošaitienė, Zavadskas and Turskis, 2013)

There are many standards for project management which are listed below.

Row	Standard	Scope of Application
1	PMBOK	Global
2	ISO 10006	Global
3	Professional Methodologies	Global
4	PRINCE 2	Semi-global
5	BS 6079	National
6	DIN 69900	National
7	AIPM	National
8	APMBOK	Regional
9	IPMA Competence Base Line	Regional

Table 2: Project Management Standards, adapted from (Barghi and Shadrokh sikari, 2020)

2.2 Prefabricated and modular construction(PMC)

Modularity is quite well-established in the historical backbone of innovation management. Technically speaking, modularity is a concept defined as the level that units in a total system or product can be produced separately and yet again be unified to create manifold systems through the same design information. (Wuni, Shen and Mahmud, 2019)

First formulated in the mid-1960s, prefabrication employs great panel technology to enable a moderately swift construction of several buildings at reasonable unit cost. This method owes its popularity to the mass production of high-standard building components as well as mitigating on-site labour costs which mean increased cost savings. Prefabrication might well be used for the complete structure or else the various separated elements. (Zhao and Riffat, 2007)

The process of assembling the elements of a building in a factory instead of constructing on-site is prefabricated method; in this manner, the completed assemblies are transported to the site at which the building is going to be erected. (Mrunali Neskar, 2020)

Producing and preassembling the elements or segments of a structure to the process of its erection in their eventual location is simply called Prefabrication. The Prefab manufacturing industry is the ground on which novel ideas could be materialized in any country`s construction business. The demand for housing is increased at present.

Therefore, much greater speed without any impact on the cost is required. However, this is not likely to happen through the medium of conventional construction. Thus, another method of construction is favoured. Prefabrication is a strategy that optimizes the overall time of construction. Prefabrication is equipped with other merits such as a noticeable reduction in the time of construction, the reduction of waste material and the enhancement of quality. (Mrunali Neskar, 2020)

By incorporating the theories of modularity along with modularization, PMC technology revolutionized the construction industry. (Wuni and Shen, 2019)

Prefabrication is an innovative idea which enables time and cost-saving and avoid projects facing significant delays and improve profitability. (Xue *et al.*, 2017)

Recent studies illustrated that the development of (PMC) as modern technology can improve accuracy in planning and minimize construction risks. Prefabrication is a process of manufacturing offsite in the factory, shipping to the project and onsite assembly. The mentioned method has been used by the 19th century and become modified, useful, and developed in recent years. Prefabrication is widely proposed as an innovative approach in the construction industry and has been proven as a safe and environmentally friendly. (Jiang *et al.*, 2018)

2.2.1 Prefabrication Manufacturing Process

Construction elements are designed and prefabricated in the factory, then transported to the final construction location and quite easily put together to accomplish the structure(Jiang *et al.*, 2018).

Factory mechanization is used in prefabrication to manufacture housing and housing segments. The factory setting is optimized for having reasonable price outcome by mixing bulk purchase, mass production, the new techniques of assembly and less specialized workers. Prefabrication is categorized into prefabricated components, modular building, along with manufactured housing. (Zhao and Riffat, 2007)

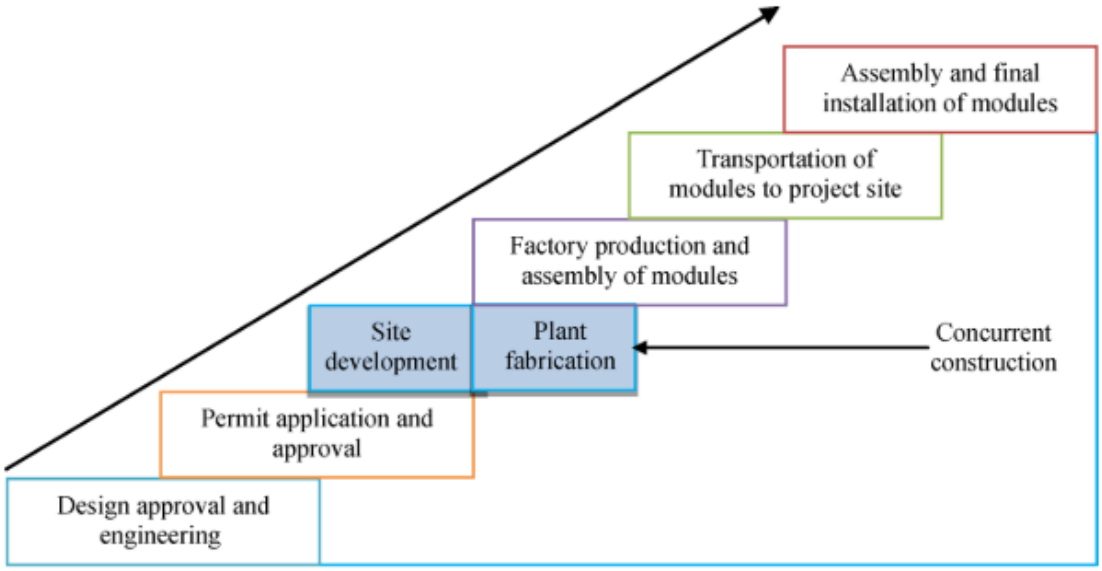


Figure 2: Prefabrication and Modular Construction (PMC) Process (Wuni, Shen and Hwang, 2020)

2.2.2 Design and Scheduling

Prefabrication has appeared as an alternative and effective method of construction and an example of flexible design. One of the important positive propriety of Prefabrication technology is accuracy in planning and control the quality in the manufacturing process which provide dynamic and reliability-driven scheduling for the parallel activities. (Fenner *et al.*, 2017).

2.2.3 Comparison with Conventional Method

Due to the current situation of economical depression, construction companies choose less construction time and cost over strengthening quality and safety enforcements. The key benefit to prefabricated components is the delivery of a fixed price solution when selling one`s house. Additionally, since volume elements are used, the lead-time is greatly decreased and become more precise in comparison to conventional construction. It happens because the manufacturing employs standard methods at work and an essentially adaptive framework. (Tam and Ng, 2007)

2.2.4 Advantages and Limitation of Prefabrication Methods

2.2.4.1 Advantages

Prefabricated constructions are proved to be economical involving the first cost or the life-cycle cost calculations. High-speed construction lessens the monetary costs since the occupants will be settling faster. This process has also been revealed to be more friendly in terms of labour and the environment. (Jiang *et al.*, 2018)

There are numerous advantages to prefabricated construction as compared to conventional construction. For instance, it leads the way to higher streamlining of the construction schedule through the production of the components concurrently on-site and in the factory. Greater operations are implemented concurrently as most of the job is being done by assembly lines. The methodical nature of the procedure renders it as highly efficient with less workforce. Moreover, it is much more environmentally safe in comparison with conventional construction. Besides using less energy, it also creates fewer waste materials and dust. Broadly speaking, prefabrication technology enhances manufacturing quality and construction schedule. All these merits the stakeholders of the industry and also promoting it to a more green, sustainable and eco-friendly technology. (Jiang *et al.*, 2018)

Perpetual quality in PMC is coupled with other advantages in terms of cost savings, material and workforce. Production and preassembly of construction elements, before their launch in the final location, are defined as prefabrication. Arguably, this technology is the foundation that will permit any county to realize novel construction designs on its ground. Prefabricated components have rendered construction far easier and as such decreasing the construction time to half of what it would take if carried out conventionally. (Tony and Kokila, 2018)

Sustainability and shorter construction time have been guaranteed by PMC technology; the total cost efficiency, higher standards of performance and quality, upgraded health and safety measures, energy and supply preservation, waste reductions, and lastly, lowered the number of greenhouse gases. (Bildsten, 2011)

According to (Mrunali Neskar, 2020) Prefabrication Technology has main advantages as below:

Advantages
• Energy-saving by increasing energy efficiency and save money • Waste material reduction and minimal inspection • Reliable construction plan • Speed up construction by parallel work on-site and off-site • Security improvement (Health, Safety and Environment (HSE)) • Sustainability (minimize site disorder, better construction material and waste management, less environmental impact) • Quality improvement (more durable construction components versus climate change)

Table 3: Main advantages of PMC(Mrunali Neskar, 2020)

Because of the various benefits above, the prefabrication technology in urban construction is in demand. (Mrunali Neskar, 2020)

The benefits of using PMC methods are as follows in terms of the availability of materials, labour and technical expertise. Prefabrication is known as an efficient waste management minimisation process.

- Off-site manufacturing of components providing products which are of high quality for more effective use of trained labour, materials, and specialist plants and equipment.
- Speeded up on-site delivery.
- New components demand emerging from improvements of envelopes or spatial redevelopment.
- Second-hand market components arising from residential changes or dwelling disturbance.
- Potential rather than demolishment for the relocation of housing.
- Limited use of on-site materials minimizes on-site and end-of-life waste. This decreases the responsibility for disposal by the producer.
- Self-supported, shutters and scaffolding are removed as the components are ready by saving on shutting costs.
- Building-component mass production results in improved efficiency and unit cost savings.

- Construction materials are assembled in factories that prevent negative effects due to inadequate weather conditions.
- Ability to install facades with renewable energy equipment and use low-cost recycled materials. (Zhao and Riffat, 2007)

2.2.4.2 Limitations

Management complexity and stakeholder fragmentation are the main barriers in PMC which have been reported in 12 research.

One of the most noticeable drawbacks of PMC technology is the high amount of initial requirement of investments cost; however, the initial sum largely depends on the degree of espousal. This issue was as well mentioned in 11 more types of research.

It is reported in more than 9 articles that the third-highest occurring Critical Risk Factors (CFRs) in the implementing of PMC is deficient integration and disturbances of the supply chain. (Wuni, Shen and Mahmud, 2019).

Compared to the conventional construction methods, the prefabrication technology comes with greater initial capital investment and transit costs. What makes this an unlikely technology to be adopted by most countries is the fact that the initial investment cost is rather high. (Jiang *et al.*, 2018)

On the initial days of this technology what made it unfavourable to be adopted was its rather high level of technical risk; however, as technological advancements somewhat eliminated those risks, it is the high initial investment capital that prevents its widespread application(Xue *et al.*, 2018).

Major barriers of PMC
Need high initial capital cost
Delivery and Transportation
Supply chain
Technology innovation and technical stuff
Ineffective motivation and work mechanism
Lack of enough research and development

Table 4: Major barriers factor of PMC, adapted from(Shen *et al.*, 2019)

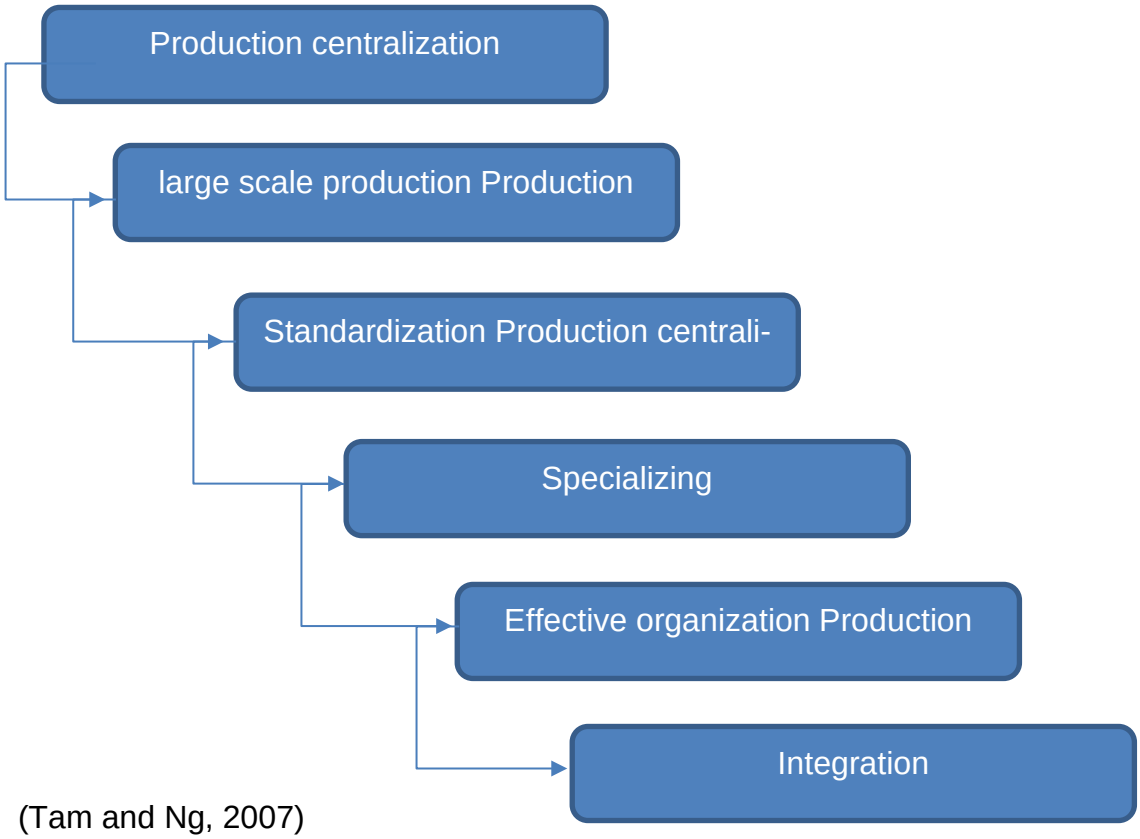
According to (Mrunali Neskar, 2020)The following limitations are considered to be present in prefabrication technology.

Present limitations of PMC
Limited design options
Reduced value for resell
Initial cost investment
Non-compatibility for substructure
Precast units transportation
Diverse risks increasing

Table 5: Present limitation in prefabrication technology, adapted from(Mrunali Neskar, 2020)

2.2.5 Critical Success Factors(CSFs)

Six preconditions are classified for the effective implementation of PMC as below.



(Tam and Ng, 2007)

Main CSFs for labour is minimizing cost on skills, rules, employ development and worker training. According to (Wuni and Shen, 2020) CSFs ranking is as below:

CSFs	*Rank*
Comprehensive Design and accuracy in drawing	1
Well cooperation, communication and information sharing between project's stakeholders	2
Effective stakeholder management	3
Extensive project scheduling	4
Key players' early commitment	5
Early advice from the construction experts	6
Early decisions and realistic feasibility study	7
Experience and knowledge of the project's main players	8
Effective use of advanced technology like building information modelling	9

Table 6: Critical Success Factor ranking, adapted from (Wuni and Shen, 2020)

The study of the proven interpretive model showed that these issues have a huge impact on the cost of PMC.

- Standard PMC in compliance with global standards.
- Appropriate site selection and consider the distance to the factory
- Education of manufacturing and installation staff. (Qing, 2020)

Classification	*Cost CSFs*
Design phase	Degree of designer experience
	Module standardization degree
	Build the rationality of the division
	Level of Prefabrication
	Builder's special circumstances
Construction phase	Level of site administration
	Installation degree hoisting
	Usage of mechanical machinery
	Utilization of built
Acquisition phase	The capacity to build the plant
	The location of the plant component
	Management of stock

Table 7: Factors impacting on prefabricated construction costs, adapted from(Qing, 2020)

2.2.6 Critical Risk Factors (CRFs)

Identifying the greatest number of possible CRFs will do a lot of good to the countries experimenting with the implementation of PMC since the huge risks of the technology are proliferate(Wuni, Shen and Mahmud, 2019).

