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Adopting Modern Methods of Construction in Low-Income Housing Projects in Egypt

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Declaration

I confirm that this work has not been submitted for an award of a degree or diploma in any university. The thesis does not contain any material previously published or written by another author except where due references are made in the thesis itself.

Yamen Bakhaty

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Abstract

Despite being one of the significant contributors to the global economy, construction has been constantly accused of productivity issues, which resulted in the continuous pursuit of innovative methods to improve its performance. Consequently, Modern Methods of Construction (MMC) was proffered as an innovative construction method that brings the advantages of industrialization to construction by manufacturing building components offsite and then transferred and installed onsite. MMC has been adopted in many developed countries to address the housing shortage as it can increase the supply of units, decrease costs and improve the quality of units.

Egypt, one of the largest countries in Africa and the Middle East and North Africa (MENA) region, is facing a severe shortage of low-income housing. Despite implementing several housing policies, the shortage continued to grow, especially with the continuous increase in population and other economic and socio-culture challenges. The rationale behind this research is to proffer MMC as a solution to address the shortage of low-income housing as well as the challenges that the Egyptian construction sector is currently facing. The research adopted an inductive approach with an ontological relativism instance and social constructionism epistemological assumption to identify all the influencing factors to MMC adoption in low-income housing projects from various data sources. Convergent parallel mixed method approach was adopted for data collection and analysis by merging qualitative and quantitative data to provide comprehensive results.

Governmental support, industrial capabilities, enhancing the socio-cultural aspects and achieving sustainability were identified as critical success factors to MMC adoption in Egypt. At the same time, high capital costs, lack of training facilities, lack of MMC knowledge and reduced technological readiness were illustrated as challenges and barriers to MMC adoption. From the results, a framework to adopt MMC in social housing projects was established, consisting of seven main pillars that cover the influencing factors on its implementation. The framework was divided into four phases to ensure successful implementation, including the role of the involved stakeholders during each stage. The framework was validated through a series of interviews with experts in construction management to ensure its effectiveness and practicality.

The framework provides a clear strategy for adopting and implementing MMC in social housing projects in Egypt by considering all the influencing factors that can impact it. It

provides an understanding of the specific nature of the Egyptian construction and housing sectors, where its main target is to integrate MMC systematically. The research contributes to the theory of adoption of MMC in developing countries by considering social and cultural factors that can help accept or reject innovation in social housing projects. This research contributes to knowledge by providing new insights into MMC implementation in developing countries by integrating the socio-cultural factors with other economic and technical factors. The study provided critical analysis on how MMC can address the current challenges in the Egyptian context such as the deteriorated architectural heritage, social-cultural needs and other economic, industrial and technical factors.

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Abbreviations

AIJ: Architectural Institute of Japan

ANUC: Authority of New Urban Communities

BIM: Building Information Modelling

BRE: Building Research Establishment

CAPMAS: Central Agency for Public Mobilization and Statistics

CAR: Central Agency for Reconstruction

GCC: Gulf Cooperation Council

GPD: Gross Domestic Product

GVA: Gross Value Added

HUB: Department of Housing and Urban Development

IMF: International Monetary Fund

KW: Kruskal-Wallis test

MC: Modular Construction

MENA: Middle East and North Africa

MHI: Manufactured Housing Institute

MMC: Modern Methods of Construction

MPED: Ministry of Planning and Economic Development

MUCH: Ministry of Urban Planning, Construction and Housing

NBA: National Building Agency

NUA: New Urban Agenda

OSM: Offsite Manufacturing

OSP: Offsite Prefabrication

PCP: Prefabricated Concrete Panels

PPP: Public Private Partnerships

SDS: Sustainable Development Strategy

SHC: Social Housing Contractors

SHMFF: Social Housing and Mortgage Finance Fund

SME: Small and Medium Enterprises

ZHUN: Zones d'Habitat Urbain Nouvelles (New Urban Habitat Zones)

1 Chapter 1: Introduction

1.1 Introduction

This chapter introduces the research by presenting the research background and the motivation to undertake it. It overviews the research problem by presenting the main challenges to the low-income housing sector and the construction industry. In addition, it presents evidence for the need to adopt Modern Methods of Construction (MMC) in low-income housing projects and the importance of the research. The chapter presents the aim of the research, the objectives and the research questions in addition to the outline of the research methodology and the thesis structure.

1.2 Background of the research

The United Nations set the 2030 Agenda for Sustainable Development in 2015, which includes 17 goals that tackle global poverty, climate change, and human rights and achieve sustainable development in its three dimensions: economic, social and environmental. The agenda has provided a framework to ensure prosperity and end poverty by building inclusive and peaceful communities. The 11th goal of the sustainable development agenda is concerned with providing affordable housing to everyone by creating safe and sustainable habitats without leaving anyone behind. In this context, the New Urban Agenda (NUA) was adopted by the United Nations at the conference of housing and sustainable urban development (Habitat III) to propose urbanisation as a vital tool for achieving sustainable and affordable housing that provides a decent standard of living to everyone (Abdel-Rahman et al., 2020). According to (NUA, 2017), urbanisation could catalyse social and cultural development, environmental protection and sustainable economic growth.

Providing adequate housing to the least advantaged households in developing countries is always a significant challenge. Numerous households cannot meet the cost of decent housing with acceptable standards supplied by the private sector, leaving the burden of supplying affordable housing to the public sector. Without social and affordable housing through the public sector, a vast proportion of the poorer society will fail to obtain decent housing. Insufficient funding, continuous increase in population, construction delays, poor quality, and low technological uptake in construction are all contributing factors to this challenge. As a result, governments have continuously developed housing programmes and policies to deliver

mass housing to shrink the gap between supply and demand. These programmes include adopting new construction methods to speed up housing delivery, introducing funding initiatives and housing policies and partnering with the private sector to increase the number of affordable housing units.

In Egypt, the shortage of housing has long been recognised, with the supply of affordable units failing to meet the increasing demand. Egypt is one of the largest countries in the Middle East and Africa in terms of population and size of the economy. The population in Egypt has exceeded 100 million, with an average increase rate of 2% (CAPMAS, 2021). The total area of Egypt is one million km², with only 5% being populated around the Nile valley and delta, while the remaining area is an unoccupied desert. Although the current inhabited population density of the country is 1473/km², the inhabited population density in Cairo, the capital, reached 52,237.4/km² in 2020 to be one of the most populous regions in the Middle East and Africa (CAPMAS, 2022). This sharp increase in the population density of Cairo is driven by migration from rural to urban, accompanied by overcrowding and slum dwellings.

The government has solely taken responsibility for reducing the housing shortage, especially for low-income households. Over the last seventy years, the government has set several housing policies to increase the housing supply. The government established low-income units with basic facilities and implemented rental systems to lower costs for low-income households under the Public Housing scheme during the period from the 1950s to the 1970s. This policy aimed to provide affordable housing options for those in need. This policy increased access to housing for low-income households by offering affordable rental units. However, it did not fully address the growing demand for social housing, as the shortage persisted. Between 1970-1981, the Open-Door policy was introduced to encourage the private sector to invest in low-income housing. The government developed financial initiatives and incentives to attract private investment in affordable housing projects. The Open-Door policy increased private sector participation in low-income housing development. It led to the construction of more affordable housing units, providing additional options for low-income households. However, the impact varied, and the housing shortage remained a significant issue (UN Habitat, 2020).

The government initiated the policy of developing new urban communities in previously undeveloped desert areas in the period between 1981 and 2011. These communities aimed to accommodate population growth and provide housing options, including low-income housing. The development of new urban communities expanded the housing supply and provided housing options for various income groups, including low-income households. However, the

impact of addressing the overall housing shortage was limited, and the demand for social housing continued to exceed supply. The government established several housing authorities and agencies to engage multiple entities in the housing provision system. These entities included public and private organizations involved in the planning, development, and management of housing projects. The establishment of housing authorities and agencies aimed to streamline and coordinate housing efforts, involving various stakeholders. This decentralized approach improved the efficiency of housing provision. However, the housing shortage remained persistent, indicating that further measures were necessary. (Abdelwahed and Hanafy, 2020; Abdel-Rahman et al., 2020). Numerous housing laws and regulations have been issued, several housing programs have been launched, and many authorities and agents have been established. However, these fluctuations have never been sufficient to satisfy the growing demand for social housing (UN Habitat, 2020).

On the other hand, the construction industry is one of the most significant contributors to the global economy, with about $10 trillion worth of related activities and goods (McKinsey Global Institute, 2017). It is a crucial industry in creating jobs, contributing to national development and accelerating other sectors' development. It plays a pivotal role in the urban development of countries through the construction of infrastructure, cities, education and treatment facilities. However, the construction sector faces numerous challenges and drawbacks affecting its performance and productivity. Globally, it suffers from low productivity, issues in maintaining quality, health and safety hazards and poor environmental impact.

The Egyptian construction industry shares the same characteristics as the rest of the world. The construction sector is the fifth highest sector adding value to the Egyptian economy, with a total value reaching $22.4 billion in 2020 (HIS Global, 2021). About 10% of the Egyptian workforce is working in construction, leading to an average growth rate of 6% annually between 2012 to 2019 (MPED, 2020). However, there are several challenges in the construction sector that affects its performance despite its notable growth and contribution to national development. The sector is struggling from severe projects delays, low productivity, poor quality, lack of technology and innovation, poor health and safety and high rates of construction and demolition waste (Abdel-Razek, 1998, ElSafty *et al*., 2012, EL-Kabbany, 2013, Marzouk & El-Rasas, 2014 and Daoud *et al*., 2021). Moreover, traditional construction is the dominant method, with concrete, steel, and bricks are the main materials being used. Heavy reliance on traditional construction methods acted as a barrier to innovation in

construction techniques and a need for more research and development of implementing innovative construction methods.

1.3 The rationale of the research

Productivity has always been a critical issue in construction, where it needs to catch up to other industries. Dolage and Chan (2013) argued that over the last three decades, technology has significantly increased productivity through Modern Methods of Construction (MMC). MMC refers to innovative techniques and processes used in the construction industry to enhance efficiency, speed, quality, and sustainability in building projects. While MMC is not a new concept, there has been a renewed interest in adopting its approaches in recent years. This interest is driven by several factors, including technological advancements and a growing awareness of the need for more sustainable construction practices. One of the key drivers behind the increased interest in MMC is advancements in technology. Over the past decade, there have been significant developments in digital design tools, building information modelling (BIM), robotics, automation, and prefabrication (Bertram et al., 2019). These technological advancements have enabled construction companies to optimize the construction process, reduce errors, and improve productivity. For example, BIM allows for virtual design and prototyping, which helps identify and rectify design issues before construction begins, reducing delays and costs (Ofori-Kuragu *et al*., 2022).

MMC also aligns with the growing demand for more sustainable and environmentally friendly construction practices. Traditional construction methods often result in significant waste generation, high energy consumption, and carbon emissions. Conversely, MMC promotes off-site manufacturing, where building components are manufactured in controlled factory environments. This approach reduces material waste, as materials can be precisely measured and utilized, and allows for better recycling and reuse of materials. Furthermore, MMC reduces the environmental impact of construction by minimizing noise, dust, and disruption on-site. In addition to the environmental benefits, MMC offers improved quality and consistency in construction projects. By manufacturing building components in a controlled environment, companies can ensure higher precision, tighter tolerances, and better quality control. This results in structures that are more durable, energy-efficient, and resilient. MMC also allows for faster construction times, as the simultaneous manufacturing of building components off-site can significantly reduce the time required for on-site assembly.

The increased interest in MMC is also driven by the need to address housing shortages and rapid urbanization. MMC offers the potential to speed up construction timelines and deliver projects more quickly, helping to meet the rising demand for housing in many urban areas. The use of standardized building components and assembly processes in MMC can facilitate faster construction, allowing for the rapid deployment of affordable housing solutions. Governments, industry bodies, and construction companies worldwide are recognizing the benefits of MMC and are actively promoting its adoption. In many countries, initiatives and policies are being developed to incentivize MMC, such as funding support, streamlined regulations, and certification schemes. This concerted effort is helping to drive innovation, collaboration, and investment in MMC technologies and approaches (Ofori-Kuragu *et al*., 2022). Many housing developers are shifting to MMC in developed countries, including the United Kingdom, the United States, Japan and Scandinavia, by taking the improved manufacturing capabilities and digital technologies to the housing construction sector (Bertram et al., 2019).

Nevertheless, the uptake of MMC in developing countries is still arrear in the construction industry even though it has the potential to address the main challenges of cost, durability, safety and sustainability within the industry (Akinradewo *et al*., 2021). Most African countries are developing countries with high populations and need to increase the capacity of their construction industry. African countries face similar challenges, including a housing shortage, a high population growth rate and high unemployment rates. The housing backlog in Africa is more than 50 million units, with significant variations across countries (Bah *et al*., 2018). Despite this massive demand for low-income and middle-income housing, MMC is mainly implemented in infrastructure and civil works. However, the demand could create a massive potential for its implementation to speed up the housing supply.

The backlog of housing in Egypt has reached 3.5 units with the supply incapable of fulfilling the growing demand (Schwab, 2017). Low-income and social housing has an average annual supply of about 50,000 units creating an estimated required annual supply of 300,000 to clear the accumulated backlog (EEDC, 2015). Furthermore, the insufficient supply over the past resulted in the growth of slum dwellings and informal housing that is not up to safe and decent standards and quality, which need to be replaced due to deterioration (Bah *et al*., 2018). It is believed that the construction practices in Egypt need to be revised to achieve the required supply of decent housing to clear the accumulated backlog of social and low-income housing. The mass production of low-income housing units creates an excellent potential for adopting MMC approaches to increase its supply. Adopting MMC can bring benefits to the housing

provision process in addition to improving the performance of the construction industry. Social housing units in Egypt are designed in the form of 3 bedroom 90 m^2 flats in five-storey flat blocks providing the opportunity of benefitting from the modular standardisation that MMC can bring.

Adopting MMC in the construction of low-income housing projects in Egypt requires careful consideration of the influencing factors to its implementation. The influencing factors need to be assessed according to their effect on the adoption process and whether these factors act as success factors or challenges. This study aims to develop a framework by identifying the critical success factors, challenges and barriers to MMC adoption in low-income housing projects. In the literature, several success factors and challenges have been identified in implementing MMC in developing countries without establishing a framework that illustrates how to implement it successfully. Moreover, in the Egyptian housing projects, there is a scarcity of research to adopt and implement MMC to increase the supply of housing units. Much of the literature on low-income housing projects focus on the drawbacks and challenges of the construction sector and housing policies.

This research explores the main challenges facing the construction industry in Egypt alongside the low-income housing sector. To identify the problems that impact low-income housing projects and how they will affect the implementation of MMC and explore the factors that have hindered its implementation until now. The research aims to investigate the enabling environment to enhance MMC implementation in low-income housing and identify the relevant prefabrication approach that can be adopted. Furthermore, the purpose of the research into the critical success factors and lessons learned from the past implementation of MMC in developed countries is to develop an adoption framework in Egyptian low-income housing projects successfully.

1.4 Research Questions

The research context develops the following questions addressing the main study areas:

- What are the critical success factors and drivers for adopting MMC in housing projects in developed countries, and how can they be adopted in different contexts?
- What are the challenges and barriers to MMC adoption in low-income housing projects in Egypt?

- How will MMC help address the low-income community's needs and preserve the socio-cultural aspects?

1.5 Research Aim and Objectives

The research aims *to develop a framework for the efficient adoption and use of modern methods of construction for low-income housing projects in Egypt.* The following objectives have been identified to achieve this aim:

1- Investigate the critical success factors for adopting MMC in housing projects in developed countries and the MENA region.

2- Analyse the drivers for MMC in Egypt and the factors associated with it.

3- Evaluate the critical factors likely to hinder the acceptance of MMC adoption in housing in Egypt.

4- Establish and validate a framework for the successful implementation of MMC in low-income housing projects in Egypt.

1.6 Outline of the research methodology

The research adopted a relativist philosophical stance with a social constructionism assumption. This philosophical stance believes that there are several perspectives on the same issue while knowledge is gained from people's beliefs and interactions. Hence, these perspectives have guided the use of an inductive approach where the research problem has been the study's core, and different data collection methods have been used. In the beginning, an extensive literature review was conducted to provide a complete overview of the Egyptian low-income housing sector, including three main points:

- Modern Methods of Construction (definitions, types, drivers, barriers).
- Chronological development of MMC
- Housing in Egypt.

The literature helped to understand how MMC originated in developed countries and to identify the contributing factors to its success in addition to the challenges and barriers to its implementation. In addition, the Egyptian housing and construction sectors were critically reviewed to discover the enabling environment of MMC and the corresponding success factors and challenges.

This research adopted a convergent parallel mixed methods approach. The research design combines both qualitative and quantitative data to offer a comprehensive analysis of the research problem. Simultaneously collecting both types of data allows for their integration and interpretation, resulting in a holistic understanding of the subject matter. Qualitative and quantitative research methods were merged to gather data through fifteen semi-structured interviews with construction professionals, governmental officials and precast factory managers. A stakeholders mapping process selected the participants of the interviews to identify the relevant stakeholders in the low-income housing provision projects. A questionnaire survey was the instrument for the quantitative data collection to gather data from the residents of two social housing case studies. The final stage of data collection was to verify and validate the adoption framework by interviewing construction management experts and academics.

Qualitative and quantitative data analysis was used in this research. Qualitative data were reduced through editing, segmenting, and summarizing. The primary goal was to reduce the data without sacrificing any information. Subsequently, coding was applied to identify themes, clusters, and patterns. The interviews were transcribed and translated from Arabic to English. The translated interviews were then imported into NVIVO software for the purpose of coding, clustering, and creating themes and patterns. On the other hand, descriptive and statistical analysis were used for the quantitative data where Kruskal Wallis test was used to evaluate the differences between the responses of the residents. The research methodology is discussed in Chapter Three in detail.

1.7 Scope and limitations of the research

This research aims to introduce MMC as an innovative construction method to increase the supply of decent housing to low-income communities. It discovers the current practices of the housing construction industry to identify the enabling environment for MMC adoption, focusing only on the residential sector without considering other sectors such as commercial, educational, industrial, etc. In the process, it investigates the critical success factors, challenges and barriers to MMC implementation in the residential sector in developed and developing countries with a particular focus on the Middle East and North Africa (MENA) region, where this region can have similar characteristics to the Egyptian housing and construction sectors. Due to resource limitations, data collection and case studies were performed in the Greater

Cairo region and its adjacent communities. However, the framework can be applied to other regions in Egypt concerning local social characteristics.

1.8 Contribution to knowledge

This research significantly contributes to the field of construction management in multiple ways. Firstly, it develops a framework for implementing Modern Methods of Construction (MMC) in the low-income housing sector in Egypt, which traditionally relies on conventional construction methods. Unlike previous studies that focused on housing policies and performance issues, this research introduces a novel construction approach and addresses various related challenges. This pioneering framework not only offers a strategic solution to increase the supply of decent housing for disadvantaged households but also presents innovative construction methods that can enhance the overall performance of the construction sector.

The insights gained from this research can be valuable for implementing MMC in similar communities facing comparable circumstances, particularly in developing countries like Egypt, known for its large population and economy. The literature review conducted in this study identifies the absence of a comprehensive adoption framework for MMC that incorporates all relevant factors and considers socio-cultural aspects as well. The identified factors can be applied to different countries, providing insights into the influencing factors and their impact on the adoption of MMC in the construction sector. Overall, this research enhances our understanding of MMC implementation and its potential implications by shedding light on the influencing factors involved.

1.9 The structure of the thesis

This thesis is composed of seven chapters. Starting with this chapter, *Chapter 1* introduces the research by showcasing its background and the motivation for conducting it. It presents the research questions, aims and objectives, including the research methodology's outline, the research's scope and limitations and its contribution to knowledge.

Chapter 2 reviews the literature on MMC by dividing it into two main sections. Firstly, it reviews the definitions of MMC, its drivers, types, advantages and disadvantages, challenges and barriers to provide an overview of its origins and practices. A literature review was performed to explore the chronological development of MMC in a selection of developed countries showcasing its implementation's critical success factors and challenges. It also

includes a review of MMC implementation in a selection of developing countries to investigate MMC adoption in residential projects.

Secondly, it explores the literature on the Egyptian housing and construction sectors by reviewing the housing policies, supply and demand, the Egyptian economy, the manufacturing industry and social and cultural aspects. This chapter illustrates the enabling environment in Egypt and investigates the factors influencing the adoption and implementation of MMC in Egypt. It presents the gaps in knowledge and a summary of the literature review.

Chapter 3 discusses the research methodology and the research design. It included a review of the research philosophies, approaches and strategies. This chapter explains the research design and methodology justification and the philosophical assumptions of the current research. It explains the data collection and analysis methods and tools, including the criteria for selecting the research participants.

Chapter 4 presents the analysis of the data collection. It showcases the qualitative analysis of the semi-structured interviews using NVIVO software. The chapter presents the quantitative analysis of the questionnaire survey of the two case studies, including the descriptive analysis and the statistical testing of the data.

Chapter 5 discusses the data analysis findings and combines these findings with the critical analysis of the literature review. The chapter is divided into two sections: qualitative findings and quantitative findings. The chapter discusses the findings, how they would affect the adoption of MMC and the challenges that might arise from its implementation.

Chapter 6 presents the critical success factors and challenges of adopting MMC in Egypt's low-income housing projects. The chapter presents and describes the framework and the required actions by the stakeholders to implement it. It also contains the analysis of the validation interviews, including the modified framework after validation.

Chapter 7 presents the conclusion of the research. It discusses the answers to the research questions, presenting how the research aim and objective were achieved and the contribution to knowledge. It also contains recommendations for future research based on the research findings.

2 Chapter 2: Modern Methods of Construction

2.1 Introduction

The construction industry is always pursuing innovative new methods to improve its performance in terms of quality, cost, duration, health and safety and sustainability, and other factors affecting its image as an industry. Innovations include discovering new sustainable materials and new techniques for construction. Modern Methods of Construction (MMC) have always been considered an innovative construction method by taking advantage of improved factory conditions at the building sites. It is an industrial system-building approach to respond to the transition to non-traditional construction methods and integrate manufacturing into the construction industry.

This chapter aims to review the literature on adopting MMC in housing projects. It aims to provide an understanding of the influencing factors, barriers and challenges to implementing offsite prefabrication in the housing sector. The first section of the literature review presents the concept of MMC, including its definitions, drivers, barriers and different types. The second section includes an analysis of the chronological development of MMC in several developed countries to provide an in-depth understanding of the factors associated with its implementation in the housing sector. It also includes the chronological development of MMC in several Middle Eastern and African countries (MENA) of similar social, economic and industrial conditions as Egypt.

This chapter reviews offsite prefabrication as an industrial approach in the construction industry, addressing its inception to its current utilisation to provide a broader vision of its utilisation in the housing context. It includes an analysis of its definitions and various terms used to describe offsite technology in addition to the emergence of its concept. Moreover, the drivers of adopting offsite prefabrication will be discussed together with its benefits, barriers and challenges encountering. Eventually, the information will be critically analysed concerning the housing projects' context.

2.2 Definitions of MMC

The literature has widely discussed definitions of offsite prefabrication correlated with manufacturing and industrialisation. Industrialisation in construction is considered a part of modernising the industry by developing production by introducing modern mechanical systems

and new technologies to produce building components. Improving quality, minimising errors, and increasing productivity are the main aims of merging industrialisation with traditional construction methods (Anuar *et al*., 2013). Traditional methods are the onsite construction process where all the construction activities are done onsite by skilled labour. Gibb (1999) defined offsite fabrication as "*Offsite fabrication in its broadest sense encompasses many contemporary construction techniques, with perhaps the simplest prefabricated component in most of the world being the building brick or block. At the other end of the spectrum, whole buildings are prefabricated, pre-assembled remote from their final destination, and installed with only the minimum of onsite work needed before they are fit for use".* Offsite has been introduced to decrease and replace the work done in construction sites with factories to benefit from better work conditions in the factory environment.

Different terms are used to describe Modern Methods of Construction, such as Offsite Prefabrication (OSP), Offsite Manufacture (OSM), Modular Construction (MC), Pre-assembly and Prefabrication. These terms are all related to industrialised and innovative methods employed in construction describing non-traditional construction approaches. They are used by researchers, academics and construction practices interchangeably, which may confuse these terms (Boothman *et al*., 2014). However, Anuar et al. (2013) argue that these terms represent the industrialisation concept in terms of innovation in construction, referring to the evolution of mechanisation and standardisation of building components.

2.3 Types of MMC

In general, offsite prefabrication involves manufacturing building components in factories to be transferred and installed onsite. These components have various categories and types, subject to development and innovation to satisfy the construction industry's requirements and capabilities. MMC applications vary from standardised components to whole buildings depending on the production facilities and design requirements. The literature (Ross et al., 2006; Gibb, 1999; Kozlovská and Spisáková, 2011; NHBC, 2016) have widely discussed and analysed the different categories of MMC as follows:

2.3.1 Volumetric

They have fully fitted out three-dimensional units produced in factories and then transferred to the prepared site for installation. The units are usually built from lightweight structures such as timber, steel frame and concrete composites. Volumetric units are most efficient in mass

production, where they are manufactured, tested and inspected in factories and then transferred to the site for installation. The standard type of volumetric unit is "pods", which are mainly for highly serviced areas such as bathrooms and kitchens. Pods are non-structural units installed on a load-bearing structure with MEP connections designed to connect with the pods' fittings. The primary considerations of volumetric units are transportation and onsite storage due to their large volume and weight, requiring a high level of coordination between the site and factory before installation.

2.3.2 Modular Building

This category describes the use of volumetric MMC to form a complete building or part of it. The whole building is built, including the internal fit-out and envelope, in the factory to be delivered to the site for installation and utilisation. Modular buildings are usually used in hotel accommodations, medium-rise buildings and identical flats.

2.3.3 Panel System

This category includes flat panel units manufactured in factories to be installed onsite in the form of walls, roofs and floors. There are two central systems of panels, Open panels and Closed panels. The open system includes the panel's structural components, which are transferred to the site where the windows, doors services and linings are completed. Closed panels are more complicated, where all the fittings are manufactured offsite and then transferred to the site for installation only. Panels could be load-bearing or non-load bearing depending on the design requirements of the main structure. Different materials are used in panels, such as steel, timber, concrete or composite, where different materials are combined to provide specific structural or insulation requirements. Panel systems require an early design freeze due to the difficulty of modification either in the panels or in the main structural building to be fitted in.

2.3.4 Hybrid system

This system combines the volumetric and panel systems in the same building. Usually, compact units such as kitchens and bathrooms are in pod form. At the same time, the rest of the building is constructed with panels—hybrid construction benefits from integrating the best elements from both systems. However, the increased number of manufacturers could act as an obstruction to the effective construction management of the project. The combination of

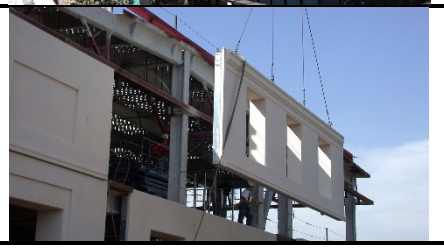
systems requires a detailed design and efficient coordination between the project's architect and manufacturers to ensure that different MMC applications will fit together onsite.

2.3.5 Sub-assemblies and components

These are manufactured components of an integral part of a building, such as a floor, foundation, and roof. Another form of this category is smaller building parts such as prefabricated dormers, chimney stacks, windows and roof cassettes. Such components are mainly only considered to be built onsite, usually supplied to construction sites by particular suppliers. However, it requires the same level of coordination and communication between the designer, construction team and factory as other categories of MMC.

The different types of MMC are summarised in table 2.1 providing a brief description and an example of each type.

Table 2.1: Types of Modern Methods of Construction

Type	Description	Example
Volumetric	Fully fitted out three dimensional units that are produced in factories then transferred to the prepared site for installation. E.g., Bathroom Pods	
Modular Building	This category describes the use of volumetric OSP to form a fully finished complete building or part of it. E.g., Identical Flats – Hotel accommodation	
Panel system	This category includes flat panel units manufactured in factories to be installed onsite. E.g., Walls, Roof and Floors	
Hybrid system	This type combines the panel system and volumetric.	
Sub-assemblies and components	These are manufactured components of an integral part of a building such as floor, foundation, and roof. E.g., chimney stacks, windows and dormers	

2.4 Drivers of MMC

The construction industry always faces challenges in terms of quality, cost and time, which are the classical sides of the construction management triangle. Research and studies are conducted for improvements and changing project delivery methods. The construction industry's overall performance could be better, requiring improvements in processes (Seidu et al., 2019). Improvements include a change in projects' design to maximise the use of standardisation in components and processes to increase the industry's performance and quality. Offsite approaches brought improvements to the industry by decreasing the building duration, increasing quality, improving health and safety, reducing costs and increasing site performance (NHBC, 2016). However, these improvements can only be made if the offsite technologies are redeveloped to be adopted in the construction process. The main drivers of implementing offsite technologies are discussed as follows:

2.4.1 Shortage in Housing

The demand for housing is rapidly growing due to the increase in population and family breakdown, resulting in more people living alone (Miles and Whitehouse, 2013). This generated higher demand for flats that requires a higher cash flow when compared with houses which can be built and sold separately. On the other hand, there is a shortage in supply primarily due to the restrictions on mortgages. Given this, a need has been generated for a faster solution for construction to speed up housing delivery which could be achieved by offsite technology. According to Buildoffsite (2012), the factory environment can achieve a production rate up to 80% higher than onsite production benefiting from the controlled processes in factories. Therefore, prefabrication has been a prospective solution to efficiently fill the gap between the demand and supply of houses.

2.4.2 Shortage in skills

The skilled workforce level in construction has recently declined due to a lack of adequate training from housebuilders. According to Seidu *et al*., (2019), there is a decline in trainees in the industry since 2005, there are too few people to replace the ageing workforce and too few people have the managerial and technical skills to cope with advances in technologies and techniques. Construction firms headed to recruit skilled labour from overseas to overcome the national shortage; as a result, it acted as a manageable issue for the industry. However, the increased complexity of houses due to higher performance requirements required more skilled

labour and special skills. The need for offsite technology has arisen to overcome the skilled labour deficit, as manufactured building units can be assembled onsite with unskilled labour. However, prefabrication requires exceptionally skilled labour for manufacturing, considering that manufacturers provide adequate training for their teams.

2.4.3 Quality

One of the critical aspects of the construction industry is providing high-quality buildings that meet the client's requirements and the designers' specifications. However, there are concerns about housing quality measured by purchasers' satisfaction level, reaching 40% in 2003 (Gaze *et al*., 2007). Usually, house builders fail to conform to quality requirements due to difficult site conditions where houses are being built using traditional construction methods. Failure could result from a change of materials defined by the designer, supply chain or labour skills. In view of that, a drive for change in building methods has been found to improve house quality in terms of materials, methods, skills and site conditions. Due to better manufacturing processes, offsite prefabrication is considered a quantum leap in house quality. Factories usually have better quality control on products and higher control on skills by maintaining their workforce and providing adequate training. In addition, manufactured products have higher accuracy and consistency, leading to lesser onsite fitting faults.

2.4.4 Health and Safety

The construction industry is categorised as one of the most danger-related industries within all industrial sectors in terms of the health and safety of workers. Construction sites are dangerous workplaces with a high possibility of accidents and mainly from falling from heights. Different approaches have been under research and study to eliminate and reduce hazards in construction sites (Bhattacharjee and Ghosh, 2011). Offsite technology improves health and safety performance in construction by reducing the work done onsite where the potential for accidents to occur is high. Manufacturing building components in factories is considered safe due to the enclosed nature of the factory environment where health and safety are more controlled; in addition, the production is more plant-oriented, reducing human interference. However, offsite prefabrication only eliminates hazards where part of the job is completed onsite in assembly and installation. Despite that, hazards are more predictable and relatively fewer if compared with traditional construction methods and could be managed effectively.

2.4.5 Sustainability

Over recent years, governments emphasised the environmental performance of construction sites and buildings due to their significant impacts on the environment in terms of pollution and sustainability. The environmental impact of construction has different forms, such as waste generation, resource depletion and land deterioration, and noise and dust generated during construction (Tam *et al*., 2017). Consequently, adopting new construction methods has been considered for the industry's sustainable development, which can reduce its impact on the environment (Tam *et al*., 2007). Prefabrication has a significant role in improving the environmental impact of construction, mainly through minimising waste generated during construction. According to Kozlovská and Spisáková (2011), producing building components in the factory helps reduce the wastage of materials due to tight control measures on production; quantities of materials controlled by obtaining accurate dimensions and reusing/recycling are more readily rather than in construction sites. Furthermore, offsite prefabrication can reduce the noise, dust and traffic hazards generated from construction sites by reducing the work done onsite, affecting the local community.

On the other hand, buildings' environmental performance and energy consumption are other motives for adopting prefabrication. Several initiatives have taken place to decrease the energy consumed, especially by houses leading to increased sustainability. The main initiative is the revision of housing building regulations, mainly concerned with two issues: conservation of power and fuel consumed by houses and acoustical insulation due to increasing densities of dwellings. These revisions will force housebuilders to consider innovative construction methods that improve buildings' performance to avoid any remedial works that could arise if the building fails any post-construction environmental tests such as air tightness and sound resistance (Gaze *et al*., 2007). Kimpton (2009) argues that prefabrication can help reduce CO2 emissions that, consequently, reduce the carbon footprints of occupiers. In addition, the thermal and acoustical performance of dwellings could be improved by using prefabricated components such as Structural Insulated Panels and double-layer-isolated panels, thus reducing running costs and bills.

2.5 Barriers of MMC

Despite the well-documented benefits of MMC in the construction sector, there are substantial barriers and limitations that the literature indicates to its implementation in the industry. The following points are the common factors that are considered as barriers to MMC.

2.5.1 Cost

The cost of MMC manufacturing is considered the primary constraint to adopting it in the construction sector. Setting up a factory, preparing a prefabrication yard, setting up the required machinery and purchasing all the relevant materials upfront to the manufacturing process of MMC leads to higher initial costs than traditional construction methods. Furthermore, factories' overhead costs are fixed despite the production; therefore, it will only be viable for factories if the quantity is large (Rahman, 2014). Gaze *et al*. (2007) stated that hybrid and volumetric approaches are slightly more expensive than traditional construction methods, although they provide several advantages, such as reduced inspections and defects.

2.5.2 Skills and experience

Many forms of MMC are considered modern innovations that need more skilled labour for production and onsite assembly. According to Rahman (2014), a few labours are learning MMC techniques due to the small market demand. However, Gaze *et al*. (2007) argued that the skills needed for MMC are more methodological and organisational rather than artisan, which, accordingly, many manufacturers are eager to train more workers to develop more erection teams in order to expand their market horizons and meet the builders' expectations.

2.5.3 Culture perception

Due to the negative reputation of the prefabricated dwellings of the post-war in terms of quality and performance, many contractors decided to avoid MMC. In addition, many types of MMC are light weight leading to a belief that they will be of low quality and might require remediation (Rahman, 2014). From the house builders' point of view, Kempton and Syms (2009) argue that they would have some doubts about the quality of prefabricated housing as their primary concern is profitability rather than the public serving public interest in increasing housing. These beliefs and the resistance to change to innovative methods in construction in

favour of traditional methods act as a primary barrier to the broader spread of MMC in the industry.

2.5.4 Technical issues

MMC requires freezing the design early before manufacturing commences, leading to a lack of flexibility for alterations (Gaze *et al*., 2007). Besides, it requires a high level of coordination and communication between the project team onsite and the manufacturers to deliver the prefabricated components on time to avoid delays successfully. There is a risk of increased defects, such as the prefabricated components would not fit together with parts of the main structure due to miscommunications and the fragmentation nature of the construction industry (Rahman, 2014).

Another technical issue stated by Li *et al.* (2014) is the vertical transportation of heavy types of MMC, such as volumetric pods, which is considered a significant difficulty in higher buildings requiring more time, effort and health and safety considerations concerning traditional methods. Moreover, total site area can act as a barrier to MMC adoption as prefabricated units tend to consume large storage areas onsite, which might not be possible in small sites or ones with limited access (Rahman, 2014; Gaze *et al*., 2007).

2.6 Chronological Development of MMC

The adoption of MMC in housing started decades ago in several developed countries. It went through different stages of development and faced and overcame several barriers for its successful implementation. The drivers, success factors and barriers to its adoption in the construction industry differ in every country. How each country faced these obstacles must be studied and analysed to extract the lessons learned. To do that, the literature available on the UK, Japan and the USA has been analysed to indicate the success factors, drivers and barriers which influenced the adoption of prefabrication for housing projects and how it developed chronologically. On the other hand, adopting MMC applications in developing countries has also been analysed to identify comparable key factors and characteristics to the Egyptian context. This analysis will provide an overview of the adoption process, indicating the key indicators affecting its performance.

2.6.1 Modern Methods of Construction in Developed Countries

2.6.1.1 United Kingdom

According to Gibb (1999), prefabrication origins go back to the twelfth century, when it was mentioned in several studies concerned about housing construction; it is the era that witnessed the implementation of industrial methods in construction. However, it did not develop steadily and was disregarded several times. The dominant construction material used was timber due to its availability, limited technology and equipment. During the 1600s to 1800s, prefabricated timber frame houses were built and exported to North America and Australia. The construction industry was affected by the Industrial Revolution in the 1800s; innovations and improvements to transportation aided the development of standardisation and prefabrication of materials and housing construction methods such as "Manning Portable Colonial Cottage" and corrugated iron sheets (O'Neill and Organ, 2016). O'Neill and Organ (2016) described the former as "*The cottage system comprised of predetermined components which could be assembled by unskilled labour, with the use of a wrench, and was an improvement on previous systems. The individual components were easy to carry. The cottage focused on standardisation of components and fast erection – factors which become associated with prefabrication*". Environmental conditions such as weather were one of the main drivers of prefabricated houses where they were faster to build, easier to transport and more weather tight. Traditional methods could obtain the latter. Another factor that encouraged the adoption of prefabrication was the increasing demand that traditional methods could not cover.

The interwar period witnessed the significant development of prefabricated houses, especially the 1920s houses (Powell, 1996). The broadly known is the Weir house, which was proposed as a temporary solution to the excessive demand for houses. Weir houses were manufactured from timber frames and external steel cladding, using the shipbuilding industry's cheap labour. However, it faced public opposition and technical failures, which resulted in limited supply (Hughes, 2002). Other manufacturers proposed different structural materials such as precast concrete, cast iron and shredded wood and concrete. The drivers which influenced the development and adoption of prefabrication, as stated by Hashemi (2013), are the World War, Modern architecture and Governmental policies. In addition, there were massive housing programmes initiated by housing authorities that had been larger than the traditional methods builders' capabilities, whether resources or skilled labour, which required alternative construction methods capable of introducing new materials and non-skilled labour.

Nonetheless, these proposed industrial solutions had several difficulties, such as cost sometimes more than traditional methods and poor performance.

After the Second World War, the demand for housing increased, facilitated by houses being destroyed or uninhabitable, slum clearance and an increase in population. Therefore, the government led by Winston Churchill declared the production of 500,000 temporary houses as an objective. Local authorities and the private sector received subsidies from the government in order to cover the high initial cost of prefabrication's new technology (Hashemi, 2013). The shortage of materials and skilled workers for traditional housing alongside the political aim enhanced the industrial renaissance and non-traditional construction methods. Despite that, only 156,623 prefabricated houses were delivered in the post-war period instead of the 500,000 announced, consisting of only four types of single-storey houses. The reason for that is most likely due to the shortage of mechanical plants and factories in the post-World War era resulting in a shortage of fulfilling the required capacity. These houses had several technical failures, such as thermal and sound performance, condensation and quality issues. In addition, they were economically infeasible compared to traditional houses despite governmental support (O'Neill and Organ, 2016). All these factors altogether provided the poor image of prefabricated houses to the public, which acted as a primary barrier to non-traditional construction methods in the future.

The years from the 1950s to the 1980s witnessed significant changes in construction methods to be more industrialised. This enthusiasm for industrial buildings and non-traditional methods was driven by the special post-war conditions and huge reconstruction demand, especially in housing. These conditions created Modern Movement led by architects who always supported the prefabrication methods. Their argument was to encourage the role of manufacturing mass production in construction, especially in housing, to cope with the enormous demand. As a response, architects had been employed, supported by politicians who believed in their skills, in governmental positions to be able to put their methods to reality being part of the decision-making process (Hasehmi, 2013).

Consequently, volumetric construction methods were employed in this period, including manufacturing modules to be assembled onsite prefabricated by lightweight frames from steel, timber or concrete. This form, alongside the aim to redevelop city centres, stimulated the decision-makers to employ high-rise construction in housing (BRE, 2002). Flats were constructed in the form of four or five-storey buildings made of volumetric modules encouraged by the development of handling methods such as tower cranes. However, public

concerns and doubts about industrialised buildings were a primary barrier to modern construction methods. That was due to the bad image of the post-war prefabricated houses, which had significant technical failures in addition to the Ronan Point collapse. It was a 22-storey building built by large prefabricated panels assembled onsite that collapsed due to a gas explosion. Besides, media coverage criticised prefabricated timber-frame dwellings, which had been the dominant structural material then, suffering from technical issues such as water tightness and decay in the structure (BRE, 2002). The government faced these incidents by introducing more strict design codes and establishing governmental bodies such as National Building Agency (NBA) that encouraged the use of system buildings in addition to emphasising research and development of modern methods of construction.

Offsite prefabrication has been remarkably encouraged from the 1990s to the present time by governmental research/initiatives, which resulted in the public starting once again to reconsider alternative modern construction techniques (BRE, 2002). These initiatives included the Latham Report '*Constructing the Team*' in 1994, the Egan Report '*Rethinking Construction*' in 1998, and the Barker Review in 2003. They encouraged the use of offsite prefabrication in constructing high-quality houses required in the UK alongside a policy promoting this type of construction. In order to bypass the negative public perception of offsite prefabrication approaches, the term '*Modern Methods of Construction*' (MMC) was introduced to describe non-traditional construction methods instead of prefabricated systems. MMC has been supported by political, economic, and environmental factors to improve the industry's image and increase productivity (O'Neill and Organ, 2016). This governmental support encouraged the private sector to invest in MMC alongside tight building regulations and planning by emphasising sustainability and environmental performance.

2.6.1.2 United States

MMC is not a new concept in housing projects in the United States. Its origins extended to the mid-1800s when army barracks had been manufactured on the East Coast and shipped to California and Australia in the form of prefabricated components during the American Civil War. The early 1900s was the first trial of mass production of houses by architects and engineers. These trials resulted in a few companies producing prefabricated houses that can be ordered and delivered through catalogues. Following World War II, housebuilders employed industrialised techniques in traditional housing systems, such as the assembly-line process. The development of prefabricated systems was mainly in the 1940s through the invention wood-

stud panels system, followed by the development of trailers by an aircraft company to produce the first designed trailer as a house (O'Brien *et al*., 2000). Trailers were mainly used as temporary houses after the war for the military and migrant workers. However, manufacturers of trailers, called after that mobile homes, fought for them to be recognised as permanent homes with the government, but in vain due to being regarded as substandard by governmental agencies (Davies, 2005). Mobile homes were built until the mid-1970s without building permits or codes, with the lack of structural foundations leading to never being considered primary houses. In 1974, mobile homes were granted official recognition through the Department of Housing and Urban Development (HUB) by obtaining congressional approval to implement a construction code. Nevertheless, mobile homes ceased production afterwards due to shifting towards manufactured homes by amending the construction codes. Modular houses emerged in the 1980s and 1990s, gaining consumers' confidence as they developed through the years (O'Brien *et al*., 2000).

MMC has advanced and becomes more reliable in the US construction industry, driven by technological innovations to build high-quality and sustainable buildings. According to Manufactured Housing Institute (MHI) (2018), the prefabricated housing industry contributes to the economy by $3 billion/per year, creating more than 40,000 jobs annually. The private sector is the major employer of manufactured houses by 66%, driven by manufactured houses being almost 50% cheaper than traditionally built houses (MHI, 2018). However, being cheaper does not mean they are of lesser quality, as HUD revised the regulatory codes to ensure their design, quality, energy efficiency and environmental performance.

Nonetheless, about 6.7% of the US population lives in prefabricated houses, which is considered very low in adopting MMC houses (MHI, 2018). The main barrier to MMC adoption in housing is due to unawareness of the owners of it, leading to architects not including it in the design. However, architects and contractors view MMC as an approach to improve productivity in terms of lesser project duration, better quality and lower costs. In addition to improving site performance by reducing waste generation, improving safety performance and decreasing onsite materials (McGraw-Hill Construction, 2011). MMC in housing in the US mainly lacks public awareness of its benefits even though most of the industry's professionals have this awareness, which is a significant hindrance to the proper implementation of MMC.

2.6.1.3 Japan

The housing market in Japan is one of the largest in the world, with over one million dwellings being built annually (Gann *et al*., 2003). Prefabricated houses represent about 14% of the overall new dwellings built throughout the last decade (Steinhardt and Manley, 2016). According to governmental reports, industrialisation in buildings emerged in Japan due to the severe shortage in housing caused by World War II, which had reached 4.2 million units—supported by the government, represented by the Architectural Institute of Japan (AIJ), architects and engineers researched for affordable solutions to mass-produce housing. Their efforts resulted in building houses using prefabricated factory-produced components for onsite assembly, alongside the establishment of the Industrialized Housing Production Association in 1946 to manage the development of prefabricated houses in addition to the issuance of technical codes for industrial buildings. Despite that, the prototypes of this era ceased to exist by 1949 almost due to supply chain and organisational management issues (Yashiro, 2014). However, in the 1950s, two types of MMC systems emerged to replace the failed prefabricated building components, the first was flats manufactured from precast concrete that had been a modified version of the MMC precast concrete methods used in European countries, and the second was MMC volumetric modules. The two types succeeded in the 1950s and 1960s, supported by high demand from the public and private sectors. The public sector encouraged investors to set up prefabrication factories by assuring them of a steady flow of demand by developing new towns and housing projects.

Moreover, the prefabrication market had been encouraged by industrial openness and material suppliers seeking new markets (Yashiro, 2014). The rise of the MMC market in housing was facilitated by the shortage of timber, requiring a shift from traditional construction methods in addition to the reduction in traditional carpenters. Furthermore, suppliers of prefabricated houses started in the mid-1960s to increase the marketing of their products by performing show homes through land leasing nationwide. Concerning increased demand and improved performance, customers started to be more concerned about customisation. Therefore, one of the leading suppliers, Misawa Homes, invented a model in 1976 where customers could customise their houses depending on their needs and requirements, which received much attention among rivals (Gann *et al*., 2003). In the 1980s, the "Pre-cut System" was introduced. The pre-cut system is a technological advance implemented for traditional timber frame houses where machines automatically cut and shape wooden posts, sills and beams with the aid of CAD-CAM (Matsumara, 2004). Consequently, technological advances in prefabricated house

manufacturing and mass customisation broke down negative public perceptions of prefabricated houses. Besides, the prefabrication industry continued to grow through the following decades (Yashiro, 2014).

2.6.2 MMC in Middle East and Africa

2.6.2.1 Nigeria

Nigeria, as an African country, has some similarities with Egypt regarding housing problems considered legitimate in developed countries. These problems include high population growth, skills shortage, rural-urban migration, inadequate regulatory housing development schemes and overreliance on cement and traditional construction methods (Kolo *et al*., 2014a). MMC used to exist in the Nigerian construction industry for the housing sector in the 1970s and 1980s but disappeared afterwards, primarily because of the lack of demand either by the public or private sector. However, MMC is almost not adopted or used at its minimal level in civil projects as precast concrete components for structural systems (Kolo *et al*., 2014b). Currently, few factories manufacture prefabricated houses as temporary houses, such as "Karmod Nigeria", which produces temporary container houses. On the other hand, a relatively small portion of prefabricated houses is being imported to provide luxurious housing because of their high cost (Adegboye, 2014).

One of the main reasons for the non-application of MMC technologies in Nigeria is the stiffness of the construction industry to adopt innovations. This is due to several reasons, lack of appropriate research on innovation, lack of funding and poor implementation of development programmes from the government. Furthermore, there is no genuine governmental willingness to widely adopt MMC as no building codes or standards are being implemented to support it in addition to the lack of knowledge about MMC benefits, infrastructure in the form of factories, and equipment and lack of local skills and negative local perception of MMC (Rahimian *et al*., 2017).

2.6.2.2 Saudi Arabia

Owing to the increase in oil and gas revenues, the construction industry in Saudi Arabia has witnessed prosperity during the last decade leading to being one of the largest construction industries in the Middle East, consequently resulting in excess funding for many construction projects. The government is the principal investor and contributor to the construction sector's

growth, contributing to 67% of the industry's activities. In 2015, the ministry of finance allocated $57.9 Billion for construction projects, including infrastructure, sports facilities, schools, colleges, hospitals and labour offices throughout the kingdom (Alotaibi *et al*., 2016). Regarding housing, the government estimated a demand for 250,000 to 300,000 affordable housing annually (Mears, 2017). Despite that, the construction industry relies on traditional methods and materials such as cement and steel. MMC is considered to have minimal adoption in residential projects, which is almost negligible. The MMC techniques implemented are mainly prefabricated concrete panels for bridges and overpasses used in highway and road projects, wall and façade panels for high-rise projects and temporary structures such as site offices. However, these panels are not manufactured in permanent factories; they are cast onsite. Thus, those workers involved in this process were untrained in the production process and mass production techniques (Aburas, 2011).

Recently, a few companies in Saudi Arabia have been trying to implement affordable prefabricated housing, such as Abdul Latif Jameel, by introducing uniquely designed houses constructed from pre-manufactured components (Abdul Latif Jameel, 2018). However, there are no accurate figures about how much these houses are implemented which are more likely to be still in their trial versions. The uptake of MMC is limited due to several barriers. Firstly, the need for more legislation and governmental willingness for innovative construction methods. Moreover, the reliance on traditional concrete and steel is a barrier to the transport and handling of prefabricated components due to their heavy weight. Timber is not used as a structural material due to its unavailability besides being inefficient in standing up to severe hot weather in the Middle East. Eventually, the general perception of prefabricated houses is low quality and temporary (Aburas, 2011).

2.6.2.3 Algeria

Due to the rapid increase in the Algerian population, the government has continued to find new ways of providing decent houses faster, especially for the most disadvantaged households. Influenced by the European model, especially being under French occupancy for over a century (1830-1962), the government initiated a prefabricated building program conjugated with the substantial industrial movement in the country during the 1970s. Starting with the National Development Plan (1974-1977), several national companies were allowed to import industrialised building systems as thought by the government to be an absolute solution to the housing shortage. In order to control and organise the industrialisation process, the government

established the Ministry of Urban Planning, Construction and Housing (MUCH) in 1977, which was responsible for setting the organisational framework of housing policies and urban development. The (MUCH) initiated an urban development policy (ZHUN) to provide mass-produced new houses using industrialised systems (Behloul, 1991).

The implementation of large-scale urban developments through the ZHUN policy aimed to create standardized five-storey flat blocks in Algeria, using European architects and building companies. These foreign companies brought in heavy prefabrication systems to provide standardized dwellings and public amenities, drawing inspiration from French 'Grand Ensemble' designs. However, these developments failed to satisfy the housing requirements of Algerians for several reasons, as highlighted by Hadjri (1993). One of the main reasons was that the houses were designed according to European standards and norms, which did not align with the social identity of Algerians. Housing design is closely tied to cultural and social factors, reflecting the needs, values, and traditions of the inhabitants. The standardized European designs did not consider the specific social and cultural preferences of the Algerian population, leading to a disconnect between the houses and the people who were supposed to live in them.

Furthermore, the building materials used in these developments were inadequate for the hot climate conditions of Algeria. The lack of suitable thermal and waterproofing insulation resulted in poor performance in terms of temperature control and protection against the elements. Algerians had to change and modify their houses to adapt them to their social and economic needs, such as enhancing privacy or creating additional space. These modifications were necessary to address the standardized designs' shortcomings and make the houses more liveable and suitable for the local context.

The ZHUN policy's implementation of large-scale urban development’s using European architects and building companies resulted in standardized five-storey flat blocks that failed to meet the housing requirements of Algerians. The houses designed according to European standards did not resonate with the social identity of the Algerian population, and the building materials used were ill-suited for the hot climate conditions. As a result, Algerians had to make modifications to their houses to meet their social and economic needs, reflecting the limitations of the standardized approach and the importance of considering local context and cultural preferences in housing design.

Consequently, the ministry decided to stop importing heavy prefabricated systems and choose another alternative to provide houses. The ministry decided to develop local building companies that utilise smaller industrial units of prefabrication techniques such as the panel system, framework construction or hybrid systems (Behloul, 1991). Eventually, the ZHUN developments failed to fulfil its targets as a solution to the housing shortage due to a lack of appropriate utilisation of prefabrication techniques for the local construction industry and economic difficulties that affected the country because of decreased oil prices.

2.7 Housing in Egypt

Egypt, one of the largest countries in the Middle East and Africa, has always faced a housing challenge. This challenge is due to overcrowding, increased population, slum dwellings and economic difficulties. To propose MMC as an innovative solution to help overcome these challenges to the construction sector, the factors affecting this process need to be identified in the Egyptian context. This chapter reviews the Egyptian housing sector, including the supply and demand, the Egyptian economy, the construction industry and social and cultural factors. It aims to provide an overview of the enabling environment to adopt and implement MMC in low-income housing projects. Moreover, assessing the current practices of the Egyptian construction sector to showcase its strengths and weaknesses in addition to determining other influencing factors, including economic, social, cultural, and industrial factors that will impact a future MMC strategy.

2.7.1 Housing policies and supply

Egypt has always needed more social and low-income housing, especially in Cairo, the capital. Since the 1950s, the government has been the leading supplier of low-income housing. It established housing institutions such as Housing Fund and General Organization for Building and Housing Co-operatives, as well as establishing construction companies. In addition, the Ministry of Housing was responsible for planning, designing and managing public housing projects. Several housing policies have been developed to tackle the housing shortages; however, the problem still exists. To highlight the magnitude of the problem, land allocation policies and housing policies are investigated to address the shortcomings of implementation.

In the 1950s and 1960s, the government aimed to provide public housing through a rental system (Abdel-Rahman *et al*., 2020). In 1954, The Construction and Social Housing company was established to provide low-income housing units to implement this policy. The company constructed housing units over several areas in Cairo and Alexandria in addition to renovating deteriorated old neighbourhoods, achieving initial success in providing low-income housing (Abdelwahed and Hanafy, 2020). The government allocated plots of land close to industrial centres targeting low-income groups and industry workers (Al-Abbasy and Eid, 2022). Dwellings were four or five-storey flat blocks consisting of one, two or three-bedroom apartments with areas varied from 25 m² to 65 m². However, these flat blocks did not meet the occupiers' needs, resulting in problems such as overcrowding and poor design that led to

transformations and alterations from the initial design (Ahmed, 2012). This policy led to the reluctance of the private sector to invest in low-income housing due to rent control laws that reduced rent by 35% of its value. As a result, the government could not solely cope with the financial burdens, resulting in poor habitability because of the lack of facilities and services (Abdel-Rahman *et al*., 2020). Consequently, the production of units decreased, and their condition deteriorated. The residents started to transform and modify their units to fulfil their needs without control from local councils leading to an increase in demand for low-income housing.

Under the Open-Door policy adopted in the 1970s, the government aimed to benefit from the cheap lands in the desert, so it adopted a policy of new towns, which had been known as the "Law of New Communities" (Al-Abbasy and Eid, 2022). Under this policy, the government reduced its responsibility to low-income housing by shifting to an ownership system instead of a rental one (Abdel-Rahman *et al*., 2020). Moreover, the private sector was encouraged to invest in low-income housing by allowing contracting companies to increase their investments to 100,000 and then 500,000 EGP (Ibid). Several cities have been initiated during this period to create new developments. However, this policy increased the number of vacant units due to the need for more services and facilities in new towns. In addition, the private sector invested in upper-income units instead of the targeted low-income due to their profitability. Furthermore, low-income groups shifted to informal construction as it was cheaper to build than formal construction (Ahmed, 2012)

In the 1980s and 1990s, the government continued to develop new urban communities away from the old, overcrowded cities benefiting from the undeveloped desert. Therefore, a new ministry, "Reconstruction, New Urban Communities and Land Reclamation", was formed in addition to the New Urban Communities Authority (NUCA) to implement this policy, creating 18 new cities and urban settlements (Abdel-Rahman *et al*., 2020). However, due to financial constraints, the government could not fulfil the demand for social housing during this period (Abdelwahed and Hanafy, 2020). To reduce the costs of construction, the government implemented two policies. Firstly, by changing the possession of flats policy to ownership instead of tenancy by providing low-interest loans to the occupiers and private construction companies to invest in low-income housing. To do so, the government established the Reconstruction and Housing bank to grant these loans alongside the housing institutions. Secondly, the housing units were built partially finished. The internal fit-outs were left to the

occupiers themselves to do it. These two initiatives resulted in a reduction in construction costs to be used in the infrastructure of these new cities (Ahmed, 2012). However, these blocks, which were also in the form of four or five-storey flat blocks, suffered from several issues. The urge to reduce costs resulted in poor-quality flats that required substantial maintenance, lack of adaptability and occupiers' amendments. These modifications took larger forms, adding more stories without legal permission due to a lack of control from local councils, mainly due to corruption (Ibid).

From the late 1990s until early 2014, low-income housing projects have been concentrated into two main projects, "Youth" and "Future" projects. The government established two separate authorities for each project who is responsible for implementing, developing and managing it. The main difference between these projects was the source of funding. "Youth project was funded from the revenues of sales of land plots to high-income residential developments and luxury villas and apartments. On the other hand, the "Future" project was funded by a public-private partnership (PPP) from the government and private investors equally and providing the land from the government. Both projects supplied a total of 90069 units in different new urban cities, mainly in Cairo, in the form of four or five-storey flat blocks of two and three-bedroom flats with areas ranging from 63 m² to 100 m². The control over these projects was stricter by preventing any alterations by the occupiers, as any modifications were immediately demolished. In addition, the urban design considered the environmental and utilisation aspects by providing more open spaces and green areas to improve the occupiers' living conditions and diversification of facade design. Despite that and due to economic difficulties, the two projects ceased to continue after trials to decrease costs by limiting the units to smaller areas of 63 m² (Ahmed, 2012).

The gap between supply and demand is expanding due to the increase in population, where the average increase rate is about 2% annually (IHS Global, 2018) (Figure 2.1). In addition, the supply rate is inefficient, where the two main projects, "Youth" and "Future", supplied about 90,000 units during their lifetime. The backlog in housing resulting from this gap reached around three million units as announced by the government, aiming to supply 300,000 units annually for new households and around 254,000 units to overcome the backlog from the past. Besides, the current low-income housing conditions have severely deteriorated due to a lack of maintenance and poverty. This generated slum dwellings that need to be replaced, although

most of the population cannot afford to buy new houses where the house price to income ratio has reached 18.4 years (EEDC, 2015).

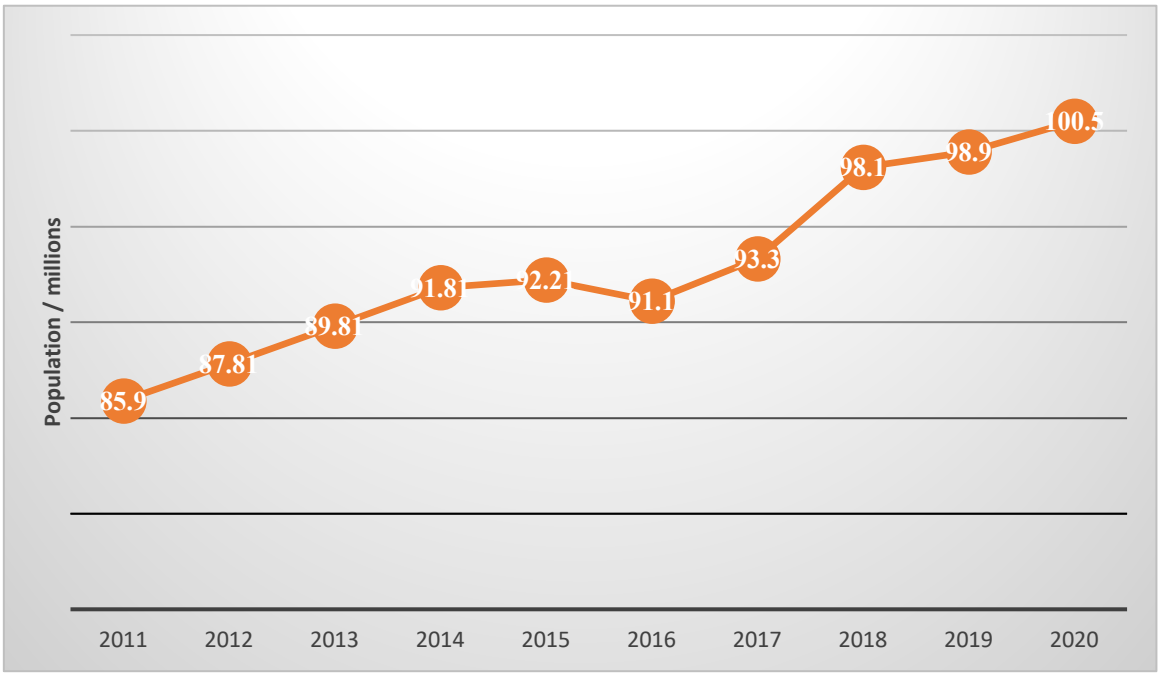


Figure 2.1: Increase in population in Egypt during the last decade

In 2014, the Social Housing Program was announced by the government to build one million low-income houses in collaboration with the World Bank, lending the government $500 million. However, only 12,000 units were built after eleven months after the project commenced (Marketline, 2017a). Moreover, in more than six years, the total number of units built was just more than 375,000 (Table 2.1) by all the government authorities, including (NUCA), (CAR) and housing directories (CAPMAS, 2021). Furthermore, most of the private sector's housing developments are targeted at the high-income and luxury market, especially in the new urban communities. Therefore, to fill this gap, cheap houses are being built by the informal sector, where families build their own houses without legal permits leading to an increase in improper housing, which is mainly considered unsafe (Marzouk and Hosny, 2016).

Table (2.2): Total number of implemented units in Social Housing project (CAPMAS, 2021)

Entity / Years	Central Agency for Reconstruction	Housing Directories	New Urban Communities Authority	Subtotal
2020	1362	6030	43,832	51,224
2019	1,890	15,478	50,336	67,704
2018	2,346	10,079	69,676	82,101
2017	3,792	4,648	27,912	36,352
2016	21,702	19,017	38,816	79,535
2015	7,704	15,154	16,282	39,140
2014	0	7,104	12,068	19,172
Total	38,796	77,510	258,922	375,228

2.7.2 Social housing projects stakeholders

Social housing projects in Egypt involve multiple stakeholders, each playing a crucial role in the planning, implementation, and management of such initiatives. According to Chaarawi *et al.* (2016), the key stakeholders involved in social housing projects in Egypt typically include:

2.7.2.1 Government Entities

Ministry of Housing, Utilities, and Urban Communities (MHUUD): The ministry is responsible for formulating housing policies, developing strategies, and overseeing the implementation of social housing projects. They collaborate with other government entities to allocate funds, acquire land, and ensure the provision of basic infrastructure and services in housing developments.

The New Urban Communities Authority (NUCA): The authority works closely with local authorities to coordinate the planning and implementation of social housing projects in the new urban communities.

The Social Housing and Mortgage Finance Fund (SHMFF): A public service authority established according to presidential decree in 2018. It aims to provide decent housing to the low- and medium-income citizens according to their financial capabilities.

2.7.2.2 Local Authorities:

Local authorities identify suitable land for social housing projects and collaborate with the government in acquiring the required land. They assist in obtaining necessary permits and clearances, facilitate infrastructure development (such as roads, water supply, and sanitation), and provide community services like schools, healthcare facilities, and public spaces.

2.7.2.3 Construction Companies:

Construction firms execute the construction work and ensure adherence to building codes, safety standards, and project timelines. They work in collaboration with developers and other stakeholders to ensure the timely completion of housing projects.

2.7.2.4 Financial Institutions:

The Housing Development Fund (HDB): It has been the financial institutions providing funding for social housing projects through loans, mortgage schemes, and other financing mechanisms. They collaborate with the government to develop affordable housing finance products that cater to the specific needs of low-income households.

The Social Housing Mortgage Finance Fund (SHMFF) is a government-affiliated institution that offers subsidized mortgage loans to eligible beneficiaries of social housing projects. They facilitate access to financing options for low-income households.

2.7.2.5 Beneficiaries:

Low-Income Households: The primary beneficiaries of social housing projects are low-income households who meet predefined eligibility criteria. They apply for housing units and participate in the selection process. Beneficiaries may be required to contribute a portion of the total housing cost or repay the subsidised mortgage loan through affordable instalments.

Informal Settlement Residents: Social housing projects also target residents of informal settlements, aiming to provide them with formal housing options and improved living conditions.

2.7.2.6 Non-Governmental Organizations (NGOs):

NGOs play a supportive role in social housing projects. They work in collaboration with the government and other stakeholders to provide technical expertise, conduct surveys, and facilitate community engagement. NGOs may assist in identifying beneficiaries, implementing social programs, and providing social support services to the residents.

2.7.2.7 International Donors and Organizations:

International donors, including bilateral and multilateral organizations, provide financial aid, technical assistance, and expertise to support social housing projects in Egypt. They collaborate with the Egyptian government to address housing challenges, promote sustainable urban development, and share best practices from global experiences.

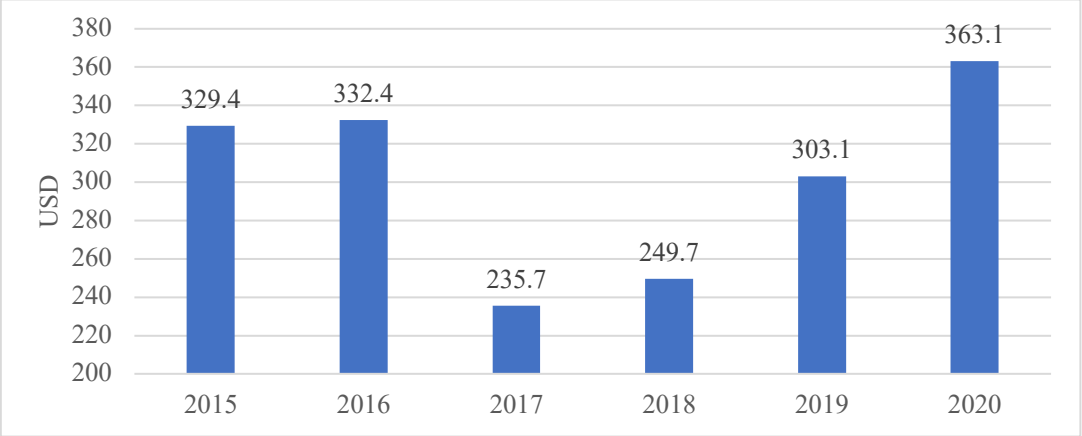
These stakeholders collectively contribute their expertise, resources, and efforts to ensure the successful implementation of social housing projects in Egypt. Collaboration, coordination, and effective communication among all stakeholders is crucial to address housing needs, reduce poverty, and foster sustainable and inclusive urban development in the country.

2.7.3 Egyptian Economy

The Egyptian economy is considered the second largest in the Middle East and one of the largest in Africa. It mainly relies on oil and gas revenues, tourism, Suez Canal toll revenues and remittances from Egyptian expatriates (CountryWatch, 2018). Egypt's Gross Domestic Product (GDP) reached US$332.3 billion in 2017, with a GDP per capita of US$3,684 (Schwab, 2017). The economy has faced challenges such as the budget deficit, high inflation rates, unemployment and political unrest since 2011. The national debt ratio has been increasing in the last two years, reaching 108.8 per cent of GDP by the end of 2017 (The World Bank, 2018).

Furthermore, the unemployment rate was around 12.5 per cent, according to CAPMAS, with the figure of young people more than double that figure. Inflation has also been rising through the latest years, reaching 23.3 per cent from 10.2 and 11.1 in 2016 and 2015, respectively (Ibid). This increase was due to severe reform measures implemented by the government to improve the economy from the deterioration that occurred since the revolution in 2011, which resulted in the ousting of Egyptian President Hosni Mubarak (CountryWatch, 2018). Reforms were in the form of imposing a value-added tax, cutting fuel and electricity subsidies, currency floating

and loans from the World Bank, International Monetary Fund (IMF) and other lending organisations in addition to grants from GCC countries (CountryWatch, 2018) (The World Bank, 2018) and (IHS Global, 2018). These reforms effectively improved the economy, where the GDP increased to $363.1 billion and GPD per capita reached $4028 in 2020 as shown in figure 2.2 where the GDP decreased in 2017 then it showed trajectory increase till 2020



(Trading Economics, 2021). In addition, unemployment and inflation rates decreased to 7.5% and 5.6% in 2021 as shown in Figures 2.3 and 2.4, respectively (Ibid).

Figure 2.2: GDP values in the last five years (Trading Economics, 2021)

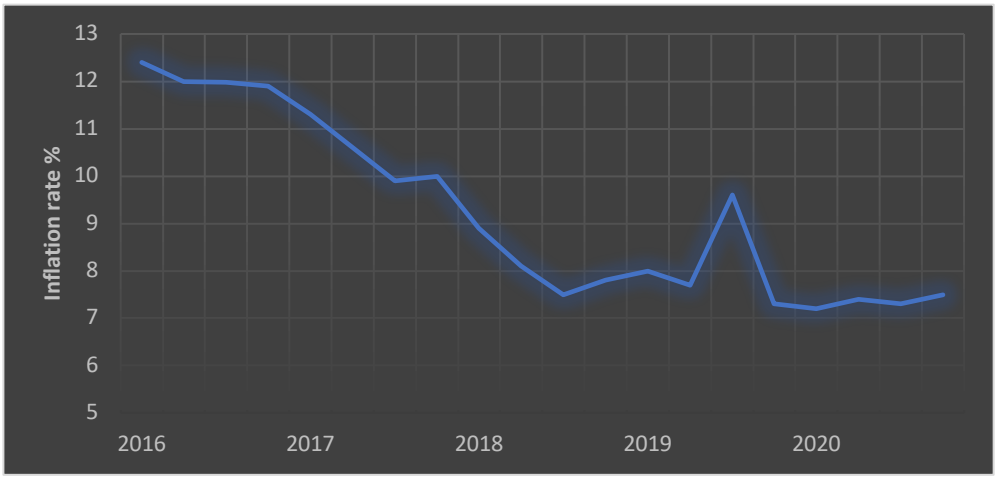


Figure 2.3: Unemployment rates for the period 2015-2020 (Trading Economics,2021)

Figure 2.4: Inflation rates in the last five years in Egypt (Trading Economics,2021)

Despite that, the country is still arrear in several fields compared to other countries in the region. According to Figure 2.5, the economy still needs to catch up in innovation, technological readiness, higher education and training, infrastructure and labour market efficiency. However, due to its high population, it precedes all the countries in the Middle East and North Africa region (MENA) in the market size and the top tier regarding financial market development. These categories could be the main factors encouraging the implementation of an innovative construction method that could improve the supply of housing arising from the increased population. In addition, the unemployment rate would be a positive point where new jobs will be created both in construction sites and factories. However, these economic challenges raise uncertainty for new approaches, mainly through technology transfer from abroad, requiring specific measures for this integration to cope with the current economic situation.

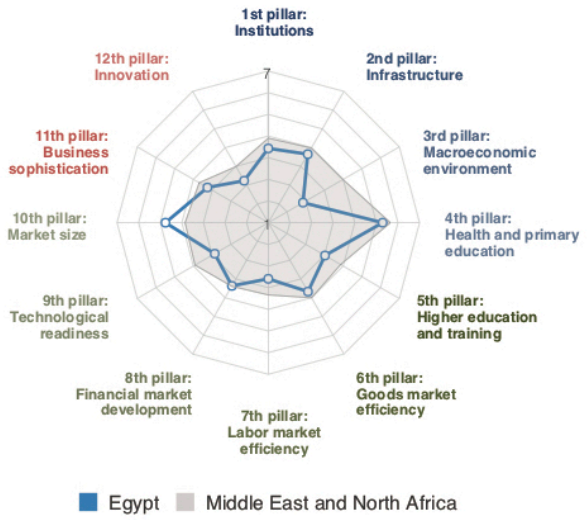


Figure 2.5: Egypt's competitiveness in the MENA region. (Schwab, 2017)

2.7.4 Construction Industry

Construction in Egypt had a 6.5% share in the GDP in 2020 with a total value of $22.4 billion, ranking fifth in the top 10 sectors adding value to the economy (IHS Global, 2021). Between 2012 and 2016, the construction sector witnessed a compound growth rate of 6.4%, with a 5.6% growth rate in the fiscal year 2018/2019 (MPED, 2020). This growth is driven by economic reformation, foreign investments and the industrial construction for significant infrastructure projects underway (Marketline, 2017b). Being one of the most active sectors, about 10% of the labour force is employed in the construction sector. In contrast, much of the industrial workforce is employed in construction-related industries such as building materials production (EL-Kabbany, 2013). However, the construction sector suffers from several issues. According to EL-Kabbany (2013), the industry suffers from a lack of infrastructure, especially in new urban developments, an increase in the cost of materials, labour and land and a lack of technological innovations.

Furthermore, there are concerns about quality in construction projects where the industry needs to improve. The main quality issues are lack of technological background, training and experience and the industry officials' dereliction in establishing specific rules and classifications of contractors and defining their responsibilities (Abdel-Razek, 1998). Moreover, project delays have been one of the main concerns in Egyptian construction. The leading causes of delays are shortage of construction materials, cost-related issues, labour shortage and low productivity (Marzouk & El-Rasas, 2014).

2.7.4.1 Construction methods and materials

The dominant construction method in Egypt is the traditional method of concrete and brick. According to Marketline (2017b), the construction materials market is concentrated on cement (concrete), steel, aluminium and bricks, with few substitutes available. Traditionally the brick industry used to be a local tradition practised by the locals to build their own houses. With modern industrialisation, the brick industry has developed and is dominated by the private sector, with around 3000 factories operating in Egypt, mainly in Cairo, the capital (EL-Kabbany, 2013). Developments and improvements occur in traditional materials with almost no change in building techniques.

Furthermore, the industry has severe issues with workforce skills and productivity. Initially, the majority of the workforce comes from rural areas and villagers to cities where most of the

construction work is conducted; therefore, most of them need proper training. There is only one big construction company in Egypt that has a proper training system, while other companies rely on governmentally educated labour which is poor and insufficient (EL-Gohary and Aziz, 2014).

Moreover, Abdel-razek (1998) argues that quality control measures adopted in Egypt have been inverted from the techniques developed in the West and Far East without any adaptation to the characteristics of the Egyptian industry leading to poor application of quality control measures and failures in ensuring high-quality end products. These issues severely impact the quality of buildings that the traditional methods can hardly improve. In terms of health and safety, a comparative study of the performance of Egyptian and US companies showed that the Egyptians suffered from incidents and injuries almost seven times higher than the US (ElSafty *et al*., 2012). The research discovered severe issues with the industry's health and safety performance, such as lack of training and orientation for workers, lack of medical facilities onsite and lack of general awareness of health and safety procedures even for personal protective equipment.

2.7.4.2 Procurement

Design/bid/build is the standard procurement method applied for public housing projects in Egypt (EL-Gohary and Aziz, 2014). The Ministry of Housing designed and planned every project and then put it to public tender. According to Soliman (2014), tendering is the strategy of selecting and appointing a contractor, which is processed as follows:

1- Negotiations: only one contractor is involved
2- Competition: an invitation for contractors to apply through different approaches

    - Open competition
    - Selective: based on a pre-qualification process
    - A combination between competition and negotiations

In most cases, price is the most critical selection criterion. However, this process and selection criteria usually affect the project's quality and duration. The government and contractors aim to reduce costs in favour of other factors.

2.7.4.3 Innovation and sustainability

Egypt has been committed to leveraging its sustainability performance on different levels. In 2015, the sustainable development strategy (SDS) "Egypt's vision 2030" was launched by the government. Its main pillars are environment, economic development, knowledge and innovation, social justice, urban development, energy and education (SDGKP, 2016). The strategy aims to improve the quality of life of the Egyptians by investing in the development and diversification of the economy depending on innovation and technology in an improved ecological system (ibid). Sustainable development goals have been presented as national goals covering its pillars and inviting all relevant sectors and stakeholders to participate in the development process to achieve the objectives of the SDS. In that regard, innovation and technology have been highly recognised by the Egyptian government as crucial drivers for sustainable development and economic growth; therefore, it appraises technology transfer to accelerate innovation and technology implementation in different industries.

The construction industry in Egypt faces several sustainability challenges. Construction and demolition waste has reached up to 40% of the total materials cost, equivalent to 16% of the total building costs, while it should be at most 4% of the total costs (Daoud *et al*., 2021). Moreover, dumping facilities lack proper health and safety precautions, leading to various environmental hazards and poor workers' practices, such as dumping waste on roads. Furthermore, the vast movements in developed countries for sustainability and the aim to create new building materials which reduce the consumption of natural resources and carbon emissions have minimal influence on Egyptian construction activities (EL-Kabbany, 2013).

Innovations in the Egyptian construction industry still need to be improved and are nearly negligible. The reliance on traditional building methods prevented the emergence of new building techniques despite using modern handling techniques, such as tower cranes and infrastructure projects for drilling, which are imported with their operators. MMC applications in the Egyptian industry are limited to producing precast concrete and caravan offices. Temporary buildings and offices are produced mainly for major infrastructure projects and precast buildings (Mostafa *et al*., 2014). Lack of research and development is considered the main barrier to innovation in Egypt, and lack of economic capabilities.