Overall cost function had been specified before in terms of cost function and risk function in PMC. This cost function comprises the machinery, workforce and the supplies needed to manufacture the module. Risk function is thought to be the expected costs connected with risk experience. Risk functions have to encompass all the modules in construction from the manufacturing stage, transportation phase down to assembly and erection. The risks in the project should necessarily include all the potential prospects of risks materializing; as well as the approximate value of their occurrence. The functions of risk and cost have been confirmed to be the estimation of all the construction costs plus the expected risks of every feasible design preferences, which were elaborated in previous steps while connecting these costs with the parameter of tolerance interest in the projects. (Wuni, Shen and Mahmud, 2019)

2.2.6.1 Previous researchers' result

Base on (Wuni *et al.*, 2020) the top 10 CRFs with high impact are as below:

CRFs of (PMC)	***Rank***
Supply chain disruption	1
Higher initial cost	2
Limited experience and expertise	3
Complexity in assembly and rework	4
Complexity in management	5
Design and order change	6
Poor communication and cooperation between project participants	7
Poor scheduling	8
Support in regulation and planning	9
Lack of proper standards and design codes	10
Limitation in modular manufacturing capacity	10

Table 8: Top 10 PMC Risk Factors, adapted from (Wuni *et al.*, 2020)

Also (Wuni, Shen and Mahmud, 2019) recognized the critical risk factors in PMC and ranked them base on their frequency in the previous research as below.

CRFs of (PMC)	***Rank***
Management complexity and stakeholder fragmentation	1
High initial cost	2
Poor integration and disruption in the supply chain	3
Delays in modular component delivery at the site	3
Poor support and protection from Government	5
Lack of code and guidelines for PMC	6
Change order and faulty design	7
Supply chain disruption	7
Inadequate scheduling	7
Limited experience and expertise in PMC	7
Modular complainants' shortage	11
Weather condition	11
Transportation	13
Lack of experienced contractor	13
lack of skilled worker	13
Poor communication and cooperation	13
Design complexity	17
Modular manufacturing capacity	18
Inadequate proper management practice	18

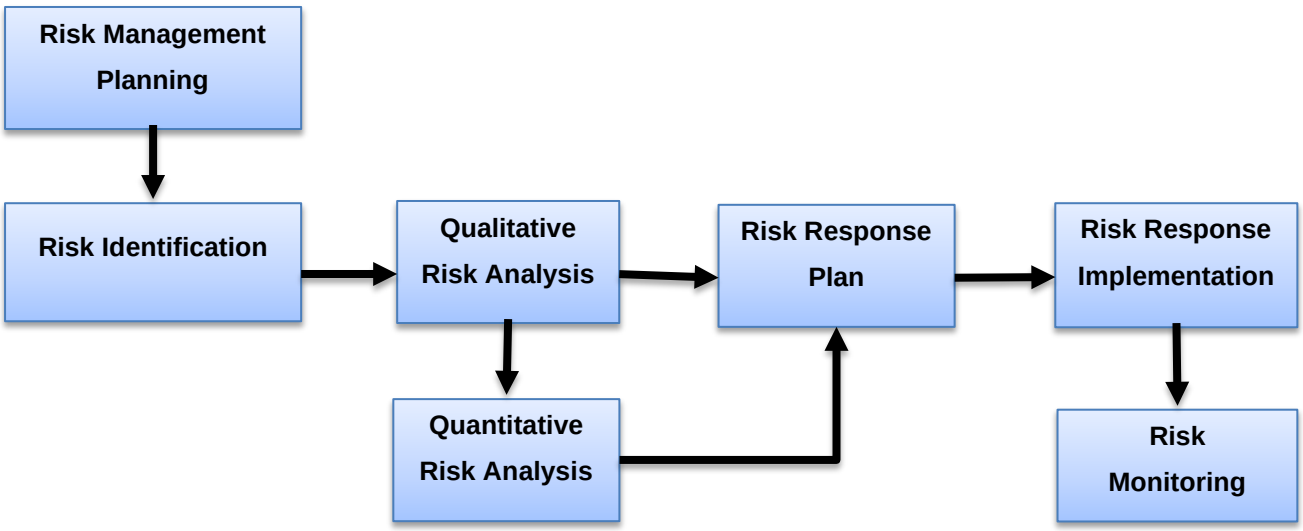
Table 9: most frequent risks in PMC, adapted from(Wuni, Shen and Mahmud, 2019)

2.3 Risk management planning

The construction industry is typically riskier than other kinds of business activities due to its complication in organizing different operations. Besides, every project is peculiar and it utilizes new methods and approaches(Karim *et al.*, 2012).

Project Risk Management processes consist of planning, identifying, analyzing, response planning and implementation, checking and controlling project risk. Enhancement of the possibility of positive risks and its ultimate influence alongside the

reduction of negative risks possibility and its ultimate influence are the Project Risk Management objectives. These are in favour of maximizing the probability of having a successful outcome. (El-Sayegh SM, 2008)(Antón, 2011)(PMI, 2017)



Risk Breakdown Structure (RBS)

RBS LEVEL 1	***RBS LEVEL 2***
TECHNICAL RISK	Scope definition Requirements definition Estimates, assumptions, and constraints Technical processes Technology Technical interfaces
MANAGEMENT RISK	Project management Program/portfolio management Operations management Organization Resourcing Communication
COMMERCIAL RISK	Contractual terms and conditions Internal procurement Suppliers and vendors Subcontracts Client/customer stability Partnerships and joint ventures
EXTERNAL RISK	Legislation

Exchange rates
Site/facilities
Environmental/weather
Competition
Regulatory

Table 10: All Risk Levels sources base on(PMI, 2017)

2.4 Risk Identification

The most effective decisions must be taken in the first stages of conducting a project so it is necessary to identify all the probable risks and uncertainties as early as possible. The framework of the whole process is established by the Risk Identification process which is the first step of risk management. Ineffectiveness in the whole process is the result of a failure in risk identification which can respectively have a serious impact on the organization's resources. In risk management, this process facilitates the organization to:

1. Identify the most appropriate data input
2. Recognize the importance of the process
3. Identify risks and their likely impacts
4. Providing decision-makers with details

With different tools and techniques, the process of risk assessment or the collection of risk information is accomplished. (Rostami, 2016)

There are two basic constituent parts for risk as inferred by the definition which is the possibility of an event to take place and the negative impact that is generated from that occurrence. These two aforementioned components are independent; however, when it comes to categorization they are operated in unison. (De Marco, 2018)

Risk identification process takes into consideration the presence of individual and overall project risks. The documentation of the attributes of the current individual project risks as well as the documentation of all sources which gave rise to the overall project risks is the most significant advantage of this process. Furthermore, it assembles data to assist the project team to figure out the identified risks to respond properly to them. This step of carrying out the Risk identification process covers a project thoroughly. (PMI, 2017)

2.4.1 Identification of hazards

To properly deal with the risks, the internal risks in the construction industry must be identified first. After risk analyzing, the second step is to bring to the notice the external risks, particularly in the economic and financial part of the process. Accurate risk identification and management are directly related to the decrease of negative impacts; as a consequence, project productivity and efficacy will be increased. (Barnes NMI, 1983) (McCallum MH, 2000) (Antón, 2011)

In general, risk factors can be classified regarding their sources and implications on the project objectives. They can also be categorized into internal, external and legal groups. The scale of predictability and possibility to conduct apt response differs, however, it is considered independent of risk event state. (Rezakhani, 2012)

Internal Risks

Internal risks are typically associated with the management team aptitude in monitoring especially in massive construction projects. Internal risks are originated from inside of the project. Whereas the external risks are caused by the macro-level. They can be classified in groups as follows: requirement of the owner, designers, building contractors, subcontractors and sellers. Respectively, they can be subcategorized into several subgroups, as a result, the overall risk structure would be formed. (Antón, 2011)

External Risks

Although the external risks are not closely associated with the construction process, they are significantly important in project success. External risks can be categorized into natural, economic, political, social, cultural and the like. (Antón, 2011)

External and internal factors are the main roots of Risk Breakdown Structure(Burcar Dunovic, Radujkovic and Vukomanovic, 2016).

Project Risks	
External (Uncontrollable)	Unpredictable Predictable
Internal (Controllable)	Technical Non-Technical

Table 11: Specific risk factors(Burcar Dunovic, Radujkovic and Vukomanovic, 2016)

It has been claimed that designers can interact with the building contractors to figure out design flaws, inaccuracies and shortcomings to enhance safety. These precautions have to be taken to prevent hazards on the construction site. (Z. Jin *et al.*, 2018)

2.4.2 Typical project risks

According (Szymański, 2017b) construction project risks are divided into 5 major groups:

Preliminary design: If the project is rejected, it can be followed by expenses loss that had been incurred within the implementation.

Tendering: Tender is the essential requirements for starting the project. It specifies the need to have a particular approach for this step of the construction process.

Detailed design: Is the step in which the cornerstone of the final project is established.

Construction Execution: Forms the implemented project. The risks included in the implementation of constructions.

Financial: Greatest risks are in the financing area.

Risks	***Example***
Preliminary design	Poor identification of competition risk Poor identification of the investors' priorities Project cost overestimating Poor self-esteem
Tendering	Tender cancellation Corruption Use of competitors' offer price Bad estimating of project profitability Client reliability The extreme cost of lobbying and marketing
Detailed design	Design team selection Project cost overestimating Improper technology selection Reduce the aesthetic level of client
Construction Execution	Soil analysis Work scheduling Equipment and machine failure Absence of employees

	Performance qualification of employees Supply chain management Material quality Standards of maintenance Control and coordination Improper work organization Work scope Extension
Financial	Political instability Economic instability Inflation Cost plan estimation Industry recession Client credit Objective and work scope changes law implementation and compliance

Table 12: Construction project risks, adapted from(Szymański, 2017b)(Keshk, Maarouf and Annany, 2018)

Also (Mehdizadeh *et al.*, 2012) Classified risks into seven groups and recognized the most frequent risks in construction projects base on probability and impact method as below.

Risks	***Example***
Political	National politics instability
Design change	lack of enough information from the customer needs
Financial	Cashflow cut and delay in payment during the execution phase Public funding restriction Project fund delay from the bank Bankruptcy
Weather condition	Unexpected changes and cold weather
Project site location	Access and geographical difficulties
Economic	Changes in Material cost price in the execution phase Critical economic situation during the execution phase Decrease internal competition market Sudden change in energy cost during the execution phase.
Time overruns	Unrealistic time estimation due to improper information Unacceptable time management due to changing the management team or strategy

Natural hazards	Weather condition
	Fire during execution
	Earthquake and landside during execution
	Flood and hurricane during execution
Quality management	Unacceptable quality management due to changing the strategy
Communication	Communication with project's stakeholders
Defective design	Public concerns due to improper safety and health management
	Improper change information between contractors
	The design doesn't comply with the project objectives

Table 13: Main frequent risks in the construction project, adapted from(Mehdizadeh *et al.*, 2012).

2.4.3 Project Risk Tools & Techniques

The standard process of risk identification base on (PMI, 2017):

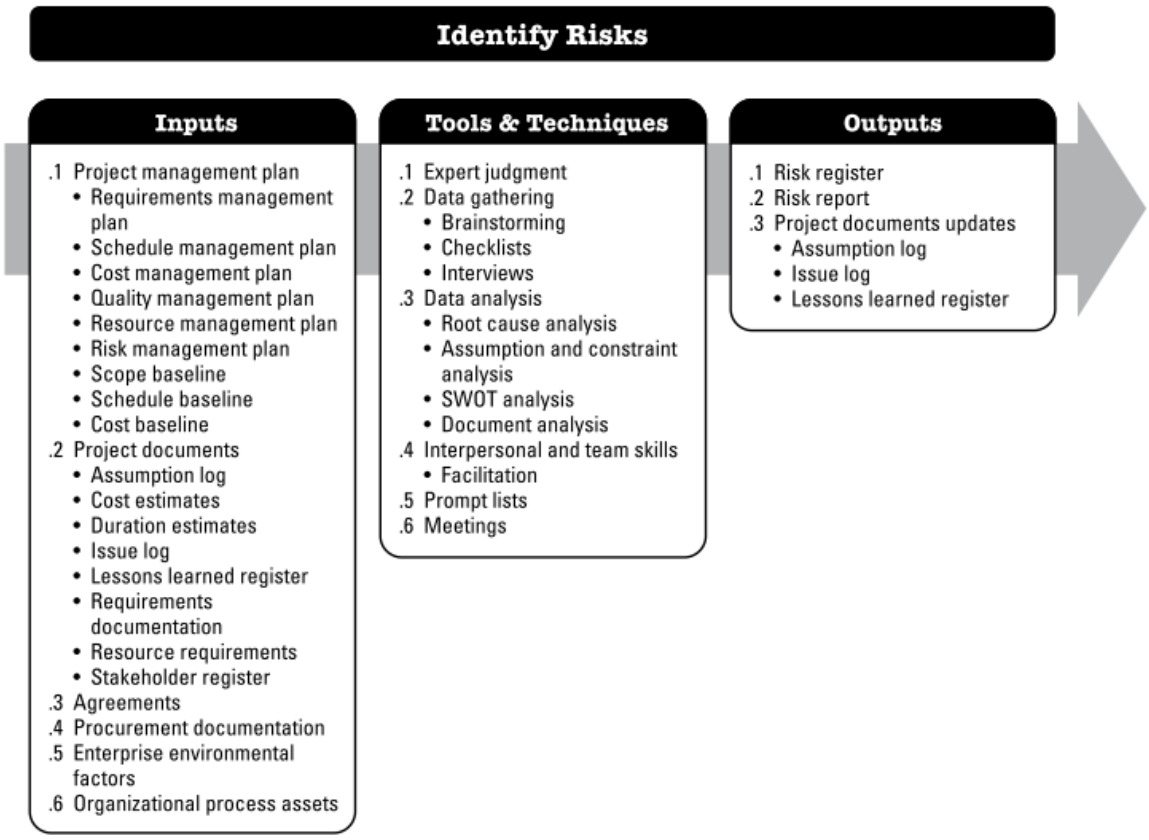


Figure 3: Risk identification process(PMI, 2017)

The risk identification procedure through the survey method can be a separate analysis or comprise a group of people. This method is specified as a resource-intensive task as a result of its prerequisites of organizational resources and time. The gathered data through this method is used to pave the way for additional risk identification. The second most prevailing method amongst construction companies is to collect information via brainstorming. The purpose of this method is to supply an inclusive list of risks by the construction team and the interdisciplinary experts. It is proved that brainstorming is a problem-solving technique that enables a significant scope of ideas in a reduced amount of time. This method includes determining the problems, generating theories, presenting and elaborating on solutions sub-processes. It was pointed out that the Expert judgment, Documentation review, Information gathering and Checklist analysing have important impacts on the risk identification process(Rostami, 2016).