2.7.5 Manufacturing and infrastructure

The manufacturing industry is a significant contributor to the Egyptian economy. According to the Fifth Economic Census (CAPMAS, 2020), 14% of the working establishments in Egypt are manufacturers, the second highest after wholesale and retail. Manufacturing employs 24% of the country's total employees, the second highest after the wholesale and retail sectors. Moreover, manufacturing activity is the highest product producer in the Egyptian economy, reaching 43.6% of the national production with 31.3% of the Gross Value Added (GVA). The public sector establishments in Egypt represent only 0.04% of the total establishments, while 99.96% are from the private sector. Egypt has a diverse industrial profile ranging from refined petroleum, food and beverages, textiles, and chemical to engineering, including fabricated metal products and machinery. Non-petroleum products account for almost 50% of the manufacturing products categorised under low-to-medium technology industries (OECD *et al*., 2021).

Over the last decade, the government has paid great attention to stimulating the growth of the industrial sector by taking serious steps to achieve it. The government has established 17 large-scale industrial complexes in 15 governorates that host one manufacturing segment with total investments worth $835m during 2014-2021. Currently, there are 127 economic zones, with 1500 new factories established in 2021 and covering 14 million square meters (OBG, 2022). Furthermore, several incentives have been offered to encourage small and medium enterprises (SMEs), such as providing industrial lands with 10-year leases, easing license issuance procedures, offering grace periods on rents and working with several banks to grant funding for up to 100% (CNN, 2022). In addition, the government aims to digitalise the industrial sector by providing digital platforms and technological solutions, especially for SMEs (MPED, 2021).

However, the sector suffers from several issues and hindrances. Investors in the manufacturing sector face economic uncertainty due to the devaluation of the currency two times in 2016 and 2022, leading to high inflation, an increase in prices and placing restrictions on importation due to lack of foreign currency. Governmental bureaucracy results in long processing times for industrial permits, in addition to complex dispute resolution procedures (CNN, 2022). Furthermore, the sector struggles with low productivity, lack of specialised skills and training facilities, poor operation, and project development and maintenance (Servert and Cerrajero, 2015). Furthermore, Egypt lags behind many global, African and Middle Eastern countries in terms of technological applications in manufacturing. Investments in digital technologies by

Egyptian firms are at the most average of 3%, although similar economies invest an average of 5% (OECD *et al*., 2021).

2.7.6 Social and Cultural Overview

Egypt is one of the largest populations in the Middle East and Africa, with a population exceeding 97 million, according to the latest census from the Central Agency for Public Mobilization and Statistics (CAPMAS), with a population growth rate of about 1.7 per cent. The majority of the population is concentrated in Cairo, Alexandria, on the banks of the Nile and along the Suez Canal, with a density reaching 3820 people per square mile. According to CAPMAS (2016), the estimated labour force has reached 29.7 per cent, whereas construction has the second highest employment rate after agriculture reaching 11.9% of the labour force.

Regarding architecture, Egypt has one of the richest architectural heritages in the world, with a span of more than 5000 years. The architectural heritage descends from the Pharaonic, Hellenistic, Roman, Islamic and European cultures. UNESCO nominated multiple sites as World Heritage Sites for their architectural and historical value. This heritage influences modern buildings and houses that can be seen in contemporary building designs (Goldschmidt *et al*., 2018). However, due to economic difficulties and lack of maintenance, deterioration has hit most houses and buildings in addition to using cheap materials in construction.

Generally, Egypt is a conservative Muslim country where Islamic practices and behaviours are highly respected culturally by most of the population. More than 90% of the population are Muslims, and the rest are Christians, with both religions practised moderately daily (CountryWatch, 2018). These practices are reflected in the Egyptians' houses and way of living; for example, in house designs, they are eager for increased privacy by using reflected glass for windows instead of clear glass in Western countries. Unlike Western communities, families are considered to have strong correlations, where teens tend to stay with their families until they get married. In addition, newly married couples from medium and low-income communities live with their parents, which is also due to being incapable of buying or renting new houses leading to overcrowding (Fahmi and Sutton, 2008). These cultural aspects affect the way of living, which decision-makers and designers must consider. Neglecting these factors has failed in several housing development projects, according to Ahmed (2012), due to not participating the community in the planning and implementation of such projects.

2.8 Gaps in knowledge

The literature has been thoroughly reviewed to identify the critical success factors in adopting MMC in developed countries by analysing its chronological development from inception until the current time. This chronological analysis has also been reviewed in developing countries to identify the challenges preventing its adoption in the construction industry and the factors to be considered for successful implementation. Furthermore, a precise analysis of the Egyptian housing sector has been reviewed, including housing policies, the construction industry, and economic, cultural and social aspects to provide a critical review of the challenges and critical factors to affect the implementation of MMC in housing projects. In addition, MMC definitions, drivers, advantages, disadvantages and different techniques have been analysed to gain knowledge of various MMC techniques utilised in different projects to identify the suitable method to be implemented in Egyptian housing projects.

Adopting MMC in the construction industry in developed countries has not started recently. It took decades to have its current influence on the industry, where it started in the United Kingdom and the United States in the 1800th while in Japan after World War II. However, MMC implementation can be considered a failure rather than successful in the early stages as it was mainly based on trial and error. It has been implemented driven by industrial and environmental factors as well as the increased demand resulting from increased population, where the Industrial Revolution in the 1800th in the UK and USA had its effect on the construction industry. However, in this early stage, the aim was to introduce an industrial method to the construction industry without considering other factors affecting the home building, such as socio-cultural factors, training and skills development.

The post-WWII era could be considered the renaissance era for MMC in developed countries. Different methods and types of prefabricated houses emerged as a faster solution to provide decent housing. The massive demand for housing mainly drove it after WWII, the shortage in trained labour and materials, and the political aim to enhance industrialisation; however, more than these factors were needed to succeed despite governmental support. Lack of building regulations and codes in the USA, shortage in manufacturing capabilities in the UK and issues with supply chain and organisational management in Japan were all factors that hindered the successful implementation of MMC alongside high initial cost and negative public perception of prefabricated houses in all these countries.

However, it can be noted that there are critical factors that lead to the current development and the increased share of MMC in the housing market. Governmental insistence on implementing and developing MMC in the housing sector can be witnessed through establishing governmental bodies such as the National Building Agency (NBA) and Building Research Establishment (BRE) in the UK, Manufactured Housing Institute in the USA and Industrialized Housing Production Association in Japan. This insistence produced research and initiatives to encourage alternative construction techniques (BRE 2002, Yashiro 2014, MHI 2018). Moreover, continuous support and never giving up on utilising MMC in the housing and construction industry are considered critical success factors, unlike in developing countries such as Nigeria. In Nigeria, MMC used to exist in housing projects in the 1970s and 1980s; however, it ceased to exist due to the lack of governmental and public insistence (Kolo et al., 2014).

Another form of governmental support to MMC is developing building codes and legislation that encourage adopting innovative and non-traditional methods of construction. The disadvantages of traditional construction methods, such as poor quality, shortage of skilled labour, health and safety issues and the impact of increased waste on the environment, backed this. Imposing new laws and building regulations is critical to successfully adopting MMC in developing countries. The Ronan Point collapse incident was one of the main reasons that the UK introduced tighter design codes to eliminate such incidents. Laws and legislation will also increase confidence in MMC, either the public or construction professionals. However, it is not easy to introduce new laws or building codes, so implementing MMC should comply with the existing building regulations to be adopted more smoothly in the current practices. To adopt MMC in the construction industry, the adoption framework should include how building codes to be modified to support its successful adoption.

Research and development have played a significant role in developing MMC, such as '*Constructing the Team*' in 1994 and the Egan Report '*Rethinking Construction*' in 1998 in the UK. Research alongside governmental initiatives has a significant role in adopting MMC, emphasising its technical, environmental and economic feasibility with respect to traditional construction methods. Research in developing countries is minimal on MMC compared to developed countries that mainly focus on improving traditional construction methods. Nevertheless, research/initiatives did not focus on specific challenges such as how to improve the negative public perception of prefabricated houses that act as one of the significant challenges to MMC globally, in addition to how to adopt different MMC methods to the culture

to be implemented in as well as how to avoid the cultural resistance to change either from the public construction professionals. In the Algerian model in the 1970s, the techniques imported from Europe did not satisfy the socio-cultural requirements of the occupiers due to utilising it with its original design and standards that did not meet the Middle Eastern conservative culture. It was considered unsuccessful resulting in ceasing importation and returning to the traditional methods.

One of the significant challenges of implementing MMC is the high initial cost of establishing the manufacturing facility. In addition, factories' overhead cost is fixed despite the production, which will be unfeasible if the produced quantity is small (Rahman, 2014). In developed countries, governments tried to overcome this economic challenge by involving the private sector in housing production. They also provided local authorities and private sector subsidies to promote MMC to cover its initial cost. In developing countries, governments usually take complete responsibility for financing low-income and affordable housing, thus, they look for the most cost-effective building solutions to build more houses. Therefore, there should be a methodological framework to integrate the private sector in emerging and developing countries to increase financial capabilities and accommodate more innovative construction methods in housing projects. In order to successfully implement MMC, the high initial cost should be absorbed so that it does not increase the overall building cost of housing projects.

Industrial and manufacturing capabilities can be a critical success factor in adopting MMC in developing countries. Developed countries utilised their manufacturing facilities to create affordable solutions for the construction industry in the early stages of mass-producing prefabricated houses. However, there needs to be a significant analysis in the literature of how to utilise the available manufacturing abilities to accommodate MMC techniques in housing projects. However, it depends on the techniques to be implemented to develop a framework for utilising the available manufacturing capabilities, including infrastructure, human resources and how they will be trained. What type of training would be required, how they will be trained, and where.

In the literature, there was no emphasis on the social and cultural aspects concerning adopting MMC. Although each country, the UK, USA and Japan, implemented MMC according to its economic, political and manufacturing aspects, the cultural aspect needed to be analysed more critically. By contrast, in Algeria, the cultural and social aspect was significant factors that caused implementing prefabrication in housing to fail and cease to exist. The cultural and social aspects strongly influence the Egyptian people concerning their religious beliefs and family

correlations. Moreover, the rich architectural heritage is almost lost due to a lack of maintenance and economic constraints. The framework to adopt MMC in the Egyptian housing projects must address these factors as it is essential to its success. In Japan, the successful model in the 1970s, Misawa Homes, took into consideration the occupiers' actual needs and requirements, resulting in increased success among its rivals. Despite this, the occupiers' social and cultural aspects need to be considered, as well as the construction professionals and workers. The cultural norms and manners should also be considered in developing the MMC adoption framework to integrate into the current construction practices.

The aim behind adopting MMC was to explore alternative construction techniques that could address the drawbacks associated with traditional methods. MMC adoption in developed countries passed through different stages of development. The early stages were based on trial and error without adequate research on the suitable implementation method. This method resulted in poor-quality houses that directly contributed to forming a negative public perception of prefabricated houses, which MMC has suffered from until now. Moreover, the lack of innovative methods in the past in manufacturing, handling methods and general knowledge were also causes of early failures. However, with governmental insistence and support alongside the development of manufacturing methods and continuous research MMC in developed countries has become an essential approach in the construction sector.

On the other hand, the adoption of MMC in developing countries is minimal and in its very early stages of implementation. Although countries like Saudi Arabia and UAE are rich, the adoption of MMC is almost negligible because of the lack of governmental consideration of innovation in construction. MMC, however, is considered the solution for developing countries suffering from a housing shortage and deteriorated construction performance. Before adopting MMC, several factors should be considered for successful implementation. Pan *et al*. (2012) mentioned over 50 decision criteria for selecting construction methods that should be considered. Factors include cost, time, quality, sustainability, procurement, health and safety regulation and legislation. Under each factor, there are sub-factors affecting the decision to select the suitable construction method that must be considered according to the specific factors of the country adopting it, such as social and cultural aspects. These factors must be researched alongside generating the governmental and public willingness to develop the construction sector.

Egypt has a severe problem with low-income housing. The supply needs to be increased to the demand, where the gap continues to grow for several reasons. The increasing population, the backlog from previous years, the deterioration of the current houses due to lack of maintenance, and the informal housing, which has turned into slum dwellings, are all reasons for the increasing gap between supply and demand of housing. However, the traditional governmental solution to the crisis needs to be revised and has severe problems due to inadequate research and development. Furthermore, the construction industry lags way behind developed countries regarding innovations and development, in addition to suffering from serious issues such as unsustainability, health and safety issues, poor quality and diversity of construction methods. Despite that, the Egyptian market is considered an encouraging market for new development and methods where the construction sector is very active and accessible. Although the cultural and social aspects play a significant role in the success or failure of anything non-traditional or new, community participation must be considered. Besides, Egypt has a wealthy architectural heritage which has been untapped in the recent housing projects. New urban communities require the revelation of this heritage through non-traditional solutions to improve the image of low-income housing and refine it.

Throughout the literature and after reviewing MMC types, drivers, advantages and barriers, it can be concluded that it has significant benefits in the construction industry that overcome its limitations. However, it can be confirmed that the significant barrier to more adoption of MMC is the human factor, as clients should be more aware of its vast benefits. In addition, further actions are needed from contractors, designers and the supply chain to provide more development to construction innovations and modern methods of construction, which will improve the industry's image. The main driver of MMC is to provide a reliable well-functional facility with high quality that does not harm the environment during its construction and throughout its life cycle. MMC takes advantage of the manufacturing credibility and reliability of construction sites.

In order to successfully adopt MMC in housing projects, it must be integrated with the current practice to overcome potential barriers and challenges. These challenges and barriers, alongside success factors identified from the developed countries that have been widely implementing MMC in their projects, need to be articulated with the country's economic, social, cultural, and technical capabilities and need to be implemented. These critical success factors, challenges, and barriers associated with the adoption framework of MMC are summarised in Figure 2.6. These factors are developed from the literature analysis within Egypt's context, which could be adapted to other developing countries. It includes the main stakeholders involved in the MMC adoption process who have significant roles in successfully implementing the framework.

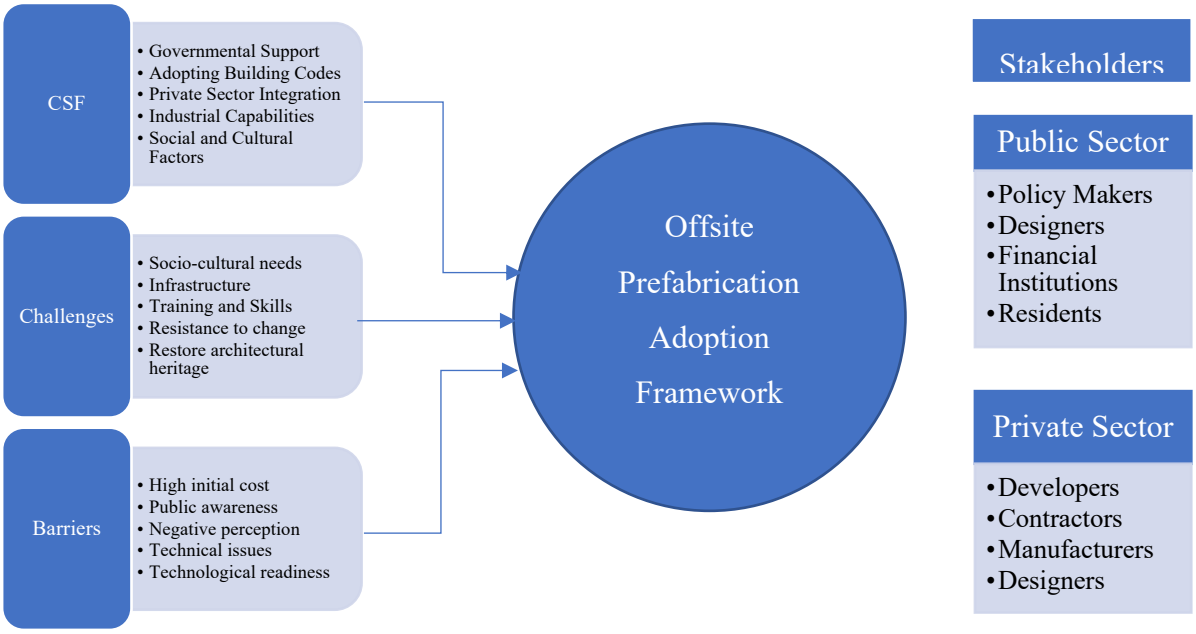


Figure 2.6: Critical success factors, barriers and challenges to adopt MMC

2.9 Chapter summary

This chapter has critically reviewed the literature on the Modern Methods of Construction including its definitions of different terminologies describing offsite prefabrication in construction. The types of MMC were also reviewed in the literature in addition to the drivers and barriers to its implementation. Moreover, the chronological development of MMC adoption in developed countries was explored to identify the critical success factors, challenges and barriers to its implementation in the United Kingdom, the United States of America and Japan. The adoption of MMC in developing countries in the MENA region was investigated to evaluate the factors that supported its implementation or hindered it.

The literature about housing in Egypt was critically reviewed to analyse the current policies of providing low-income housing, how they are executed and who are the relevant stakeholders.

The Egyptian economy, construction and manufacturing sectors were also investigated in addition to the social and cultural aspects of the social housing residents to identify the influencing factors of MMC implementation in social housing projects. The chapter has been concluded by a critical discussion of the gaps in knowledge related to MMC implementation and the lessons learned from its adoption in developed and developing countries. in addition, the critical success factors, barriers and challenges to the implementation of MMC in Egypt have been evaluated and identified showcasing the influence on the adoption process of MMC.

3 Chapter 3: Research methodology

3.1 Introduction

Conducting scientific research requires following a robust research methodology to draw precise conclusions to solve questions and develop knowledge. Research can be described as "an organised, systematic and logical process of inquiry using empirical information to answer a question or test hypotheses" (Punch, 2014). Described as a systematic process, scientific research must follow certain procedures and have a specific plan to reach logical conclusions that can be relied on. The research plan involves designing every step starting from the broad assumptions to detailed methods of data collection, analysis and interpretation (Creswell, 2014). Figure 3.1 shows an overview of the main steps in performing scientific research that start with the research questions and their central role in the research process all the way to obtaining the answers and drawing up critical conclusions.

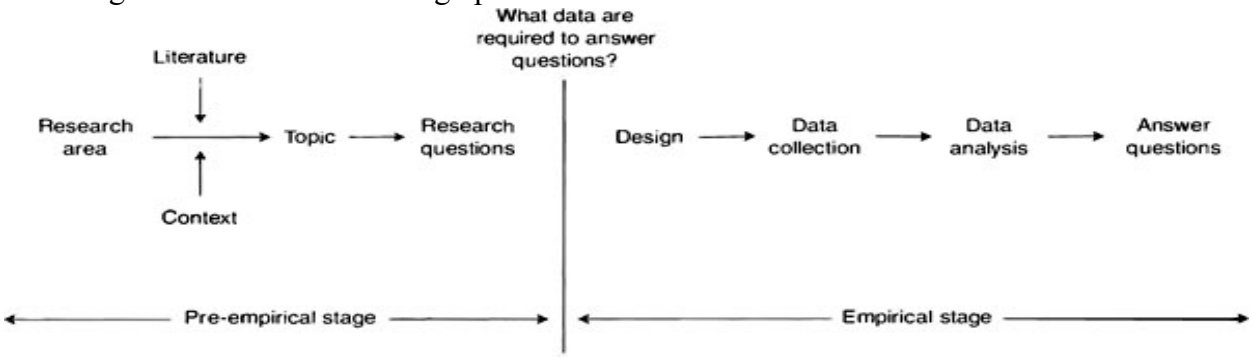


Figure 3.1: Simplified model of research (Punch, 2014).

According to Knight and Ruddock (2008), construction management (CM) research derives from both natural and social sciences. Therefore, several research methodologies and paradigms apply when designing it, considering the researcher's philosophical and theoretical assumptions for the enquiry of the research. These assumptions, in return, influence the research design affecting the methods of how data are collected, analysed and interpreted. The research design refers to the framework for performing research by providing the ways in which the data is collected, analysed and interpreted to answer the research questions. The research methodology must be carefully considered to identify the most suitable research methods that are applied with respect to the research questions, aims and objectives (Fellows and Liu, 2008). To reach robust conclusions, research needs to be flexible to create links between previous studies, theories and methods in order to create a coherent chain. Figure 3.2 shows the suggested CM research process from the Specially Promoted Programme (SPP) held in the 1980s showing how the research stages are linked and how flexible it should be. It

describes the stages of research from inception and the possible outcomes of research. The stages involve going forward and backwards between stages to evaluate the outcome of each stage and how it is linked to a previous or a later stage. The main objective of the construction management research process, according to Figure 3.2, is to emphasis on the flexibility required by the researcher and to have clear connection between all the research stages to ensure coherence in research.

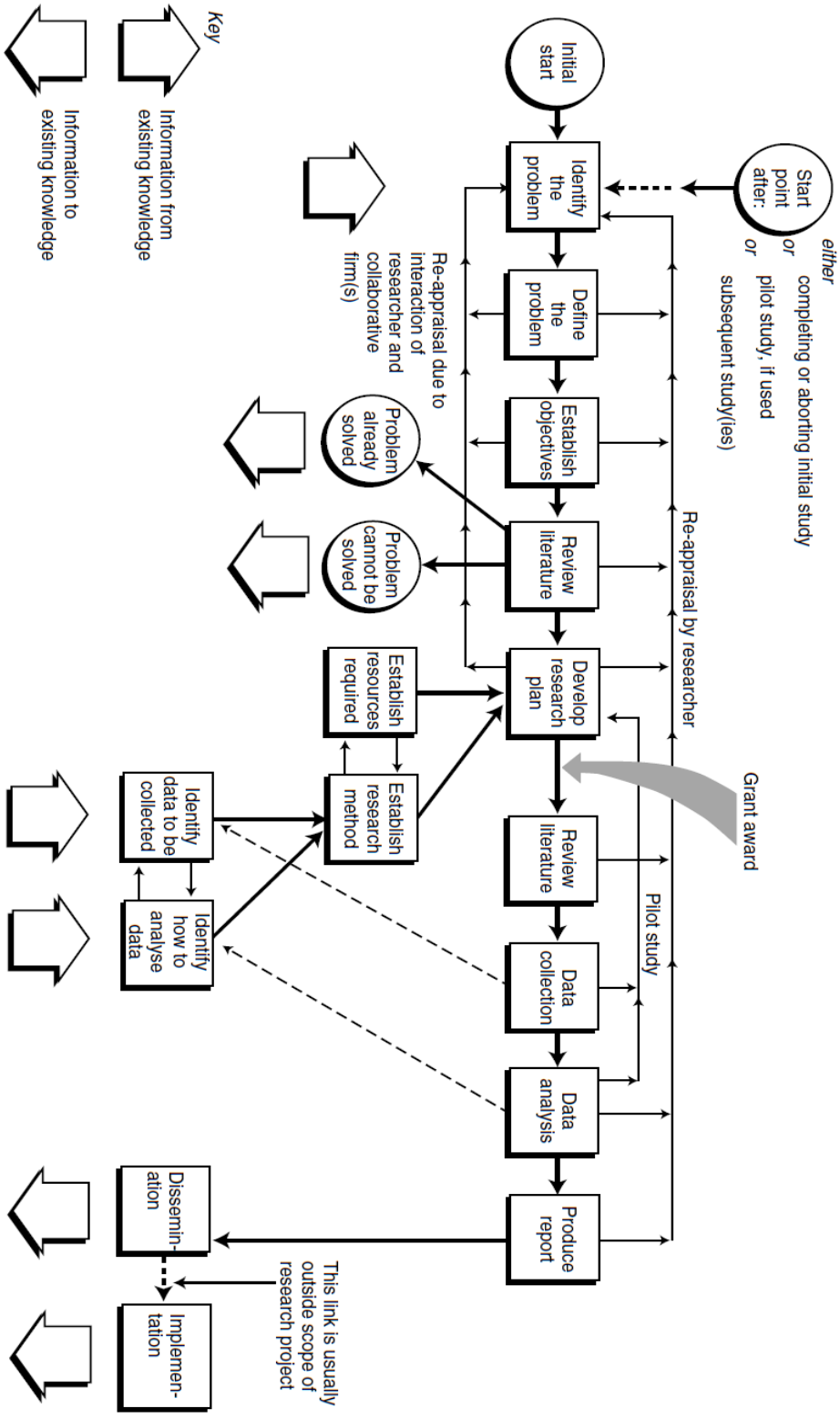


Figure 3.2: Suggested CM research process (Fellows and Liu, 2008)

For this research, the researcher has followed the Research Onion framework produced by Saunders et al., 2019 which describes research design as onion layers. The outer layer represents the research philosophy, and the inner layers represent the research approach, methodological choice, strategy and data collection and data analysis techniques as shown in Figure 3.3. Each layer represents part of the research process helping define and develop each stage and link them together to maintain the complementarity of the research.

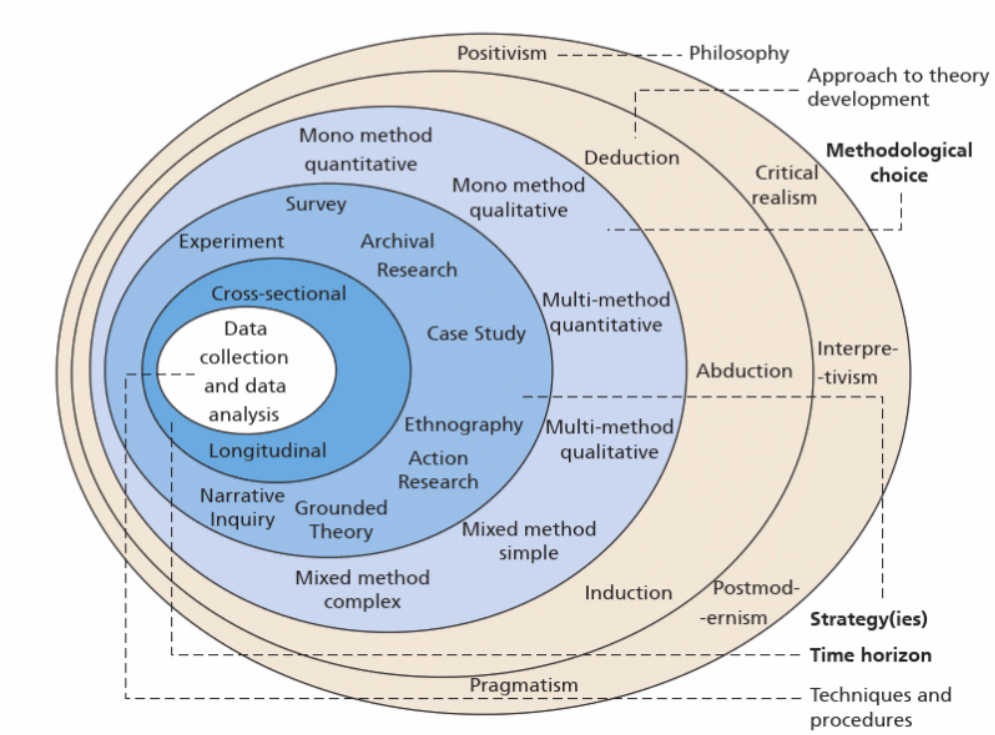


Figure 3.3: Research Onion (Saunders *et al.* 2019)

3.2 Research Philosophy

Research philosophy demonstrates the researcher's assumptions about the nature of reality and knowledge. It involves the researcher's beliefs and how he/she thinks about questions, makes interpretations and explores ideas. These philosophical considerations are the keystone of research design which considers what kinds of evidence are required to answer research questions in addition to how this evidence is gathered and interpreted (Easterby-Smith *et al.*, 2012). A well-defined set of research assumptions will help form a consistent research philosophy that supports the research design, data collection methods and analysis techniques to conduct coherent research (Saunders *et al.*, 2019). Moreover, understanding and identifying the philosophical foundations of the research will provide an understanding of how the research questions are answered from the chosen data that has been collected and how it is interpreted

(Easterby-Smith *et al*., 2018). Generally, the researcher's beliefs will be the base of his/her assumptions leading to choosing a qualitative, quantitative or mixed methods approach (Creswell, 2014).

Research philosophy deals with the ontological and epistemological consideration of research and research activities. In the social science research methods literature, research philosophy deals with the main branches, ontology and epistemology. Ontology concerns the nature of reality and how the researcher believes what constitutes social reality. Epistemology deals with the assumptions of the nature of knowledge and its criteria in the field of study. The ontological assumptions shape the relationship of the researcher's understanding with the epistemological knowledge of the study area and the selected research methods (Easterby-Smith et al., 2018). The ontological and epistemological beliefs of the researcher affect the choice of the research strategy and how the research questions will be answered.

Although these assumptions offer different philosophies that deal with the researcher's beliefs and research questions, there are two opposing extremes where most research philosophies lie (Saunders *et al*., 2019). These extremes are objectivism and subjectivism where objectivism assumes that all social actors identify only one social reality. Objectivists believe that knowledge can be gained through observable and measurable facts that can be generalised to all social entities. On the other hand, subjectivism incorporates assumptions that actions and perceptions of people are the foundations of social reality through their interactions and experiences. People's perceptions and experiences are different from one another, meaning that, from a subjectivist's point of view, there are multiple realities rather than a single reality, as in the objectivist's perception.

- **Ontology**

Ontology and epistemology are the main philosophical assumptions followed by social scientists in their research. Ontology refers to the nature of reality, whether it exists or is in the researcher's mind (Holden and Lynch, 2004). Ontological assumptions shape the way in which research is carried out through the researcher's view of the world of their chosen field of study and how the research objects are studied. In management research, research objects include organisations and organisational events as well as the individual's lives and beliefs (Saunders et al, 2019). To conduct social research, philosophers debated several philosophies concerning their ontological assumptions to develop their research methodologies. According to Easterby-Smith *et al*. (2018), the debate has developed a continuum of philosophies that most social research currently follows, mostly between objectivism and subjectivism. Generally, the

philosophical debate lies between three main philosophies: internal realism, relativism and nominalism. Figure 3.4 describes each ontological philosophy and its tendency towards which philosophical position.

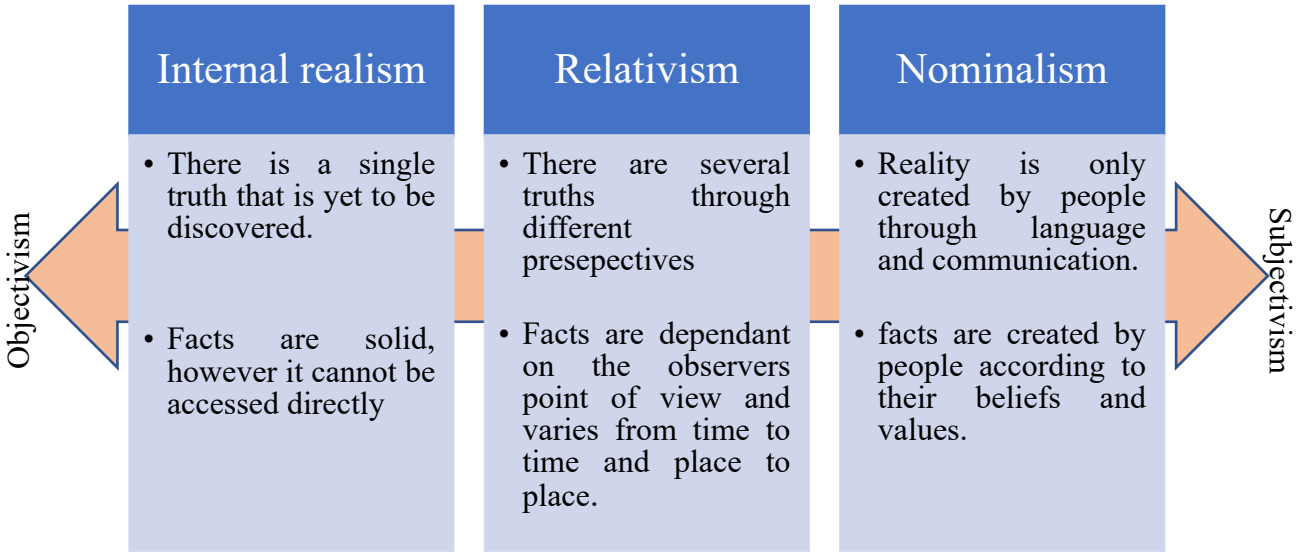


Figure 3.4: Ontological positions

The internal realist believes that there is only one single independent reality which is still undiscovered. This reality cannot be discovered directly; however, it is only discovered through indirect evidence gathered through observations and human interactions and the mental processing occurring after observations (Saunders *et al*., 2019). Relativists believe that there is no single reality but there are multiple perspectives on the same issue. According to relativism, facts are dependent on the observer and their point of view where truth can be different from place to place and from time to time (Easterby-Smith *et al*, 2018). On the other hand, nominalists believe that what counts as reality is created through the interaction and communication of people. Accordingly, facts are created by people's beliefs, and truth can be claimed and negotiated without the existence of actual truth.

This research aims to develop a framework for adopting MMC in Egyptian low-income housing projects. Thus, the researcher considers the reality through the current construction professionals' and residents' experiences and beliefs. The truth will be explored from the perspectives of the current stakeholders of the housing system. Moreover, the study is concerned about the current barriers, challenges and success factors viewed and believed by the stakeholders, specifically for the least advantaged households trying to identify the truth from their perspective. Therefore, the ontological position of the current research tends towards

relativism. Relativism claims that reality is knowable through human minds and from meanings constructed socially (Ritchie *et al.*, 2014). Furthermore, the research investigates the factors affecting the adoption of MMC, including the social influences and people's perceptions which supports the relativism assumption of the research.

- **Epistemology**

Epistemology refers to assumptions about the nature of knowledge, dealing with questions about what is considered acceptable knowledge and how knowledge is transferred to others (Saunders *et al.*, 2019). The two prominent epistemological positions are positivism and social constructionism or interpretivism (Easterby-Smith *et al.*, 2012). Positivists have an objective view of the world where descriptions and explanations of science can be developed through universal laws and quantitative data and information (Punch, 2013). On the other hand, social constructionism believes that knowledge is gained through people's beliefs and interactions. The real world is determined through the subjective interpretation of people's feelings and behaviour. Constructionists assume that there are different views of reality; hence, researchers need to collect different forms of qualitative and quantitative data from various views to gain precise information (Easterby-Smith *et al.*, 2012). The social constructionism assumptions are closely related to the current research, which explores the potential of adopting MMC in Egypt through the experiences and views of construction professionals. In addition, it investigates the success factors, barriers and challenges from various sources, including a literature review and analysis of experts' views and residents' perceptions.

3.3 Research Approach

The next layer in the Research Onion is the research approach. The research approach is concerned with the use of theory either building it or corroborating/falsifying it. Identifying the research approach is an integral part of the research design that increases the validity of the research (Creswell 2013). Deciding the research approach is typically derived from the research questions and the aim of the research which, subsequently, leads to the decision of choosing the research methods of data collection and analysis. According to Saunders *et al*. (2019), the reasoning adopted by researchers in formulating their research design is usually two contrasting approaches: inductive and deductive.

3.3.1 Inductive

In the inductive reasoning approach, the research starts by studying a phenomenon through data collection to generate a theory or framework. The fundamental research problem is the core of research, where different data collection methods are utilised to obtain different views of the problem. Inductive reasoning allows alternative explanations for the events taking place related to the research problem providing an in-depth understanding. This understanding takes into consideration human behaviour to identify the link between causes and effects of human interpretation of the social world (Saunders *et al*., 2019). In the inductive approach, various methods are used to collect and analyse data to generalise and develop a theory or framework. A small sample is considered more appropriate as induction is more concerned with the context of the events taking place. The inductive approach permits advances in knowledge through the development of theory, which can later be falsified or approved through deduction (Fellows and Liu, 2008).

3.3.2 Deductive

In contrast to inductive reasoning, deductive research starts with a theory or hypothesis that the research will falsify or approve. It is more related to scientific research than social research, where a theory is subject to strict tests to corroborate or falsify it. The main feature of the deductive approach is generalising from the specific where hypotheses are reached from a logical process of tests, data collection and analysis (Ritchie *et al.*, 2014). It starts with setting a hypothesis or a relationship between two or more concepts, ideas or variables forming a theory. The theory is examined against existing literature and through appropriate data collection to measure and analyse the variables. The analysis results are then compared to the hypothesis to corroborate or falsify the theory. In the deductive approach, research methods explore relationships between variables or concepts requiring precise identification of the data to be collected. This precision may lead to neglecting other factors affecting the theory under study, raising doubts about its reliability. Moreover, to generalise, the data to be collected should be of an appropriate size to provide sufficient information to develop a robust theory (Saunders et al., 2019).

3.3.3 The adopted research approach

The research design of this study attempts to answer the research questions illustrated in the Introduction chapter. The research questions are set to find answers to two fundamental aspects.

The first aspect explores and identifies the influencing factors on adopting MMC and what constitutes successful implementation in housing projects. The second aspect is related to the Egyptian housing and construction sectors to identify the current challenges and drawbacks and how MMC can help overcome and improve these issues. The research design has adopted a mixed-method approach to address these aspects and their interrelationships to answer the research questions.

A literature review has been performed to gather information relevant to both aspects to identify the current themes related to MMC adoption and the Egyptian construction and low-income housing sectors. Firstly, data were collected to explore how MMC adoption has developed chronologically in several developed countries, in addition to exploring any similar adoption trials in countries in the MENA region. This was done to identify the critical factors influencing the adoption process and how the challenges can be mitigated. On the other hand, the characteristics of the Egyptian housing and construction sector have been identified to determine the challenges and barriers that might hinder the adoption of MMC. Both aspects have been explored to determine the themes and overlapping factors emerging from the literature to be used in the primary data collection.

From the information extracted from the literature, an investigation was required to explore and identify the challenges, barriers and critical success factors of the Egyptian construction sector and low-income housing projects. Semi-structured interviews were chosen to identify the influencing factors based on expert opinions, views and beliefs of project stakeholders in Egypt. Semi-structured interviews were selected to gain in-depth knowledge and opinions while having the chance to obtain data for qualitative analysis and, at the same time, be possible to compare the answers. Furthermore, a questionnaire survey was conducted with social housing residents to identify the issues and drawbacks of the current housing system and explore their needs that the current housing does not fulfil. The questionnaire was selected to provide the ability to distribute it to a large number of residents in addition to being a convenient method for non-experts to give their opinions and beliefs that will help in formulating the framework successfully. Moreover, unstructured interviews were used to validate and verify the framework to ensure its efficiency and practicality. Unstructured interviews were selected to provide an in-depth discussion about the research findings and the implementation of the framework giving the participants the freedom to express their opinions and insights to avoid any biases that could be developed from structured or semi-structured questions. Given that, a mixed-method research design was selected to achieve the research

aim and objectives. The inductive approach of the current research aims to collect these data to generalise and then develop a framework to implement MMC in low-income housing projects in Egypt.