Risk identification tools and techniques
• Expert Judgment • Data Gathering • Brainstorming • Standard Checklists • Interviews • Root cause analysis • Assumption and constraint analysis • SWOT • Documentation review and analysis • Delphi Technique • Influence Diagram • Failure Mode and Effect Analysis • Flowchart • Hazard and Operability Study • Cause-and-Effect Diagrams (Ishikawa(fishbone) diagrams) • Information gathering

Table 14: most common risk identification tools and technique, adapted from(PMI, 2017)(Rostami, 2016)(K. Jayasudha, 2014)(Tamošaitienė and Lapeikytė, 2019) (Szymański, 2017a)(Qing, 2020)

The interview and brainstorming strategies are reported to be the most common data gathering strategies for identifying risks. In the risk identification step, reliable data and information gathering is an important factor. In this step there are many methods for qualitative data gathering as below:

Information and Date gathering methods
• Brainstorming • Interview • Questionnaires • Workshops • Expert consultation • Previous experience • Delphi technique • Location visit • Risk breakdown structure

Table 15: Main information-gathering methods, adapted from(Ubani, 2015)(Crnković and Vukomanović, 2016)(Priscila Ferreira de Araújo Lima, 2020)

2.4.4 Cost and Time Estimation

One feature in construction project management that assumes consideration is the management of cost in a way in line with the budgets of the client. Appropriate cost planning needs considering the management of costs by the clients' budgets. Appropriate cost planning should guarantee the creation of sensible construction project budgets (baselines), and following cost management should stop unwelcoming results in cost overruns, conflicts and project rejection. Numerous experimental researches revealed that pre-tender cost estimate accuracies are greatly influenced by the level of risk data accessible to estimators. (Johnson Adafin, 2020)

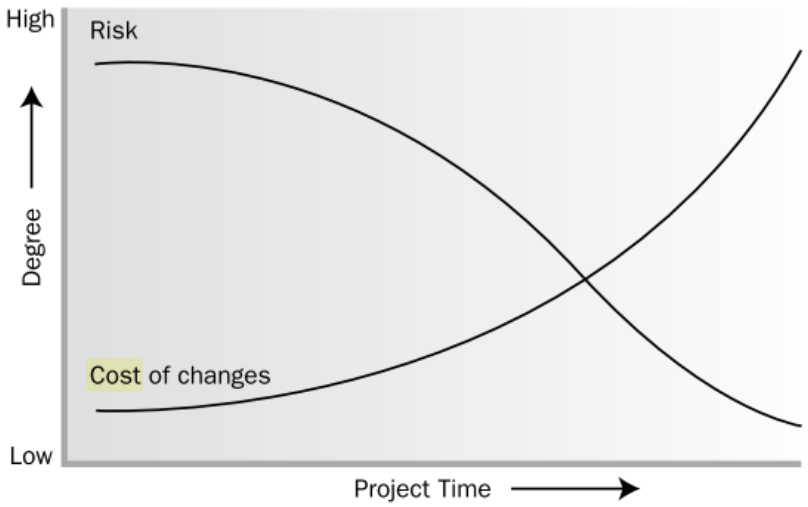


Figure 4: Risk vs Cost during the project life(PMI, 2017)

Percentage cost against time graph is revealing how significant decisions are made at the beginning of any project. (Smith, Merna and Jobling, 2006)

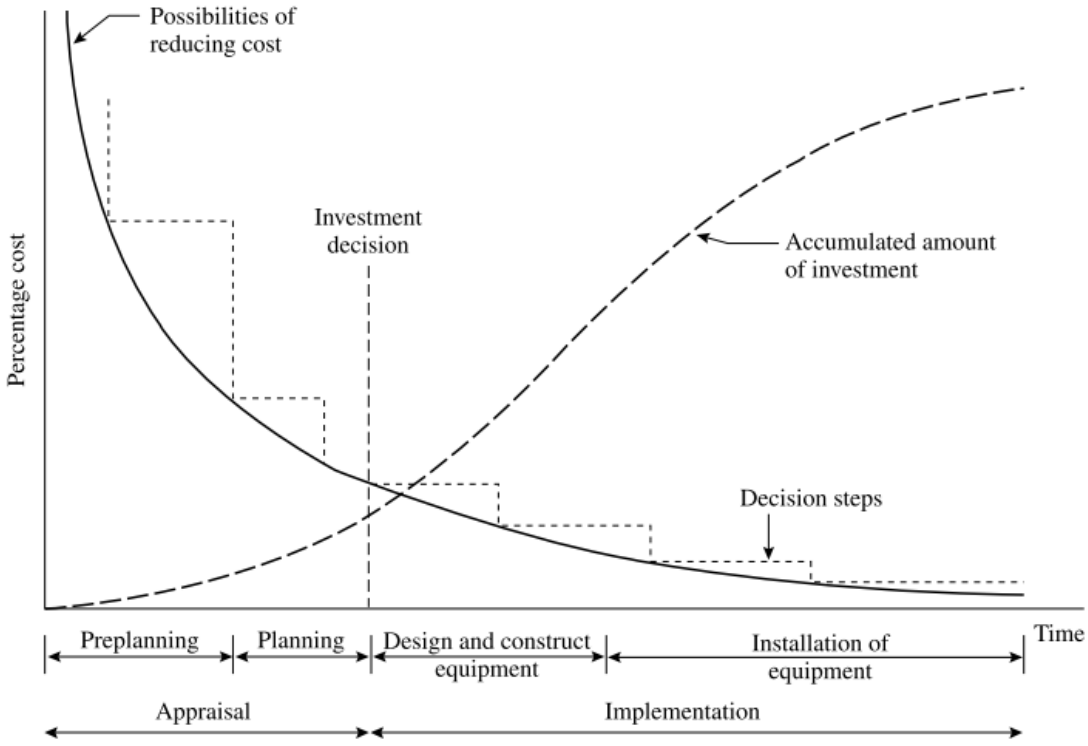


Figure 5: Possibility of Cost reduction against the time of a project(Smith, Merna and Jobling, 2006)

2.4.5 Cost and Time Overrun

Cost-performance ratio is evidence of project success, the cost overrun created results from inefficient construction management and weakly constructed cost monitoring system. (Rahman, Memon and Karim, 2013)

When studying 107 building projects, materialized in the shifting period between 1991-2001 in Croatia, cost and time overruns were the most critical results of risk occurred. These incidents are the worst results which influence the project failure scenarios. It has been proved that time and cost overruns are regular, as seen from global accounts. There is a small number of construction projects completed on time, based on the initial planning. Time overruns are more frequent than cost overruns in a project. The basis for this is more from customer inclination to fixed-price contracts or higher cost control than time control in projects. (Radujkovic and Car-Pusic, 2004)

The most common effects of risk frequency are overruns in initially scheduled, time and cost. The construction industry endures heavily in such events in developing countries. (Radujkovic and Car-Pusic, 2004)(M. Radujkovid, 1996)

Above 50% of internal risks show the growing liability of management. According to project management, the internal risk generators are more significant, since they can be handled by the project team. It is evident that quite frequently projects are begun without final preparation procedures, analyses and sufficient help. The detailed framework on risk sources reveals that in a building project contract cost overruns and time are frequently affected by numerous almost uniformly created internal risk source groups. (Radujkovic and Car-Pusic, 2004)

Contradictorily, countries in transition usually overlook risks in construction or cope with it by merely including 5% to the overall cost estimation. In construction projects, uncertainties and risks create cost overrun, poor execution quality and scheduling delay and at their end. Unsatisfactory cost functioning of building projects appears to be the standard rather than the exception, and both contractors and clients experience major monetary losses owing to the cost overruns. (Nerija Banaitiene, 2012)(Wang MT, 2003)(Robert K. Wysocki, 2014)

It is reported that basis of budget overrun in the UK using a questionnaire and figured out that principal reasons of overruns were changed in design, development factors in

designing, data accessibility, estimation method, project management and design team functioning (Hameed *et al.*, 2013).

Previous researchers studied cost and time overrun elements using a controlled questionnaire and discovered cost control preventing elements were design shifts, risk and incertitude associated with projects, erroneous measurement of project`s time/duration, non-operation of employers and appointed providers, work difficulty, disagreement between project parties, inconsistencies in contract documentation, definition and contract explanation disagreement, inflation, funding and payment for completed work, inadequate training and experience of task manager, unqualified workforce, unforeseeable weather conditions, reliance on imported supplies, absence of required software, variable interest rate, varying currency/exchange rate, poor supervision and control, project corruption and cheat, unsteady government policies. (Hameed *et al.*, 2013)

Base on the previous studies, cost and time overrun elements using a controlled questionnaire, discovered the ranks of risks which influence on cost and time overruns as below:

Cost-effective risks in (PMC)	***Rank***
Design change	1
Risk and incertitude associated with projects	2
Erroneous measurement of the project`s time/duration	3
Non-operation of employers and appointed providers	4
Work difficulty and complexity	5
The disagreement between project parties	6
Inconsistencies in contract documentation	7
Definition and contract explanation disagreement	8
Inflation	9
Funding and payment for completed work	10
Inadequate training and experience of task manager	11
Unqualified workforce	12
Unforeseeable weather conditions	13
Reliance on imported supplies	14
Absence of required software	15
Variable interest rate	16
Varying currency/exchange rate	17

Poor supervision and control	18
Project cheat and dishonesty	19
Unsteady government policies	20

Table 16: Main cost-effective risks in PMC, adapted from(Hameed *et al.*, 2013)

Cost and time overrun are international challenges and connected to almost every project. Control the scheduled time to finish the project plan in time is the main aim and objective of project control and coordination. Time and cost overruns are caused by numerous elements which may threaten project achievement and regarded as a major risk. (Hameed *et al.*, 2013)(Assaf and Al-Hejji 2006) (Arantes and Ferreira, 2020)(Rahman, Ismail and Jaber, 2018)

2.4.6 Investment and Profit margin

In construction projects, risks could severely impact its principal goals: cost, time, quality and scope, which could indicate further cost and thus a lower rate of yield on the project for the client and a loss of revenue for the contractor, along with other implications. Nevertheless, risk communication is approximate, deficient, and changeable through the chain of value in construction projects. (Tah and Carr, 2001a; Aven, 2011) (Serpell *et al.*, 2014) (Aven, 2011)

Since construction projects are continually susceptible to risks and are considered as projects with larger intrinsic risk because of the engagement of many stakeholders, project risk analysis from two separate viewpoints is possible. One of them is from client's stance whose decision-making is essential for the project, and the other one is from contractor's stance, who conventionally raises costs to evade risks, however, it should be considered that if marginal utility is decreasing, the business will become unproductive. (Baloi, P, Price, 2003).

These two parties have differing actions against the risks of the project along with distinct options of conveying risks to a group that is capable to manage them in the best way (Wang et al, 2011)(Serpell *et al.*, 2014).

Since the client's engagement in the construction project is minimum, skilful planning, effective resources employment and proper control could lower the costs and make the best profit out of it(Smith, Merna and Jobling, 2006).

In multiple projects, in this level, the financial cost is not taken into account in the cash-flow. Several organizations favour the usage of the return on investment (ROI) as the standard rate of return.

The inadequacy in financial solvency is claimed as another utmost risk to contemplate whether from the owners or contractors. Customarily, for enhancing the opportunity to win the project, contractors lessen their profit, which is of the highest risk at the time of the construction phase. The financial implications of these kinds of risks are rather evident which are: reduced productivity, limited performance and increased costs in the project(Antón, 2011).

Output: **Risk registration**

The Risk Registry documents the minutes of particular project risks. Findings on Performing Qualitative Risk Analysis, which is arranging risks for future examination, Planning of Risk Responses, which is the increase of opportunities and decrease of hazards, Implement Risk Responses, which is the execution of some actions responding to project risks, and Monitoring risks, should be accounted for the registration of risks. The risk register can be comprised of restricted or widespread risk data according to the project parameters for instance in its size and complexity.

Risk register's content could be comprised of the followings when the Identify Risk process has been done:

- **List of identified risks**: In the risk register, every individual project risk is granted with a singular identifier. To guarantee a clear understanding, the identification of risks has been performed in a thoroughly detailed form as demanded.
- **Potential risk owners**: The risk owner is listed in the registration of risks if possible, a risk owner has been spotted within the Identity Risks procedure. The verification would occur within the stage of performing the Qualitative Risk Analysis procedure.
- **Potential risk responses list:** If any possible risk response is detected within Identity Risks procedure, the recording of it should be done on the risk register. Its verification would be performed within the Plan Risk Response procedure.

According to the risk register format specified in the risk, further information could be listed for any identified risk. (PMI, 2017)

2.5 Risk Analysis

Risk analysis is defined as a measurement of risk effect on the success of project guidelines. The probabilistic approach is the most customary approach within the existing risk analysis approaches. Risk analysis is a process comprised of incertitude in a quantitative method. It utilizes probability theory for assessment of the effects of the possible risk. (Al-Bahar, 1990)

The significance of the origins of risk and uncertainty on the aims of the project is specified by Risk and uncertainty evaluation. Risk assessment could be done through the estimation of the probability of events and the intensity of risk impacts. (Zavadskas, Turskis and Tamošaitiene, 2010)

Finding the risks, the likelihood of loss arising from risk, the impact of the losses to cost, the alternatives, reduction or minimizing losses, the probability of the alternatives to provide other risks are the important questions in risk analysis which have to answer during the process(Robert K. Wysocki, 2014).

In construction companies, Qualitative approaches to risk assessment are most often applied to the projects before the quantitative approaches. Risks are assessed through their placement on a matrix of risk impact against probability in construction project risk management. To assure the risk tolerance and inclination of the construction company, predefined limits are used as a source for mitigation options. The development of the risk management pattern for construction projects can be done by incorporating qualitative and quantitative approaches to risk analysis. (Nerija Banaitiene, 2012)

By integrating qualitative and quantitative techniques for risk analysis the risk management process for construction projects can be developed.

A variety of mathematical methods are available to estimate the size of the likelihood of risk. They mainly allow incomplete information to be formalized and the risks of failure to predict future analyzed.

Risk Analysis Techniques

- Influence Diagrams
- Probability Impact Matrix
- Risk Rating
- Risk Mapping

- Direct Judgment
- Sensitivity Analysis
- Monte Carlo Simulation (MCS)
- Comparison option
- PERT method
- Decision Trees
- Descriptive analysis
- Fuzzy sets
- Artificial Neural Networks
- Scenario analysis

Table 17: Various risk analysis technique, adapted from(Szymański, 2017a)(Chris Chapman, 1998)

2.5.1 Qualitative Risk Analysis

The process of ranking each project risks aimed at having additional analysis or action is to Perform Qualitative Risk Analysis that is accomplished through evaluating their happening probability and impact along with other features. The utmost advantage of this procedure is to concentrates on efforts of high-rank risks. The course is carried out at all time during the project. (PMI, 2017)

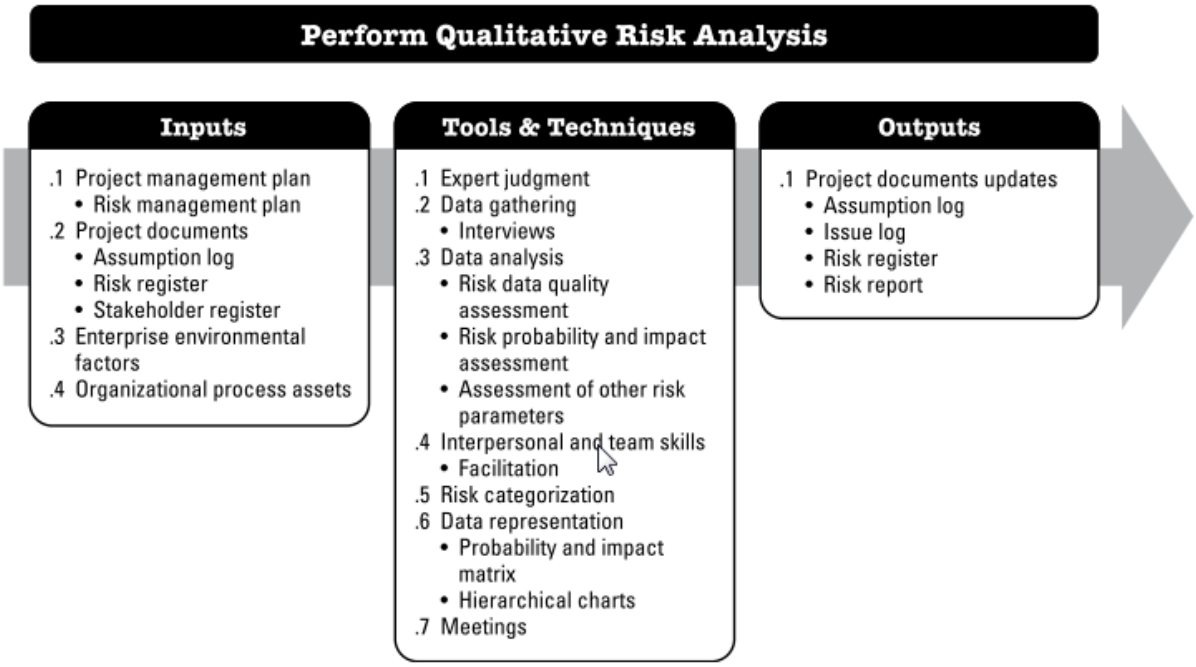


Figure 6:Qualitative risk analysis process(PMI, 2017)

Qualitative analysis is the most crucial one in the project as claimed by the authors who had been worked on risks(Radujkovic and Car-Pusic, 2004).

The primacy of spotted individual project risks is evaluated by Qualitative Risk Analysis which assesses the happening probability and subsequent effect on the objectives of the project in case the risks have the chance to take place as well as other elements. The related priorities of each project risks are created by Plan Responses Perform Qualitative Risk Analysis. It identifies a risk owner for individual risk whose task is to manage an effective risk response as well as to certify that the implementation has been carried out. Perform Qualitative Risk Analysis additionally forms the basis of Perform Quantitative Risk Analysis. (PMI, 2017)

The qualitative evaluation is very useful to assess the importance of hazards as well as the need to know what treatment beforehand needs, this evaluation relies on some computational and graphic methods, one of which is likelihood and consequences arrangement matrices, the so-called "probability impact risk matrix." (Keshk, Maarouf and Annany, 2018)

Descriptive scales make the foundation of Qualitative approaches of risk evaluation; they are employed for specifying the probability and implication of a risk. Qualitative approaches are connected with the quantitative approaches, and in some instances make up its grounds. (PMI, 2008)(Ubani, 2015)

Tools and technique:

A variety of instruments for measuring and classifying risk are used in quality evaluations. The most important of these are:

- Indicative risk factor likelihood assessment and its impact;
- Matrix of risk evaluation index;
- Estimated risk importance evaluation for the project;
- Research the reliability of project assumptions and the resilience of the projects to any changes;
- Techniques of data rating in terms of risk analysis usability;
- Identifying the risk index as a function of the likelihood of occurrence of a particular risk factor and the value of risk for the project if a particular risk factor occurs(Szymański, 2017a)

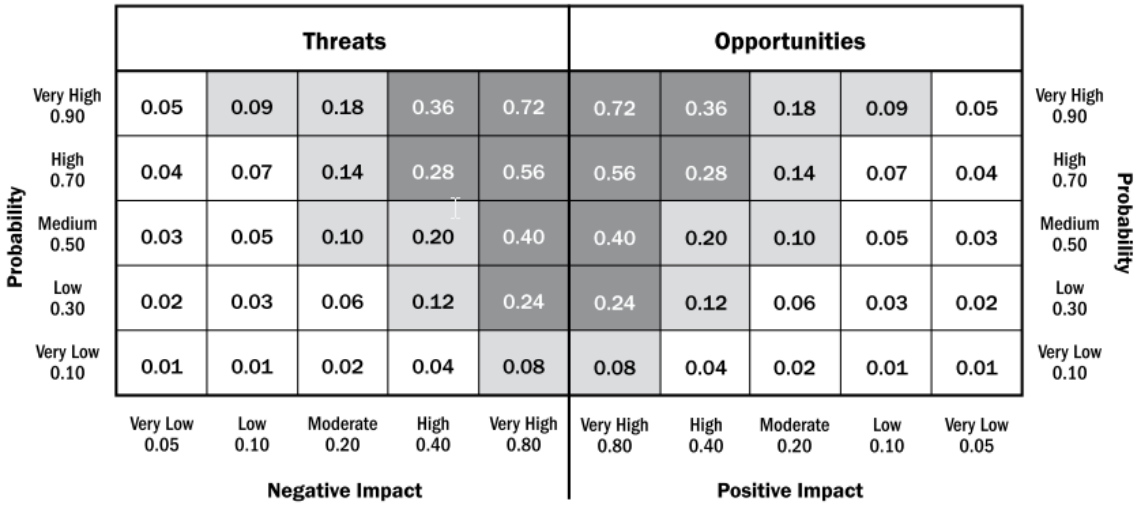


Table 18: probability/ Impact Matrix(PMI, 2017)

2.5.2 Quantitative Risk Analysis

Perform Quantitative Analysis numerically analyzes the merged impact of identified individual project risks along with origins of ambiguity upon project objectives generally. The overall project risk exposure quantification is the most beneficial advantage of the process, and it could as well present further quantitative risk data to back up risk response planning. (PMI, 2017)

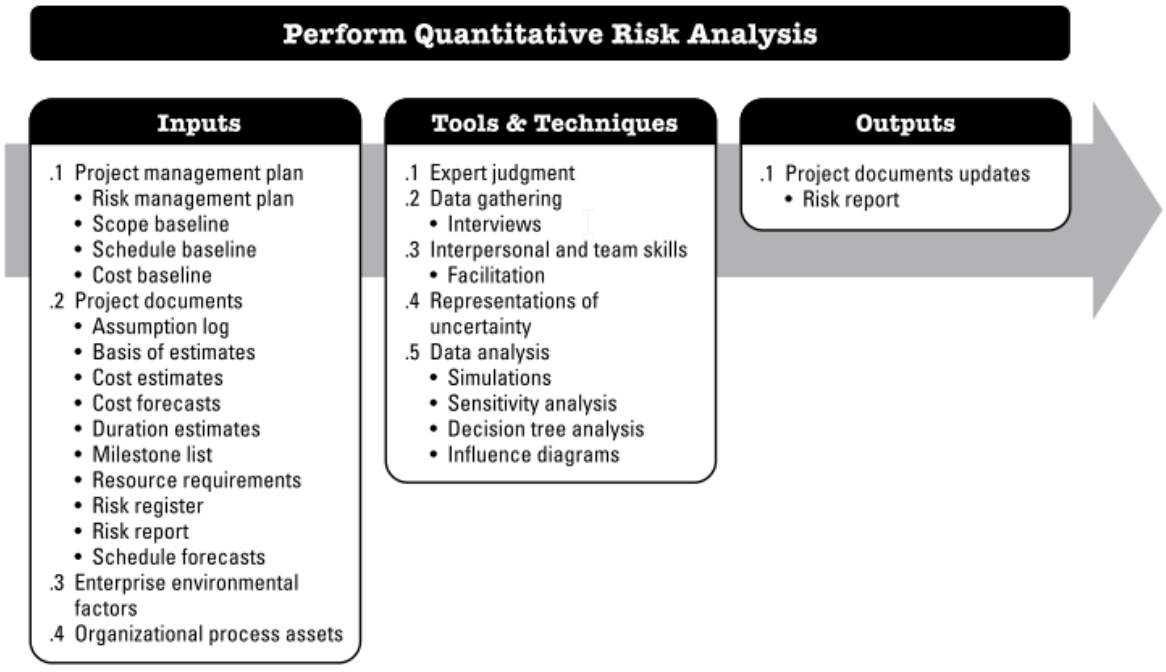


Figure 7: The process of quantitative risk analysis(PMI, 2017)

Perform Quantitative Analysis employs data on individual project risks. The information had been previously evaluated by the Perform Qualitative Risk Analysis process. And potentially, it is capable of having a major influence on the project`s objectives. (PMI, 2017)

It is mandatory to have some information to specify risk founded on quantitative analysis; the likelihood of risk which is well specified on the grounds of an effectively large, consistent and valid data sample, alongside the assessment of risk results. According to the information, which is assembled, the specification of a weighted arithmetic value can be performed. This would be addressed as a measure of risk analyzed with the equation shown below. (Szymański, 2017a)

Quantitative Assessment

There are diverse approaches in their amount of complexity; however, they may have a richer capability to face it and lessen its effect by undertaking the right measurements. (Keshk, Maarouf and Annany, 2018)

- **Probability and Impact Analysis**

Process	***Steps***
Probability/ Impact Analysis	1
Risk matrix	2
Prioritization of project risks	3
Rating the risks	4
Quantitative result trends of risk analysis	5
Risk response recommendation	6

Figure 8: Risk assessment by Probability and Impact analysis, adapted from(PMI, 2017)

- **Rating the Risks**

If the likelihood of occurrence and effect cannot be analytically assessed, the following method is possible:

1. Decide the risk factor components (attributes),

2. Decide on the attributes' alternative significance,

3. Assess the risk ratings for each alternative

4. Summing of all risk ratings weighted

In this approach, the level of risks that could not be quantified can be quantified by objective measures such as the risk for quality, safety risk, political risks, etc.

2.6 Risk Response Plan

The process of acquiring choices, picking the right strategies, deciding on measures to be taken on overall project risk exposure, along with addressing individual projects is called Plan Risk Responses. One of the central advantages in this course of action is to find suitable techniques for administration of overall project risk together with individual project risks. This method also offers tools and injects those activities into the project documentation and the project management plan if needed. (PMI, 2017)

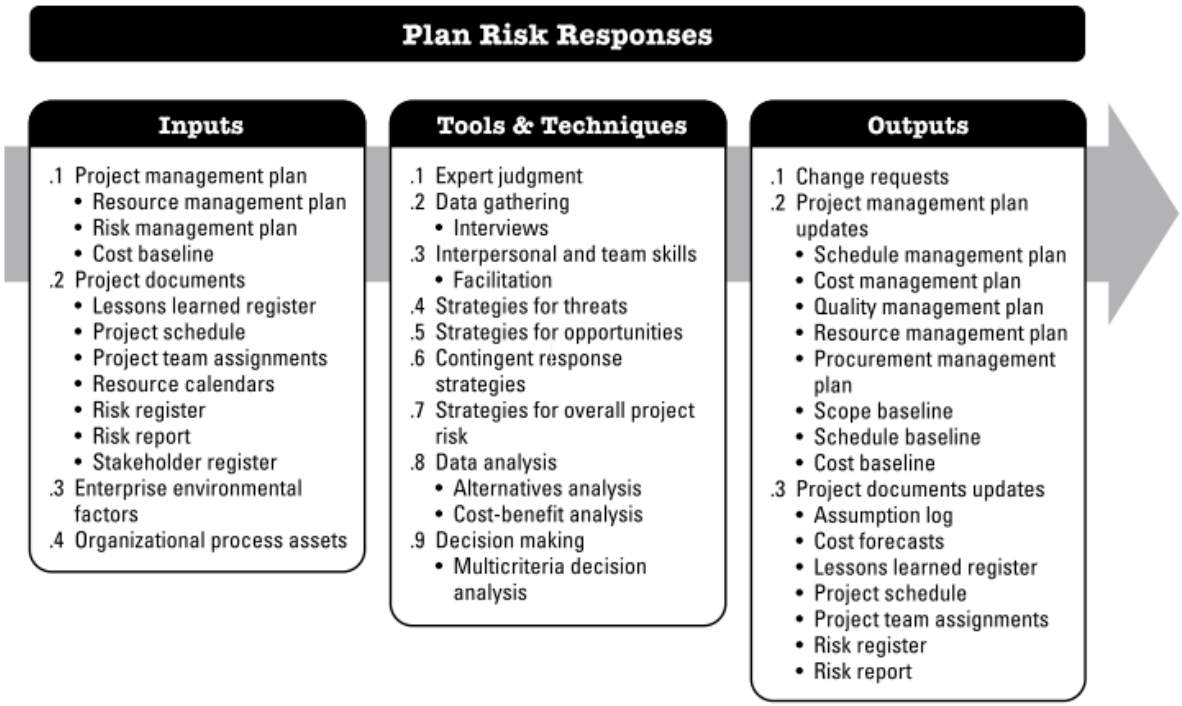


Figure 9:Risk response plan process(PMI, 2017)

Efficient and relevant risk responses can reduce individual hazards and increase individual chances; besides it can minimize the exposure of overall project risk. Improper responding to risks can bring about the reverse impact. After the identification, examination, arrangement of the risks, the selected risk owner should develop plans to administer every individual project risk. As a result of the dangers that can be exposed to the project goals or possible chances it may provide, the project team is regarded as appropriately significant. Risk responses should be suitable concerning the

importance of the risk. In meeting the needs, they must be cost-effective, they should be realistic to the context, and negotiated by all the parties involved, as well as handled by a person in charge. Here, the requirement is to choose the finest risk response from numerous options. For any risks, effectual strategies should be selected. For selecting the most suitable response, organized decision-making techniques should be used. (Raftery, 1994)

The action phase of the Risk Management System includes the identification of the risk so the contractor can be capable of developing appropriate risk management strategies before the occurrence of the problem. These strategies objectives attempt to eliminate probable impacts and raising risk control management as much as possible. (McKim, 1992)

The most critical step of risk management is risk response but is a field that has not been studied, where project managers can decide on the risks. While the manager has not lost much of the cost and time to react to risks, Risk response planning is an underrated aspect of the risk management project**.** (I. Naji and Hussein Ali, 2017)

2.6.1 Risk Response Strategies

To Cope with risks, base on the (PMI, 2017) there are four strategies as a mitigation plan as below:

Anti- risk measures

- **Avoidance**

It is necessary to change the project plan to escape a dangerous situation. It is the best strategy to avoid the estimated risks during the project.

- **Transfer:**

When it is not possible to avoid the risk, the best strategy is to transfer completely or share the risk. The routes for risk transfer in construction projects and contracts are generally from client to contractor and contractor to subcontractor or client, contractor and subcontractor to the insurance companies and guarantor.

- **Mitigation**

Mitigation is a common term for describing the state of decreasing the possibility or after-effects of an undesirable risk occurrence. On exceptional cases, this can result in the total removal of hazards, as referred to in "risk avoidance". Although, it is inadequate to just address the resultant expected value, since, the risk stays unacceptable in case that possible impact is more than a certain amount. In this instance, another method would have to be chosen.

- **Acceptance**

There are some responses which are meant to be employed only in the case that particular events take place. Making a responding plan to be carried out through particular pre-established situations by the project team is suitable for some risks. In this case, it is asserted that there have to be an appropriate warning before the implementation of the plan. (Ubani, 2015)(PMI, 2017)

Cost-Benefit Analysis

By using benefit-cost analysis, the profitability of substitute risk response methodologies might be expressed, but this is possible when the quantification of the effect of individual project risk in financial terms has been conducted. Results of the profitability of responses methods are achieved through the dividing ratio of variation in implication level by the cost implementation; it means that the higher the ratio is, the more effective the response can be. (PMI, 2017)

2.7 Risk Response Implementation

The procedure of carrying out previously negotiated risk response plans is the Implement Risk Response. The process principal advantage is to guarantee that the execution of agreed-upon risk responses is as what is organized before, this is to address the overall project risk exposure, reducing individual project hazards along with increasing individual project possibilities. The whole project is under the influence of this process. (PMI, 2017)

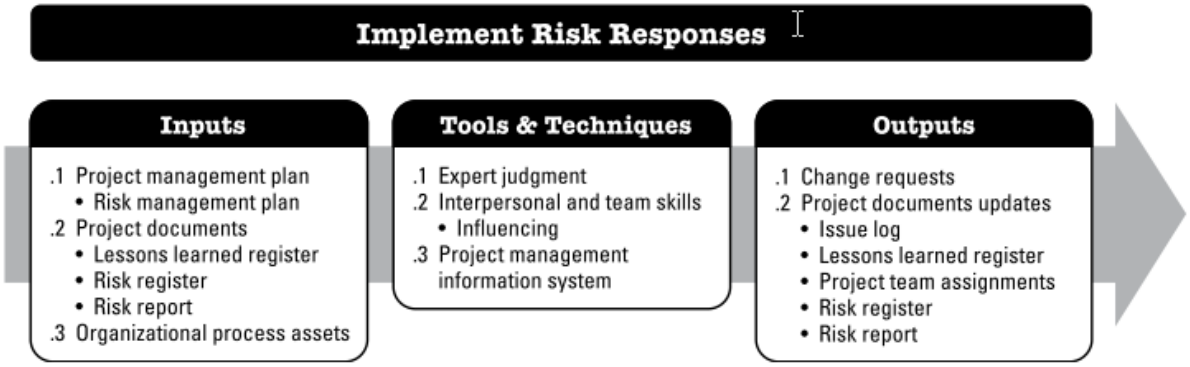


Figure 11-18. Implement Risk Responses: Inputs, Tools & Techniques, and Outputs

Inadequacy in system formality alongside the deficiency of consolidative medium of risk management among the different parties of a project is the leading obstacles in the way of implementation of an effectual risk management system. Moreover, risk management is not employed in a project as vigorously as other issues in the project management procedure are taken into account. (Serpell *et al.*, 2014)

Implementing risk responses: Output

Change requests

A change request might arise from Risk response Implementation stage that is regarding the request concerning the cost as well as planning standards and also other project management plan elements. Change requests are administered for assessment along with arrangement via Perform Integrated Change Control process. (PMI, 2017)

2.8 Risk Monitoring

Monitoring Risks is the stage of supervising the prearranged risk response plans implementation, locating spotted risks, detecting as well as examining recent risks, along with measuring risk process efficiency within the project. The process main advantage is that project decisions can be found on the present data on the exposure of overall project risk together with individual project risk. Across the whole project, the procedure has been carried out all the time.