3.4 Methodological choices

After establishing the research questions and considering the research philosophy and approach to theory development, the next stage of research design is deciding on the data collection and analysis methods. Data collection and analysis methods depend on the type of data required to answer the research questions and fulfil its objectives. Research methods must be coherent with the research philosophy and approach to provide consistent research and robust conclusions (Saunders *et al*.,2019). According to the research onion framework, methodological choices refer to the decision to follow a qualitative, quantitative or mixed methods approach. In the literature, there is an ongoing debate on the merits and demerits of each approach and which is better than the other in a specific research environment. However, the main point to consider is what type of information is required in a study and what kind of knowledge needs to be discovered to decide which approach to choose (Davies and Hughes, 2014). Therefore, no method can be considered better than the other (Creswell, 2013).

3.4.1 Qualitative approach

The qualitative approach aims to understand people's perceptions of the problem under study by investigating their opinions, views and beliefs (Fellows and Liu, 2008). It seeks to obtain the participants' experiences by collecting non-numeric data through interviews and observations to extract the meanings and relationships between them. Data are analysed to develop a theoretical framework and conceptualisation from relatively fewer participants than in the quantitative approach, although taking longer contact with participants (Dawson, 2019). The qualitative approach tends to be used more in inductive research due to its nature of obtaining and analysing data from a small number of participants in order to generalise and develop theories (Saunders *et al*., 2019). Moreover, qualitative research is more related to social constructionism and interpretivism, where it is more reliant on human interactions and beliefs to develop knowledge and gain reality.

Data in qualitative research are primarily unstructured and raw; however, it is considered rich in information and more in-depth (Fellows and Liu, 2008). Qualitative data are extracted or created from numerous verbal, textual and visual forms (Saunders *et al*, 2019). These forms

are collected through various methods including interviews, observations, and focus groups. Therefore, the researcher is more involved in the data collection as the data is collected in its natural setting, allowing the researcher to gain increased insights into the context of the data. Such involvement increases the opportunity to observe unexpected variables that were not considered in earlier research stages. As a result, new themes could be developed from the qualitative analysis to provide a more contextual explanation. However, analysing qualitative data could be more complicated than quantitative data as it requires more effort to organise and extract useful information. The qualitative analysis includes interpreting large amounts of words and, in some cases, images, where each sentence may have a different meaning and could be interpreted differently.

3.4.2 Quantitative approach

Quantitative research generally adopts a positivist point of view where it is believed that there is one actual reality that can be measured using scientific techniques (Saunder *et al*, 2019). In quantitative research, reality tends to be conceptualised into variables where these variables are measured numerically to explore the relationships between them (Punch, 2014). Creswell (2014) defines variables as:

"A variable refers to a characteristic or attribute of an individual or an organisation that can be measured or observed and varies among the people or organisation being studied."

Variables could be gender, age, sociocultural status and attitudes or behaviours. The relationships between variables are used to develop interpretations of facts to test a theory. Quantitative research tends to be deductive in nature, where the results aim to answer questions related to a hypothesis under study. The researcher either states a hypothesis and then collects and analyses quantitative data to falsify or corroborate it or develops several hypotheses where the data can identify which one is correct (Easterby-Smith *et al*., 2012).

Data in quantitative research are collected to be measured. Thus, data needs to be standardised to develop measurable variables that can be analysed statistically to identify relationships and make comparisons. Fellows and Liu (2008) identify two main questions that need to be answered in order to identify which data collection and analysis methods to be used. Firstly, what is required to be measured and, secondly, how it is measured. These issues need to be addressed thoroughly prior to commencing quantitative research to avoid missing important factors affecting the research questions that might affect the validity of the research output. Quantitative data could be collected through one or multiple methods and analysed using a

corresponding data analysis method. The former is known as a mono-method quantitative study, and the latter is known as a multi-method quantitative study (Saunder *et al*, 2019). Creswell (2014) identified two main quantitative research designs that include quantitative data collection and analysis:

- **Survey research:** Data is collected using questionnaires or structured interviews to provide numeric data to describe behaviours, opinions or trends from a calculated sample of the intended population under study.
- **Experimental research:** Data are collected by applying a specific treatment to assess its outcome. This is typically done by applying it to a group and preventing it from another group to identify its influence by measurable methods.

Generally, in quantitative research, the researcher is more independent from participants than in qualitative research. This might affect the research outcome as the researcher would need more in-depth insights into other influencing factors, especially in social research.

3.4.3 Mixed methods approach

In the mixed methods approach, qualitative and quantitative data collection and analysis are both used in single research. The mixed research method combines the strengths of each method and tries to eliminate the weaknesses of each as much as possible. The focus of the mixed research method is the research problem rather than the methodology or the research paradigm, where the decision is more focused on answering the research questions (Punch, 2013). Creswell (2014) described three main models of mixed research methods:

- Convergent parallel mixed methods
- Explanatory sequential mixed methods
- Exploratory sequential mixed methods

The current research follows **convergent parallel mixed methods** where Creswell (2014) describes this form of research design in which both qualitative and quantitative data are merged to provide a comprehensive data analysis of the research problem. Both types of data were collected simultaneously then their interpretation is integrated for the overall results. The quantitative data collection method and analysis provide significant and reliable numerical data while qualitative data provides in-depth and reliable validation. Qualitative data were collected through semi-structured interviews with governmental officials, house designers, and contractors to gain in-depth knowledge of the housing projects' process from inception to completion. In addition, unstructured interviews were performed to validate and verify the final

framework. On the other hand, quantitative data were collected and analysed from a post-occupancy survey in a selected low-income housing project as a case study to identify the drawbacks and problems associated.

3.4.4 Framework justification

A framework showcases the relationships between several factors, which may be called variables, related to a specific problem under investigation (ZeePedia, 2019). The framework is often illustrated through a graphic presentation where arrows between the variables show the relationships. The variables are identified through collected data by several methods such as interviews, observations, surveys and literature analysis. These factors are analysed, grouped and named, setting out their interrelationships and leading to a framework (Miles and Huberman, 1994). A theory can be developed from a hypothesis extracted from the framework through critical analysis. Analysis and testing are crucial in framework, and theory development as the factors are derived from observations of human behaviours which may lead to various interpretations, so further testing is required to avoid misleading results (Fellows and Liu, 2008). Accordingly, the resulting framework must be practical and represents reality as much as possible to provide a robust solution to the research problem and answer the research questions.

The Logical Framework Analysis (LFA) is a systematic and structured tool used in project planning, management, and evaluation. It provides a logical and comprehensive framework for designing, implementing, and assessing the success of projects or programs. LFA is widely used in the field of international development, but it can be applied to various sectors and contexts (Bond 2003). LFA is typically presented in a matrix format that provides a concise summary of the project's components, including the goal, purpose, outputs, activities, indicators, assumptions, and means of verification. It serves as a management and monitoring tool, guiding project implementation and evaluation. Mainly, LFA consists of four key components:

- Goal: The goal represents the long-term objective or the desired outcome that the project intends to achieve. It describes the broader impact or change that the project aims to contribute to, often aligned with the organization's mission or development goals.

- Purpose: The purpose is a more specific statement that defines the intended outcome of the project. It explains how the project will contribute to achieving the overall goal. The purpose should be measurable, achievable, and directly linked to the goal.
- Outputs: Outputs are the tangible and measurable results or deliverables of the project. They are the immediate products or services that the project will provide. Each output should be clearly defined and specified in terms of quantity, quality, and time.
- Activities: Activities represent the specific actions, tasks, or interventions that need to be carried out to produce the desired outputs. They describe the steps required to implement the project effectively. Activities should be realistic, feasible, and directly connected to the outputs.

LFA promotes a logical and systematic thought process that enables project planners to identify the cause-and-effect relationships between project elements. It helps in clarifying project objectives, designing appropriate activities, setting measurable indicators, and managing risks and assumptions.

Consequently, a logical framework approach is considered to be the optimum tool for the research problem under investigation in this study. The framework will be a tool to guide the stakeholders of low-income housing projects to successfully adopt MMC in their projects, addressing the challenges and barriers of the adoption process. It will develop a practical implementation strategy that meets the current practices of the Egyptian construction industry. Taking into consideration that MMC has not been utilised in low-income projects previously, a framework is selected to be the tool that guides projects participants through the implementation process of MMC to assist them in understanding the process by identifying the success factors, what challenges they might face and the barriers they need to overcome.

3.5 Research strategies

Research strategies include the methods used to collect and analyse data to answer the research questions. It is the plan of action to achieve the research aims and objectives. Research strategy is the link between the research philosophy and the chosen methods to collect and analyse data in order to achieve coherence in the overall research design (Saunders *et al*, 2019). In deciding the research strategy, questions must be answered regarding what data shall be collected and how, this includes what tools are required and the skills the researcher has to conduct data collection (Easterby-Smith *et al.*, 2012). Although the chosen strategy depends on the

philosophical instance adopted by the researcher where positivists may consider different strategies than social constructionists as they have different views on reality and knowledge. There are mainly seven research strategies adopted in qualitative and quantitative social and construction management research:

- Quantitative: Experiment, Quasi-experiment and surveys.
- Qualitative: Case study, ethnography, action research and grounded theory.

3.5.1 Case study

The research will adopt a case study research strategy. "*A case study strategy has the capacity to generate insights from intensive and in-depth research into the study of a phenomenon in its real-life context, leading to rich, empirical descriptions and the development of theory*" (Saunders *et al.*, 2016). The case study strategy helps to understand what is happening in the current situation and why in order to identify the effects and, therefore, the implications for actions (Ibid). This strategy will provide the research with an in-depth understanding of to what extent the current housing satisfies the needs of the residents and what challenges it encounters.

The research will rely on data collected from two different social housing projects as case studies. The two case studies were selected in two different locations, the first is close to the city centre and the other is in one of the new urban communities. these two locations were chosen to identify any specific differences in the users' needs and evaluation of social housing either in the city centre or new urban communities. This is because social housing units are being built with the same design all over the country, so selecting two different locations would help in developing a holistic overview of all influencing factors on the users. Selecting two case studies is to identify the common factors, challenges and gaps in the housing system to be able to generalise. This will provide greater knowledge and understanding of the critical factors affecting housing projects that will be taken into consideration to develop a framework to adopt MMC in housing projects. General considerations are considered when selecting case studies which are as follows:

- Both projects are to be similar in size and the number of units to identify aspects of comparison and differences.
- Projects to be in different locations to identify different challenges and needs.
- Potential to include a considerable use of MMC/Prefabricated elements.

3.6 Data Collection Types

3.6.1 Primary Data

The primary purpose of research is to provide genuine information and create new knowledge; this comes from primary data, which the researcher originally generates through various methods. Primary data will include different types to fulfil the research questions and objectives, which are as follows:

3.6.1.1 Semi-structured interviews:

According to Saunders *et al.* (2016), semi-structured interviews are very useful in inductive and exploratory research to gain in-depth knowledge of what is happening in the real world and to understand the context. They provide qualitative data on the people's understanding and experience of specific problems relating to the research context. Based on the information from the literature review and the themes generated, the researcher decided what information is required from primary data collection sources. The information needed to include all the aspects of the Egyptian housing and construction sector to obtain in-depth data that extracted all related factors. A semi-structured interview was selected as the primary data collection method to allow participants to express their opinions and views freely while also assisting the researcher in collecting organised data for qualitative analysis. Interview questions were designed to cover three main themes, barriers, challenges and critical success factors, with general questions about the participant at the beginning. Under each theme, several factors were pinned, on which the questions have been based. The questions covered the main factors extracted from the literature while integrating them with the current issues and challenges in the Egyptian construction and housing sector to satisfy the research questions and objectives. The nature of semi-structured interviews provided the opportunity for the participants to share their opinions and thoughts freely and in-depth to provide vital information that comprehends the subject under investigation. A total of 15 interviews have been performed with housing and construction experts as shown in table 3.1.

Table 3.1: Details of the interview participants

Code	Role	Years of Experience	Organization
GovPh1	Project engineer	6	Ministry of Housing
GovPh2	Senior project Engineer	18	Ministry of Housing
GovPh3	Head of Eng. Department	20	Ministry of Planning
ContPh1	Site Engineer/civil	5	Contractor
ContPh2	Project Manager	18	Contractor
ContPh3	Project Manager	18	Contractor
ContPh4	Construction Manager	18	Contractor
ContPh5	Site Manager	7	Contractor
ContPh6	Project Manager	27	Contractor
ContPh7	Site Manager	9	Contractor
ArchPh1	Architect	10	Designer
ArchPh2	Senior Architect	25	Designer
ArchPh3	Architect	14	Designer
PrctF2f1	Production Manager	12	Production Manager
ContF2f1	Factory Manager	21	Ready Mix Concrete Manager

Interviewees were selected according to their wealth of experience in the construction industry, knowledge of MMC and senior position within their role. The interviews discussed the critical factors that might affect the implementation of MMC, the current challenges of the low-income housing sector, and how MMC can improve it. Information obtained helped achieve the *second* and *third* objectives.

3.6.1.2 Survey:

The main aim of the questionnaire is to explore and identify the challenges and drawbacks of the current social housing units from the residents' point of view. In addition, investigate their needs that their units are not satisfying, as well as their expectations if living in prefabricated units. Understanding the occupiers' requirements and beliefs can help develop the framework to efficiently implement MMC in low-income housing projects by exploring mitigating factors that can hinder the successful implementation of MMC. As previously mentioned in Chapter 2, social and cultural aspects could negatively affect MMC adoption if it fails to meet the users' needs and requirements.

A post-occupancy survey questionnaire has been performed with residents of the two case studies in order to identify the challenges, defects, advantages and disadvantages of their houses. In addition, to explore their specific needs and expectations from their homes. The questionnaire was designed to be easily read and answered by non-experts and took at most 10 minutes to answer. The first section consisted of general questions such as gender, age group, number of occupants and duration of stay in the unit. The following section concerns knowledge of MMC and the structural system of the building. The third section was a 5-point Likert rating question about rating their doubts against prefabricated houses, ratings of their current homes and finally rating of important factors affecting their decision on choosing their new homes. Respondents have been selected by systematic random sampling technique according to Figure 3.5. Systematic random sampling (SRS) involves selecting a sample from the sampling frame in regular intervals calculated by the following steps (De Vaus, 2014):

- Identify the sample frame.
- Identify the sample size.
- Calculate the sampling fraction (n=population ÷ sample)
- Select starting point from the first 5 cases.
- Select case every n^{th} case.

For each case study, the number of units is the population where the cases were selected according to the calculated sampling fraction. The sampling frame is the total number of units in each project which have been obtained from the project's information. The total number of flats in the two case studies is 5160 flats which corresponds to the total number of the target population. The sample size was selected according to Table 3.2 which describes the different sample sizes for the target population at a 95 per cent confidence interval. Thus, the

corresponding sample size to a 5000 target population is 357 responses as highlighted in Table 3.2. The vast majority of management research works at a 95 per cent confidence interval within 3 to 5 margins of error when calculating the selected and adjusted minimum sample size (Saunders *et al.*, 2016). A total of 141 questionnaires have been collected from residents of both case studies from 350 questionnaires distributed with a response rate of 40.3%. The distribution and collection of the questionnaires and responses are described in detail in Chapter 4. The questionnaire provided data to be analysed quantitatively to achieve the *fourth objective*.

Table 3.2: Sample size of different sizes of target population at 95 per cent confidence Interval (Saunders *et al.*, 2016).

	Margin of error			
Target population	5%	3%	2%	1%
50	44	48	49	50
100	79	91	96	99
150	108	132	141	148
200	132	168	185	196
250	151	203	226	244
300	168	234	267	291
400	196	291	343	384
500	217	340	414	475
750	254	440	571	696
1 000	278	516	706	906
2 000	322	696	1091	1655
5 000	357	879	1622	3288
10 000	370	964	1936	4899
100 000	383	1056	2345	8762
1 000 000	384	1066	2395	9513
10 000 000	384	1067	2400	9595

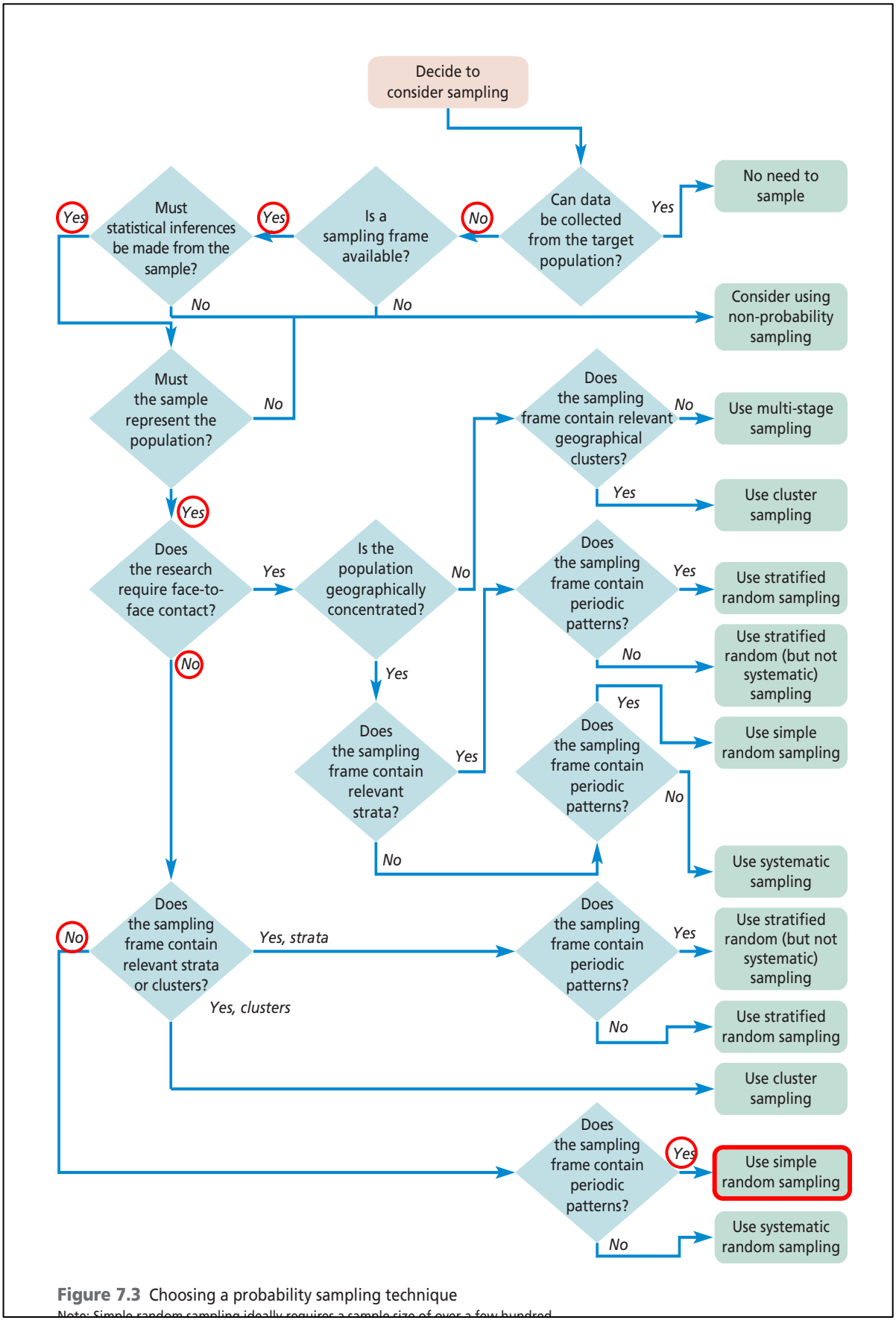


Figure 7.3 Choosing a probability sampling technique

Note: Simple random sampling ideally requires a sample size of over a few hundred

Figure 3.5: Choosing a probability sampling technique (Saunders *et al.*, 2016).

3.6.1.3 Unstructured interviews

In qualitative research, unstructured interviews are a common method used to gather rich and in-depth data from participants. Unstructured interviews involve open-ended questions that allow participants to express their thoughts, experiences, and perspectives freely. Unlike structured interviews with predetermined questions, unstructured interviews provide flexibility and encourage participants to delve into specific topics in detail. The absence of a fixed set of questions in unstructured interviews allows the researcher to adapt the interview based on the participant's responses. This flexibility allows for a more personalized and participant-centred approach, enhancing the quality and depth of the data collected (Saunders *et al*, 2019). Unstructured interviews were used in this research to validate and verify the framework. Seven interviews were performed to assess the findings of the research and discuss the practicality and inclusivity of the framework. The participants were selected according to their experience and knowledge of the Egyptian housing and construction sectors in addition to their scientific nature as shown in Table 3.3. To also validate the research methodology according to precise construction management research methods.

Table 3.3 Participants' profiles of the validation interviews

Role	Years of experience
Lecturer in Construction Management	11
Senior Lecturer in Construction Management	15
Professor in Construction Management	20
CEO; PhD in Architecture	25
COO; Architect and urban designer	10
Lecturer in Architecture and built environment	22
Senior technical office manager	18

3.6.2 Secondary Data

Secondary data has been collected to gain in-depth knowledge of the research problem and identify the research context. Secondary data has been gathered from different sources, including published journals, governmental websites, books and internet web searches. The author has used secondary data to develop the research's questions and objectives by reviewing the relevant literature on MMC adoption and implementation in developed countries as well as prevalence in Africa and especially in the MENA region, to analyse the benefits, cultural drawbacks and constraints of MMC. However, secondary data collection have been continued to the last day of the research journey in order to gain up-to-date data and information to cover the research context.

Data collection have gone through the following stages:

1- Perform stakeholder mapping to determine all the stakeholders affected by housing projects.

2- Perform interviews with house designers, governmental officials and contractors.

3- Design the questionnaire survey for the case study.

4- Perform the case study through a questionnaire survey.

5- Perform another phase of interviews for framework validation.

3.7 Avoiding bias in research

Bias in construction management research, like in any field of research, can arise from various sources, and affect the validity and reliability of the findings. If the sample of projects, participants, or data used in the research is not representative of the entire construction industry, the results may not be applicable to the broader context (Loosemore and Tan, 2000). For example, if the research focuses solely on large-scale projects or specific regions, it may not capture the challenges and practices of smaller projects or different geographical areas. In addition, construction management practices, technologies, and regulations evolve over time. Research that does not account for these changes may not accurately reflect the current state of the industry. On the other hand, positive or statistically significant results are more likely to be published, while negative or inconclusive findings might remain unpublished. This can lead to an overrepresentation of certain perspectives or solutions, distorting the overall understanding of construction management issues (Loosemore and Tan, 2000).

Moreover, construction management research conducted in one cultural context might not be directly applicable to another culture. Cultural differences can influence project management practices, communication styles, and decision-making processes, leading to biased generalizations (Hoffman, 2022). If research does not adequately consider the perspectives and experiences of diverse groups within the construction industry, it may reinforce existing gender and diversity biases. Researchers' personal beliefs, experiences, or affiliations can influence the way they design studies, collect data, and interpret results. This bias can manifest in the choice of research questions, methodology, and even the framing of research findings. The methods used to collect data, such as surveys or interviews, may introduce bias if the questions are leading or if participants' responses are misinterpreted or selectively reported. Construction management research conducted in a particular language may not accurately convey certain concepts or nuances when translated into another language. This can result in misinterpretations or misunderstandings. Furthermore, researchers may unconsciously seek out or give more weight to information that confirms their pre-existing beliefs or hypotheses while downplaying or ignoring contradictory evidence (Flyvbjerg, 2021).

To address bias in construction management research, it is important for researchers to be aware of these potential sources of bias and take steps to minimize their impact. Peer review, transparent reporting of methods and limitations, diverse and representative sampling, and a commitment to unbiased analysis and interpretation are essential for producing credible and valuable research in the field. To avoid bias in this research, several mitigation measures have been considered.

Firstly, a diverse group of participants have been recruited in this study for the interviews and the questionnaire survey to obtain a holistic overview of MMC, social housing projects and the Egyptian construction industry. The participants were of both genders, worked in different locations and was of different years of experiences. Furthermore, semi-structured interviews were used to collect data to provide the participants the chance to express their opinions freely without guiding them with closed questions. the questions were designed to discuss all the possible factors that could influence the adoption of MMC in terms of success factors, challenges and barriers in order to evaluate the data without bias on success or failure of the adoption process. To avoid misinterpretation due to translations, professional translation service was used in addition to personal recheck and comparison between the original and translated transcripts was done.

3.8 Data Analysis

Data analysis is a critical stage in a research project that starts after collecting primary and secondary data. Different data analysis methods will be used hence mixed research method has been adopted. Data analysis software will be used in analysing quantitative and qualitative data to create robust and reliable data.

3.8.1 Qualitative data

Qualitative data produces a large amount of information concentrating on human behaviour and how they interpret their beliefs and experience. Analysing this information in order to get reliable data that answers the research question is a complex process. The current research followed the Miles and Huberman framework for qualitative data analysis, which traces the relationships among social phenomena (Punch, 2013). The framework consists of three main components:

- Data reduction
- Data display
- Drawing and verifying conclusions

Data are reduced throughout the analysis by editing, segmenting, and summarising then coding takes place to find themes, clusters and patterns. The main objective of data reduction is to reduce data without losing any form of information. Afterwards, data are displayed through graphs, charts, diagrams and any form of assembling and compressing it. The final stage is to draw out conclusions from the data in the form of propositions in order to verify them (Punch, 2013). The interviews were transcribed, translated from Arabic to English then imported to NVIVO software for coding, clustering and creating themes and patterns.

3.8.2 Quantitative data

Questionnaires were analysed by Ms Excel software. The data obtained from the questionnaires were imported to Ms Excel software for categorization, sorting and evaluating the responses according to the questions of the questionnaires. The data analysis was conducted in two stages, firstly, descriptive analysis which included a description of the personal and background information of the participants. The ratings of their evaluation of their current homes, their needs in future homes and their expected concerns from prefabricated homes. Secondly, the responses were grouped into three main groups according to the skill level of the respondents

to identify any significant differences between them. The responses of the three groups were analysed statistically by the Kruskal-Wallis test which compares the mean rank of each group to distinguish the differences. The quantitative analysis of the questionnaire helped in recognizing the needs and challenges of the residents in social housing units, in addition, evaluate how MMC can address the sociocultural needs of the social housing projects community. Table 3.4 illustrates the relationship between the data collection stages and the research objectives.

Table 3.4: The relationship between data collection method and research objectives.

Objective	Literature review	Semi-struct. interviews	Survey question*naire*	Unstruct. interviews
Investigate the critical success factors for adopting MMC in housing projects in developed countries and the MENA region.	●			
Analyse the drivers for MMC in Egypt and the factors associated with it.	●	●	●	
Evaluate the critical factors likely to hinder the acceptance of MMC adoption in housing in Egypt.	●	●	●	
Establish and validate a framework for the successful implementation of MMC in low-income housing projects in Egypt.	●	●	●	●

3.9 Chapter summary

This chapter presented the research methodology and methods adopted in this research. The research methodologies were discussed, including different research philosophies and approaches. The research followed the Research Onion framework that the stages of research as onion layers starting with the research philosophy as the outer layers and then going through all layers to data collection and analysis. This research has adopted an ontological relativism position and social constructionism epistemological position. These philosophical assumptions correspond to the aim and objectives of the research in identifying the factors influencing the adoption of MMC from different sources and the stakeholders' points of view and beliefs. Moreover, this chapter describes the research approach, strategy, data collection, and analysis techniques. The types of data collection adopted in this research were presented and discussed by providing a precise justification for each stage alongside the data analysis methods.

The next chapter presents in full detail the primary data analysis according to the chosen analysis methods as described in this chapter. Qualitative and quantitative data analysis techniques were employed to provide robust results to fulfil the research objectives.

4 Chapter 4: Data analysis

4.1 Introduction

Chapter 4 analyses the results of interviews and questionnaires undertaken during the primary data collection stage. The first section presents the qualitative analysis of the interviews by describing the profiles of the interviewees and how the interviews were performed. The themes and factors extracted from the analysis are presented and explained. The second section is concerned with presenting the findings of the questionnaire survey. This section presents the statistical and descriptive analysis of the questionnaire and its results.

4.2 Interviews

The qualitative method was used across the fifteen semi-structured interviews involving construction professionals with their details are shown in Table 4.1. Thirteen interviews have been performed remotely due to the Covid-19 pandemic, as travel restrictions and social distancing measures meant that interviewees could only be reached through telephone interviews. After travel restrictions were lifted, only two interviews were performed in person, using suitable personal protective equipment (PPE) and fulfilling social distancing measures. The researcher approached the participants according to his points of contacts and personal relations from past experiences. The participants were recruited according to their work experience in public housing projects and to be in senior positions. The researcher has reached out to as many people as possible from different backgrounds according to the stakeholders mapping in order to collect all the required information. In addition, after each interview, the participant was asked if they could provide contact details for any potential person to interview.

Table 4.1: Profiles of the semi-structured interview participants

Code	Role	Years of Experience	Organization
GovPh1	Project engineer	6	Ministry of Housing
GovPh2	Senior project Engineer	18	Ministry of Housing
GovPh3	Head of Eng. Department	20	Ministry of Planning
ContPh1	Site Engineer/civil	5	Contractor
ContPh2	Project Manager	18	Contractor
ContPh3	Project Manager	18	Contractor
ContPh4	Construction Manager	18	Contractor
ContPh5	Site Manager	7	Contractor
ContPh6	Project Manager	27	Contractor
ContPh7	Site Manager	9	Contractor
ArchPh1	Architect	10	Designer
ArchPh2	Senior Architect	25	Designer
ArchPh3	Architect	14	Designer
PrctF2f1	Production Manager	12	Production Manager
ContF2f1	Factory Manager	21	Ready Mix Concrete Manager

An email invitation had been sent to the interview, including the participant's information sheet and consent form. In order to make sure to get all the information, early consent to record the interview was obtained from each interviewee. All interviews have been transcribed and carefully extracted; all are translated from Arabic to English using Systran Professional Translation Pro tool. It is an online translation tool available by subscription that professionally translates text and documents to different languages. To ensure the privacy of the participants and the safety of the information included, the text was reviewed before it has been inserted in

the software and any sensitive or personal data removed. The translated transcripts were then reread and revised to prevent any misinterpretations or errors to ensure the accuracy of the translation. The transcriptions were then coded to maximise and respect the confidentiality and anonymity statement given to the interviewees.

4.2.1 Overview of the interviews

Interviewees were senior managers and directors with various roles, including government officials, contractors, consultants, and house designers. Most of the participants, 80%, have more than ten years of professional experience in order to have in-depth knowledge of the housing process and a decision-making role as shown in Figure 4.1. 73% of the participants were from the private sector, and 27% were from the public sector because contractors from the private sector are the prominent builders of low-income and social housing in Egypt. The government procures the majority of public housing projects to private contractors, so it is essential to know their experiences and knowledge of the process. This variation in roles and experiences was to obtain different views and opinions. The interviews were semi-structured open-ended questions to provide flexibility and in-depth discussions about the practices of low-income housing projects. The questions were designed according to findings from the literature review on adopting MMC. The interview questions were divided into three main parts: challenges, barriers and success factors.

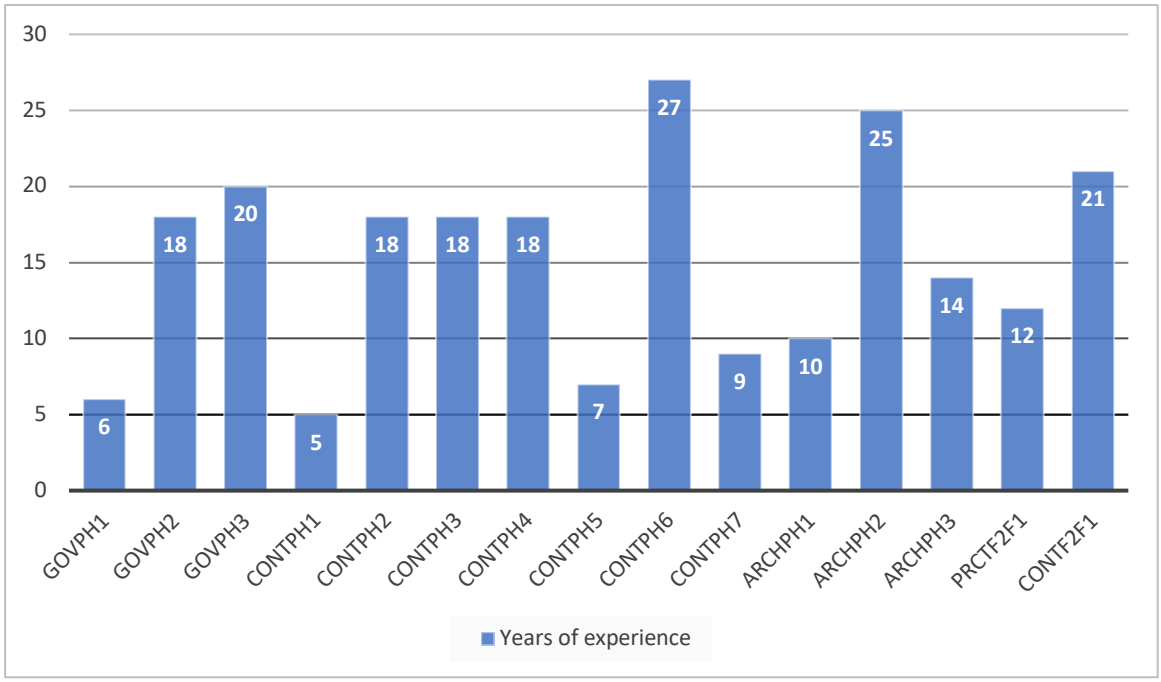


Figure 4.1: Years of experience of interviewees

The interviews developed a large volume of qualitative data that required precise data analysis. The transcripts have been inserted into NVivo software for the qualitative analysis. Each transcript has been read thoroughly to identify the key themes and patterns arising from the different opinions of the participants. Patterns arose from the transcripts that were given specific codes relevant to the research questions and objectives. The codes were grouped into three main groups: 1. Barriers; 2. Challenges; 3. Critical success factors according to the participants' views and opinions of the potential uptake of offsite prefabrication in housing projects. The grouping of the codes is shown in Figure 4.2.

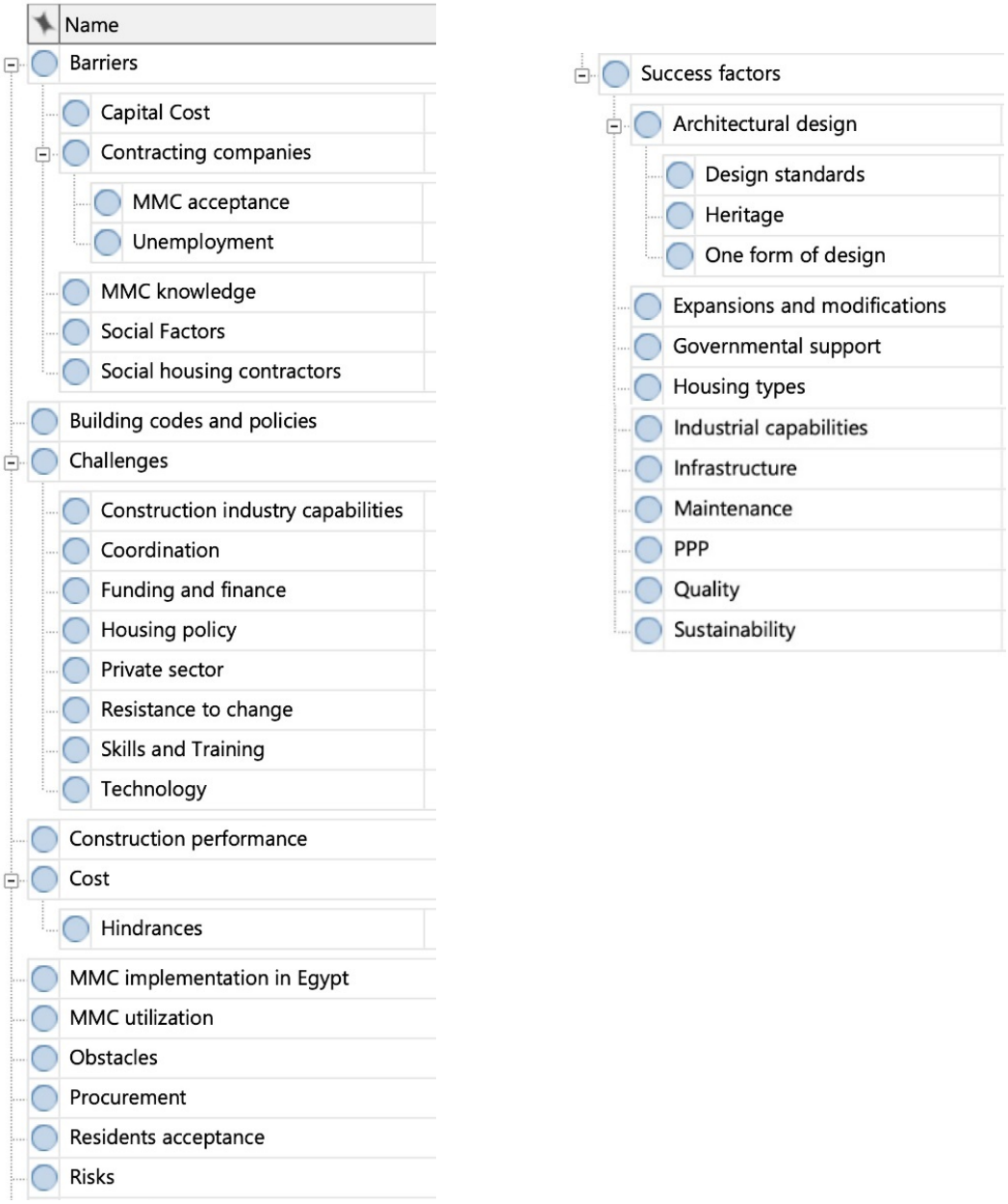


Figure 4.2: Codes extracted from the interviews

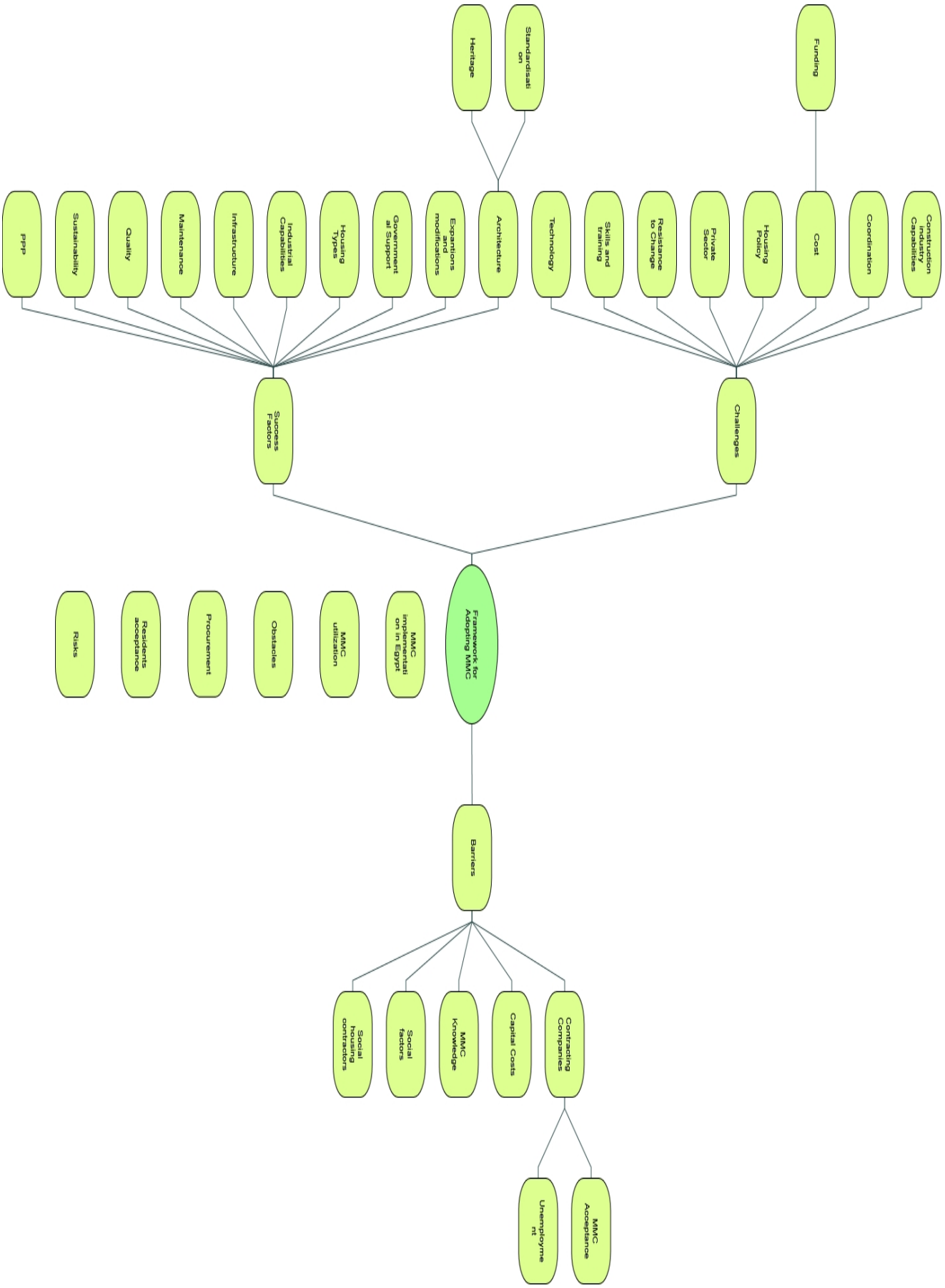


Figure 4.3: Map of categories and codes

Figure 4.3 shows how each code relates to barriers, success factors or challenges according to the participants' views. For example, "architecture", including its sub-factors "standardisation" and "heritage", is considered a success factor for the implementation of prefabrication in housing projects. "MMC knowledge" is assigned under barriers from the data extracted under this code. Under each code, the views and opinions of the participants are analysed and examined to provide results and answers to the research questions and objectives.

4.2.2 Barriers

The first section is concerned with the main barriers to adopting and implementing OSP in low-income housing projects in Egypt. The following points show the main factors identified by the participants that would act as barriers to the implementation process.

4.2.2.1 Capital costs

All the participants agreed that the initial capital cost will act as the main barrier to implementing MMC in social housing projects. When asked how this high cost could be absorbed to mitigate the risk, 8 participants stated that securing a high number of units before starting will help absorb the high initial cost of setting up a factory. (ContPh3) stated:

> *"In order to have this cost absorbed you need to secure a high volume of units to be built. I mean that as a contractor or developer, you have to secure contracts with the government to build a high volume of units in order to have the high initial cost absorbed with a large number of units manufactured and built."*

Participant (ContPh6) believed that to implement this method, a feasibility study must be done before starting to identify the minimum units required to be secured to start. Another participant has agreed that the savings from prefabricating most of the construction components in the factories will help reduce the costs and, consequently, the setup costs. However, one participant (GovPh1) argued that the current economic difficulties that Egypt suffers from would act as the main barrier to injecting huge investments in this method due to high-interest rates and high inflation. (GovPh3) mentioned that an industrial investor would be capable of implementing this method as they will have the industrial and infrastructure capabilities to do it.

4.2.2.2 Contracting companies

- **MMC acceptance**

Participant (ArchPh2) argued that most social housing contractors are small contracting companies. Therefore, they need more financial and technical resources to modernise and develop their construction methods. They are looking for higher profit margins with the least possible expenses without having the ability to train their workforce on any other construction method rather than the traditional methods. Furthermore, (ArchPh3) mentioned that MMC would not be considered a desirable development by contracting companies because there is an abundance in the volume of construction work recently that traditional methods are coping with it, so there is no need to invest in developing new construction methods.

- **Unemployment**

(ArchPh2) stated that replacing traditional methods with MMC might increase the risk of unemployment due to manufacturing construction components requiring fewer on-site or offsite workers. (ArchPh2) stated:

> "*If you use MMC, you eliminate some jobs such as carpenters working in form works, or plasterers or painters if you do these tasks in factories using machines. These people might lose their jobs to MMC which might lead to increase in unemployment. Small contractors would be against it to retain their teams."*

This might cause small contracting companies to be reluctant to adopt MMC due to the risk of losing their workforce. (ArchPh3) also argued that MMC will reduce the need for maintenance, reduce the need for workers and increase the risk of unemployment.

4.2.2.3 MMC Knowledge

All participants agreed that the vast majority of the public and a significant proportion of the construction professionals lacks knowledge of MMC and its applications. 2 participants stated that to raise awareness of MMC, the organisation willing to implement it should start with a small housing development to promote the idea of MMC and introduce it to the construction sector as well as the public. According to (ContPh5):,

> *"The organization that plans to present this method needs to market its product and show off its capabilities, specifications and model. I think the organization has to make a marketing plan through conferences or shows to introduce it to the public alongside construction experts. This can be done as well by building a model or a whole building to present it and introduce it to people showing its advantages, specifications and how this method can improve the construction process."*

There is a need to persuade the housing authorities and construction professionals of MMC to raise the benefits it will bring to the construction sector. The main stakeholders of the social housing sector need to understand what is MMC including its advantages and disadvantages

4.2.2.4 Social Factors

Six participants agreed that MMC would not improve the residents' social aspects, whereas, in their opinion, the final product will be the same, a flat with basic facilities, so there will be no difference to the residents when living in traditionally built or prefabricated houses. However, (ContPh3) mentioned that it might help deliver houses faster, allowing younger generations to start their families and lower the average marriage age leading to improvements in their social lives. (ContPh3) mentioned:

> *"We have had cultural and social problems since the Pharaohs! We currently occupy only 6% of Egypt's total land area. When children start to grow up, starting to live independently and getting married, they want to live next to their parents. In the same street or even in the same building. The government tries to convince them to move to new urban developments, but they refuse and start making excuses such as lack of schools and transport. Then the government provides all that, but they hardly go, it's in their beliefs."*

In Egyptian culture, relationships are only allowed and acceptable through formal marriage according to Islamic beliefs. Another participant (ContPh5) stated that MMC could help improve the residents' social aspects, where they will feel appreciated to be offered innovative and improved houses. According to participants, there are several social barriers to adopting MMC in low-income housing. These barriers can be classified into the following points:

1- **Social Needs:**

- Families need to live close to each other. In poorer families, younger adults, especially females, tend to live with their parents until they get married. In some cases, they might still be living together after marriage due to the unaffordability to start their own families independently. Therefore, flexibility is required in their houses to accommodate growing families, which they might not be able to do in prefabricated houses due to their complexity.
- The houses should satisfy their religious beliefs. More than 90% of the Egyptian population are Muslims, and it affects their everyday lives. (ContPh4) stated:

"The bathrooms have oriental seats that include water source not as European toilet seats that doesn't care about water, because Muslims need water in everything in the bathroom, other than the other places. As for the direction to the north, it also takes into consideration, as Egyptians love it. People want in the bathrooms to consider customs and traditions, religion, not like Europeans, because they need it for ablution, the direction of the bathrooms is the opposite of the Qiblah (prayer direction)."

It is essential for the residents to orient toilets away from the direction of Qibla, their direction of praying, as it is a religious requirement in Islam.

2- Resident's issues:

- Five participants agreed that housing users do not have the mentality to maintain their houses properly due to financial or knowledge reasons. They do not follow proper maintenance schedules or methods.
- Poor utilisation and lack of preservation of public or private properties are prevalent in social and low-income housing. For example, (GovPh1) stated that in a housing project there where solar panels installed on the roofs have been stolen by residents. Another example stated by (ArchPh2) is that in some areas, the residents dismantled the children's play area and sold its steel for profit, so the local council has employed security personnel to secure the neighbourhood from being stolen by residents.

3- Worker's issues:

- Three participants stated that Egyptian workers hardly follow work standards as they tend to work with common sense. Strict supervision is required to ensure all details are correctly done because workers are intractable and moody. Moreover, one participant (ContPh2) mentioned that workers tend to do the job with the least possible effort, lack understanding of high standards, and even use construction site facilities carelessly.
- Workers hardly accept new methods as most of their experience is gained from their peers, not from proper technical education. Teaching them a different construction method can be a barrier to implementing MMC, especially within small contracting companies.

4.2.2.5 Social housing contractors

Social housing builders are all small contracting companies, as agreed by 5 participants. These small contractors do not have the financial or technical abilities to adopt MMC in social

housing. (GovPh2) stated that to implement MMC, it should not exceed the cost of traditional construction because social housing contractors cannot afford more. Two participants mentioned that locals must be involved in the construction process where basic construction materials must be bought from them. They agreed that even the government must pay them to allow the construction to start. According to (GovPh2):

> *"Each area has its specific circumstances and working conditions. For example, in this project we cannot bring in the basic materials (sand and aggregate) from external suppliers even if it belongs to the government, you have to buy it from the natives. Every time there is concrete pouring, we have to pay them to allow it."*

The specific conditions in each area where the project is executed need to be carefully considered and, according to the participants, the best to deal with these conditions are the small local contractors. Social housing contractors need to be qualified before implementing MMC in their projects.

4.2.2.6 Building codes and policies

When asked about the current building codes and housing policies and if they would hinder the adoption of MMC in low-income housing, 8 participants stated that the current building codes and policies could easily accommodate MMC. (ArchPh2) stated that most of these laws and policies are regulatorily concerned about height restrictions, recesses, etc., so it will not hinder implementing new construction methods. According to (ArchPh2):

> "*These are the existing laws, most of them are regulatory laws, I mean the organization, they are relative rules, relating to heights, recess and so on. Sure if he will rise to big heights, of course, he will be subject to the Egyptian law, but for all our information in the New Cairo local council or the new cities we don't have high heights."*

In order to construct social housing units using MMC, the participants agreed that it should follow the design and structural codes currently being in place by the housing authorities. Housing authorities only considers that the final build is following the regulatory frameworks and standards without consideration of the construction method itself. On the contrary, they would welcome innovative methods that would improve the quality of houses and reduce the delivery times of projects while ensuring that the buildings are safe for public use.

4.2.3 Challenges

This section is concerned with the challenges that would face the implementation of MMC in low-income housing projects. The participants mentioned several challenges that need to be considered when implementing MMC. 8 participants mentioned that meeting the costs of traditional construction methods is the main challenge. (ArchPh3) confirmed that MMC is an innovative method that will benefit the Egyptian construction industry; however, it must be within the current costs of the traditional method. When reducing costs, the quality might reduce respectively. The government is already financing the whole housing provision process, so it cannot afford any increase in the costs, as stated by (ContPh3).

Training and lack of knowledge are also considered as one of the main challenges by the participants. Seven participants agreed that Egyptian workers would need thorough training on MMC as a new construction method. (ContPh3) stated that construction companies will be required to make large investments in training due to weak technical education creating a significant challenge, especially for small construction companies operating in social housing. According to (GovPh3), workers with the knowledge and skills to work with MMC will cost construction companies double or triple their normal wages, creating a higher challenge for employers to cover and retain their costs.

Other challenges mentioned by the participants include transportation, safety considerations, installation mechanisms and economic and political stability. (ContPh2) stated:

> "*The public sector competes with the private sector; note that they have all the resources and decision-makers. Currently, the public sector is doing everything in developing, selling units and anything else. I am not the only one saying this, but some large investors say the same as I am*."

According to (ContPh5) agreed that MMC will benefit the construction industry as there is currently a construction boom in Egypt; however, there is a risk that there might be depression in the short term due to the ample supply of housing units by the private sector.

The following factors are mentioned by the participants that will create possible challenges when adopting or implementing MMC in low-income housing:

4.2.3.1 Construction industry capabilities

Five participants believed that the Egyptian construction industry has the capabilities to implement MMC. However, six participants believed implementing it would be challenging because it would be considered an enormous jump from the dominant traditional method. It will be challenging in terms of costs, handling equipment and skills. On the contrary, Participant (ContPh6) argued that the construction industry does not have the capabilities to implement MMC where he stated:

> "*Our construction industry capabilities did not reach the required level to adopt MMC. It requires high-tech tools, experienced workers, and knowledgeable engineers, and Egypt currently lacks all of that. MMC will create economic and technical challenges that exceed the current construction industry capabilities."*

4.2.3.2 Coordination

According to participants, there are currently coordination issues in the construction industry. According to (ContPh6), there is usually miscoordination between subcontractors and the main contractor in residential projects. Lack of coordination results in huge problems increasing construction costs. MMC requires a higher level of coordination than the traditional construction method creating a more significant challenge in terms of coordination between the stakeholders of projects.

4.2.3.3 Funding and finance

All participants agreed that funding MMC would be a serious challenge. This is due to the initial high cost of setting up the MMC factory and its related finances. (ArchPh1) stated that the current economic situation will create a challenge to find an investor willing to invest a large sum of money in MMC. This investor will need to have strong relations with lenders and housing authorities in order to take this risk with big projects. On the other hand, according to (ArchPh2), funders have already financed real estate projects; they funded the construction phase; nevertheless, no funder has financed the pre-construction phase, such as, in this case, the MMC factory. Another challenge is that lenders offer mortgages to registered properties only; however, property registration in Egypt is not easy, and not everyone registers his/her property. (GovPh1) mentioned that the private sector does not finance social housing and low-

income housing projects because it is subsidised, and the private sector is already struggling to finance its projects.

4.2.3.4 Housing policy

According to participants, the current housing policy is to build housing units as much as possible with the lowest cost and shorter duration. Five participants agreed that presenting a new construction method such as MMC in this pressured environment is only possible with support from housing authorities and the private sector. The current housing policy is to build units everywhere in Egypt, according to (ArchPh2), so this will be challenging in terms of where to build the factory, transportation and handling.

4.2.3.5 The private sector

The participants agreed that the private sector is not involved in social and low-income housing, rather than contractors, due to a lack of profitability. Social housing units' costs are the lowest, and they are sold out to residents without any profit. According to (ContPh5):

> "*What actually happens here in Egypt is that small contractors enter into low-income housing projects with the government or local councils to increase their business capacity and grow through traditional and easy work. It provides them with experience and knowledge as small companies and, of course, increases their profits. They will start to have a strong financial position to invest in their property development projects, gaining larger profits reaching 200-300%. So, mainly working in social housing is a stage to increase their portfolio; nobody wants to invest in social or low-income housing*."

The private sector is only interested in high-end and luxury residential units as it is far more profitable, stated (ContPh3). ContPh7 argued that the private sector does not bother to adopt new methods for social housing projects. This is because housing authorities set the specifications, so the private sector does not have the flexibility to adopt new methods, especially with a tight budget and limited finance.

4.2.3.6 Resistance to change

Four participants agreed that the residents would not resist the change significantly because they had no real choice affecting the decision to adopt MMC. This is due to the nature of the

low-income housing provision process, which is all within the housing authorities' hands. However, (ArchPh1) and (GovPh3) agreed that people need to know about MMC and raise awareness of it by doing much marketing and publicising success stories in similar countries as Egypt in the MENA region. They agreed it would take time, but people will accept it due to its known benefits.

Regarding the workers, 6 participants agreed that adopting MMC would be met with rebellion and would resist it. (ContPh6) agreed that although they will first resist the change, they will be happy to learn new construction methods, and by the end, the worker will find that he/she must learn and work with MMC because if he/she refuses, then others will accept. Moreover, (ContPh5) stated:

> "*It needs to emerge gradually. Workers can take courses and training on the new method, but they will need to become more familiar with it. In order to avoid resistance to change, as I said, it needs to be gradual, and I must bring an experienced worker to work with this method. He will teach it to other workers practically then this team will grow to create an experienced team that I can depend on. This team will be an experienced team who got used to this method and can then pass their knowledge to other teams."*

On the other hand, (ArchPh2) said that workers are easier to change; however, they will need excessive training to change their mindset and mitigate their resistance to change. He recommended working with younger adults, 20-30 years old, where they will be more flexible than older workers and willing to accept new and innovative construction methods.

Two participants argued that organisational change would be the hardest, where it is easy to train and qualify workers. However, the main challenge is to persuade construction companies to change the construction method they are adopting and make a profit. (GovPh1) stated that traditional construction methods are considered faster and easier within construction companies, so why would they change it and try another construction method that will cost them more and might reduce their profits?

4.2.3.7 Skills and training

Ten participants emphasised that Egyptian workers have the skills and abilities to learn and train on new construction methods such as MMC. (ArchPh1) stated that they can succeed in MMC if they receive appropriate training, while (ContPh7) stated that they need to be

convinced about it to learn and work on it. According to (ContPh6), Egyptian workers are very diverse; there are workers from all levels, from general labourers to highly skilled technicians and specialists. He added:

> "*It is like a pyramid, a pyramid, the base is the work of some schools, some social housing buildings, and some of the residential buildings which are working on this, your pyramid in the top is qualified who work in luxury palaces and the luxury work, and this has its workers, and this is its workers especially the majority in Egypt is not qualified*."

Moreover, (ArchPh3) stated that workers usually learn from their peers, and they generally pass the knowledge to each other due to a lack of proper technical education. Four participants agreed with that, where they mentioned that skills and knowledge are passed between the workers through their colleagues, parents, siblings or cousins. Therefore, (ContPh6) emphasised that MMC cannot just be imported to Egypt; seniors and educators shall travel abroad to get the knowledge and techniques and then pass it to the workers to understand.

Furthermore, all participants agreed that only some construction companies have proper training facilities. Only the big organisations have adequate training facilities that can accommodate MMC training requirements. (ContPh5) mentioned that social housing contractors do not have training facilities; they have skilled teams for each construction item. However, if the government or housing authority obliged them to adopt MMC, they would be forced to train and qualify their workers. Adopting MMC in social housing projects will be challenging due to the lack of proper technical education and inadequate training facilities.

4.2.3.8 Technology

When asked about the technological readiness in Egypt to adopt MMC, only 4 participants agreed that the construction industry is ready and can accommodate MMC. However, all other participants mentioned that it would be challenging to implement MMC, especially in social housing projects. To emphasise that the Egyptian construction industry is not technologically ready, (ContPh3) stated:

> "*Our construction industry needs to look into the details. For example, using this method requires specific bolts; this must be supplied exactly as described in the method statement. It will require factories to work into the fine details to produce high-quality products. Proper transport methods to ensure delivering these units properly and in*

their original condition. We struggle with all these complications in traditional methods, so what about prefabrication."

(ContPh2) stated that in social housing projects, only manual handling is utilised by the contractors, and there are no tower cranes, so he claimed how MMC would be implemented. (ArchPh1) added that most of the construction methods used in the industry are the old traditional methods that have been used for more than 40 or 50 years. In addition, one participant (ContPh6) stated that technology in Egypt is expensive because it is all imported, so it costs much more in Egypt than in developed countries. Furthermore, (GovPh2) mentioned that some private developers tried to use new types of bricks; however, they failed, so traditional cement and bricks are still dominant.

4.2.3.9 Construction industry performance

Nine participants have spoken about the construction industry performance, and five of them agreed that MMC would help improve the construction industry performance in terms of quality, time, health and safety in addition to introducing new thinking and new mindsets. (ContPh7) mentioned that implementation of MMC in social housing can increase supply capacity, so Egypt would start exporting housing units and its technology to other African countries with similar conditions. Moreover, (GovPh3) has stated the advantages that MMC can bring to the Egyptian construction industry and how it can improve its performance; where she said:

When a prefabricated project succeeds, when a project or two succeed, and it proves to the people that a simple cost and a safe building in less time will succeed, then it will succeed in Egypt. It will integrate the advantages of manufacturing into construction and, consequently, improve safety and quality and reduce construction duration."

On the other hand, (ContPh5) mentioned that there are issues in the current practices where inexperienced engineers and managers are given tasks they are not qualified to do, resulting in construction delays, increases in costs and poor quality. In addition, there are health and safety issues where he stated:

"*Health and safety factor here is ignored, especially in such projects. Using MMC means you will mainly depend on tower cranes and heavy loads, so H&S must be highly sought after. Workers and even site engineers neglect H&S, where you can find a site*

engineer climbing on a scaffolding without the essential PPE, and the scaffolding itself is not safe enough; this is just to get the job done and get paid.

4.2.4 Critical Success Factors

The third section of the interviews concerned the factors that will lead to the successful implementation of MMC in housing projects. All participants agreed that reducing construction duration would be a crucial success factor as it will match the current housing authority's policy to increase access to low-income and social housing as much as possible. Reducing unit delivery time, which MMC can achieve, will be a crucial success factor in implementing it. Three participants emphasised that reducing time might be more important to housing authorities than costs due to the high demand for housing. Moreover, eight participants stated that matching the cost of traditional construction will be an important success factor as the government wants to keep costs the same. (ContPh6) stated that reducing costs could come from high demand and an increased number of units required, which will help absorb the initial high cost.

Governmental support is a critical success factor in MMC implementation. According to (ContPh4):

> *"MMC will succeed if the political leadership has been convinced of it; they will support it and publicise it in the media to increase public awareness of its benefits. In recent years, this is how things have been going in Egypt since the 2010s."*

Achieving the government's aims of increasing access to housing units and reducing costs will convince the government to support and implement MMC in housing projects. (GovPh2) agreed that housing authorities will not oppose implementing MMC as long as it costs the same or less than traditional construction in addition to obtaining industrial approval. Bureaucracy will be beneficial in this case, where once developers obtain industrial approval, housing authorities will be obliged to accept MMC according to (GovPh3). Furthermore, two participants stated that the current shortage and continuous demand for low-income in the long and short term would be another success factor for MMC. (ContPh7) indicated that MMC would be favourable for the current social housing system, where the units are identical all over Egypt, making it easier to implement and spread in different locations.

According to participants (PrctF2f1) and (ContF2f1), a further success factor is the current abundance of precast concrete factories in Egypt. These factories can quickly implement and

adapt their production to MMC approaches for housing projects. Private developers are currently executing private housing developments using prefabricated concrete panels. All the housing unit components, including floorings, ceilings and walls, are prefabricated offsite and then transferred to sites for assembly.

The participants identified the following factors as potential success factors for MMC implementation in low-income housing projects:

4.2.4.1 Architectural design

Six participants agreed that the current social housing projects have poor architectural designs that MMC could improve through prefabrication technology. (ArchPh2) stated that current architectural designs are identical 63 m² flats with ugly façade designs, understood to be due to economic and limited financial reasons. Improving architectural design would be a critical success factor for MMC in housing projects where, according to (GovPh1), decision-makers recently are considering improving architectural designs of social housing to improve the public image of this type of housing.

4.2.4.2 Restoring architectural heritage

One of the potential success factors agreed upon by the participants is restoring architectural heritage. Four participants (ArchPh1, ArchPh2, ContPh2 and ContPh3) stated that Egypt has a vast and rich architectural heritage starting from Pharaonic through the Roman, Greek, Islamic, and Coptic up to the modern era. However, the only real Egyptian is the Pharaonic heritage. (ContPh3) stated:

> *"There is no Egyptian architectural heritage. The heritage we have here in Egyptian houses is either Spanish, Italian, British, Islamic or Ottoman. The only Egyptian heritage we have is the ancient Egyptian (i.e., Pharaonic). In all the heritages mentioned above, there is always a unique plot for each, a symbol in their windows, facades, how the columns look…etc. Here in Egypt, most of the buildings are just concrete boxes. In the past, flats used to have high ceilings and windows to provide natural ventilation; nowadays, the heights are reduced, smaller windows and A/Cs everywhere."*

However, in the current housing stock, this heritage is considered lost. Five participants indicated financial and economic difficulties as the main reason this heritage is lost. According

to (ArchPh1), no one can afford to build houses with such details. (ContPh4) and (ContPh5) stated that social housing projects are supposed to be built with the lowest cost ever possible. It is almost impossible to replicate any architectural style using traditional methods, which need high costs and large areas; neither are available in social housing.

Nevertheless, five participants agreed that MMC could help restore the architectural heritage, provided it does not increase costs. They emphasised that the flexibility of prefabricated components and factory conditions can easily manufacture artistic components that match any architectural style within the agreed cost. (GovPh2) stated that housing authorities would accept this from within the government's plans to improve the public image of social housing.

4.2.4.3 Expansions and modifications

Five participants stated that MMC has the advantage of making expansions and modifications rather than the traditional construction method. This advantage will favour MMC in housing projects because residents always want to increase and modify their houses to satisfy their growing needs. According to (ContPh3):

> *"By giving them a choice to modify, Egyptians love to add personal touches to anything that belongs to them. In order to succeed with this method, you must give them the freedom to modify, for example, to choose windows colours, internal fittings, wall colours…etc. Areas as well, do not make all houses the same area. Some women need larger kitchens; others say it does not matter."*

This is also related to the residents' social and cultural aspects, where young Egyptians tend to live with their families until marriage. Participant (ContPh5) stated that prefabrication could provide the flexibility to modify and expand, stating an example of private developers who sell housing units without internal walls leaving it to the residents' preferences.

4.2.4.4 Governmental support

Participants have agreed that governmental support is a critical success factor in implementing MMC. Three participants insisted that if government officials are convinced to adopt MMC in social housing, housing authorities can provide huge areas to implement with a massive number of units to be built. However, participant (Contph5) stated that government officials have rigid mindsets that are hard to change. In addition, 2 participants mentioned that government officials might not have the power to authorise MMC or be hesitant to do; they emphasised that

a high-ranking official, such as a minister, deputy minister or political leader, should approve it to be implemented. Participant (GovPh3) stated:

> *"I told you that a committee from the Ministry of Housing must be convinced with this method. He does it himself and convinces this committee that this method has been applied in developed countries. He saw it there once from an Egyptian point of view and convinced them that this subject would benefit Egyptian policy from a nationalist point of view."*

Reducing the duration of delivering units has been mentioned by 8 participants as the main factor to convince housing authorities and government officials to implement MMC. 5 participants emphasised that housing authorities will be convinced by and approve MMC if it meets the traditional method costs or reduce it. Participant (GovPh2) stated that a highly skilled and knowledgeable project manager is responsible for managing and executing MMC projects in front of the housing authority. Although (GovPh2) mentioned that it is not the housing authority's responsibility to choose the construction method, their responsibility is to appoint accredited contractors and subcontractors according to regulations and have their appropriate official documentation.

4.2.4.5 Industrial capabilities

All participants have agreed that Egypt has the required industrial capabilities to accommodate the manufacturing needs of MMC. They emphasised that there are currently plenty of industrial cities in several locations all over Egypt with various industrial facilities that can adopt MMC production. Participant (ContPh5) stated:

> *"We have here many factories like cement, steel, marble, etc. In all construction aspects, we have several factories and some factories export to the Middle East and even Europe, like the AL-Jalala marble factory that exports to MENA and France. When it was found that there was feasibility for it, the Jalala factory was built with one of the largest product lines in the MENA."*

According to participants, there are factories that manufacture most of the construction industry's needs, from basic materials such as steel, cement, bricks and blocks all the way to specialised building materials and chemicals in addition to construction components such as windows, doors, etc. Five participants mentioned that there are plenty of precast concrete factories in Egypt that produce prefabricated concrete panels such as beams and slabs. They

agreed these factories could be utilised and updated to manufacture required components for prefabricated housing units. Participant (ContPh3) stated that there are foreign companies that have precast factories, such as Samcrete and Premco, indicating that there is potential for investing in prefabrication in Egypt.

However, the participant (ContPh6) mentioned a need for better quality control in Egyptian factories and more modern and advanced equipment. He insisted that MMC would be far more advanced than the current industrial capabilities.

> *"I cannot say that it is a high-level industrial country. I can tell you that the machines, equipment and factories that produce all this need development, all of them mean their capabilities are weak; I mean, the industry exists in Egypt but with weak, primitive and modest capabilities. I need an update of all the existing technology in order to be able to produce better."*

Although there are industrial capabilities, 2 participants insisted that it needs technological and advanced equipment to facilitate and improve its performance for MMC to succeed in housing projects.

4.2.4.6 Infrastructure

Thirteen participants agreed that there had been significant improvement in the infrastructure in Egypt in the last decade, especially the road network. The improvements have been mainly in urban areas and connecting new cities to old ones. This will support MMC in terms of wider roads to transport large, prefabricated components and connect factories to building sites. However, old city centres have not seen such improvements in road networks or water, drainage and electricity services. (ContPh5) stated that some areas need basic infrastructure, such as a proper drainage system. Moreover, according to (ContPh6), some old and rural areas have dilapidated roads and infrastructure that will not allow heavy transport vehicles to go through them. Nevertheless, participant (GovPh3) confirmed that housing authorities would provide the required infrastructure to any potential plot of land.

4.2.4.7 Maintenance

Four participants have mentioned lesser maintenance that prefabricated units would potentially require as one of the critical success factors supporting MMC in low-income housing. Accordingly, this will be a supporting factor for MMC as one of the main issues in the current

housing stock is the lack of maintenance from residents or local councils. Participant (ContPh2) stated:

> *"There could be pre-agreed maintenance contracts that will improve the living conditions of the residents and keep their houses in long-lasting good conditions rather than the current conditions."*

This could also be related to the social and cultural aspects of current users of social housing units. The users of social housing units lack the awareness of continuous maintenance to their houses, this has been emphasized by (ContPh2) as follows:

> *"Users of social and low-income housing lack understanding of high standards in finishes and quality, people here do not do proper maintenance to their properties. Even workers, they tend to finish the job with the minimum effort and least quality. They just want the job to be done and finished as quick and easy as possible regardless of work standards and specifications. They do this in their everyday life. You need to increase their awareness and knowledge from the very beginning, from their early learning while they are still children."*

As previously mentioned, MMC could overcome this issue by providing an improved product that requires less maintenance which could be pre-contracted with the suppliers. Building social housing units that require lesser maintenance could be considered one of the main success factors to MMC in favour to traditional methods that lacks quality. It could lead to improved quality of life for the users and fewer running costs of the units.

4.2.4.8 Public-private partnerships

According to two participants (ArchPh1 and ArchPh2), entering the PPP procurement route would leverage the implementation of MMC with housing authorities. They emphasised that the government will immediately support partnering with a private developer or investors to implement MMC as the cost risk will be transferred to the private sector. (ArchPh2) stated that housing authorities have recently partnered with several developers by providing a plot of land free of charge in exchange for a percentage of finished units. Housing authorities then sell these units at the highest price to gain the maximum possible profits in addition to the land's price.

4.2.4.9 Quality

Eight participants have mentioned the improved quality that prefabrication will bring to social housing projects. They agreed that the current housing projects suffer from poor quality, significantly affecting their performance and increasing their utilisation costs. Participant (ArchPh2) stated that:

> *"MMC will definitely help reduce poor quality issues as well as poor skills from workers by transferring the work to machines. We suffer from these issues daily from the first day in construction up to the utilisation phase."*

Participant (ContPh5) mentioned that poor quality and skills are causing structural issues in some cases. Furthermore, participant (ContPh6) added:

> *"In social housing, you will find the worst painter, worst carpenter, the worst materials that enter these sites, and the worst supervision, because your product is not produced with high quality, so if you enter a site like this, you will discover that these are the people who are working who are not qualified except for the basic engineering job."*

Prefabrication will help improve the residents' living conditions by improving the quality of their homes and reducing maintenance and issues.

4.2.4.10 Sustainability

Sustainability is not seriously considered in the construction process of social housing. According to two participants, environmental factors are not considered either during construction or after completion. (ContPh2) stated:

> *"There's the environmental factor too, here in Egypt, we do not consider thermal and sound insulation really much. Unlike European countries for example, the main structural material is timber, however, houses are thermally insulated in addition to installing heating systems. We do not do that here. As long as it basically functions well as a house then that's it."*

Social housing projects are built to be structurally safe only without considering thermal and sound insulation, energy consumption, etc. Participants agreed that the construction of social housing units considers the basic structural and architectural requirements. they mentioned that current building standards of these projects do not oblige the designers or the contractors to use heat or sound insulators to improve the energy performance or emphasize on using durable materials. Moreover, participants mentioned that the current construction practices in social

housing projects produces high volume of construction waste which sometimes is dumped unsustainably or even burned which contribute to the environmental pollution. Integrating manufacturing into the construction process will help introduce more sustainable practices and materials that will increase the sustainability performance of social and low-income housing.

4.2.5 Other influencing factors

4.2.5.1 MMC implementation in Egypt

Participants were asked about the previous implementation of MMC in residential projects. Five participants stated there were trials in the 1980s using precast concrete panels used as wall panels in residential towers. Participants (ContPh7, GovPh2, and GovPh3) cited several projects that used prefab concrete wall panels, such as residential towers for the armed forces and residential flat blocks for returning expats from Gulf countries due to the Gulf War. These projects faced several challenges, including difficulties in maintenance, poor quality, unsustainability and high construction costs. 4 participants mentioned that the current utilisation of prefabrication is only in precast concrete components such as precast concrete beams and columns that are used in bridges and tunnels in addition to portable cabins as site offices in construction projects. (ContPh6) stated that:

> "*This industry is considered to exist in Egypt, but in the narrowest limits, and not used in social housing, that is why no one sees it. It has been used in private projects like tunnels, bridges, and private buildings*."

Participant (PrctF2f1) stated that, as a private prefab factory, they started to manufacture prefabricated housing developments for private developers. They manufacture prefabricated concrete houses using a panel system where the panels are manufactured offsite and then transferred to the site for assembly and finishing. It is used in high-end luxury housing development stating that it is more expensive than traditional methods, but it is feasible due to the high selling price of the units.

When asked about what hindered the implementation of MMC in Egyptian housing projects, the participants stated different reasons and issues. The main issue, according to (ArchPh2), is that there is no actual willingness to adopt new construction methods that can improve the provision of social housing from the stakeholders. 2 participants (GovPh1) and (ContPh5) argued that implementing MMC will not be through the government, the private sector must adopt it, and it would fit the luxurious sector, not the low-income and social housing. On the

other hand, (ContF2f1) stated that it could be easily implemented in Egypt by precast factories where there is an abundance of them and they have all the required tools and equipment.

4.2.5.2 MMC utilization in Egypt

Participants provided their opinions on the possible utilisation of MMC in Egypt. Three participants stated that the best utilisation of MMC is to implement it in large projects such as hospitals, schools and shopping malls in order to have the capacity and financial ability to implement it. Furthermore, 2 participants agreed that MMC would be more beneficial if implemented by private developers in high-end residential projects as there is an abundance of this type of project. It can be implemented in ongoing mega projects such as the new Administrative Capital and AL-Alamin city in northern Egypt. Participant (GovPh2) stated:

> *"You can start using this method in an item or two in the building, not the whole building. You will need to agree on a deal with a big company to execute an item or two using MMC. That company will already have the vision for such a method and has the ability to provide you with your requirements. These methods must be used in other projects, not social housing."*

This will provide the publicity needed to spread MMC in housing projects in Egypt to increase its knowledge and awareness in the construction industry.

4.2.5.3 Procurement

Participants stated that the primary procurement method for social housing projects is open bidding, where the main factor it considers is cost. The cheapest bid is always preferred by housing authorities in order to reduce costs as much as possible. According to participant (GovPh1):

> *"I will tell you how things are going in the government. As a government, I need to build, for example, ten blocks of flats, I will be looking to get the most out of it with the least cost, and this is its specifications. So, each company presents its price offer, and the company which presents the best offer will win the job regardless of its construction methods."*

Three participants agreed that if MMC is adopted by the private construction company and matches the traditional method pricing, it will be able to be implemented in low-income

projects. Furthermore, participant (GovPh2) stated that this method would require industrial approval, which, if obtained, housing authorities will be obliged to accept it.

4.2.5.4 Residents Acceptance

Participants were asked whether the residents would accept their homes prefabricated rather than traditionally built. Twelve participants agreed that residence acceptance would be relatively easy to implement MMC for different reasons. Participant (ArchPh3) stated that residents would feel valued and appreciated by the government for adopting such an innovative method to build their houses. A further 2 participants explained that residents have little choice nor the knowledge or experience to choose how houses are being built. Moreover, participant (GovPh1) further explained that these are low-income housing, so without them, residents might not have elsewhere to live; therefore, their last concern is the construction method.

On the other hand, 2 participants disagreed that residents would easily accept their houses using this method. Participant (ArchPh1) stated that these residents have rigid mindsets where it is hard to convince them to accept and live in prefabricated houses. However, all participants mentioned that residents need houses with lower prices and running costs, better quality and safety no matter the construction method used to build them.

4.2.5.5 Notable risks

When asked about other notable risks to be considered in MMC implementation, 4 participants mentioned specific risks that might arise when adopting and implementing MMC in low-income housing. Participant (ArchPh1) mentioned a corruption risk when implementing MMC as it will be considered a new construction approach where, if successful, other parties would jump on the developer's success. Another sort of corruption risk might arise from governmental officials approving and allowing MMC in public housing projects. There should be some legal protection for the implementing investor/developer to protect their rights. Participant (ArchPh2) spoke about risks related to the users themselves. She said:

> "*It will be a high risk to develop something very innovative for the least advantaged; before the place develops, you must develop the person himself*."

She insisted that the construction method should not be so sophisticated, bearing in mind that the users mostly have no knowledge or experience with innovation. Furthermore, participant (ContPh2) mentioned that if there is no continuous demand for MMC houses, it will incur high

risk for the investor/developer who invested high capital into the factory and training. Moreover, participant (ContPh7) stated that there is an unemployment risk when adopting MMC, which reduces the need for construction workers. Although some workers might be relocated to factories after receiving the required MMC training, a percentage of workers might lose their jobs and increase unemployment.