Following risks identification, qualification, quantification as well as the development of plan responses, it is the time for those results to be actualized. Risk monitoring and control include the risk plan implementation, that must be one of the essential parts of the project plan. Two prominent difficulties are connected with monitoring and

controlling. Firstly, implementing the risk plans should be carried out and then it is time for making sure that the plans are still convincing. The second one is creating sound documentation to back up the procedure. (Ubani, 2015)

The last step in the illustration of the risk management flow selected here includes the assuredness in the usage of the preceding phases. It narrows down to make sure that the identified risks, which are considered significant, are also supervised in the way that was prearranged in the response step. New risks can be identified in the control step as well and then the ongoing process proceeds. Risk control focuses on restricting deviance, decreasing risks and optimizing the value of the project. The management of risks has conducted to fulfil project objectives as easily and effectively as possible. Remedial steps for the monitoring of construction projects risks are as below:

- Change schedules, work scope and forecasts against risks.
- Regular risk monitoring, alternative plans for managing predictable risks, if needed.
- Timely decision making
- Be aware of potential risks to all concerned. (Ubani, 2015)

Monitor Risks: Tools and technique

Data Analysis

For this method, analytical techniques that can be used include:

Analysis of technological performance

Technical performance analysis weighs technical achievements within project performance against the planning of technical accomplishments. It demands the specification of goals and technical performance quantifiable measures, which could be used to draw compassion between real-life results and targets. Such technical performance measures might comprise of operation times, weight, storage capacity, the record of delivered defects and the like. Deviation signifies the probable influence of hazards or opportunities.

Analysis of reserve

Several individual project risks might happen upon budget or plan contingency reserves all through project implementation, positively or negatively. In the project, analysis of reserves is to measure the contingency reserves residual amount to the risk

residual amount in certain times, this is happened to find out whether the remaining of reserve stays sufficient or not. Through numerous graphical, it can be reported. (PMI, 2017)

Risk Monitoring: Output

Information about work performance

Work performance information comprises details about in what manner project risk management can be performed. This can be realized by contrasting how the individual risks have happened to the assumption of in what way they might happen. These statistics suggest the efficacy in response planning and response application procedures.

Requests changing

The Monitor Risks process might bring about change requests for the cost and schedule standards as well as other existing elements in the project. The assessment and also disposition of a project are generated from the dealing with change requests under the process of Integrated Change Control. Change requests might be comprised of suggested restorative and prohibitive actions. They can manage to address the existing overall project risk level along with handling the individual project risks level.

Updating the Management plan

Changing project management plans must be approved by the company`s change control procedure based on a change request. There is a chance for this to influence any element in the project management plan. (PMI, 2017)

3 Methodology

This research uses a systematic literature review (SLR) and questionnaire survey by specialists in construction projects to define and classify the most important financial risk factors with their potential to have a major effect on the cost of construction projects continuum. The actual aim of prefabricated construction method proposed is to mitigate the most significant factors of financial risk.

Attempts were placed to choose construction experts who had an adequate level of knowledge in prefabricated construction and risk management.

The idea is to apply two questionnaires based on the selected critical risk factors and dimensions in both conventional and prefabricated construction method that is important to measure and send to a group of construction experts who work in the area of risk management and prefabricated construction.

The first questionnaire is divided into the two sections, the probability and impact of selected risks which affected directly and indirectly on the economic objectives of the conventional construction projects and important to measure to find the weight and rank them by probability/ impact matrix method. Also, work experience of participants is included in the first questionnaire design.

The second questionnaire is designed with the probability and impact of Critical risk factors same to the first questionnaire but in the area of prefabricated construction method plus the advantages, barrios, critical success factors to assess and evaluate the economic benefits of applying PMC method in the construction industry which has mentioned in the results and discussion in detailed.

The second questionnaire survey included the common information about the participants' background and selected critical risk factors, same as the first questionnaire but in the PMC method and the other benefits and barrios of PMC method which practised and obtained from the literature review and previous researches' results.

The aim of designing two questionnaires is to compare the result of the probability and impact matrix of conventional and PMC method to show the amount of percentage impact of PMC Method on mitigating the financial construction risks.

3.1 Data Gathering

Standard questionnaire form with an emphasis on projects costs and time considering the effects of using prefabrication in construction projects is used in this research. The questionnaire survey included the common information about the participants' background and selected critical risk factors, same as the first questionnaire but in the PMC method and the other benefits and barrios of PMC method which obtained with literature review, brain Storming by attention to the economic risks group and the checklist of potential construction risks and the result of previous researches and questionnaire surveys.

Data are collected from the questionnaire form and converting the qualitative data to quantitative data was the standard method of data gathering and the main aim was converting the qualitative data to a digital data source.

3.2 Data Analysis

Statistical analysis is applied to quantitative data were collected from the participants' answers and transferred to the excel sheets to find data coherence and correlations. Experts were asked to identify and rate the most critical risk factors, success factors, advantages and barriers of PMC method on a five-point scale from "Very Low" to "Very High".

$$Score = \frac{(Very\ low * 1) + (Low * 2) + (Moderate * 3) + (High * 4) + (Very\ high * 5)}{Number\ of\ Participants}$$

By drawing graphs, tables and arrange the data on different graphical output all analyzed data was mentioned and explained.

Probability/ Impact Method

By applying probability and impact method a professional comparison between the achieved statistical result from conventional methods and PMC methods was down to verify the result of current research.

The steps of statistical data analyzing are as below:

- Data filtering and arrangement

- Qualitative and Quantitative Analyzing
- Risk ranking in Excel
- Probability/ Impact evaluation

Impact	***Very High 0.90***	0.09	0.27	0.45	0.63	0.81
	High 0.70	0.07	0.21	0.35	0.49	0.63
	Moderate 0.50	0.05	0.15	0.25	0.35	0.45
	Low 0.30	0.03	0.09	0.15	0.21	0.27
	Very Low 0.10	0.01	0.03	0.05	0.07	0.09
Proximity Matrix		***Very Low 0.10***	***Low 0.30***	***Moderate 0.50***	***High 0.70***	***Very High 0.90***
		Probability				

Table 19: Probability and impact matrix pattern which is used in this research

Risk Probability		***Description***
Relative	***Numerical***	
Very Low	0.1	Highly unlikely to occur
Low	0.3	Will most likely not occur
Moderate	0.5	Possible to occur
High	0.7	Likely to occur
Very High	0.9	Highly likely to occur

Table 20: the numerical and description of risk probability

Risk Impact		***Description***
Relative	***Numerical***	
Very Low	0.1	Insignificant change in cost
Low	0.3	< 5% increase
Moderate	0.5	5 -15 % increase
High	0.7	15 - 25% increase
Very High	0.9	>25 - 35% increase

Table 21: the numerical and description of financial risk impact

Proximity = Probability * Impact

In the end, the proximity of selected risks from conventional and PMC method was compared in a table to show the amount of change in each risk and tried to make a proper conclusion and recommendation due to data comparison and current research results.

4 Results and Discussion

The qualitative and quantitative approach of studies is used utilizing a questionnaire and considering previous study findings to address the questions of current research about the possible financial risks of construction projects. Such approaches considered the various real experience projects for both the cost and the time of prefabricated construction. Furthermore, the findings obtained to compare with the previous study or actual project experiences.

As mentioned in the methodology, two questionnaires were designed. In the expert questionnaire, 14 experts from Germany, Finland, France and Iran, selected and invited to participate in this survey. The questionnaire designed online in the google form format and the invitation is placed by sending the link via the email and LinkedIn individually and also interview is done with many of them to explain the aims and objectives of this survey.

In the general questionnaire, about 350 persons in the area of civil engineering, architecture, PMC, construction and risk management were invited by sending the online questionnaire link to all of them one by one, via email and LinkedIn message. 65 persons responded to the online questionnaire (about 20%). The most of responders were from Germany, Finland, UK, France and Iran.

4.1 Participants' Background

Profession

As it is shown in the graph below, more participants were project manager and civil engineer. 22% of participants were project manager and 20% were civil engineers. General contractors, structure engineers, construction engineers, architects, off-site manufacturers and power engineers were in the next ranks. The information of participants has mentioned in a detailed table in section Appendix B.

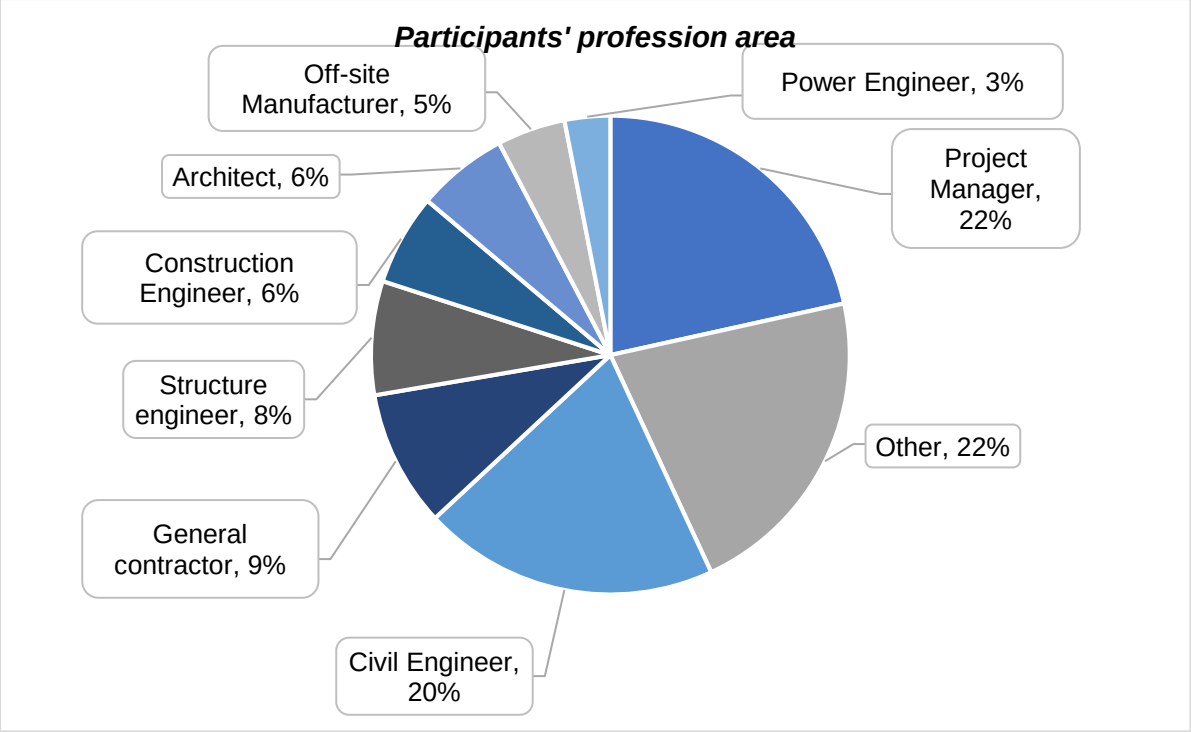


Figure 10: participants' profession area, adapted from the questionnaire survey.

Education

54% of participants had a master's degree, 26% Bachelor's degree, 11% Doctoral degree, 3% Associate degree and 6% had another degree which has mentioned in appendix B.

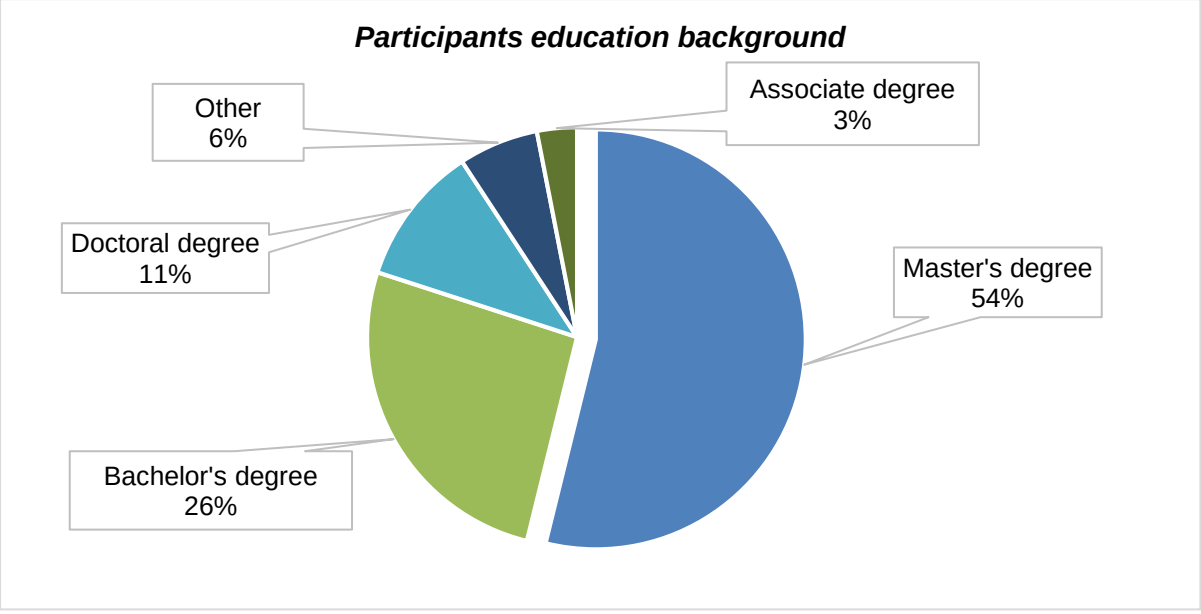


Figure 11: participants' education background, adapted from the questionnaire survey.

Work Experience

11% of participants had between 1 to 3 years experiences in the construction industry, 22% between 4 to 7 years, 28% between 8 to 12 years, 18% between 13 to 20 years and 22% over 20 years.

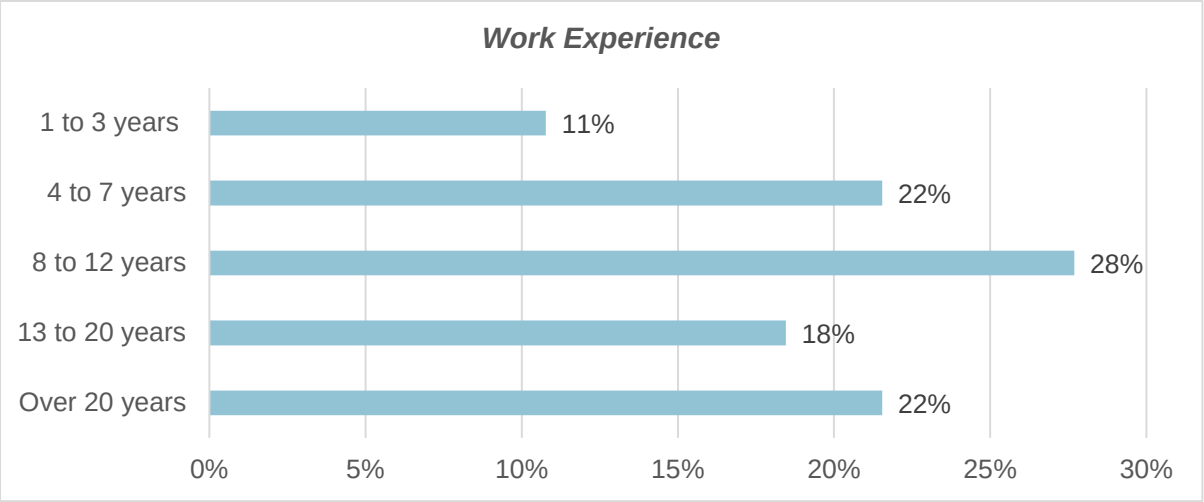


Figure 12: participants' work experience, adapted from the questionnaire survey.

Scale of Project

Currently or in the past, 12% of participants had participated in projects with a scale of less than 1500 square meters, 20% between 1501 to 3500 m2, 15% between 3501 to 5500 m2, 20% between 5501 to 10000 m2 and 32% more than 10000 m2.

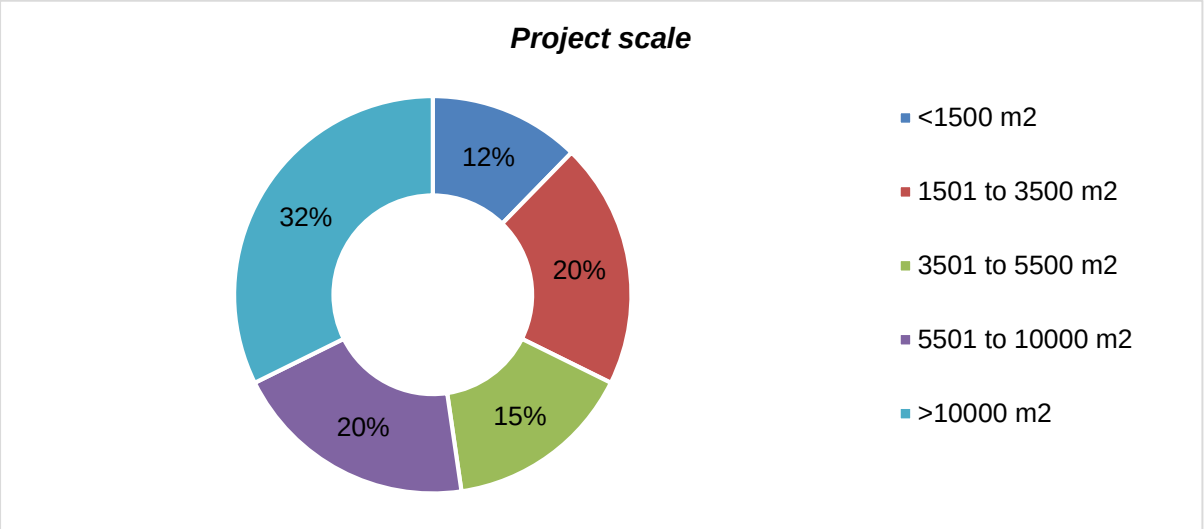


Figure 13: participants' project scale, adapted from the questionnaire survey.

Also, more than 75% of participants had been involved in a prefabricated construction project in the past 5 years.

4.2 Participants' General Perspective

According to this survey, in the 80% of participants' opinion, today's off-site construction environment is different compared to five years ago and it has changed.

Besides, 71% of participants have agreed that the cost of maintenance and facility management for a prefabricated building is less than a traditional building which means it can increase the profit margins during the prefabricated building lifecycle.

4.3 Benefits and Advantages of (PMC)

According to this survey, the main 3 advantages of PMC base on participants' opinion were Time Overrun Avoidance by 71% of votes, Consistency & Quality Improvement by 65% of votes and Waste Material Reduction by 57% of votes. Besides, Cost Overrun Avoidance by 42%, Better safety & Security by 23%, Profit Margin Improvement by 15% and Independent in Weather Condition by 3% of votes were in the next ranks. Other benefits were optional to mentioned by the participants and they voted 8% to the other advantages which have mentioned in the detailed table in section appendix B.

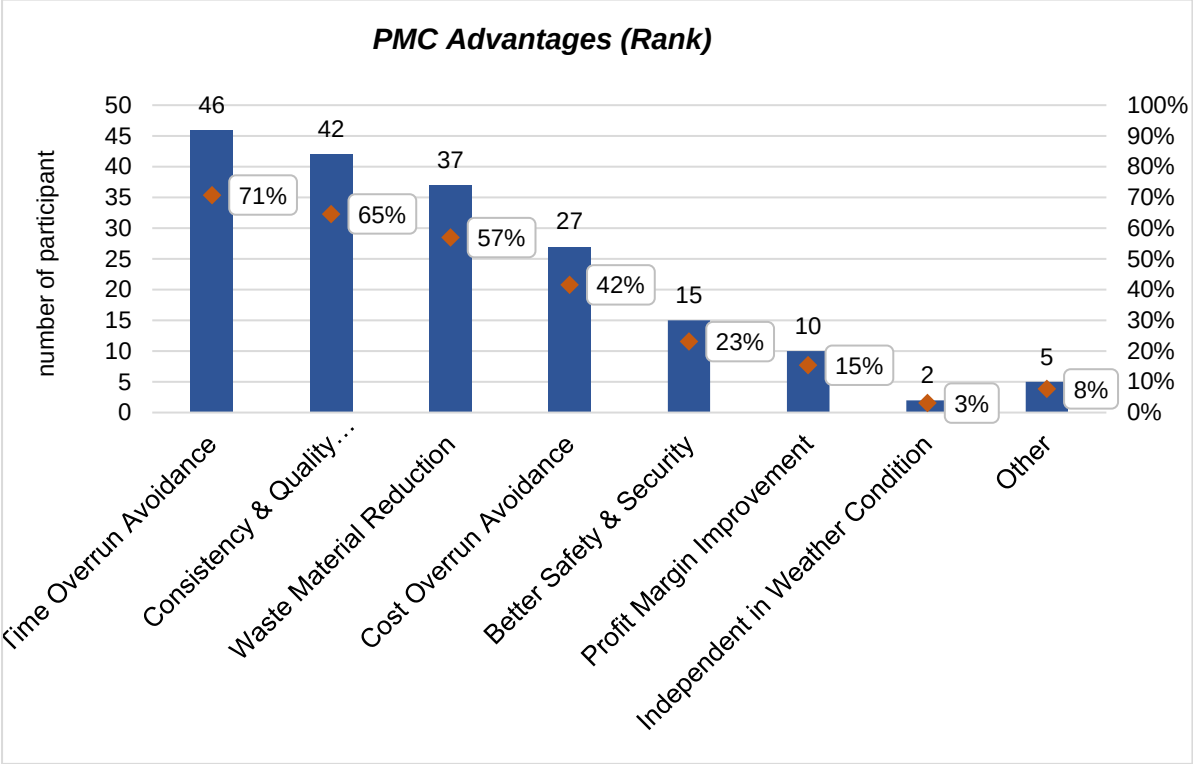


Table 22: the advantages of the PMC method, adapted from the questionnaire survey.

Participants were asked to score the main benefits of PMC over conventional methods from (very low=1) to (very high=5). The main benefit of PMC in compare with conventional methods was'' Reducing time to project completion and avoid delays'' by score 4.06 of 5, and the ranks of other benefits were as mentioned in the table below.

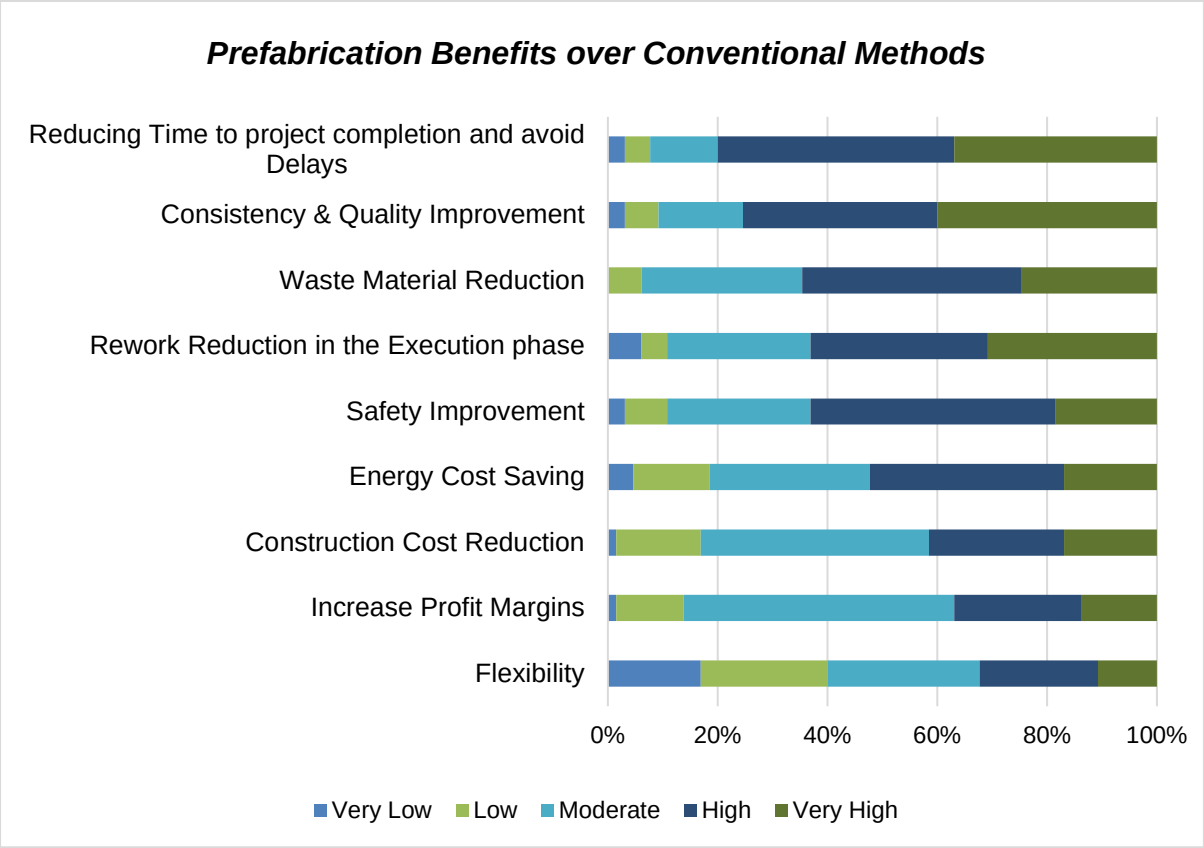


Table 23: the rank of prefabrication benefits, adapted from the questionnaire survey.

According to the participants' opinion and the result from their voting, Tracking the quality by 60% of votes, was the main criteria to measure the effectiveness of prefabrication efforts, Tracking the cost-saving by 44.6%, Tracking the unit/labour hour by 43.1% and tracking the ROI and Profit margin by 21.5% by far were in the next ranks as it is shown in the table below.

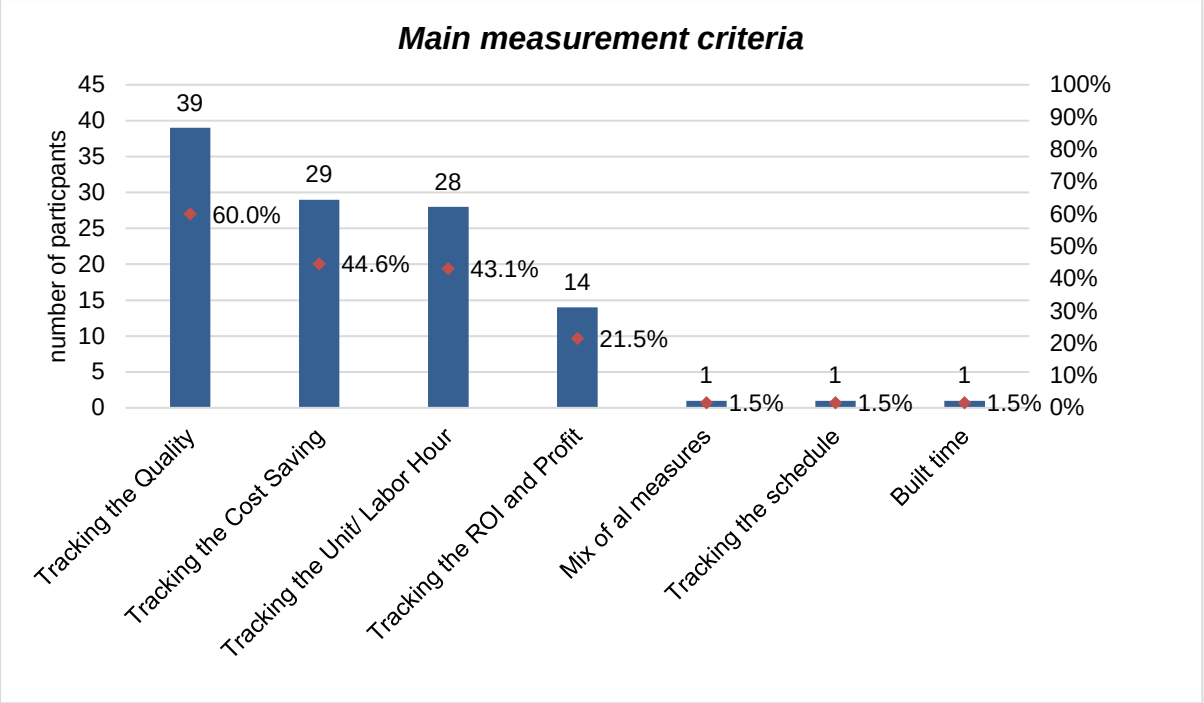


Table 24: main 3 criteria to measure the prefabrication efforts, adapted from the questionnaire survey.

In this survey also participants were asked to score the factors from (very low=1) to (very high=5) that to what extent the promotion of prefabricated construction can increase the degree of Economic Performance?

''Improving the construction industry'' by score 4.15 was the major factor which can increase the degree of the economic performance of PMC, ''reducing the lifecycle cost'' by score 3.65 and ''Increasing profit margin'' by 3.51 score was in the next rank as below.

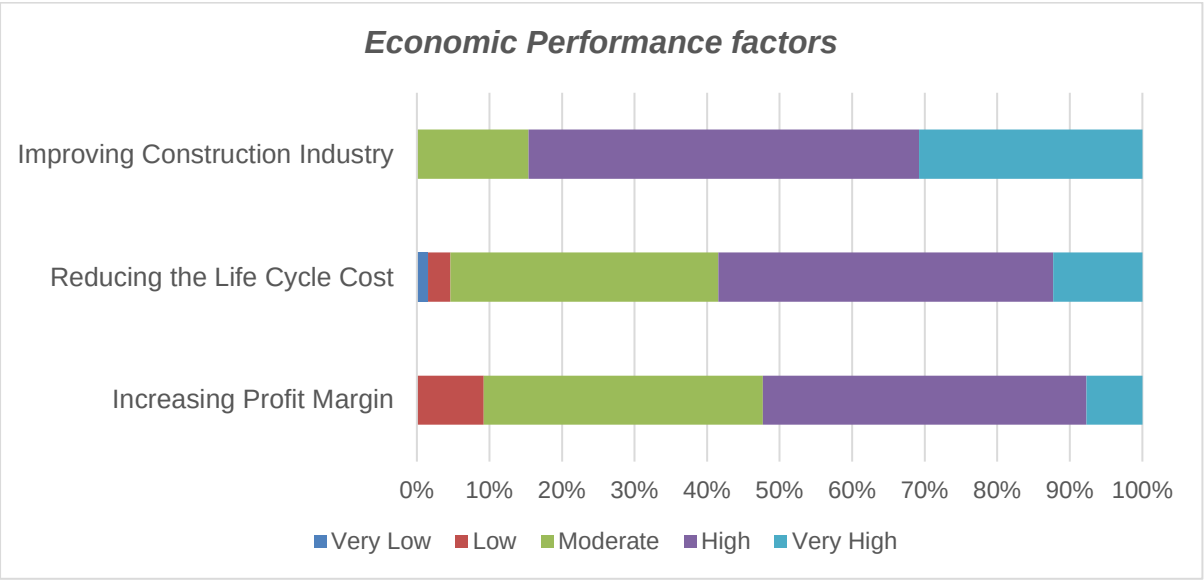


Table 25:the Economic performance factor of PMC promotion, adapted from the questionnaire survey.