4.3 Questionnaire survey

A case study survey has been performed with residents of two social housing projects in different location in Egypt to identify the challenges and needs of the residents in their social housing houses. Two case studies have been selected, the first in EL-Salam district in Cairo and the second is in Tenth of Ramadan city in Ash-Sharqia Governorate. The two case studies have been chosen in different locations to provide a broader view of all the factors affecting the residents in social housing projects. The details of both case studies are as follows:

- **Cairo project (CS1):**

The project consists of 103 6-storey building blocks of 63 m² flats. Each building block consists of 24 flats with total number of flats in the project 2472 flats. Figure 4.4 shows the aerial view of the project showing that it is divided into two adjacent plots, the Northern plot consists of 63 blocks and the Southern plots consists of 40 blocks.

Figure 4.4: Aerial view of Cairo Project CS1 (Google maps, 2020)

- **Ash Sharqia Project (CS2):**

The project consists of 112 6-storey building blocks of 63 m² flats. Similar to CS1, each building block consists of 24 flats with total number of flats in the project 2688 flats. Figure 4.5 shows aerial view of the project.

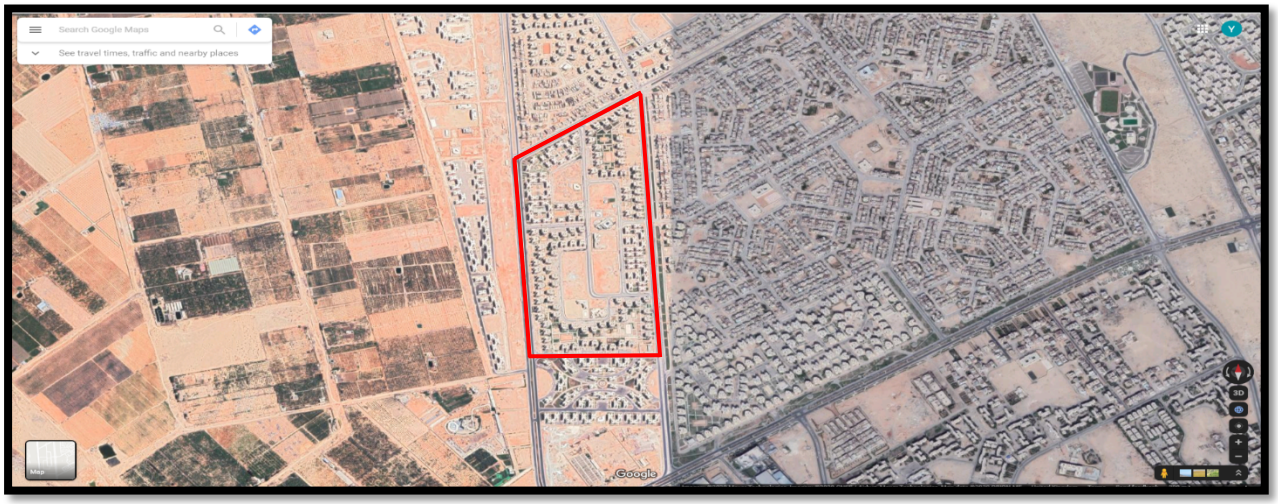


Figure 4.5: Aerial View of Ash Sharqia Project (CS2) (Google maps, 2020)

4.3.1 Overview of the questionnaire

The first section of the questionnaire was general questions including the participant's gender, age group, marital status, number of occupants, occupation and how long have he/she been living in this house. Other questions were about whether they know the structural system of the building or not and how important to them knowing the structural system. The next part was about their knowledge of MMC and if they know it which method they know. The second section was concerned with rating the factors of their current house, rating any doubts that might arise if their house is built with MMC and rating the factors according to their importance when choosing their new homes. The ratings were in a 5-point Likert scale format. The questionnaire was created and distributed via the JISC Online Survey website to ensure the security of the gathered information. A sharing link has been created through JISC for the secure and efficient distribution of the questionnaire.

4.3.2 Pilot survey

Prior to launching the survey, a pilot survey was carried out to examine the questionnaire in terms of length, order of questions and the time required to complete it. In order to have a successful pilot survey, the pilot study was targeting participants with knowledge of research methods and familiarity with the research topic. the initial version of the questionnaire was distributed to three PhD students at London South Bank University who are in the late stages of their studies with previous experience in questionnaire survey design. The participants provided feedback about the questionnaire layout, duration and the clarity of the questions. Following the feedback, the questionnaire was modified to include more general questions about the participants' backgrounds. Furthermore, the questionnaire was then distributed to seven points of contact of the researcher in the construction management field and non-construction management professionals who has experience in data collection and analysis. It was sent to each contact via email and held a phone call with each participant for feedback. The respondents indicated that the average completion time for the questionnaire is 10-15 minutes. They mentioned that there were some repeated and unnecessary questions which have been removed or modified. The feedback helped in improving the final version prior to distribution to the residents. The response rate for the pilot study was 100%

4.3.3 Sample size and questionnaire distribution

The size of the targeted sample was calculated from Saunders *et al* (2016) table of the sample size of the target population at a 95 per cent confidence interval Table 4.2. The total number of flats (2472+2688=5160 flats) is the sampling frame, therefore, the minimum sample size is approximately 360 units.

Table 4.2: Sample size of different sizes of target population at 95 per cent confidence Interval (Saunders *et al*, 2016).

	Margin of error			
Target population	5%	3%	2%	1%
50	44	48	49	50
100	79	91	96	99
150	108	132	141	148
200	132	168	185	196
250	151	203	226	244
300	168	234	267	291
400	196	291	343	384
500	217	340	414	475
750	254	440	571	696
1 000	278	516	706	906
2 000	322	696	1091	1655
5 000	357	879	1622	3288
10 000	370	964	1936	4899
100 000	383	1056	2345	8762
1 000 000	384	1066	2395	9513
10 000 000	384	1067	2400	9595

Respondents were selected by systematic random sampling technique. Systematic random sampling (SRS) involves selecting a sample from the sampling frame in regular intervals calculated by the following steps (De Vaus, 2014):

- Identify the sample frame.
- Identify the sample size.
- Calculate the sampling fraction (n=population ÷ sample)
- Select starting point from the first 5 cases.
- Select case every n^{th} case.

For each case study, the number of units is the population where the cases were selected according to the calculated sampling fraction. The sample fraction is:

- N= 5160 ÷ 360 = 14

Every 14th unit was selected to participate in the survey by asking the adult living in the household face-to-face to complete the questionnaire.

With respect to the Covid-19 pandemic situation, flights restrictions and social distancing rules, invitation flyers were distributed by depositing them into mailboxes of selected respondents. The flyers were distributed by an authorised person from the researcher by providing him a map of the selected area and the selection criteria. The sampling fraction was decreased to increase the number of distributed flyers to avoid decrease of response rate due to change from face-to-face to mail distribution. Decreasing the sampling fraction by 25% resulted in distributing the flyers to 1440 flats (360 x 4 = 1440).

The flyers, as shown in Appendix A, were printed on A5 size containing a QR code to ensure an easy access the survey by the respondents. To encourage respondents and to increase response rate, a random draw on five EGP500 gift cards was performed on completed surveys. The respondents were asked to provide the flat and building number without inserting any personal or sensitive data in the questionnaire to provide access to any selected survey if required by the researcher.

A total of 141 questionnaires were collected from residents of both case studies from 360 questionnaires required according to the sample size with response rate 40.3%. The first phase of questionnaires was distributed through flyers in two social housing areas containing a QR code two login to the questionnaire. This distribution method was an alternative to face-to-face distribution due to Covid-19 restrictions. The total responses from the first phase were 68 responses. A second phase was performed after the travel restrictions were lifted so the researcher visited the two areas and met with residents taking into consideration Covid-19 social distancing and restrictions measures to ensure the safety of the researcher and the participants. A total of 73 responses collected to reach a total of 141 responses.

4.3.4 Descriptive analysis of the questionnaire

The descriptive analysis of the questionnaire includes description of the personal and background information of the participants. Furthermore, it illustrates the participants main concerns of prefabrication, evaluation of their current homes in addition to rating of factors according to their importance for their future homes.

4.3.4.1 Respondents' gender

The first question in the questionnaire was about the gender of participants. Almost two-thirds of the participants (69%) were males and one-third (31%) were females from the total of 141 participants. The figure below shows the gender of the respondents.

4.3.4.2 Age groups of the respondents

The most frequent age group of the respondents were 26-35 (65) followed by 36-45 (45). Furthermore, (21) respondents were 18-25 years old and (15) were 46-55 then finally (5) were over 56 years old. Table 4.3 below demonstrates the results of the age group classification.

Table 4.3: Age groups of the respondents

Age group	Frequency	Percentage	Cumulative percent
18-25	21	14	14
26-35	65	43	57
36-45	45	30	87
46-55	15	10	97
55+	5	3	100
Total	141	100	

4.3.4.3 Occupation of the respondents

The third question was about the respondents' occupation, the predominant occupation was employee (43) out of the 141 respondents followed by unemployed (33). Moreover, there were (17) self-employed respondents, (10) respondents were labour, (7) housewives and (3) drivers. Then there were (2) respondents carpenters, retired, sales agents, site supervisors and students each. Eventually, there was (1) respondent accountant, admin, electrician, engineer, factory manager, health and safety specialist, journalist, lawyer, nurse, programmer, QC supervisor, real estate agent, restaurant manager, secretary, surveyor, taxi driver, teacher, and technician. The table below demonstrates this information.

Table 4.4: Number of respondents according to occupations

Occupation	Number of respondents
Accountant	1
Admin	1
Carpenter	2
Driver	3
Electrician	1
Employee	43
Engineer	1
Factory manager	1
Health and safety specialist	1
Housewife	7
Journalist	1
Labour	10
Lawyer	1
Nurse	1
Programmer	1
QC supervisor	1
Real estate agent	1
Restaurant manager	1
Retired	2
Sales agent	2
Secretary	1
Self-employed	17
Site supervisor	2
Student	2
Surveyor	1
Taxi driver	1
Teacher	1
Technician	1
Unemployed	33

4.3.4.4 Number of occupants in household

Among the 141 respondents, (53) of them were 4 persons living in the same household. This is equivalent to 37% of the respondents. Furthermore, (39) respondents were 3 occupants in the household and (34) were 5 or more occupants in the same household. Only (14) participants were 2 occupants in the household and finally only (1) respondent were single household. Figure 4.6 below demonstrates the information given above.

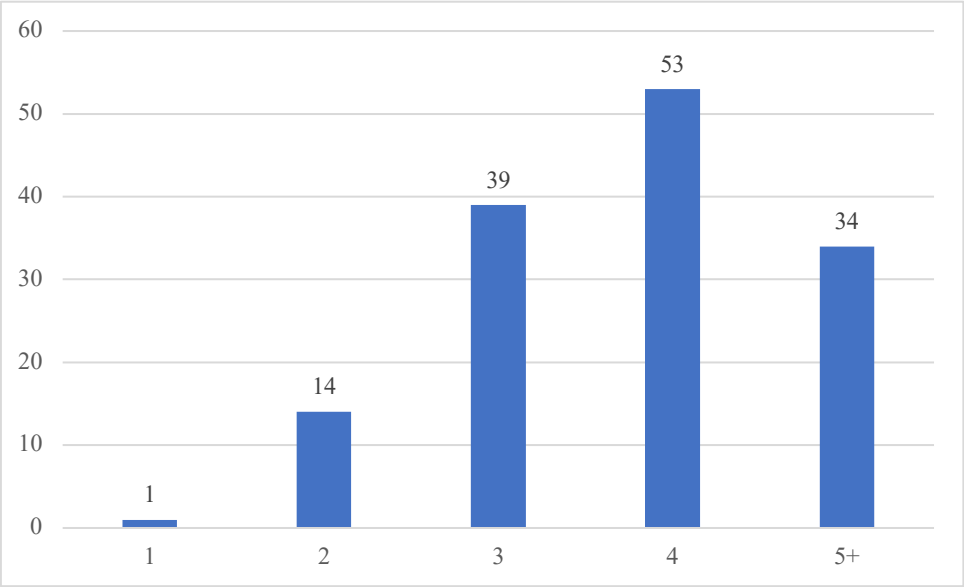


Figure 4.6: Number of occupants in household

4.3.4.5 Length of stay in the property

Respondents were asked how long they have been living in the property. The majority of them (33) have been living for 3 years, (26) have been living for 5 years. (23) respondents stated that they have been living in their properties for 2 years while (22) stated 1 year and (22) stated 4 years. (12) respondents have been residents for 6 years and (3) were residents for 7 years. Figure 4.7 illustrate the information above.

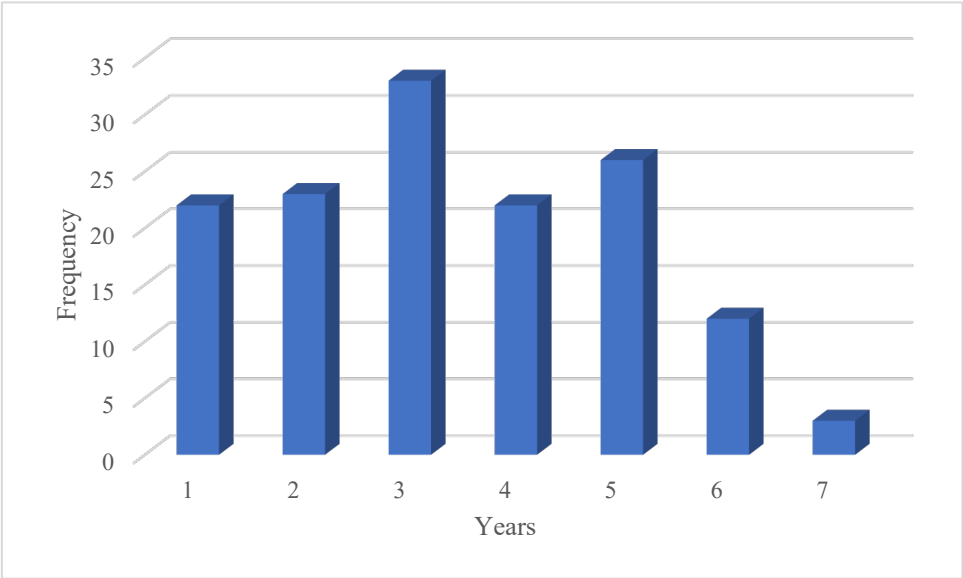


Figure 4.7: Respondents' length of stay in the property

4.3.4.6 Knowledge of structural system

Among the respondents, only (17%) stated that they know the structural system of their houses, while (83%) answered no. When asked about how important knowing the structural system of their houses, (60) respondents answered Important, followed by (41) responded Neutral then (18) respondents stated Very important. The least ratings were Not important and Not at all important as mentioned by (17) and (5) respondents respectively. The graph below shows the information provided.

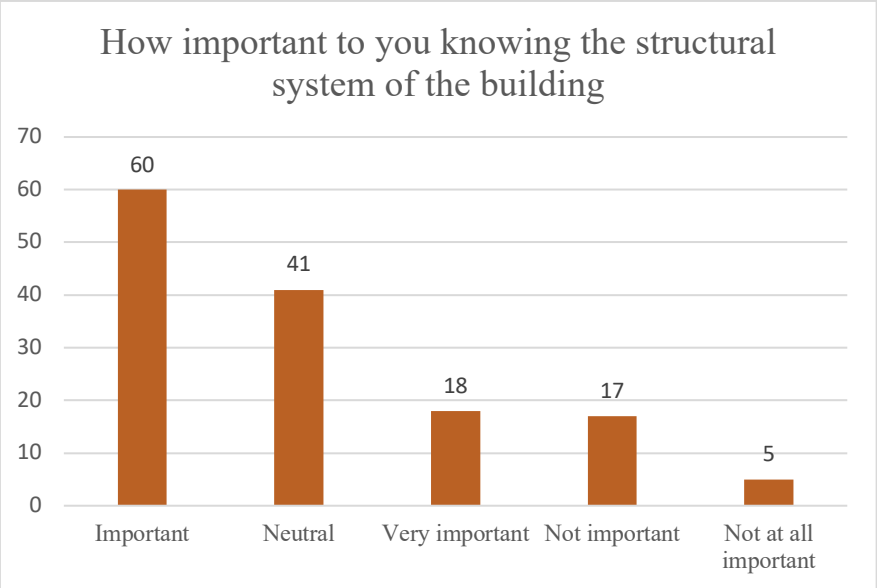


Figure 4.8: Respondents' ratings on the importance of knowing the structural system

4.3.4.7 Knowledge of MMC/OSP

Only (9) respondents said Yes when asked whether they knew MMC or OSP while (132) said they do not know what it is. This is the equivalent to only (6%) who have the knowledge of MMC/OSP to (94%) who lacks it.

4.3.4.8 Concerns from MMC

The respondents were asked to rate the factors of concern that they might arise if their house built with MMC. Each respondents rated the factors on a 5-point Likert scale with ratings Very high, High, Average, Low and Very low. The factors included Quality, Affordability, Ability to expand, Ability to modify, Safety, Privacy, Architectural design, Ease of maintenance, Sound/thermal insulation and Ventilation. The responses were converted to numerical figure according to Table 4.5 to calculate the average of each factor then put in order of the highest score. Table 4.6 illustrates the averages and order of the factors accordingly. The highest factor was affordability, and the lowest factor was Sound/thermal insulation.

Table 4.5: Conversion of responses from 5-point Likert scale

Very high	**5**
High	4
Average	3
Low	2
Very low	1

Table 4.6: Concerns from MMC according to respondents

Factors	Mean
Affordability	2.76
Ease of maintenance	2.50
Ability to modify	2.45
Ventilation	2.43
Ability to expand	2.41
Quality	2.31
Architectural design	2.30
Safety	2.27
Privacy	2.26
Sound/thermal insulation	2.21

4.3.4.9 Rating of the respondents' current homes

In their current homes, to evaluate accurately the problems and issues in their current homes, the respondents were asked to rate factors including Exterior design, Interior Design, Quality of finishes, Ability to expand, ability to modify, Safety, Privacy, Ease of maintenance, Thermal insulation, Sound insultation, Natural lighting and Natural ventilation. The ratings were on 5-point Likert scale ranging from Excellent, Good, Average, Fair to Poor. The average score for each factor was calculated and the factors were ordered according to the highest average. The reason to ask this question is to evaluate the condition of the current social housing stock and its living conditions as evaluated by the users. The responses provided clear insights of the most severe issues facing the residents and the factors of concern. The data obtained are demonstrated in Table 4.7. As shown in the table, the factor with highest evaluation in the current social housing is Privacy followed by Exterior design and Safety. On the other hand, the lowest evaluation was the Quality of finishes and the second lowest was the Ability to expand. The results confirmed the issues of quality, sustainability and the need to consider the growing family needs as previously highlighted in the literature and the qualitative data analysis. These serious problems need to be carefully considered during the implementation of MMC in social housing projects in order to increase the users' satisfaction and the adaptability of the social housing units.

Table 4.7: Respondents' evaluation of their current homes

Factors	Mean
Privacy	2.80
Exterior design	2.78
Safety	2.78
Natural Ventilation	2.66
Ease of maintenance	2.65
Natural Lighting	2.62
Interior design	2.56
Ability to modify	2.53
Sound insulation	2.44
Thermal insulation	2.43
Ability to expand	2.25
Quality of finishes	2.07

4.3.4.10 Influencing factors on choosing homes

The last question was concerned about the influencing factors when the respondents chose their homes. The factors were the same as in the previous question with the respondents rating them Very important, Important, Neutral, Not important and Not at all important. The aim of this question is to investigate the needs of the residents in their future homes in order to understand the most important factors that affects their decision. The analysis of these factors will help in developing a more inclusive framework that considers the actual needs of the residents and provide an understanding of the influencing factors on them. Consideration of these factors helps in minimising the effect of the negative perception of the users on the adoption of MMC which has been highlighted in the literature review previously as one of the main barriers to MMC adoption. The factors were ordered according to the highest averages as shown in Table 4.8. According to the results, the highest influencing factor is Safety followed by Quality then Privacy. These factors are followed by Interior design and Affordability then Thermal insulation. These results imply the importance of the social factors presented in safety and privacy as noted by the residents. Moreover, the second important factors are related to the quality of houses, architectural design and sustainability. Taking careful consideration of these

factors in the adoption of MMC would help in achieving successful implementation in social housing projects.

Table 4.8: Rating of influencing factors on choice of homes

Factors	Mean
Safety	3.56
Quality	3.49
Privacy	3.48
Interior design	3.48
Affordability	3.38
Thermal insulation	3.27
Exterior design	3.26
Sound insulation	3.23
Natural ventilation	3.19
Ability to expand	3.14
Ease of maintenance	3.12
Ability to modify	3.10
Natural lighting	3.10

4.3.5 Statistical analysis

Statistical analysis is used to identify any significant differences in the perceptions of the respondents with respect to their skill level. It is assumed that each skill level will have their specific vision and attitudes towards their housing needs and challenges. From the literature review, it was indicated that the social and cultural aspects would play a significant role on the successful implementation of MMC in housing projects. In the ZHUN policy in Algeria, the imported prefabricated houses failed to meet the specific social identity of the residents, resulting in moving away from using prefabricated systems in residential projects. Therefore, it is crucial to have in-depth understanding of the residents' needs and challenges in their current and future housing. In order to provide this, the responses of the residents were grouped into three main groups according to their skill level. It is believed that each group could represent a social class according to their knowledge and awareness. The differences between these three groups would shed a light on specific social or cultural understandings and beliefs

that could be different from the other groups. Identifying these differences help in formulating the framework to address the challenges and needs of the residents of low-income housing projects on all levels. Thus, the respondents were grouped into three groups according to skill level: highly skilled, semi-skilled and lowly-skilled. The grouping was based according to the occupation of the respondents as shown in Table 4.9.

Table 4.9: Grouping of the occupation of the respondents

Highly skilled	Semi-skilled	Lowly skilled
Self-employed	Labour	Housewife
Lawyer	Employee	Unemployed
Engineer	Driver	Student
Carpenter		
Teacher		
Factory manager		

Table 4.10: Sample distribution by skill level

Highly skilled	Semi-skilled	Lowly skilled
42	57	42

Table 4.11: Sample distribution of skill level by age group

	18-25	26-35	36-45	46-55	55+	Total
Highly Skilled	5	19	10	6	2	42
Semi-skilled	6	20	22	8	1	57
Lowly skilled	10	22	8	1	1	42
Total	21	61	40	15	4	141
Percentage						
	18-25	26-35	36-45	46-55	55+	Total
Highly Skilled	3.55	13.48	7.09	4.26	1.42	29.79
Semi-skilled	4.26	14.18	15.60	5.67	0.71	40.43
Lowly skilled	7.09	15.60	5.67	0.71	0.71	29.79
Total	14.89	43.26	28.37	10.64	2.84	100

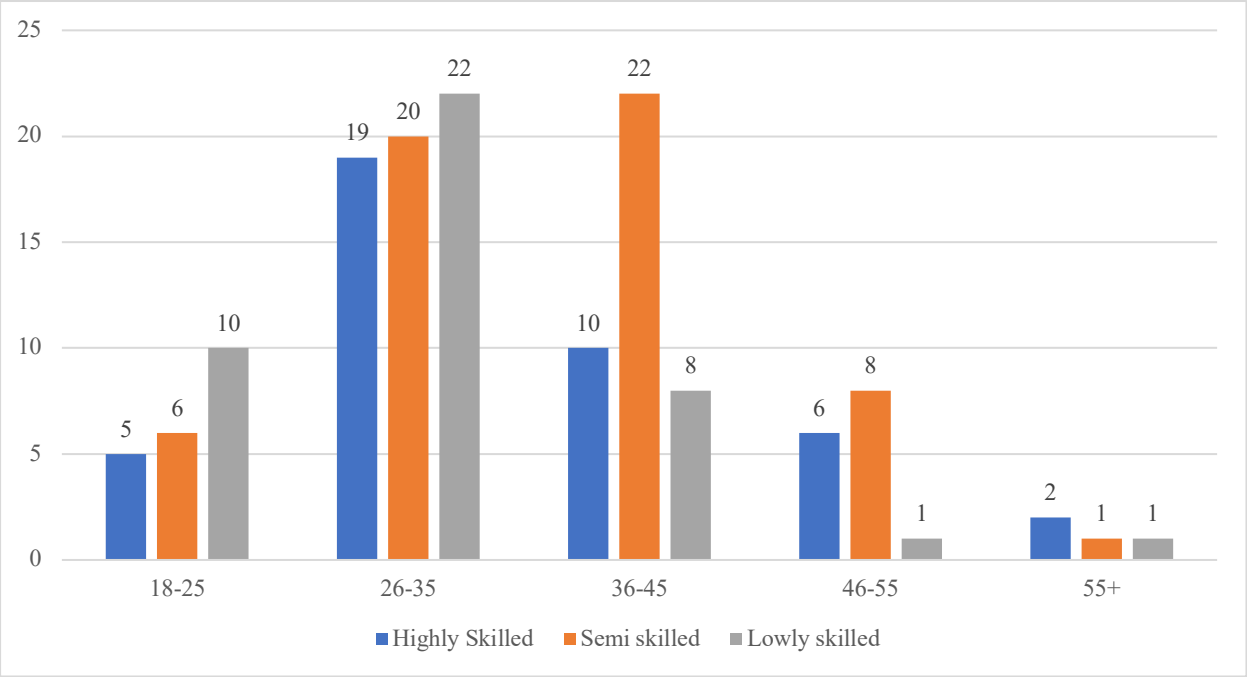


Figure 4.9: Sample distribution of skill level by age group

Table 4.12: Sample distribution of skill level by gender

	Males	Females	Total
Highly Skilled	40	2	42
Semi-skilled	54	3	57
Lowly skilled	3	39	42
Total	97	44	141
Percentage			
	Males	Females	Total
Highly Skilled	28.37	1.42	29.79
Semi-skilled	38.30	2.13	40.43
Lowly skilled	2.13	27.66	29.79
Total	68.79	31.21	100.00

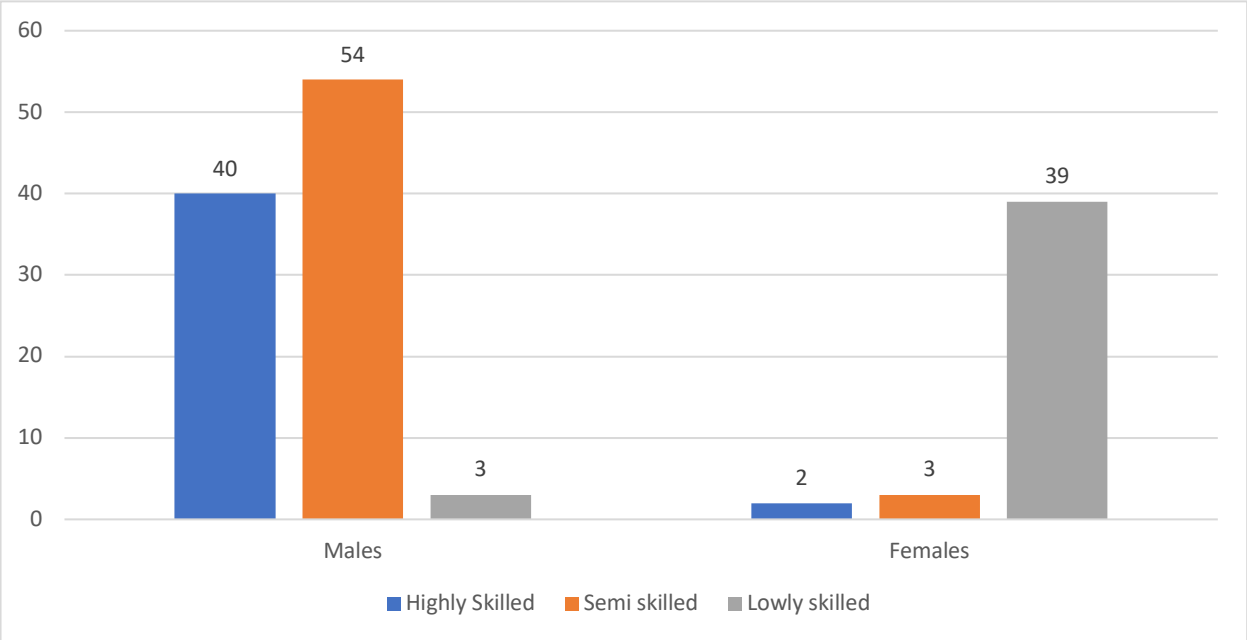


Figure 4.10: Sample distribution of skill level by gender

Table 4.13: Sample distribution of skill level by number of households

	1	2	3	4	5+	Total
Highly Skilled	1	7	9	16	9	42
Semi-skilled	0	5	16	23	13	57
Lowly skilled	0	2	14	14	12	42
Total	2	16	42	57	34	141
Percentage						
	1	2	3	4	5+	Total
Highly Skilled	0.71	4.96	6.38	11.35	6.38	29.79
Semi-skilled	0.00	3.55	11.35	16.31	9.22	40.43
Lowly skilled	0.00	1.42	9.93	9.93	8.51	29.79
Total	0.71	9.93	27.66	37.59	24.11	100

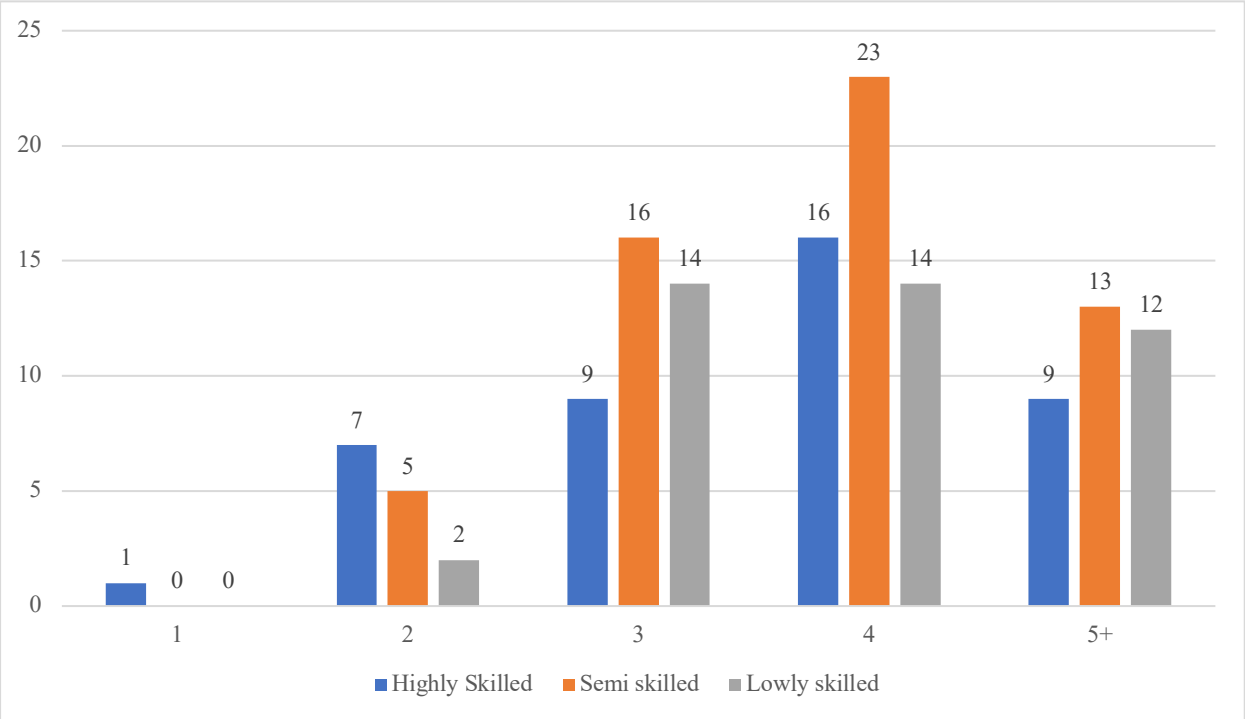


Figure 4.11: Sample distribution of skill level by number of households

4.3.5.1 Kruskal-Wallis test

The Kruskal-Wallis is a non-parametric test identifies any significant differences between the perception of the three groups. The test compares the mean rank of each group against the overall mean rand (Saunders *et al*, 2019). The test's null hypothesis states that the ranks of the three groups are all the same while the alternative hypothesis stated that at least one group has significant differences between the ranks. The ratings of the respondents in the last three questions of the questionnaire were analysed using the KW test to assess any significant differences in their perceptions. The results of the tests were compared to the corresponding Chi-squared critical value according to the degree of freedom of the study in order to accept or reject the null hypothesis as shown in Table 4.14. The corresponding degree of freedom (df) for the study is calculated at 3 groups -1 = 2 (df). The KW test is calculated through the following equation:

$$H = \frac{12}{n(n+1)} \sum_{j=1}^{c} \frac{T_j{}^2}{n_j} - 3(n+1)$$

n = sum of samples for all samples

c = number of samples

T_j = sum of ranks in the j^{th} sample

n_j = size of the j^{th} sample

If the static value H is larger than the corresponding Chi-squared table value, then the null hypothesis can be rejected meaning that there are significant differences between the three groups. If the H value is smaller than the corresponding Chi-squared table value, then the null hypothesis can be accepted stating that there are no differences in the perceptions of the respondents.

Table 4.14: Critical values for Chi-square distribution (Purdue University, 2010)

Critical Values for Chi-Square Distribution.

	Upper Tail Probability									
df	0.2	0.1	0.05	0.04	0.03	0.025	0.02	0.01	0.005	0.0005
1	1.642	2.706	3.841	4.218	4.709	5.024	5.412	6.635	7.879	12.116
2	3.219	4.605	5.991	6.438	7.013	7.378	7.824	9.210	10.597	15.202
3	4.642	6.251	7.815	8.311	8.947	9.348	9.837	11.345	12.838	17.730
4	5.989	7.779	9.488	10.026	10.712	11.143	11.668	13.277	14.860	19.997
5	7.289	9.236	11.070	11.644	12.375	12.833	13.388	15.086	16.750	22.105
6	8.558	10.645	12.592	13.198	13.968	14.449	15.033	16.812	18.548	24.103
7	9.803	12.017	14.067	14.703	15.509	16.013	16.622	18.475	20.278	26.018
8	11.030	13.362	15.507	16.171	17.010	17.535	18.168	20.090	21.955	27.868
9	12.242	14.684	16.919	17.608	18.480	19.023	19.679	21.666	23.589	29.666
10	13.442	15.987	18.307	19.021	19.922	20.483	21.161	23.209	25.188	31.420
11	14.631	17.275	19.675	20.412	21.342	21.920	22.618	24.725	26.757	33.137
12	15.812	18.549	21.026	21.785	22.742	23.337	24.054	26.217	28.300	34.821
13	16.985	19.812	22.362	23.142	24.125	24.736	25.472	27.688	29.819	36.478
14	18.151	21.064	23.685	24.485	25.493	26.119	26.873	29.141	31.319	38.109
15	19.311	22.307	24.996	25.816	26.848	27.488	28.259	30.578	32.801	39.719
16	20.465	23.542	26.296	27.136	28.191	28.845	29.633	32.000	34.267	41.308
17	21.615	24.769	27.587	28.445	29.523	30.191	30.995	33.409	35.718	42.879
18	22.760	25.989	28.869	29.745	30.845	31.526	32.346	34.805	37.156	44.434
19	23.900	27.204	30.144	31.037	32.158	32.852	33.687	36.191	38.582	45.973
20	25.038	28.412	31.410	32.321	33.462	34.170	35.020	37.566	39.997	47.498
21	26.171	29.615	32.671	33.597	34.759	35.479	36.343	38.932	41.401	49.011
22	27.301	30.813	33.924	34.867	36.049	36.781	37.659	40.289	42.796	50.511
23	28.429	32.007	35.172	36.131	37.332	38.076	38.968	41.638	44.181	52.000
24	29.553	33.196	36.415	37.389	38.609	39.364	40.270	42.980	45.559	53.479
25	30.675	34.382	37.652	38.642	39.880	40.646	41.566	44.314	46.928	54.947

4.3.5.1.1 Residents' concerns from MMC

The means of the respondents' ratings were calculated from the three groups, highly skilled, semi-skilled and lowly skilled. The means of all groups were sorted from the highest mean to the lowest as shown in Table 4.15 and Figure 4.12. The hypotheses for the test were as follows:

- **H_0** Null Hypothesis: all the residents have similar concerns.
- **H_1** Alternative Hypothesis: at least one group has different concerns than the rest of the residents.

Table 4.15: Sorting of all factors from all groups according to their concerns from MMC

Factors	Means	Rankings
Affordability	3.02	1
Ventilation	2.90	2
Quality	2.83	3
Affordability	2.82	4
Ease of maintenance	2.79	5.5
Privacy	2.79	5.5
Ability to expand	2.76	8
Safety	2.76	8
Architectural Design	2.76	8
Ability to modify	2.71	10
Sound/thermal insulation	2.60	11
Ease of maintenance	2.58	12
Ability to modify	2.51	13
Ability to expand	2.47	14.5
Architectural Design	2.47	14.5
Quality	2.46	16
Ventilation	2.44	17
Affordability	2.43	18
Safety	2.42	19
Privacy	2.32	20
Sound/thermal insulation	2.30	21
Ease of maintenance	2.12	22.5
Ability to modify	2.12	22.5
Ability to expand	2.00	24
Ventilation	1.95	25
Sound/thermal insulation	1.69	26
Privacy	1.67	27
Architectural Design	1.62	28
Quality	1.60	29
Safety	1.57	30

Highly skilled Semi-skilled Lowly skilled

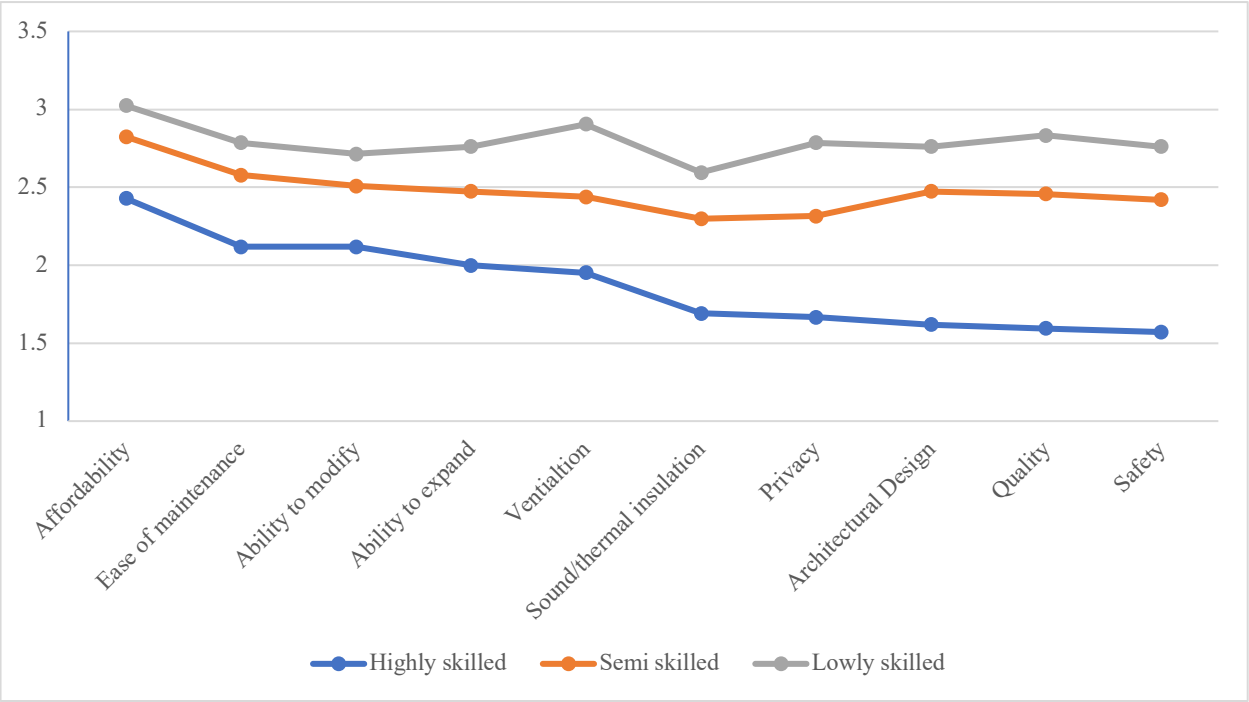


Figure 4.12: The mean ratings of the concerns of the respondents from MMC of all groups

The H value for the test was 23.32 and the Chi-square table value is 5.991 at 95% confidence level with corresponding degree of freedom (df) calculated at 3groups – 1 = 2. Hence the H value was greater than the table value, therefore, the null hypothesis can be rejected. According to the test result, there are notable differences in their concerns towards MMC where the highly skilled group showed lower concerns from MMC than the other two groups. These differences require wider consideration of all the doubts and concerns from MMC before implementing it in low-income and social housing projects to avoid harder resistance from the residents.

4.3.5.1.2 Respondents rating of their current homes

The mean values of the rating from each group were calculated and sorted from the highest to the lowest Table 4.16 and Figure 4.13. The values were combined in one table accordingly to calculate the H value and its corresponding Chi-square table value to accept or reject the hypotheses which are as follows:

- **H_0** Null Hypothesis: There is no difference in the resident's evaluation of their current homes.
- **H_1** Alternative Hypothesis: at least one group has different evaluation than the rest of the residents.

Table 4.16: Sorting of all factors from all groups according to rating of their homes

Factors	Means	Ranking
Exterior design	3.29	1
Privacy	3.19	2
Ease of maintenance	3.00	3
Interior design	2.98	4
Ability to modify	2.93	5
Safety	2.90	6
Safety	2.89	7
Natural ventilation	2.88	8
Privacy	2.79	9.5
Exterior design	2.79	9.5
Sound insulation	2.79	11
Natural lighting	2.76	12
Ease of maintenance	2.74	13
Natural lighting	2.72	14
Thermal insulation	2.71	15
Natural ventilation	2.68	16
Interior design	2.67	17
Ability to expand	2.60	18
Ability to modify	2.56	19.5
Thermal insulation	2.56	19.5
Quality of finishes	2.52	21
Sound insulation	2.51	22
Safety	2.50	23
Privacy	2.43	24.5
Natural ventilation	2.43	24.5
Natural lighting	2.36	26
Ability to expand	2.35	27
Quality of finishes	2.32	28
Exterior design	2.29	29
Ease of maintenance	2.21	30
Ability to modify	2.12	31
Interior design	2.02	32.5
Sound insulation	2.02	32.5
Thermal insulation	1.98	34
Ability to expand	1.79	35
Quality of finishes	1.29	36

Highly skilled Semi-skilled Lowly skilled

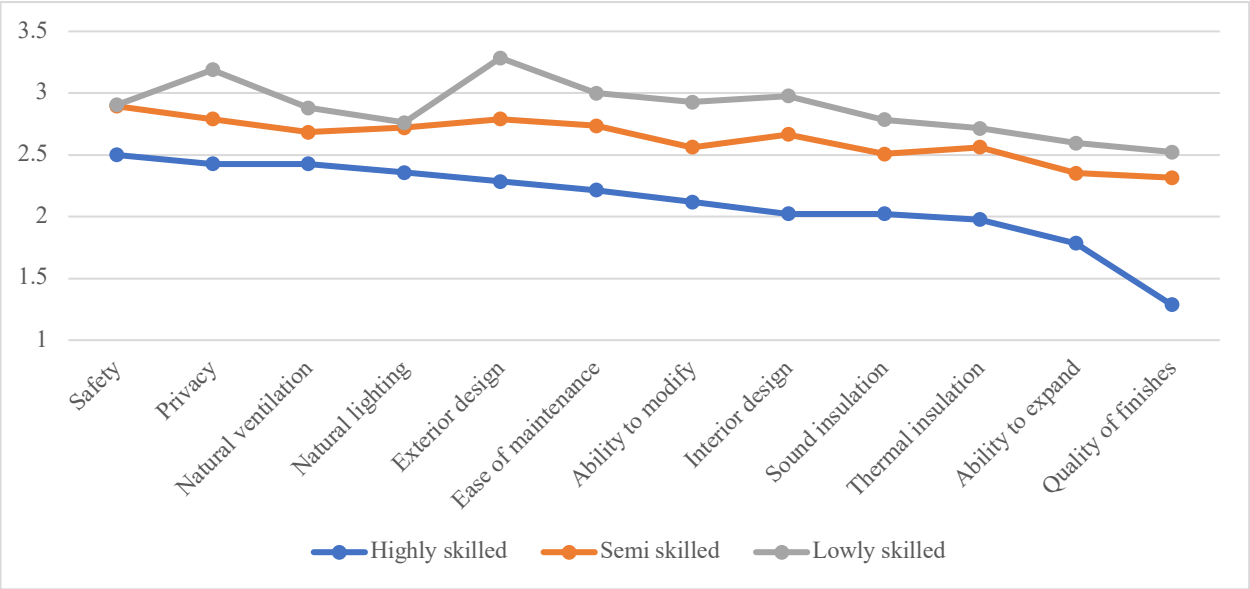


Figure 4.13: Resident's average evaluation of their current homes

The H value for the test was 24.29 and the Chi-square table value is 5.991 at a 95% confidence level with the corresponding degree of freedom (df) calculated at 3groups – 1 = 2. Hence the H value was greater than the table value, therefore, the null hypothesis can be rejected. The KW test was performed to identify if there are notable differences in the residents' opinions about their current homes and their evaluation. The result confirmed that there are significant differences requiring more attention to a wider set of factors to consider in order to tackle the challenges and disadvantages of the current housing. This will help provide a more precise framework that satisfies the actual needs of the residents, thus, increasing the possibility of successful implementation and adoption of MMC in low-income housing projects.

4.3.5.1.3 Influencing factors on choosing prospective homes

The mean values of the rating from each group were calculated and sorted from the highest to the lowest Table 4.17 and Figure 4.14. The values were combined in one table accordingly to calculate the H value and its corresponding Chi-square table value to accept or reject the hypotheses which are as follows:

- **H_0** Null Hypothesis: All groups have the same influencing factors when choosing their new home.
- **H_1** Alternative Hypothesis: at least one group have different evaluation when choosing their new homes.

Table 4.17: Sorting of all factors from all groups according to rating of their future homes

Factors	Means	Rankings
Safety	3.83	1
Quality of finishes	3.79	2
Privacy	3.57	3
Safety	3.56	4
Privacy	3.54	5
Quality of finishes	3.51	6
Affordability	3.50	7.5
Interior design	3.50	7.5
Interior design	3.48	9
Interior design	3.47	10
Natural ventilation	3.43	11
Affordability	3.37	12
Thermal insulation	3.36	13
Privacy	3.33	14
Exterior design	3.31	15
Affordability	3.29	16.5
Safety	3.29	16.5
Thermal insulation	3.26	18
Sound insulation	3.26	19
Sound insulation	3.25	20.5
Exterior design	3.25	20.5
Ease of maintenance	3.24	22.5
Exterior design	3.24	22.5
Thermal insulation	3.21	24
Ability to expand	3.19	26
Quality of finishes	3.19	26
Sound insulation	3.19	26
Natural lighting	3.17	28
Ability to expand	3.14	30
Natural ventilation	3.14	30
Ease of maintenance	3.14	30
Ability to modify	3.12	32.5
Ability to modify	3.12	32.5
Ability to expand	3.10	34
Natural lighting	3.09	35
Ability to modify	3.09	36
Natural lighting	3.07	37
Natural ventilation	3.05	38
Ease of maintenance	3.03	39

Highly skilled Semi-skilled Lowly skilled

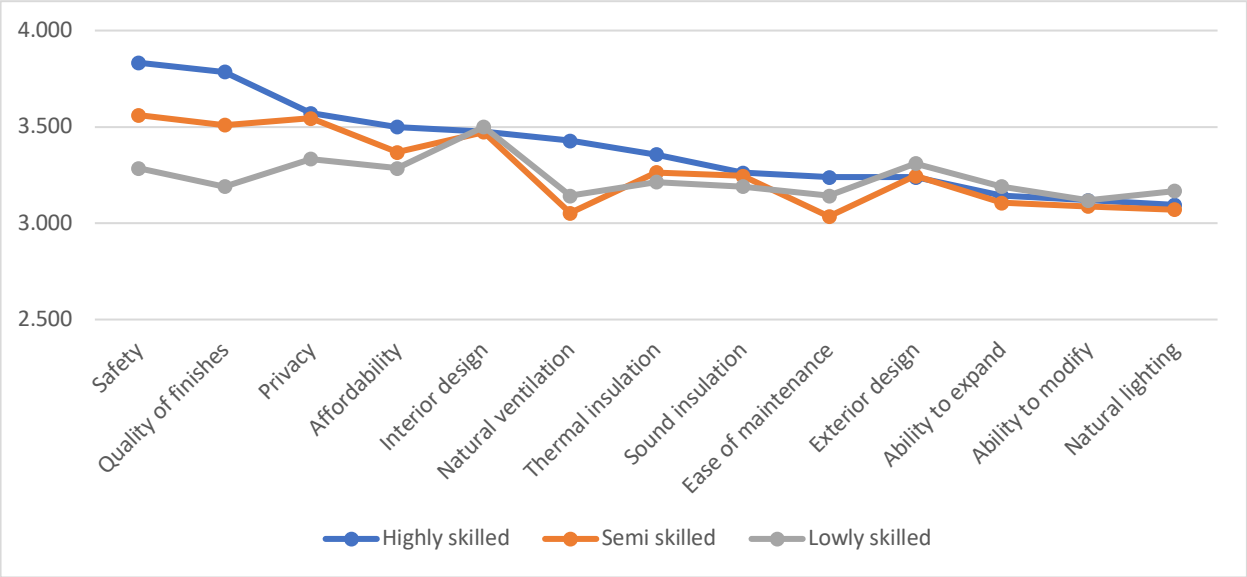


Figure 4.14: Residents' priorities when choosing the new homes

The H value for the test was 2.69 and the Chi-square table value is 5.991 at a 95% confidence level with the corresponding degree of freedom (df) calculated at 3 groups – 1 = 2. The H_0 cannot be rejected and therefore there are no significant differences between the three groups. The KW test was done to identify any notable differences in the main factors that the residents take into consideration when choosing their new homes. The result determined that there are no significant differences in the answers of the three groups which means that the overall decisive factors are convergent. These factors identify the actual needs of the residents when choosing their new homes and their priorities to them. The results will help aim the framework to adopt MMC in low-income housing to satisfy the users' needs and underpin the critical factors that support efficient utilization of prefabrication to the users.

4.4 Summary of findings

The qualitative and quantitative analysis produced a large amount of data which required careful extraction of the main themes and patterns relevant to the research context. The main themes extracted from the data analysis are summarised in Figure 4.15. As shown in Figure 4.15, the main critical success factors, challenges and barriers are identified according to the information provided by the participants of the interviews and the survey. The factors

influencing the adoption of MMC in social housing projects are summarised as follows:

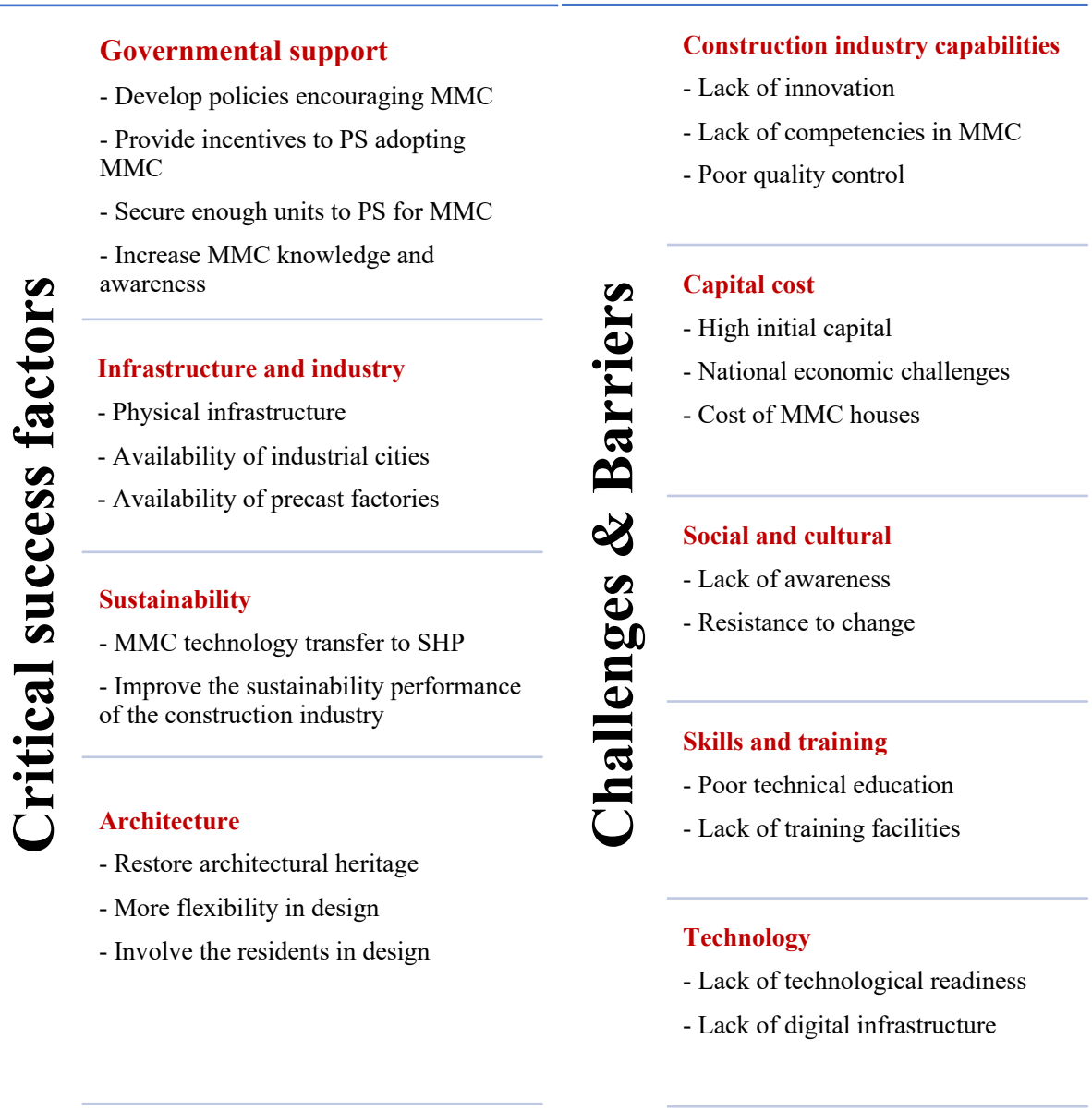


Figure 4.15 Summary of findings from data analysis

4.4.1 Critical success factors

4.4.1.1 Governmental support

Government support is crucial to the successful adoption of MMC, governmental support could be in different forms, firstly, develop policies that encourage the adoption of MMC in social housing projects. Secondly, provide incentives to the private sector that adopts MMC in their social housing projects. In addition, secure a large number of units for the private sector that adopts MMC in order to absorb the high capital costs of it. Another form of governmental

support is to increase the awareness and knowledge of MMC to acquaint the public and social housing contractors of its benefits and advantages.

4.4.1.2 Infrastructure and industry

The current improvement in the physical infrastructure provides the opportunity to implement MMC in terms of roads and the provision of infrastructure to new urban communities. Moreover, the increase in industrial cities and abundance of precast concrete factories facilitates the adoption of MMC where the precast factories could be adapted to manufacture prefabricated components of social housing projects.

4.4.1.3 Sustainability

One of the crucial success factors of MMC in social housing projects is improving the sustainability performance of them and the construction industry overall. From the literature and the data analysis, MMC can improve sustainability by reducing construction waste, using more durable materials to reduce utilization costs and reducing the carbon footprint of social housing units. Furthermore, the country is shifting to introducing innovation in all fields, thus, innovation can be transferred to social housing projects and construction in general through MMC. MMC can address the lack of innovation in the construction of social housing projects by leveraging its construction methods.

4.4.1.4 Architecture

Architecture can enhance the adoption of MMC in different methods. MMC can help in restoring the lost architectural heritage in the current housing stock, especially in low-income housing projects. The standardization and modularization benefits of MMC can support in the production of architectural forms that help in restoring the Egyptian architectural heritage in housing. Furthermore, more flexibility in design is required to satisfy the growing family needs of the social housing community which can be achieved through MMC. Involving the residents in the early design stage could be one of the main success factors for MMC to achieve their needs and understand any potential challenges in the provision of housing.

4.4.2 Challenges and barriers

4.4.2.1 Construction industry capabilities

The Egyptian construction industry faces many challenges that could hinder the adoption of MMC. The lack of innovation in the industry where the dominant construction method is the traditional method would be a barrier to MMC implementation. In addition, the lack of knowledge and awareness about MMC among the workers. The construction industry is suffering from poor quality control measures which are required by MMC in order to avoid costly failures when implementing it.

4.4.2.2 Capital costs

One of the main barriers to MMC implementation in Egypt is the high capital costs. The current economic challenges facing the government and the private sector cannot withstand the massive investment required to adopt MMC. The cost of MMC could initially be higher than traditionally built houses due to capital and training costs, therefore, large number of units need to be secured to the entity willing to adopt MMC in order to absorb the high initial costs and reduce the value of unit.

4.4.2.3 Social and cultural

The negative perception and lack of awareness of MMC technology would be one of the critical challenges to adopt MMC. Moreover, the lack of knowledge among construction professionals would create a barrier to MMC implementation due to the resistance to change. Workers would resist the change of construction method they are used to as well as the contracting companies. The social and cultural aspects are proven to be of high importance to the implementation of new methods that are different from what is currently used as previously discussed in Chapter 2 and from the analysis.

Skill and training

The adoption of MMC requires specialized skills and knowledge. There might be a lack of awareness and training among local contractors and workers, making it difficult to carry out projects using these techniques. The lack of training facilities would make it harder for contracting companies to train and develop the required skills among their teams. In addition,

the poor technical education in Egypt would be a barrier as well where the workers have minimal knowledge about new construction methods.

4.4.2.4 Technology

The lack of technological readiness and digital infrastructure would make it harder to adopt MMC due to its technological features and requirements when compared to traditional construction methods. From the data analysis and the literature review, innovation in the Egyptian construction industry is very low creating a potential barrier to MMC implementation.

4.5 Chapter summary

This chapter has presented the primary data analysis and findings. The first section provided a detailed description of the qualitative data collected through semi-structured interviews. The interviews were performed with construction professionals, architects, governmental officials and precast concrete factory managers. The analysis included a descriptive analysis of the participants showcasing their variation in roles, experience and their organizations. Furthermore, the qualitative analysis was performed using NVIVO software to extract the relevant codes and factors and extract the relationships between them.

The quantitative analysis of the questionnaire survey was demonstrated in the second section of this chapter. The questionnaire was performed with the residents of two case studies of social housing projects. The descriptive analysis included a description of both case studies and the sample size of the population. Moreover, a detailed analysis of each question of the questionnaire was presented outlining the respondents' views and opinions of their current homes in addition to their concerns if their houses were built using MMC rather than traditional construction methods. The statistical analysis was performed using the Kruskal-Wallis test where the respondents were grouped into three groups according to their skill level to identify any notable differences in their opinions and concerns regarding their current and future homes and towards MMC.

The findings from the data analysis have helped in identifying the critical success factors, challenges and barriers to implementing MMC in low-income housing projects in Egypt. A stakeholder analysis was carried out to identify the current stakeholders of the housing provision system to obtain a comprehensive vision of it. This stakeholder analysis helped in choosing the participants in the interviews. The questionnaire survey was executed with the current residents of social housing to identify the challenges they are currently facing in

addition to identifying their needs that should be looked after in future housing projects. The findings will formulate the framework to implement MMC in low-income housing projects alongside the findings from the literature review.

5 Chapter 5: Discussion

5.1 Introduction

This chapter provides a comprehensive discussion of the findings of the literature review alongside the analysis of the qualitative and quantitative data. It describes the findings from the analysis of the interviews to extract the factors influencing the adoption process of MMC in social housing units compared to the factors identified from the literature. Moreover, this chapter discusses the findings from the questionnaire analysis describing the factors associated with the residents' needs and challenges in the current social housing units. It discusses the impact of these factors on the implementation process and how the challenges and barriers can be mitigated.

5.2 Qualitative findings

5.2.1 Capital costs

As mentioned in the literature, the initial capital costs of prefabrication will be one of the substantial hindrances to the adoption of MMC. Social housing projects in Egypt will not be an exception, where all the interview participants confirmed that the required high capital is the main barrier to MMC adoption. The current economic instability caused by high inflation and tight budget within the housing authorities will discourage any increase in costs in the construction of housing units where the public sector bears the responsibility of its funding. Moreover, the private sector is struggling with financing its projects as it does not have the ability to fund the large investments required to implement MMC. Contracting companies operating in social housing projects do not have the financial capacity to invest in an expensive construction method, nor do they have industrial knowledge.

With the current economic situation in Egypt, it will be very challenging for either the private or the public sector to invest large investments in MMC, especially in social housing projects that need to be supplied at the lowest possible cost. Although the country is experiencing economic growth, it is currently encountering severe challenges owing to the global increase in inflation, the war in Ukraine and the impact of the Covid-19 pandemic. According to The World Bank (2022), these challenges are creating new burdens on the government's economic reforms that created growth in the last six years leading to widening the budget deficit. As a result, the government has introduced mitigation measures to averse these burdens by

depreciating the currency, increasing interest rates and imposing an import ban alongside other measures.

Implementing MMC requires enormous investments in terms of manufacturing facilities, training facilities and transportation and mobilisation investments. The contracting companies operating in social housing projects are small contractors with limited abilities. As previously mentioned in Chapter 4, they do not have the financial or technical abilities to cope with MMC requirements. On the other hand, large construction firms are only developing high-end and luxurious residential projects that offer them guaranteed profits. The private sector's only interest in social housing is to gain experience as small contractors to grow and enter the luxurious housing market.

From the qualitative analysis in Chapter 5, to overcome the high capital costs required for MMC, a large number of units must be secured to investors as mass production will help absorb the initial cost. Securing large volumes of units to contractors using MMC will help reduce the cost per unit and thus absorb the high initial cost. The procurement method currently employed in social housing projects leaves the burden of the construction method on the contractors. Besides, contractors must use the least expensive construction method to cope with the tight budget of social housing projects. However, it has been indicated that the current procurement method, where the Social Housing and Mortgage Finance Fund (SHMFF) has sole responsibility for financing social housing projects, is insufficient to fulfil the growing demand. Less than 400,000 units have been built until 2020 in the one million social housing units program announced in 2014 that was supposed to be completed within five years (CAPMAS, 2022).

Therefore, partnering between the private and public sectors to implement MMC in social housing projects would create an enabling environment to increase the supply of housing units. According to Law (93), in 2018, SHMFF has the authority to invest and set up policies that aim to benefit the development of low-income and social housing units. Consequently, this could lead to a partnership between SHMFF and construction companies to invest in MMC factories and infrastructure. Through this partnership, SHMFF can adhere to procuring a specific number of units to be built that will help absorb the high initial capital and lowers the cost of a unit in the long term. It will benefit from the exemption from all the taxes and fees of any loans and finances granted to the SHMFF, as stated in Law (93), helping reduce the cost of funding for this kind of project.

5.2.2 Construction industry capabilities

Although the construction industry plays a pivotal role in the Egyptian economy, being one of the top 10 operating sectors, its performance lags in several aspects. The data analysis shows that the construction industry suffers from poor quality, low productivity, health and safety issues, project delays, waste, and sustainability issues. Furthermore, there are more than 32 causes of construction delays, the most significant being financial difficulties, poor quality, low quality of construction materials, total workforce, Covid-19 pandemic, corruption and tendering strategies (Abd El-Razek *et al*., 2008; Shibani *et al*., 2021). In addition, the industry's severe health and safety issues were mentioned both by the interview participants and in the literature. These issues have caused the construction industry to underperform despite being one of the top sectors contributing to the Egyptian economy. The industry needs innovation and sustainable approaches to address these issues and improve its performance.

In residential projects, the dominant construction method is traditional, either in the low-income and social housing or the high-end and luxurious projects. Social housing contractors employ the most cost-effective construction method without consideration of any other approach. However, from the interviews and the literature review, social housing units has the lowest quality of finishings, and the number of units built annually has been less than half of the planned. Throughout the past five decades, traditional construction methods have not been sufficient to reduce the housing shortage and increase its supply. Other countries have been in the process of adopting offsite prefabrication in order to increase the supply of housing and improve the performance of the construction industry. As illustrated in the literature, benefits from offsite prefabrication include improving quality, reducing construction duration, health and safety and overall construction performance. These benefits are crucial for the Egyptian housing sector, which is already struggling in those areas.

However, importing MMC systems from developing countries that have already adopted it would not guarantee its success, as in the case of the Algerian ZHUN policy previously discussed in Chapter 2. Adopting MMC in housing projects with tight budgets, such as social housing, requires qualifying the contracting companies with the knowledge and skills to implement it. According to the qualitative analysis, social housing contractors are all small companies who lack the capabilities to adopt such innovative methods. They are small companies with minimal resources, including skilled workers. They mainly depend on workers who learn skills from their peers rather than from proper technical education.

Moreover, contracting companies must have training facilities to provide the required training to work with advanced methods such as MMC. However, it is worth mentioning that there is an abundance of an unskilled workforce that, with proper training facilities, can easily be taught and gain all the required knowledge and skills. Social housing contractor needs governmental support to provide technical training to unskilled workers in order to implement innovative construction methods. This support could be in the form of subsidies, financial support or long-term contractual relationship to provide them with a steady workflow. The governmental support could provide contractors with land to establish their factories close to futuristic residential developments.

It has been agreed from the literature and the qualitative analysis that social housing units suffer from poor quality, lack of maintenance and poor health and safety performance. These issues are common in the Egyptian construction industry, affecting buildings' utilisation performance and increasing their running costs. Offsite prefabrication addresses these matters by reducing work onsite and manufacturing building components in a more controlled factory environment that results in improved quality. The Egyptian construction industry has been struggling with these drawbacks for a long time without considering new construction methods that can mitigate or eliminate them, as previous studies have identified the causes without mentioning alternative construction methods. Implementing MMC in social housing projects can positively impact the overall construction performance and utilisation of units by raising the execution standards brought by MMC.

5.2.3 Architecture and housing types

Even though Egypt has a vast architectural heritage spanning more than 5000 years, the current housing stock has lost its distinctive architectural character. This is due to economic and technical reasons where the mass production of housing has led to the continuous pursuit of reducing costs by eliminating architectural forms from houses. The lack of highly skilled workers who can produce sophisticated architectural forms related to specific architectural eras is also considered one of the main reasons. The current design trend in social and low-income housing projects is to create housing units by making the maximum possible benefit from the allocated area. This trend does not consider any architectural design forms that can boost the exterior façade designs.

Moreover, interior design has suffered from similar issues. Several scholars have discussed the issues incorporated in social and low-income housing projects where it suffered deterioration

and alterations by the residents due to design errors and disregard for the users' needs by designers. It is worth mentioning that social housing users are not included in the design stage of housing projects. According to (Diab and Abd El Aziz, N. A., 2018), the physical design of low-income housing has been indicated to be incompatible with the users' needs and actual behaviour as they are not involved in the design process.

Residents' alterations and modifications are significant issues in low-income and social housing. Residents always tend to modify their units after moving in for several reasons. They close the balconies to increase the interior space in the living rooms or bedrooms. Illegal expansions are made on the ground floor flats to add more rooms. Even they vandalise the elevations to distinguish the exterior looks from similar blocks. They add iron protection to windows for safety in ground-floor flats (Diab and Abd El Aziz, N. A., 2018). The reason behind this is mainly because of the lack of involvement of the residents in the design process. Designers and planners of social housing projects neglect the users' behaviours and cultural norms for budget savings and economic benefits. Housing associations and local councils tried to face these alterations by imposing fines and removing any illegal alterations by tight control on every neighbourhood. They partially succeeded in this as during the 1990s, alterations have reached adding full stories illegally, but recently it does not exceed more than closing balconies or modifying internal spaces.

However, users' alterations continued due to their growing cultural and physical needs. Immediate family members often reside as close to each other as possible, and young adults usually live with their parents until marriage, especially females (Florin, 2008). Social housing units must be able to accommodate expansions and modifications to satisfy extended family requirements. This can be provided by using removable prefabricated partitions instead of permanent internal block walls that can provide the flexibility of rearranging the internal spaces of the flats or even merging two adjacent units. Social housing units are designed as standard three-bedroom 90 m^2 flats built in modular five-storey flat blocks. MMC can satisfy all the users' internal and external design needs through standardisation and modularisation of volumetric flat design. Flats can be designed as volumetric modular units to be manufactured and transported to sites providing improved social housing units in terms of quality, flexibility and shorter construction duration.

5.2.4 Governmental policies and issues

Throughout the last 70 years, the government has carried the burden of providing low-income housing by developing several housing policies to increase the supply of affordable housing. These housing policies over the years did not meet the growing demand driven by population growth and socioeconomic challenges in the low-income sector. The housing shortage has surpassed over 2.5 million units ranging between new units to be built and deterioration of the existing stock. Housing policies have fluctuated with the change in the country's political leadership. Between the 1950s -1970, the Public Housing scheme was implemented to provide fully finished units with fixed subsidised rent. The ministry of housing was the sole provider of these units, taking full responsibility for financing, executing and monitoring housing projects. Between 1970-1981 the Open Door policy was in place where the government introduced partnerships with the private sector to provide low-income housing units to increase its supply and to target more social groups, although sticking with the rental system in provision. During 1982-2011, several policies were implemented, introducing multi actors in the housing provision system, including housing authorities, the private sector and international organisations to execute numerous housing projects. The government's role was financing, mediating, and regulating, as well as providing either fully finished units with ownership systems or providing plots of land in new urban communities with complete infrastructure. The latest policy currently underway is the National Social Housing Project (NSHP), where the government is providing housing units with the participation of housing authorities, the private sector as the executor and banks as financers to the residents. Most of the units are for ownership, and rental units are for a few numbers of them (Abdel-Rahman *et al*., 2020).

These changes and policy fluctuations have incurred problems, disparities in the housing provision system between different social groups and inefficiency in executing housing projects. Since the 1950s, the government has issued several laws to reduce the rental value, which led to the private sector avoiding investing in low-income housing. This resulted in the government carrying all the financial burden of providing housing units to the low and middle income. Although the later policies shifted to the ownership system, the private sector still invests only in high-income and luxury housing, which is more profitable. With the growing demand, the public sector continuously fails to supply the required units, increasing the housing shortage. With the latest policy, NSHP, the same issue is still ongoing where the private sector's role is only an executor without actually investing in the social housing system.

Moreover, housing policies disregarded the cultural and social factors of the residents. The policies deal with economic and quantitative challenges in providing the largest number of units possible and how to fund these projects. Housing projects did not consider the extended family point of view when planning and executing units. From the qualitative data and the literature, Egyptian families always seek to live close to each other. Middle and low-income families continuously tend to extend their properties to accommodate the largest number of members possible. Families were reluctant to move to new social housing units in new urban cities due to longer travel distances from their extended families or workplaces. The lack of facilities and recreational areas had a significant role in the failures of several housing policies. Housing policies should consider the social and cultural aspects of the residents to encourage them to move into new communities by engaging them in the decision-making process of new policies. In addition, policies need to consider the diversity of people as there are significant cultural differences, such as between people from the north and people from Upper Egypt in the south. No policy has considered these differences where usually the policy is set by the central government for the whole country.

MMC can support housing policies and the housing provision in Egypt by addressing the shortcomings in implementation. One of the main issues in low-income housing policies is the private sector's reluctance to invest. According to the latest housing strategy, the government plans to introduce policies encouraging the private sector to participate in low-income housing through developing public-private partnerships (UN Habitat, 2020). These partnerships can be developed to adopt and implement MMC in low-income housing, taking advantage of its faster build, improved quality and cost-effective solutions. The initiative to adopt MMC with the SHMFF can benefit the private sector from tax cuts, subsidies and low-interest rates provided by the SHMFF law.

In the current housing strategy set by the ministry of housing, one of the main pillars is to prompt innovative housing in the field of affordable housing. Introducing MMC to housing authorities as an innovative approach to executing low-income housing projects can achieve the governmental officials' support. The construction with MMC will be considered very advanced compared to the current construction methods used in social housing units. Through MMC, several goals of the Egyptian housing policy can be achieved, increasing the supply of housing units, improving the quality and efficiency of units, and diversifying the units' areas and designs to accommodate the users' growing needs. From the analysis of the interviews, it has been emphasised that introducing MMC to housing authorities and government officials

will be supported as innovation and sustainable approaches are currently promoted by the country's leadership. However, to succeed in implementing MMC in social housing, knowledgeable leadership is essential to deal with the housing authorities who can deal with their tough mindset and the inherent bureaucracy. Managing the change in implementation will be challenging for the entity willing to adopt MMC in social housing projects. They will need to deal with behavioural change with the decision-makers and manage their resistance to the change in the construction methods used.

Although the country has set several environmental goals to achieve by 2030 according to its Egypt 2030 policy, sustainability is a derelict topic in social housing projects. Egypt's 2030 environmental policy aims to increase its dependence on renewable and clean energy resources, reduce carbon emissions, and minimise waste. However, the construction industry still produces vast amounts of construction and demolition waste contributing to environmental contamination. Construction waste has reached 40% of the total construction materials where it is dumped either on roads or in inefficient dumping sites lacking precautionary measures to prevent waste burning and environmental pollution (Daoud *et al*., 2021). In social housing units, unsustainable construction has increased renovation requirements due to using non-durable materials. In addition, the units lacked insulation materials that could prevent excessive heat in the summer, which required installing air conditioning units to cool them indoors. Traditional construction approaches are incapable of achieving sustainable solutions in social housing units. It has been indicated that traditional methods increase the possibility of construction waste in addition to unproviding sustainable units that can reduce energy consumption. In social housing projects, it is a must to provide cost-effective and sustainable solutions to reduce utilisation costs, not only construction costs. This will help increase the affordability of units to the low-income and improve their living conditions. MMC can improve the sustainability of social housing projects and units by reducing construction waste by integrating manufacturing capabilities into the construction process. Innovating the housing provision system through MMC can be a practical tool to tackle the construction industry's unsustainability challenges.

5.2.5 Social and cultural issues

As previously mentioned, the growing family needs still need to be satisfied in the current social housing units. The main issue is that the residents are not involved in the design process of social housing projects leading to gaps between the design and function of housing projects.

Moreover, Egyptians are strongly connected to their habits and traditions where they require more privacy in their houses, for example, reflecting glass windows instead of transparent glass in their homes. They tend to separate their living areas from the guest rooms, where they decorate them in a more valuable manner to show their most valuable belongings. The resident's social behaviour plays a significant role in the housing provision system. It has been concluded from the interviews that in new urban communities, the residents do not have strong local ties to the environment that encourage them to preserve it. This can be deduced from the feeling that this place does not belong to them, or they feel like expats, which is not their usual settlement. The features of the built environment and the involvement of the residents in structuring it plays a significant role in creating social ties to the community, which has been observed in informal settlements the residents built (Eldefrawi, 2015). Developing communities that satisfy the users' needs and meet their social and cultural beliefs create stronger local ties to the community leading to preserving their units and helping to reduce their deterioration which, subsequently, supports reducing the housing shortage.

Developing social housing units using MMC approaches can positively influence the residents' social and cultural aspects. The improvements brought by MMC in terms of improved quality will contribute to increasing the residents' feeling of appreciation from the decision-makers. This will reflect on their utilisation of the units, encourage them to preserve them, and increase their sense of responsibility towards the local community. According to the collected data, it is likely for the residents to accept their homes being built by this method as their primary concern is the final product. Providing homes with better quality, giving the flexibility to modify and extend and engaging them in the decision-making process are all factors that can contribute to the success of MMC adoption in social housing.

Regarding the workers, adopting MMC in the construction of social housing units might be challenging with respect to their acceptance and the quality of work. Special training will be required to qualify the workers and habilitate them to employ a new and different construction method than what they are used to. Developers willing to employ MMC need to seek younger generations of workers with higher motivation and the ability to learn new construction methods. It will help them absorb new knowledge and avoid resistance to change from the older generation of workers. Trainers will need to understand the workers' mentality and work on broadening their horizons to accommodate that advanced construction method. Moreover, the Egyptian workers' rebellious mindsets will require intense supervision during all

construction phases. Egyptian workers tend to override the rules and standards to finish any given task easier or comfortably.

5.2.6 Technology

Regarding technology, Egypt has achieved a low ranking in its innovation capabilities in the global competitiveness report (Schwab, 2017; Schwab, 2019). Egypt has fallen behind in ICT adoption and technological readiness, including robotics, artificial intelligence …etc. This can be due to the current emphasis on the physical infrastructure, such as roads but not much focus on the technological infrastructure. Lack of knowledge and limited resources in higher and technical education could be a contributing factor where Egypt has a low ranking in the quality of vocational training, the skillset of graduates and critical thinking in teaching (Schwab, 2019). In social housing construction, contractors are using manual handling methods, and traditional onsite construction approaches. The contractors do not have the knowledge or capabilities to modernise their construction methods.

A private residential developer has implemented prefabricated concrete panels (PCP) in a luxurious development. They have used the already available precast concrete technology to build residential units using PCP for the walls and floors of the units cast offsite, then transferred to the site for assembly. Although it might be expensive, this method of transferring and localising an MMC approach could be the optimum method to overcome the challenge of transferring MMC technology. It can introduce the MMC technology in a more suitable way to the conditions and knowledge of the construction professionals. Importing a closed system does not guarantee its successful implementation as it might be more expensive and unfeasible for social housing projects. Moreover, it might not be socially and technically compatible with the users, as the case in the ZHUN policy in Algeria in the 1970s, as previously mentioned in Chapter 2.