4.4 Barriers and Risks of PMC

Barriers

There are many barriers to implementing off-site construction, 8 major barriers were selected and asked from participant to score the importance of them from (Very Low=1) to (Very High=5), based on the participants' answers, '' Design and Construction Culture problems'' by score 3.94 was the major barrier of PMC implementation. The second one was'' Lack of enough Industry Knowledge'' by score 3.83 and the third one was'' No flexibility in design change'' by score 3.51. The other barriers were in the next ranks as it is shown in the table below.

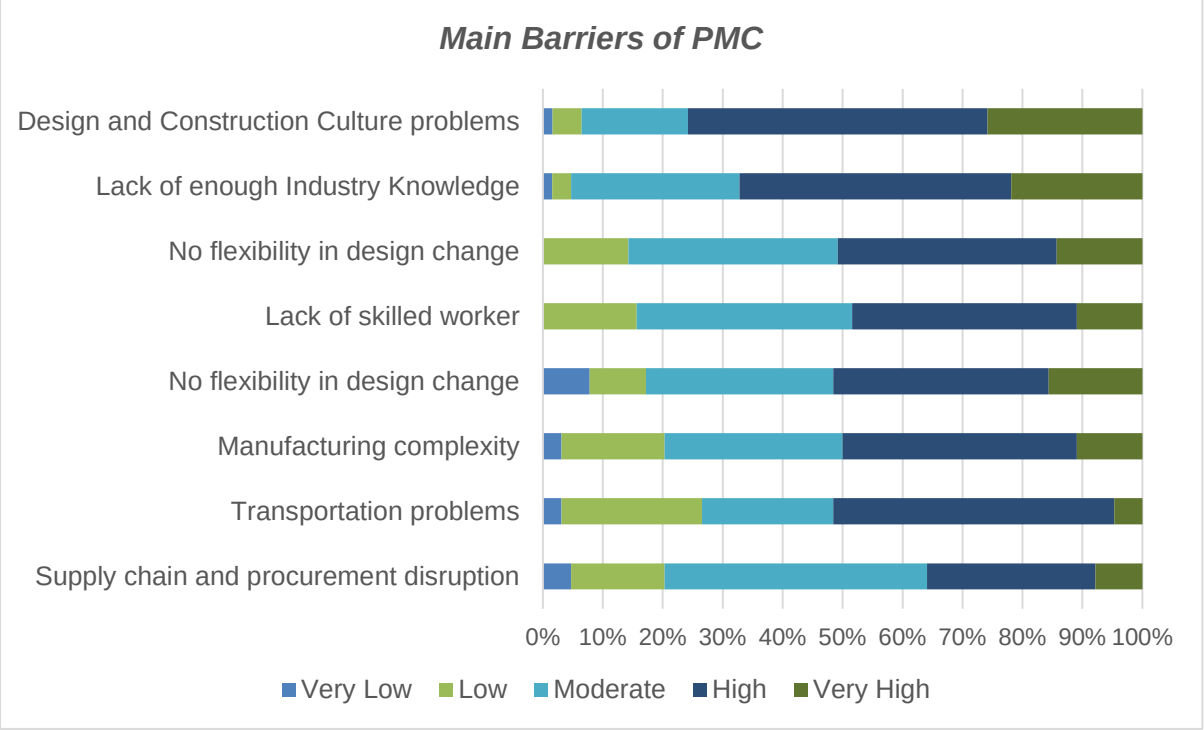


Table 26: the rank of PMC barriers, adapted from the questionnaire survey.

Risks

Probability/ Impact Matrix of Conventional methods

In the first survey (Expert questionnaire), participants were invited to estimate the probability of each selected risk occurring and assign it a rating in the conventional methods from (Very Low=0.1) to (Very High=0.9). then after, they were asked to estimate the economic impact of each risk from (Very Low=0.1) to (Very High=0.9) If the risk occurred. According to the experts' response, the results of probability and impact were as it is shown in the matrix below.

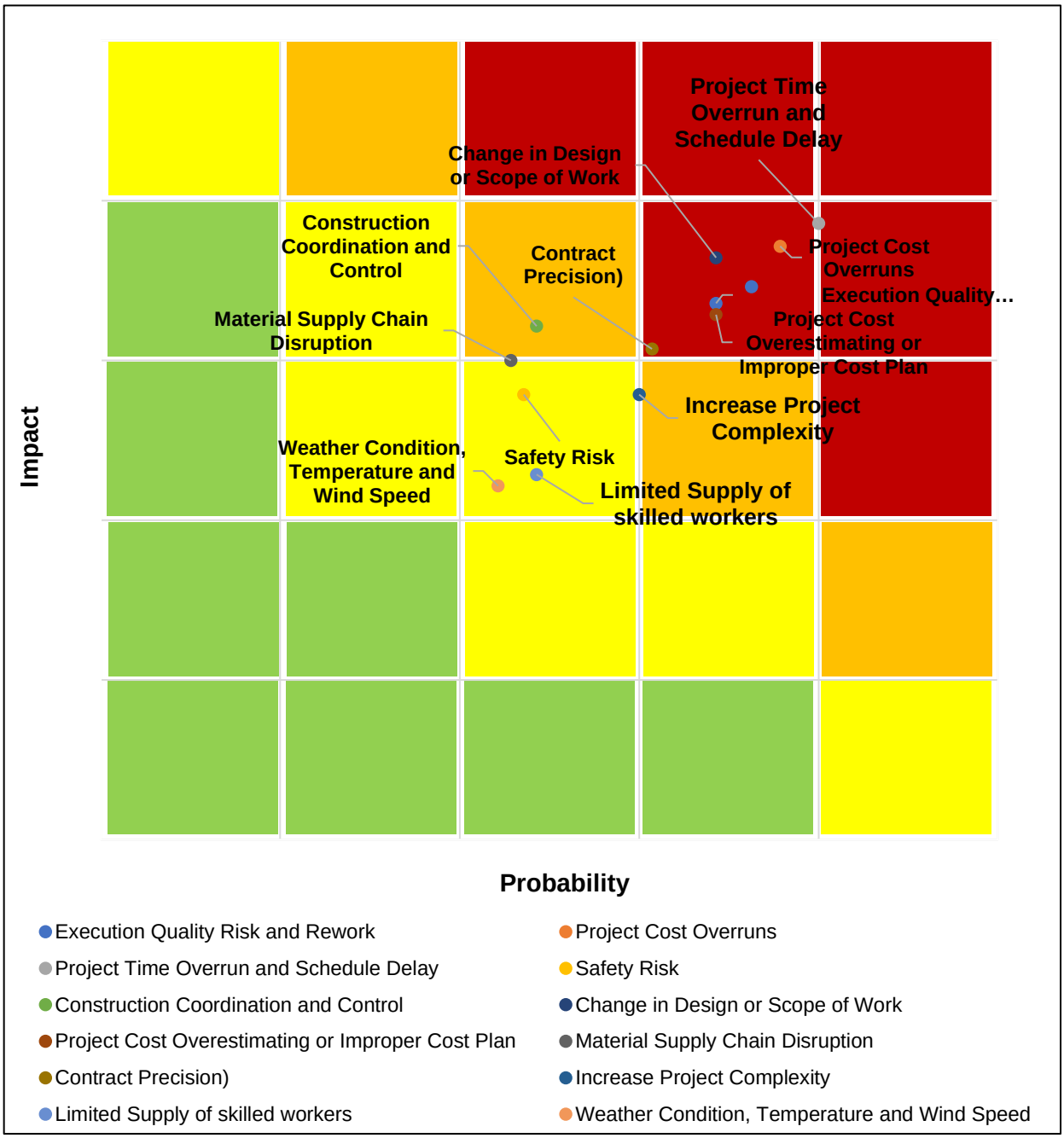


Table 27: Probability/ Impact matrix of conventional methods' risks, adapted from the questionnaire survey.

Probability/ Impact Matrix of PMC

In the second survey (general questionnaire), participants were invited to estimate the probability of each selected risk occurring and assign it a rating in the PMC methods from (Very Low=0.1) to (Very High=0.9). then after, they were asked to estimate the economic impact of each risk from (Very Low=0.1) to (Very High=0.9) If the risk occurred. According to the participants' responses, the results of probability and impact were as it is shown in the matrix below.

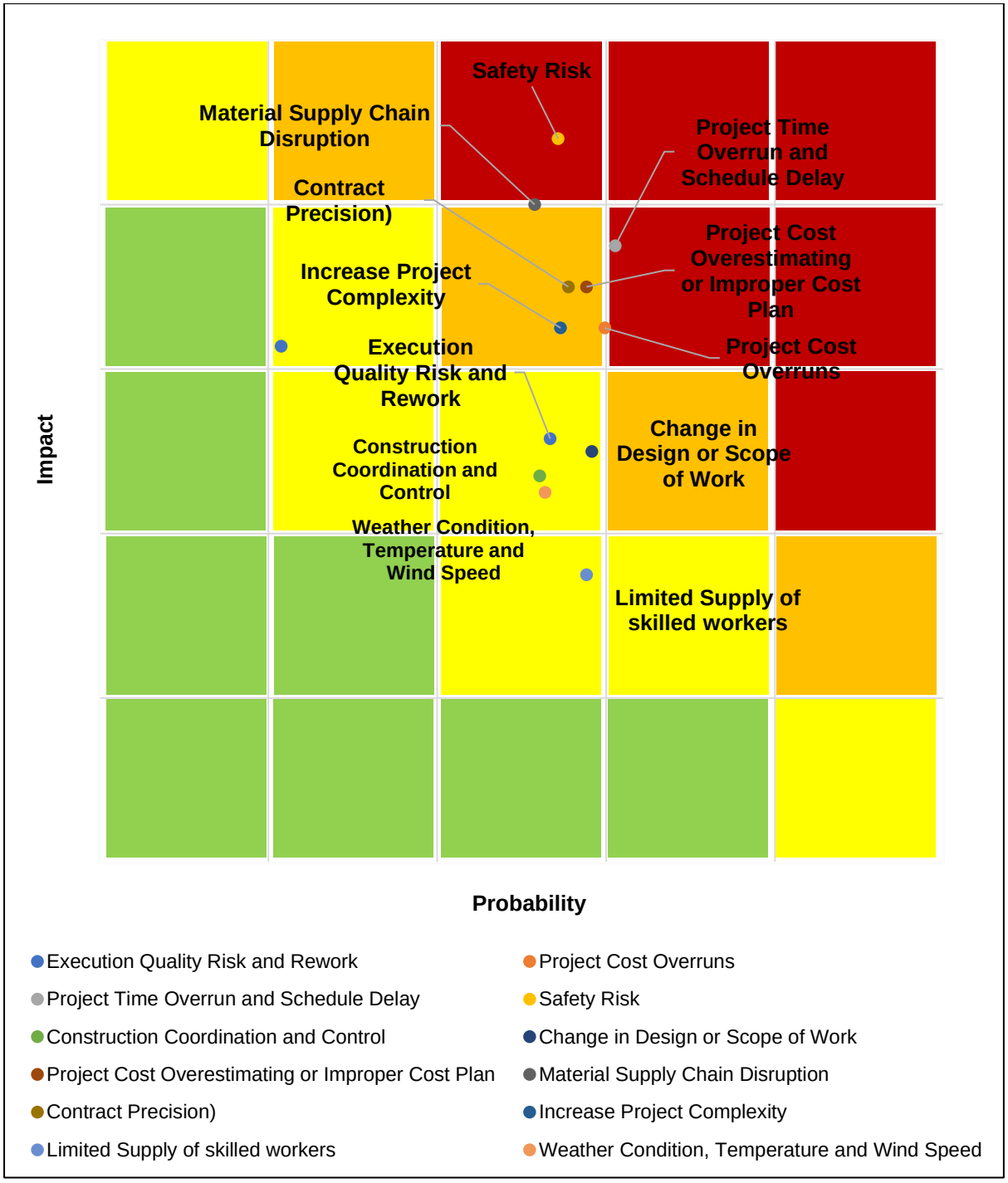


Table 28: Probability/ Impact matrix of PMC method's risks, adapted from the questionnaire survey.

Comparison Probability/ Impact matrix of PMC and conventional methods

According to the quality of participants' answer of risk probability and risk economic impacts, the proximity of each risk in PMC and the conventional method was calculated and compared with together which the list of risks proximity is shown in the table below.

Proximity				
ID	***Risks description***	***Conventional methods***	***(PMC) method***	***Delta***
1	Change in Design or Scope of Work	0.477	0.292	39%
2	Execution Quality Risk and Rework	0.401	0.275	31%
3	Project Cost Overruns	0.538	0.389	28%
4	Limited Supply of skilled workers	0.267	0.202	24%
5	Project Time Overrun and Schedule Delay	0.575	0.458	20%
6	Project Cost Overestimating or Improper Cost Plan	0.444	0.404	9%
7	Construction Coordination and Control	0.255	0.245	4%
8	Contract Precision (claims and litigation)	0.369	0.389	-5%
9	Increase Project Complexity	0.311	0.355	-14%
10	Weather Condition, Temperature and Wind Speed	0.173	0.237	-37%
11	Material Supply Chain Disruption	0.274	0.412	-50%
12	Safety Risk	0.266	0.478	-80%

Table 29: Proximity of the risk of conventional and PMC method, adapted from the questionnaire survey.

The results indicated that the use of PMC method can reduce the risk of ''Change in Design or Scope of Work'' by 39%, the risk of '' Execution Quality Risk and Rework'' by 31%, the risk of ''Project Cost Overruns'' by 28%, the risk of '' Limited Supply of skilled workers'' by 24%, the risk of '' Project Time Overrun and Schedule Delay'' by 20%, the risk of '' Project Cost Overestimating or Improper Cost Plan'' by 9% and the risk of '' Construction Coordination and Control'' by 4%.

These positive changes like 'Consistency & Quality Improvement' 'Cost Overrun Avoidance' and 'Time Overrun Avoidance'' have also proved as the main advantages and benefits of PMC in the previous researches and the results of this survey.

The results also indicated that many risks may increase in PMC method, based on this survey the use of PMC method increases the risk of 'Contract Precision (claims and litigation)' by 5%, the risk of 'Increase Project Complexity' by 14%, the risk of 'Weather

Condition, Temperature and Wind Speed’ by 37%, the risk of ‘Material Supply Chain Disruption’ by 50% and most unexpected result was increasing the safety risk by 80%.

4.5 Summary

Based on the participants‘ background, Most of the participants were project manager and civil engineer and 54% of participants had a master's degree. 67% of participants had more than 8 years of work experience and 32% of them had the experience of presence in the in projects of more than 10000 m2 scale.

More than 70% of participants had agreed that in general, today’s off-site construction environment is different compared to five years ago and the cost of a prefabricated building is less than a traditional building.

The results showed that the main advantage of using PMC method is ,‘ Time Overrun Avoidance‘‘ and the main benefit of using PMC over the conventional method is ,‘Reducing Time to Project Completion and Avoid Delays‘.

Based on the participants‘ opinion, quality is the main criteria to measure the effectiveness of prefabrication efforts.

The main barriers of PMC were ,‘Design and Construction Culture problems‘, ‘Lack of enough Industry Knowledge‘, and ‘No flexibility in design change‘.

Based on the quality of participants‘ answers, the probability and impact of each risk were calculated and by comparing the rank of risks‘ proximity in conventional risk matrix and PMC risk matrix, the results show that the risk of ‘ Project Time Overrun and Schedule Delay‘ as the main probable risk in conventional method reduces by 20% in PMC method. Also using the PMC method can reduce 39% the risk of ,‘Change in Design or Scope of Work’ and 31% the risk of ‘Execution Quality Risk and Rework’ which effects directly on project time overruns. Therefore By reducing the time of PMC projects, the period of return on investment starts sooner than conventional projects.

Also, the result shows that using the PMC method reduces 28% the risk of ‘Project Cost Overruns’ and by considering the 9% improvement in the risk of ‘Project Cost Overestimating or Improper Cost Plan’ PMC method can increase the construction profit margin and reduce the period of return on investment.

5 Conclusion

This research aims to assess the positive impact of using prefabricated and modular construction on construction financial risks and introduce the PMC method as an alternative strategy plan which can mitigate the construction concerns and encourage the construction investors to use the new construction methods, motivated by increased profit margins and reduced the construction risks.

This research tries to introduce critical success factors, benefits and advantages of PMC method over conventional methods and compare the critical financial risks in PMC and conventional methods in the probability and impact matrix based on systematic literature findings and questionnaire survey to assess and analyse the quality of participants' answers and find the weight of factors in the assessment prosses.

Development of this research was useful to find the significant idea and positive factors in the construction risk management and PMC method in the scope of the project costs and time.

Construction risk management is a systematic and comprehensive process of risk identification, risk analysing and responds to the risk to achieve the objectives of the project.

Exposure to risk in a project is inevitable and risks will always be as a threat of the project objectives, which can have negative effects on the approach and completion of a project. In the process of project management, the management team are always dealing with the potential risks and to minimize the negative impact of certain risks, risk response and alternative strategy plan is an essential stage of risk management in the preplanning phase and to identify unexpected risks in the projects, risk identification tools and technics is an essential step in the risk management process, brainstorming is one of the risk identification tools which needs knowledge and experience, therefore expert judgment and the lesson learned from the previous projects are essential and useful method. Also, risk identification, assessment and impact analysis in the early stage of the project play the main role in project success.

To give the proper weight of risks, probability and impact method is one of the useful methods that can show the more realistic negative impact of probable risks and unpredictable events which may occur.

The most challenges which the today construction industry faces are low-profit margin and competitive market and accomplishment the project within the specified time and allocated budget. Therefore it is essential to implement the new methods which can bring the needs of users by reducing the time and cost of the project and increase the stakeholders' profit margins.

The research results show that, by applying the PMC method, project time overruns and schedule delays reduce about 20% and besides, mitigating the risk of change in design and scope of work and execution rework can directly have a positive impact to accomplish the project in the specified time.

To accomplish the project within the budget and increase the profit margin of project, the results show that PMC method can improve the quality and reduce the cost of maintenance also by waste material reduction and cost overrun avoidance can reduce the cost of a project.

the profit margin increases from two aspects, first by reducing the time of a project, the period of return on investment (ROI) starts earlier and by reducing the cost of a project the period of ROI will be shorter in comparison with the conventional methods.

Based on this research, results show, reducing time to project completion and avoid delays are the main benefits of PMC method and Time overruns and cost overrun avoidance and quality improvement are the main advantages of the PMC method over conventional methods, despite the positive advantages and benefits of PMC method there are still many barriers to implementing PMC such as design and Construction Culture problems, Lack of enough knowledge in this area which needs more attention in the construction industry. Also, the high initial investment of off-site manufacturing and transportation of prefabricated components from the factory to the construction site is still a big problem of applying the PMC.

Recommendation

There is still insufficient attention to the risk management process in the construction management companies and more investment in this area is needed.

Making the list of priority risks at the start of the project is helpful to analyse the negative impact of project objectives. Quantification method to find the weight the impact of each prior and unexpected risk in the early stage makes it more tangible to aware

of the negative impact of risks on each aspect of the project objectives and then it is easier to think about the alternative scenarios from the construction manager.

There is always a big gap between theoretical and practical. so, many times in reality the project progress is not as well as it planned. Therefore in the construction planning phase, the construction companies need to use the experience and advice of construction experts who have experience in the real projects in the construction phase to estimate a proper cost plan as much as possible to reality and make more accurate project schedule.

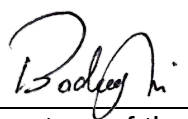
Because of the limitation of national resources and the negative impact of the construction industry on the environment, the new methods like PMC tries to reduce the waste in material and increase the lifetime of buildings. To achieve the desired results, more investment in changing the consumerism and construction culture is needed to attract and motivate the construction's investors to apply the new methods.

To promote and overcome the obstacles of the PMC method, more investment is needed in this area to improve industry knowledge, train more skilled worker and construction culture to introduce the PMC method as an alternative and reliable method.

Declaration of Authorship

I hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, 27.10.2020



Location, Date

Signature of the student

Appendix

Appendix A

Expert Questionnaire (Conventional Construction Method) with answers

1. There are many potential risks in the construction industry below, how do you estimate the probability of these risks in conventional construction projects?

ID	*Risks*	*Very Low*	*Low*	*Moderate*	*High*	*Very High*	*Rank*
3	Project Time Overrun and Schedule Delay	0	0	1	5	8	80.0
2	Project Cost Overruns	0	0	0	10	4	75.7
1	Execution Quality Risk and Rework	0	0	2	11	1	68.6
6	Change in Design or Scope of Work	0	1	1	10	2	68.6
7	Project Cost Overestimating or Improper Cost Plan	0	1	2	8	3	68.6
9	Contract Precision)	1	1	4	5	3	61.4
10	Increase Project Complexity	0	2	4	7	1	60.0
5	Construction Coordination and Control	0	4	7	3	0	48.6
11	Limited Supply of skilled workers	4	1	3	4	2	48.6
4	Safety Risk	1	2	10	0	1	47.1
8	Material Supply Chain Disruption	1	6	4	1	2	45.7
12	Weather Condition, Temperature and Wind Speed	0	5	8	1	0	44.3

Table 30: the rank of experts' score to the probability of potential risks of conventional construction, adapted from the questionnaire survey.

2. There are many potential risks in the construction industry below, if these risks occur, how do you estimate the financial impact on conventional construction projects?

ID	*Risks*	*Very Low*	*Low*	*Moderate*	*High*	*Very High*	*Rank*
3	Project Time Overrun and Schedule Delay	0	0	0	9	5	77.1
2	Project Cost Overruns	0	0	2	7	5	74.3
6	Change in Design or Scope of Work	0	0	2	8	4	72.9
1	Execution Quality Risk and Rework	0	1	1	11	1	67.1
7	Project Cost Overestimating or Improper Cost Plan	0	2	1	9	2	65.7
5	Construction Coordination and Control	0	0	5	8	1	64.3

9	Contract Precision)	0	2	4	6	2	61.4
8	Material Supply Chain Disruption	0	4	2	5	3	60.0
4	Safety Risk	0	2	8	2	2	55.7
10	Increase Project Complexity	0	2	7	4	1	55.7
11	Limited Supply of skilled workers	4	2	3	3	2	45.7
12	Weather Condition, Temperature and Wind Speed	0	4	10	0	0	44.3

Table 31: the rank of experts' score to the financial impact of potential risks of conventional construction, adapted from the questionnaire survey.

3. How much experience do you have in the construction industry?

Experience	*Participants*	*In per cent*
1 to 3 years	2	3%
4 to 7 years	1	2%
8 to 12 years	2	3%
13 to 20 years	7	11%
Over 20 years	2	3%

Table 32: experts' work experience, adapted from the questionnaire survey.

Appendix B

General Questionnaire (Prefabricated and modular Construction Method) with answers

1. Have you been involved in a prefabricated construction project in the past 5 years?

Answer	*Participants number*	*in Percent*
NO	16	24.6%
YES	49	75.4%

Table 33: Percentage of participants in prefabricated projects in the last 5 years, adapted from the questionnaire survey

2. In your opinion, is today's off-site construction environment different compared to five years ago?

Answer	*Participants number*	*In Percent*
NO	13	20.0%
YES	52	80.0%

Table 34: Percentage of participants' opinion about the changing in today off-site construction environment compared to five years ago, adapted from the questionnaire survey.

3. What is the scale of project which you have participated currently or in the past?

Area	*Participants*	*In Percent*
<1500 m2	8	12.3%
1501 to 3500 m2	13	20.0%
3501 to 5500 m2	10	15.4%

5501 to 10000 m2	13	20.0%
>10000 m2	21	32.3%

Table 35: the scale of participants' project which they have had participated currently or in the past, adapted from the questionnaire survey.

4. In your opinion, what are the main 3 advantages of prefabricated construction?

Prefabrication Advantages Rank	*Participants*	*In Percent*
Time Overrun Avoidance	46	71%
Consistency & Quality Improvement	42	65%
Waste Material Reduction	37	57%
Cost Overrun Avoidance	27	42%
Better Safety & Security	15	23%
Profit Margin Improvement	10	15%
Independent in Weather Condition	2	3%
Other	5	8%

Table 36:participants' opinion about the main 3 advantages of prefabricated construction, adapted from the questionnaire survey.

5. There are some benefits of prefabricated construction, how do you find these advantages of Prefabrication over conventional methods?

Benefits	*Very Low*	*Low*	*Moderate*	*High*	*Very High*	*Rank*
Reducing Time to project completion and avoid Delays	2	3	8	28	24	4.06
Consistency & Quality Improvement	2	4	10	23	26	4.03
Waste Material Reduction	0	4	19	26	16	3.83
Rework Reduction in the Execution phase	4	3	17	21	20	3.77
Safety Improvement	2	5	17	29	12	3.68
Energy Cost Saving	3	9	19	23	11	3.46
Construction Cost Reduction	1	10	27	16	11	3.4
Increase Profit Margins	1	8	32	15	9	3.35
Flexibility	11	15	18	14	7	2.86

Table 37:the rank of participants' score to the benefits of prefabricated construction, adapted from the questionnaire survey.

6. By tracking what criteria do you measure the effectiveness of prefabrication efforts?

Measures	*Participants*	*Percentages*
Tracking the Quality	39	60.0%
Tracking the Cost Saving	29	44.6%
Tracking the Unit/ Labor Hour	28	43.1%
Tracking the ROI and Profit	14	21.5%
The mix of all measures	1	1.5%
Tracking the schedule	1	1.5%
Built time	1	1.5%

Table 38: the participants' criteria to measure the effectiveness of pf prefabrication efforts, adapted from the questionnaire survey.

7. There are many potential risks in the construction industry below, how do you estimate the probability of these risks in a construction project?

Risks	*Very Low*	*Low*	*Moderate*	*High*	*Very High*	*Rank*
Project Time Overrun and Schedule Delay	4	6	20	20	15	61.1
Project Cost Overruns	1	10	21	22	11	59.8
Change in Design or Scope of Work	1	15	14	26	9	58.3
Project Cost Overestimating or Improper Cost Plan	2	12	19	23	9	57.7
Limited Supply of skilled workers	2	10	22	23	8	57.7
Contract Precision (claims and litigation)	3	12	25	14	11	55.5
Increase Project Complexity	3	13	22	20	7	54.6
Safety Risk	3	10	28	18	6	54.3
Execution Quality Risk and Rework	4	13	24	16	8	53.4
Weather Condition, Temperature and Wind Speed	6	16	16	17	10	52.8
Construction Coordination and Control	5	12	25	17	6	52.2
Material Supply Chain Disruption	2	16	27	15	5	51.5

Table 39: the rank of participants' score to the probability of potential risks of prefabricated construction, adapted from the questionnaire survey.

8. There are many potential risks in prefabrication and modular construction below, how do you estimate the economic impact of these risks in a construction project?

Risks	*Very Low*	*Low*	*Moderate*	*High*	*Very High*	*Rank*
Change in Design or Scope of Work	2	10	19	18	16	61.08
Project Cost Overestimating or Improper Cost Plan	3	10	18	22	12	59.23
Project Cost Overruns	0	16	19	20	10	57.38
Construction Coordination and Control	3	8	26	21	7	56.46
Project Time Overrun and Schedule Delay	3	16	17	19	10	55.23
Increase Project Complexity	4	13	22	17	9	54.31
Material Supply Chain Disruption	5	11	23	19	7	53.69
Safety Risk	3	14	22	22	4	53.08
Contract Precision (claims and litigation)	5	14	20	20	6	52.46
Execution Quality Risk and Rework	5	17	20	14	9	51.54
Limited Supply of skilled workers	5	18	21	15	6	49.69
Weather Condition, Temperature and Wind Speed	9	23	15	11	7	45.08

Table 40: the rank of participants' score to the financial impact of potential risks of prefabricated construction, adapted from the questionnaire survey.

9. Do you agree that the cost of maintenance and facility management for a prefabricated building is less than a traditional building?

answer	*Participants*	*Column1*
YES	46	70.8%
NO	19	29.2%

Table 41: participants' votes regarding the lower cost of prefabricated building maintenance, adapted from the questionnaire survey.

10. To what extent the promotion of prefabricated construction can increase the degree of Economic Performance?

Column1	*Very Low*	*Low*	*Moderate*	*High*	*Very High*	*Score*
Improving Construction Industry	0	0	10	35	20	4.15
Reducing the Life Cycle Cost	1	2	24	30	8	3.65
Increasing Profit Margin	0	6	25	29	5	3.51

Table 42: participants' votes on the economic performance of promotion the prefabricated construction, adapted from the questionnaire survey.

11. There are some barriers to implementing off-site construction, how important do you find these barriers in prefabricated construction?

List Of main Barriers	*Very Low*	*Low*	*Moderate*	*High*	*Very High*	*Score*
Design and Construction Culture problems	1	3	11	31	16	3.94
Lack of enough Industry Knowledge	1	2	18	29	14	3.83
No flexibility in design change	0	9	22	23	9	3.51
Lack of skilled worker	0	10	23	24	7	3.44
No flexibility in design change	5	6	20	23	10	3.42
Manufacturing complexity	2	11	19	25	7	3.38
Transportation problems	2	15	14	30	3	3.27
Supply chain and procurement disruption	3	10	28	18	5	3.19

Table 43: participants' score on the barriers of prefabricated construction, adapted from the questionnaire survey.

12. How much experience do you have in the construction industry?

Experience	*Participants*	*In per cent*
1 to 3 years	7	11%
4 to 7 years	14	22%
8 to 12 years	18	28%
13 to 20 years	12	18%
Over 20 years	14	22%

Table 44: participants' work experience, adapted from the questionnaire survey.

13. Which of these field describes better your current profession?

Profession	***Participants***
Project Manager	14
Civil Engineer	13
General contractor	6
Structure engineer	5
Construction Engineer	4
Architect	4
Off-site Manufacturer	3
Power Engineer	2
Director	1
Operations/Construction Director	1
Construction Commercial	1
Brokerage, property and facility management	1
Consultant	1
Offsite consultant	1
Modular Building Advisor	1
Manufactured Truss Designer	1
Lecturer	1
Development Engineer in BIM and Digitalization	1
Researcher	1
Home Designer	1
Site supervisor	1
Sub-Contractor	1

Table 45: participants' profession area, adapted from the questionnaire survey.

14. What is your education background?

Education	***Participants***
Master's degree	35
Bachelor's degree	17
Doctoral degree	7
Associate degree	2
Diploma in Construction	1
Industry training	1
HS / Some College / Trade School	1
Artisan	1

Table 46: participants' education background, adapted from the questionnaire survey.

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