5.2.7 Infrastructure and industrial capabilities

Adopting MMC requires an industrial capability to accommodate innovation to produce new processes and products. Egypt has the physical capacity in terms of industrial cities and several factories in different locations, in addition to the improvements in the road network connecting industrial cities with new urban communities. Moreover, the Ministry of Planning and Economic Development (MPED) has published plans to establish 13 industrial complexes for SMEs and provide 10 million m2 of industrial lands to investors to increase the country's

industrial capacity and attract foreign investments. In addition, precast concrete factories are already available and produce precast concrete beams and columns for structural components. This means that the manufacturing of prefabricated construction components can easily be implemented in industrial facilities and infrastructure. MMC factories can be located close to new urban cities where new projects can be initiated to produce new social housing projects different from the traditional ones.

However, the challenge will come from the lack of innovation in the industrial sector as well as infrastructure. The majority of manufacturing firms are from the private sector. However, the innovation rate in other economic activities, including the construction sector, is less than 2% (Mohamed Ramadan A. Rezk *et al*., 2016). Moreover, the Egyptian workforce is still in arrears in digital skills and digitalisation as there needs to be more knowledge about innovative and technological terms such as artificial intelligence and robotics (Tariq, 2019). The Egyptian manufacturing industry has a long journey to achieve innovation as widely as developed countries. Thus, adopting MMC will require the gradual implementation of its approaches to avoid resistance and eliminate the risk of failure and rejection. MMC can be implemented by the manufacturing of some components of the social housing projects, such as toilet and kitchen pods or floor and wall panels. MMC components can be easily manufactured using the current industrial environment in Egypt. This will require advanced levels of quality control and coordination between construction and manufacturing teams which is quite challenging in both sectors in Egypt.

5.3 Quantitative findings

The questionnaire survey was conducted to identify the suitability of social housing units to the residents' needs and recognise issues and challenges in the current social housing. These findings are related to the research questions intended to recognise how MMC can address the socio-cultural needs of social housing residents. The questionnaire investigated three main factors that might affect the adoption of MMC in social housing in terms of adaptability and utilisation. The main points under investigation were:

1- The residents’ concerns from MMC.
2- Ratings of their current homes.
3- Their needs in future homes.

The analysis showed differences in the residents' opinions regarding the doubts arising from MMC and the ratings of their current homes. However, it did not show notable differences in

opinions concerning their needs in future homes. These differences were identified after grouping the resident according to their skill level, creating three main groups; highly skilled, semi-skilled and lowly skilled, where these assumptions have been made from their occupations. The findings from the quantitative analysis are discussed in the following sections.

5.3.1 Residents' concerns from MMC

The mean values of the residents' ratings for their concerns that would arise if their houses were prefabricated varied across the three groups. These values represented several factors to identify their importance to social housing units' current and future users. The highest-rated factor across all groups is "affordability". The affordability of units is the critical factor and primary concern in adopting MMC in social housing units. With the rising inflation rates and devaluation of the Egyptian pound, the affordability of units to the low-income groups decreases. This indicates the importance of the cost factor, previously confirmed by the qualitative findings, as prefabricated units must not exceed the cost of traditionally built units. However, according to the KW test results, there were significant differences in the residents' opinions regarding other factors. Overall, the highly skilled group had lesser concerns regarding MMC houses, as their average seemed lower than the other two groups. This could be corresponded to their knowledge and awareness level to trust innovative and technological construction methods.

On the other hand, the lowly skilled had the most significant concerns from all the factors regardless of their order which is different across the three groups as shown in Table 5.1, indicating that their skill and awareness level decreases their doubts against MMC would increase. Social housing units are targeted to the least advantaged households, meaning that the lowly skilled are the broader segment of users requiring more attention to increasing the awareness of MMC prior to implementing it. From the analysis, 94% of the participants indicated that they did not know the term Offsite prefabrication or MMC nor its applications.

Table 5.1: The differences in ratings of factors of concern from MMC between three groups

Highly skilled	Semi-skilled	Lowly skilled
Affordability	Affordability	Affordability
Ease of maintenance	Ease of maintenance	Ventilation
Ability to modify	Ability to modify	Quality
Ability to expand	Ability to expand	Ease of maintenance
Ventilation	Architectural design	Privacy
Sound/thermal insulation	Quality	Ability to expand
Privacy	Ventilation	Safety
Architectural design	Safety	Architectural design
Quality	Privacy	Ability to modify
Safety	Sound/thermal insulation	Sound/thermal insulation

The following highest doubts were "Ease of maintenance", "Ability to modify", and "Ability to expand", where they have been similar in highly skilled and semi-skilled groups. The lowly skilled group they were concerned with "Ventilation", "Quality", and "Ease of maintenance". Although "Ease of maintenance" was rated differently across the three groups, it is still a high factor of concern, highlighting the lack of maintenance issues in low-income units previously discussed in the literature and the qualitative findings. Implementing prefabricated social housing units must ensure high durability and ease of maintenance mechanisms. On the other hand, MMC units should provide the flexibility required for the residents to expand and modify their units as they were serious concerns from the high and semi-skilled groups. This confirms the importance of socio-cultural factors in adopting MMC, as discussed in Chapters 2 and 4. MMC should address the cultural norms of the residents and the importance of satisfying the extended family needs of the social housing users.

5.3.2 Ratings of current social housing units

The second part of the questionnaire was to evaluate the current housing units by the users by rating several factors. The results were ranked according to the residents' mean evaluation values. The KW test showed that there are significant differences between the three groups. The differences were in the rating values of the users' evaluation of their units, where the highly skilled groups gave the lowest overall ratings. In contrast, the lowly skilled group provided the highest ratings.

Moreover, there were notable differences between the ratings of factors which can be understood according to each group's preferences as shown in Figure 5.1. The lowly skilled group has given the highest mean values for the evaluation of their current homes opposite to the highly skilled whose ratings were the lowest. This can be interpreted as the highly skilled group tend to be more ambitious and looking for the better, so they see the current units as low standard. On the other hand, the lowly skilled group has given high evaluation meaning they believe that these houses are of high standard which could be interpreted as they appreciate what has been provided to them by the government. These differences in evaluation means that social housing units need to have more variations in designs and standards to increase the satisfaction levels of the residents in contrast to the single design and form currently being provided. Providing different social housing types could increase the potential of MMC to address the users' different needs instead of the current system of creating only a single form of units.

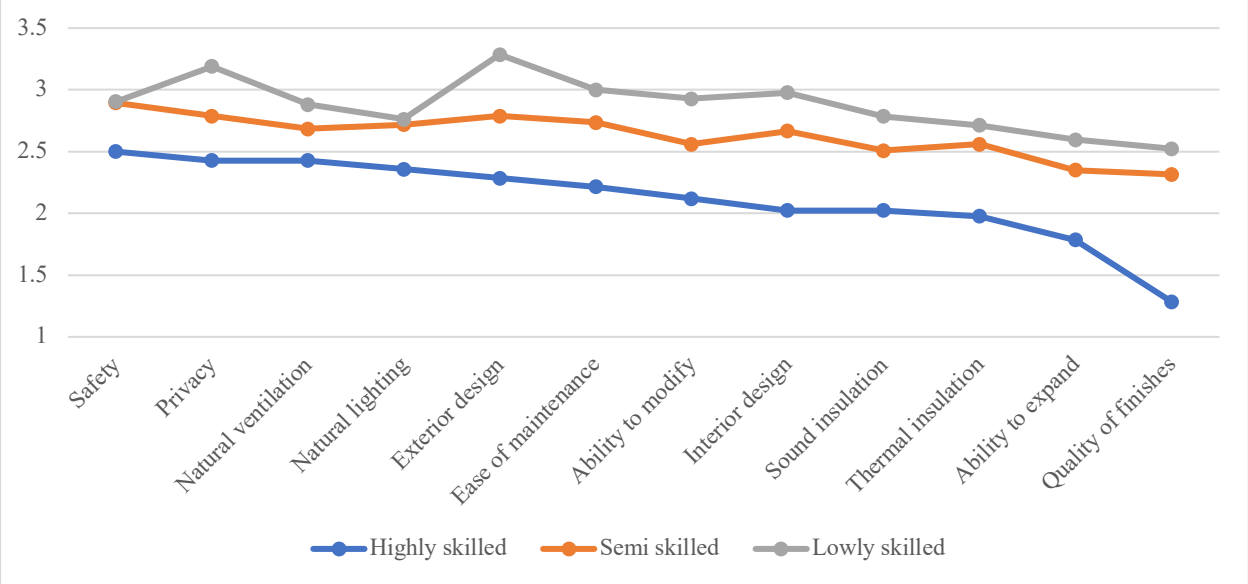


Figure 5.1: Resident's average evaluation of their current homes

The highest rated factors were "Safety", "Safety", and "Exterior design" in the highly skilled, semi-skilled and lowly skilled, respectively. In contrast, the second highest factor across the three groups was "Privacy", as shown in Table 5.2. These results disagree with previous studies; according to Diab and Abd El Aziz (2018), residents were not satisfied with the safety levels in their low-income housing. However, this indicates improvements in the safety and privacy levels in social housing units, especially in the capital rather than in other cities, as in Diab and Abd El Aziz's (2018) study. In addition, this could be related to improved architectural design where privacy has been better considered.

Table 5.2: Residents' ratings of current social housing units

Highly skilled	Semi-skilled	Lowly skilled
Safety	Safety	Exterior design
Privacy	Privacy	Privacy
Natural ventilation	Exterior design	Ease of maintenance
Natural lighting	Ease of maintenance	Interior design
Exterior design	Natural lighting	Ability to modify
Ease of maintenance	Natural ventilation	Safety
Ability to modify	Interior design	Natural ventilation
Interior design	Ability to modify	Sound insulation
Sound insulation	Thermal insulation	Natural lighting
Thermal insulation	Sound insulation	Thermal insulation
Ability to expand	Ability to expand	Ability to expand
Quality of finishes	Quality of finishes	Quality of finishes

In general, the highly skilled group were the least satisfied group, scoring the lowest evaluation among the three groups, while the lowly skilled group provided the highest averages. Furthermore, "Quality of finishes" has the lowest ranking among the three groups and obtains the lowest overall rating. This emphasises the ongoing issue of poor quality in social housing

units that have not been addressed until now. Adopting MMC requires prioritising the issue of poor quality of units which will, consequently, improve the durability of units and reduce maintenance needs. Moreover, other than "Ability to expand", "Thermal insulation", "Sound insulation", and "Natural lighting" achieved the third lowest ranking across the three groups. This indicates how the current housing system disregards the issue of sustainability and energy-efficient solutions in the built environment. Poor thermal and sound insulation and lack of natural lighting incur more energy consumption, leading to increased financial and environmental burdens on the users and the climate. More sustainable and environmentally friendly materials, designs and construction methods are required to improve the sustainability performance of social housing units which could be achieved through MMC approaches.

5.3.3 Residents' needs in future homes

Rating the factors influencing the residents in choosing their future homes was the objective of the final part of the questionnaire. The residents rated the factors according to their importance to them and how they might affect their decisions. The analysis of the results according to the KW test showed no significant differences between the answers of the three groups. This indicates that there are no considerable differences in the users' needs in future homes where the factors are ranked similarly across the three groups of residents, as shown in Table 5.3.

Table 5.3: Residents' needs in future homes

Highly skilled	Semi-skilled	Lowly skilled
Safety	Safety	Interior design
Quality of finishes	Privacy	Privacy
Privacy	Quality of finishes	Exterior design
Affordability	Interior design	Affordability
Interior design	Affordability	Safety
Natural ventilation	Thermal insulation	Thermal insulation
Thermal insulation	Sound insulation	Ability to expand
Sound insulation	Exterior design	Quality of finishes
Ease of maintenance	Ability to expand	Sound insulation
Exterior design	Ability to modify	Natural lighting
Ability to expand	Natural lighting	Natural ventilation
Ability to modify	Natural ventilation	Ease of maintenance
Natural lighting	Ease of maintenance	Ability to modify

The highest rated factors are "Safety", "Quality of finishes", and "Privacy", followed by "Affordability" and "Interior design". These factors can be achieved through MMC technology, where safety and privacy could be obtained through contemporary interior design, taking these into consideration in the early design stage. Moreover, the quality of finishes could be achieved from the improvements brought by MMC in the construction of units. As previously discussed, affordability could be obtained by the mass production of units in mega housing projects where the demand for an increased supply of social units is already in place.

5.4 Chapter summary

This chapter presented the discussion developed from the qualitative and quantitative data findings. The qualitative findings presented the main factors identified from the interviews and their interrelationships with the findings from the literature. The findings revealed seven key influencing factors that directly affect the implementation of MMC in Egypt. The seven factors include capital costs, construction industry capabilities, architecture and housing types, governmental policies and issues, social and cultural issues, technology and infrastructure and industrial capabilities. Furthermore, the quantitative findings presented the main challenges and needs of the residents in their current and future houses. It covered three main areas, the residents' concerns from MMC, the ratings of their current homes and needs in future homes. These findings establish the base for developing the framework for adopting MMC in social housing projects which will be discussed in detail in the next chapter.

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6 Chapter 6: Framework to adopt MMC for housing in Egypt

6.1 Introduction

In general, the results of the analysis of the collected data and the literature review showcased the relationships between the influencing factors and how they act as success factors, challenges or barriers to implementing MMC in social housing projects. The findings showed the problems that might arise from adopting MMC and how they can be mitigated or eliminated. The stakeholders in the social housing provision system have been identified, and what roles they could play in adopting MMC to implement it successfully. The relationships between factors and the information from the arguments allowed the researcher to formulate an adoption framework that considers the key factors affecting the implementation of MMC in social housing projects. This chapter will discuss the approach to developing a framework according to the research findings.

6.2 Critical success factors

Certain success factors can prompt MMC implementation in Egypt's low-income housing projects. These factors have been identified from the literature and the analysis of collected data. Modularisation and standardisation are success factors of MMC which corresponds to the nature of social housing projects. Social housing projects are designed in a single form of two- and three-bedroom flats. Implementing MMC in social housing will benefit from the modularisation advantage of producing modular units offsite and then transferring them to the site for installation.

Moreover, MMC can address the loss of architectural heritage through the modularisation of exterior elevations, which could be cheaper with the manufacturing production of units. Manufacturing architectural components could give architects better abilities to produce forms corresponding to any specific architectural style. Furthermore, MMC can provide more flexibility in designs to achieve the residents' needs for expansions and modifications. Achieving these benefits could gain the support of the government to encourage the implementation of MMC by increasing the supply of housing units and improving its performance.

Governmental support is a critical factor for MMC to be adopted and succeed in Egypt. The government can support MMC adoption in social housing projects in several ways:

- Develop policies that encourage the use of MMC approaches in social housing projects.
- Provide incentives for developers to stimulate investment in MMC for social housing projects.
- Secure enough units for the private sector implementing MMC to help absorb the high initial capital required for manufacturing facilities.
- Increase the awareness and knowledge of MMC to avoid the negative perception that might hinder its implementation.
- Ensure the engagement of social housing users in the decision-making process of developing new social housing units using MMC, considering their social and cultural requirements as well as their concerns and doubts.

Due to the complexity of adopting MMC and the requirement of large investments, the public sector should develop partnerships with the private sector while providing them with guaranteed financial and execution security.

From the literature review findings and the data collection, the current improvements in the physical infrastructure and the development of manufacturing facilities could create an adequate enabling environment to implement MMC. The availability of manufacturing capabilities alongside developed infrastructure in new cities and improved road networks have been determined to be a critical success factor for MMC implementation. In addition, the current precast concrete factories manufacturing precast concrete panels widely used in road and bridge construction could be developed to accommodate MMC for social housing units using the same technology. These factories can manufacture floor, wall and ceiling panels for housing units and create volumetric modular pods to be transferred and installed onsite.

Achieving sustainability in social housing units would be one of the critical success factors for MMC. As previously mentioned in Chapter 2, the country is taking serious steps to achieve its sustainable development goals, including encouraging innovation and technology and improving its sectors' environmental performance. Implementing MMC can help in achieving SDS goals through technology transfer of MMC technology to the social housing sector. MMC can address the housing shortage by increasing the supply of units to provide decent housing to a larger segment of the least advantaged households. Furthermore, it can help improve the sustainability performance of the construction sector by reducing construction waste and improving the quality and energy performance of social housing units. These factors meet the overarching goals of SDS, Egypt 2030, as well as the Egyptian housing policy, as has been

previously mentioned in Chapters 2 and 5, making it one of the critical success factors for MMC.

Developing partnerships with the private sector would enhance the implementation of MMC, making it one of the main factors for its success. Public-Private Partnerships (PPP) would bring mutual benefits for the private and public sectors to implement MMC in social housing units. These benefits include increasing the supply of social housing units, relieving the financial burden on the government and encouraging the private sector to invest in social housing by providing them with financial incentives and tax reliefs allowed by the current SHMFF law. This is because it will be challenging for the private sector to adopt MMC without the support of the public sector represented in the housing authorities to reduce the financial risk of the high initial capital in addition to securing large quantities of units. On the other hand, the public sector will not adopt MMC independently. The initiative to adopt it will come from the private sector as the government only provides plots of land and then contracts with contractors from the private sector to construct social housing units, as previously discussed in Chapters 2 and 5.

6.3 Challenges

Adopting MMC in social housing projects comes with numerous challenges that would hinder its successful implementation. Adopting MMC would be challenging with respect to the current capabilities of the construction industry, especially within the social housing contractors. Traditional construction is the sole method used to construct social housing units. Lack of innovation and technology in the construction industry will result in complications in transferring MMC technology to social housing projects. In addition, the need for more competencies and expertise, from the workers to the senior management, of MMC requirements in coordination and quality control would be another challenging factor. However, adopting MMC could upgrade the construction industry's capabilities to improve its performance with an experienced leader with the tools and expertise to coordinate and manage the implementation process from its inception to completion.

The high initial capital of establishing prefabrication factories to manufacture MMC components is the main challenge to its adoption. The government is struggling with economic challenges of high inflation, currency depreciation, the effects of the Covid-19 pandemic and the Russian-Ukrainian war. On the other hand, the private sector is facing economic challenges, too, including increasing prices and high inflation rates. Social housing contractors cannot

afford alone such high capital to support the implementation of MMC factories and their running costs. To adopt MMC in social housing projects, the unit cost should meet the current cost of traditionally built units which the cooperation of the private and public sectors can only achieve. This can be achieved by securing a large number of units in addition to using local materials and minimising the need to import any components as much as possible. Furthermore, private sector developers are only interested in investing in high-end and luxurious residential developments where it is much more profitable, according to the literature and the data analysis. Getting the private sector to invest in social housing projects would be one of the critical challenges where they must ensure substantial profits as much as they gain in luxurious developments.

From the literature review and data analysis, one of the main challenges to adopting and implementing MMC in housing is the negative perception and lack of awareness. Egypt's case would not be different; it is expected for MMC units to face resistance to its implementation from the workers and the residents. Although the resistance to change from the residents will be insignificant, where their primary concern is to obtain decent housing regardless of its construction method, it is expected to be more from the local workers. As previously discussed, the majority of construction workers gain their knowledge from their peers without proper technical education. It would be difficult to change their mindsets and the techniques they used to work with, which they learned from the beginning of their career, usually starting at a very young age.

The scarcity of technical education and training facilities within the construction sector will be challenging to adopt MMC. MMC requires a high level of skills and training due to the complexity of its manufacture and assembly. The issues of poor quality and low health and safety performance in the Egyptian construction sector must be addressed before implementing MMC, as it might cause severe problems during onsite assembly and handling. Although there is an abundance of unskilled workers due to the high unemployment rate and high population, it is challenging to train and qualify the required number of workers without developing proper training facilities.

Although the country is on the way to achieving its sustainable development plan, where one of its main pillars is promoting technology, innovation and digitalisation, in practice, the construction and manufacturing sectors are still arrear in implementing technology and innovation. Technology transfer in the social housing sector will be challenging due to the lack of technological readiness. It relies only on manual handling and traditional construction

methods, in addition to a lack of digital infrastructure. MMC is considered an advanced innovation with respect to the current social housing construction environment, creating a high challenge to its implementation without considering the capabilities and knowledge of the current practitioners. This has been reflected in the limited adoption of MMC approaches in the Egyptian construction industry of precast concrete panels used in civil works.

6.4 Barriers

From the data analysis and the literature review, several factors have been identified as foreseeable barriers to MMC adoption in social housing projects. Firstly, contracting companies operating in social housing projects would only accept MMC as a construction method if they were familiar with it. As previously discussed in Chapter 5, the contractors working in social housing projects are small contractors mainly employing traditional methods that their workers have learnt from their predecessors. They are expected to have inflexible mindsets that are hard to accept change in methods. Moreover, there would be speculations that MMC would lead to unemployment among social housing workers as manufacturing would replace their skills, and they would not be needed anymore.

In the same context, a lack of knowledge about MMC would be a barrier to its implementation as well as a challenge, as previously mentioned. It would cause several hindrances to its implementation among decision-makers, workers, residents and financial institutions. Knowledge of MMC needs to be shared among all stakeholders emphasising the advantages and benefits it could bring to the social housing and construction sectors. Accepting MMC would act as one of the main barriers to its implementation in social housing projects requiring strong leadership and project management skills to manage change as needed with the contractors and the workers.

These barriers are interrelated with the Egyptian workers' and residents' social and cultural aspects. Change management is required to deal with the abovementioned barriers, including the lack of MMC knowledge, the resistance to change and rigid mindsets. According to Lines *et al*. (2015), precise change management is required while implementing a new practice to simultaneously assist the transition from traditional approaches. Change management agents may be required to foster the implementation of MMC within SHC to mitigate the effect of change on the stakeholders. The main task of these agents is to deal with the framework's short- and long-term goals and manage the coordination between different organisations.

Furthermore, the capital costs of MMC would be one of the main barriers to its implementation as well as a challenge. Securing the initial funding to establish the required facilities to implement MMC would be extremely difficult, especially with the current economic challenges facing the Egyptian economy. It is believed that social housing contractors (SHC) do not have the economic capacity to fund the capital costs of MMC. This would require collaboration between the private and public sectors to fund this capital to reduce the financial risks of MMC implementation.

6.5 The framework

Considering all the factors, the proposed framework in Table 6.1 consists of seven main pillars. These pillars consider the critical success factors and the challenges and barriers, including the phases of implementation to ensure the successful adoption of MMC in social housing projects. The framework is based on the findings from the literature review analysis and the findings of the qualitative and quantitative data analysis. The seven pillars are discussed in the following sub-sections.

6.5.1 Costs

The high capital cost of establishing factories is the main challenge to adopting MMC in social housing projects. The housing ministry is continuously challenged to provide affordable housing units to the poorest at the lowest possible cost. Adopting MMC must not incur any extra financial burden on the public or private sectors. To overcome this challenge, partnerships between the private sector and SHMFF must be established to benefit from tax redemption. Financial incentives could be obtained according to law (93) of the mortgage law. This will help reduce the initial costs and, consequently, increase the SHMFF investments in social housing. Furthermore, SHMFF should secure contracts with a large number of units to the entity adopting MMC to absorb the high capital cost and reduce the unit cost. The adoption of MMC in social housing projects should be in the form of collaboration between the private sector, as leaving the financial burden on one entity will not be economically viable.

6.5.2 Skills and training

Social housing contractors (SHC) must have the technical or financial capacity to provide adequate training facilities to unskilled workers on MMC. The government, alongside technical education providers, should support SHC in developing technical training facilities, including

MMC. From the analysis, respondents stated that SHC might need to learn about MMC, including its advantages and known benefits. In order to improve the performance of the construction industry, technical education providers and the government need to support contractors in increasing their training facilities. Furthermore, this will also lead to benefiting from the unskilled workers available in abundance in Egypt.

6.5.3 Architecture design

From the analysis, architecture design is considered one of the critical success factors for MMC in social housing projects for several reasons. It has been indicated that social housing units have poor architectural designs, lack flexibility and have a single-unit design. In addition, residents are not involved in the early design stages. Resolving these issues using MMC could significantly improve the function ability, usability and residents' satisfaction. MMC could have a significant role in restoring the architectural heritage, which will act as a supporting factor in implementing it. In the framework, Designers, SHMFF, local councils and the residents would collaborate to design social housing units to satisfy the users' needs and improve the interior and exterior designs using MMC approaches.

6.5.4 Governmental support and policies

Including MMC in housing policies and encouraging them by the government is influential in implementing MMC. Housing policies need to address MMC in social housing, where the current housing policies aim to prompt innovative housing approaches to affordable housing. However, it is not applied, as the dominant construction method is the traditional method. The government can support MMC implementation by providing financial incentives to SHCs that adopt MMC. The government should also increase the awareness and knowledge of MMC approaches to contractors and users.

Moreover, the framework provides insights into sustainability issues and cost efficiency to be addressed through MMC. The framework seeks to emphasise the government's sustainability policy aiming to develop environmentally friendly smart cities through encouraging innovation and technology in social housing. The framework also addresses the diversity of the residents, where policies should ensure the specific needs of the locals in each area according to their culture and local environment.

6.5.5 Social and culture

The social and cultural aspects have been indicated to influence the adoption of MMC in housing projects strongly. To adopt MMC, the residents need to be involved in the early design stages, as previously discussed in Chapter 5. According to the quantitative analysis, privacy and safety features were among the highest factors that need to be considered in social housing designs. Moreover, the framework addresses the factor of MMC knowledge and awareness due to its influence on MMC adoption, as indicated in previous studies. On the other hand, from the workers' aspect, the framework targets the younger generation of new workers to learn and develop the skills required for the MMC approach to eliminate the resistance to change that might hinder its implementation from older workers. Strong leadership and supervision are addressed in the framework, which should be from the local community for easy communication and coordination with the workers.

6.5.6 Technology

Referring to the weak technological environment of Egypt and the need for more innovation in the construction industry, the technology transfer of MMC to social housing projects needs to be gradual to avoid resistance and failure of its implementation. The gradual adoption of MMC approaches could be using prefabricated panel systems or volumetric modular systems for bathroom and kitchen pods. The available precast concrete factories in Egypt can be modernised to include MMC systems for social housing projects benefiting from its current knowledge and experience in precast concrete. This will allow developers and investors to cope with the poor technological readiness in the construction sector and to adapt gradually to MMC approaches.

6.5.7 Manufacturing industry

Due to economic and technical challenges, it will not be practical to establish new factories from scratch to adopt MMC in social housing. It would be more feasible to utilise the current precast concrete factories to adopt MMC techniques for social housing projects. This will help integrate the concepts of MMC into the manufacturing industry to adopt it and elevate its implementation gradually. Furthermore, new social housing projects must be launched close to current industrial zones to reduce transportation costs and duration. This could potentially encourage manufacturers and SHCs to invest in MMC for social housing projects. However, to achieve success in adopting MMC, strong project management and leadership are required

to ensure robust coordination between construction sites and factories. In addition, to ensure that quality control and assurance measures are in place to prevent costly issues as much as possible

Table 6.1: Framework for adopting MMC in social housing projects.

Influencing Factors	Objective	Activity	Key stakeholders
Costs	- Ensure the cost of prefabricated units is ≤ traditional methods. - Absorb capital costs by securing contracts with a large number of units	- Establish partnerships with the private sector to build social housing units - Secure contracts with a large number of units	- SHMFF - Social housing contractors (SHC)
Skills and training	- Increase training facilities for SHC. - Train and develop unskilled workers available in abundance. - Modernise current construction methods	- Provide training support to SHC. - Provide technical education incentives to SHC.	- SHC - SHMFF - Education providers
Architecture design	- To restore the architectural heritage. - Provide more flexibility for expansions and modifications. - Increase the users' satisfaction.	- Improve the architectural design of interiors and exteriors - Work on more flexible design of units - Increase the variations of designs. - Involve the residents in the early design stage	- Designers - Social housing residents - Local councils - SHMFF
Governmental support and policies	- Increase knowledge and awareness of MMC.	- Include MMC in social housing policies.	- Housing authorities. - SHC

	- Encourage SHC and the private sector to invest in MMC. - Improve the sustainability of the social housing projects in the construction and utilisation phases. - Ensure addressing the specific needs of the residents in each area according to their local environment and culture.	- Provide financial incentives to the private sector and SHC implementing MMC. - Ensure sustainability and cost efficiency through MMC in social housing. - Develop policies that consider cultural and social aspects of the residents, including diversity.	- SHMFF
Social and culture	- To reduce resistance to change. - To ensure good quality in manufacturing or assembly. - To increase the adaptability and satisfaction of residents and workers.	Residents: - Increase the safety and privacy aspects of social housing units. - Increase knowledge and awareness of MMC.	- Project managers - Designers - SHC - SHMFF
		Workers: - Attract the younger generation of workers to learn MMC methods. - Ensure strong local leadership and supervision.	

Technology	- To cope with poor technological readiness. - Gradual adaptation to MMC approaches.	- Ensure gradual technology transfer. - Employ available prefabrication manufacturing capabilities and modernize them.	- Manufacturers. - SHC - Designers - Project managers
Manufacturing industry	- Gradual adaptation to MMC approaches and upgrading of current manufacturing facilities. - Encourage manufacturers and SHCs to invest and implement MMC in social housing. - Improve quality control measures and ensure robust coordination between factories and construction sites.	- Utilize the current precast factories to adopt MMC in social housing. - Launch new social housing projects close to current industrial cities. - Provide strong project management and leadership.	- Manufacturers - SHC - Private sector investors. - SHMFF

The main influencing factors identified from the data analysis and the literature are the critical pillars of the framework. As shown in Table 6.1, the framework provides a series of activities linked to a set of objectives that influence the implementation of MMC. For each factor, specific objectives are to be achieved by implementing the relevant activities by the relevant stakeholders. The framework presents a holistic approach that covers all corresponding factors affecting the adoption process of MMC. It focuses on the challenges and barriers of the housing and construction sectors and how they can be addressed. In addition, it concentrates on the critical success factors that will help achieve the successful implementation of MMC. The factors, as investigated from the data analysis and the literature review, are compiled in Figure 6.1 alongside the key stakeholders to implement the framework.

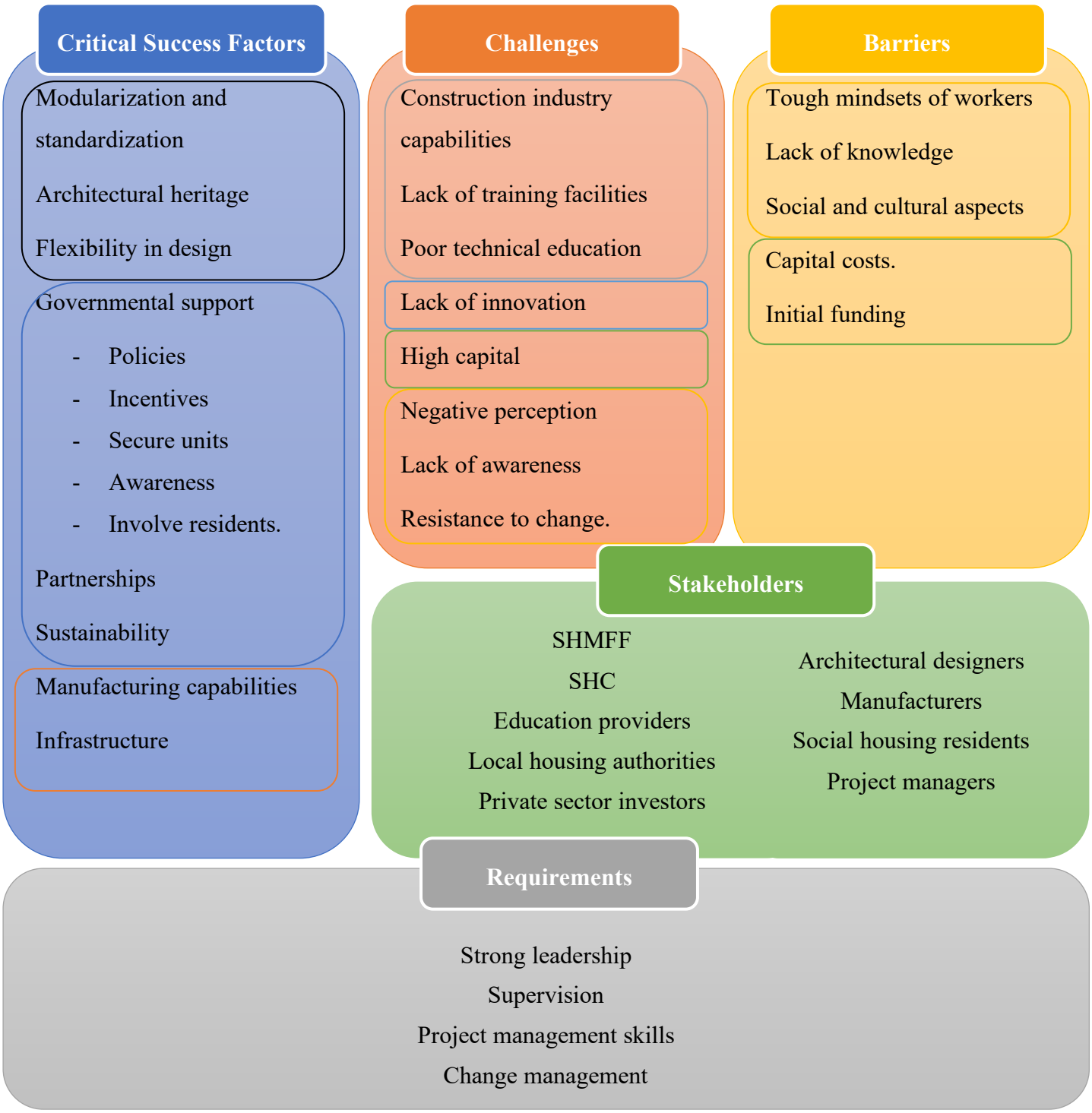

Figure 6.1: Factors and stakeholders of the framework

6.6 Factors-pillars relationships

The factors in Figure 6.1 have influenced the development of the framework in relation to its pillars and the activities in each one. Certain factors influenced the activities and objectives of each pillar by taking into consideration the success factors, challenges and barriers. The factors are interrelated to the activities and objectives directly and indirectly. Thus, it is important to show the connection between all the elements as a whole to provide a clear understanding of

the implementation of the framework. The relationships between the factors and the pillars are discussed below.

6.6.1 Costs

The first pillar is concerned about the initial funding and high capital costs which are the main challenges and barriers to the framework. The objectives of this pillar are based on the findings of the qualitative and quantitative data analysis where the main factor of concern was the cost per unit of MMC does not exceed the cost of traditionally built units. In addition, according to Table 5.1, Affordability was the highest factor of concern of MMC from the residents. Thus, it is crucial to ensure that the construction costs of MMC units does not exceed the costs of the traditional units. It could be achieved by securing large number of units to the entity implementing MMC in social housing projects to absorb the high capital costs. Moreover, a partnership between SHMFF and SHC is one of the main success factors for MMC to help in securing the initial funding required to establish the manufacturing facilities of MMC in addition to the governmental support represented in the financial incentives and policies to include MMC in social housing projects.

The key stakeholders of this pillar are the SHMFF and SHC where their partnership would help in minimizing the challenge and barrier of high capital costs and initial funding. This partnership would reduce the financial risk by distributing it on both parties through securing large number of units to the partnership to absorb the high initial capital. In addition to benefit from the tax reliefs and financial incentives that SHMFF could provide to the framework.

6.6.2 Skills and training

The second pillar addresses the identified challenges of the construction industry's capabilities. Several factors have influenced the second pillar including the lack of training facilities from the private sector and the poor technical education. The aim of this pillar is to improve the performance of the Egyptian construction industry through the implementation of MMC in social housing projects. This would happen through the collaboration between SHMFF, SHC and education providers to work on several axis related to training and skills. SHMFF would provide incentives to SHC to increase their training facilities to develop MMC knowledge and skills to their current workforce. Moreover, SHMFF and education providers to develop the technical education facilities to include technological knowledge of MMC to novice workers in construction.

This pillar combines the critical success factors of governmental support which includes providing training incentives and the abundance of unskilled workers with the challenges of lack of training and poor technical education to achieve successful implementation of MMC and help in improving the performance of the Egyptian construction industry. achieving the objectives of this pillar would support in leveraging the skills and knowledge of MMC in the Egyptian construction industry and, consequently, improve its capabilities.

6.6.3 Architecture design

The architecture pillar considers several factors that would support the implementation of MMC by combining the success factors identified from the data analysis and the challenges and the needs of the residents as identified from the quantitative analysis. Architectural designers would collaborate with the SHMFF, local councils and residents to improve the liveability and function ability of social housing units with emphasis on the social and cultural requirements of the residents including the growing family needs. The pillar takes into consideration the lack of awareness and knowledge of MMC among the residents where house designers will work closely with the residents to raise their knowledge of MMC and its advantages that could bring to their living conditions. In addition, designer to work with local councils in increasing the variations in design in accordance with the specific requirements of each area in order to consider the social and cultural differences between different regions.

The standardisation and modularization factors are considered as success factors in the architecture pillar by benefiting from the single design form of social housing units. In order to achieve this, designers and SHMFF should consider MMC in the early design stages to identify the maximum potential of MMC technology that could be adopted in social housing projects. Furthermore, the architectural heritage is also considered where the designers to include the architectural components that correspond to the Egyptian heritage to social housing projects in cooperation with SHMFF while ensuring that the overall costs do not exceed the cost of traditional construction methods.

6.6.4 Governmental support and policies

The governmental support pillar takes into account the critical factors that can achieve success in adopting MMC in social housing projects in Egypt. The aim of governmental support is to enhance the factors that can prompt the implementation of MMC by developing a series of activities. The SHMFF as the main governmental entity of providing and planning social

housing projects would be responsible for supporting the implementation of MMC in their projects. SHMFF would collaborate with SHC to provide financial incentives in order to encourage them to invest in MMC. The financial benefits would be conditional on adopting MMC to encourage the private sector and SHC to start investing in it. This is to mitigate the financial risks addressing the costs challenges and barriers. The SHMFF to address the lack of knowledge and awareness of MMC by conducting media campaigns to introduce the advantages of MMC including its social, cultural and sustainability benefits.

Moreover, SHMFF to address the cultural and social aspects of the residents through collaborations with the local councils and housing authorities to develop housing policies that address the needs of the residents locally through MMC. The main aim is to consider the diversity of the residents between different regions in the country which could be achieved by involving the residents by the local councils in the early design stages of social housing projects. early consideration of the cultural, environmental and social factors in design and implementation increases the success rates of MMC according to the data obtained from the literature review previously in Chapter Two. On the other hand, adopting MMC helps in achieving the sustainability and innovation goals of the government in accordance with the country's Egypt 2030 policy. SHMFF would work with housing authorities and SHC to set new housing policies that encourage the adoption of MMC in social housing projects to foster the sustainability performance and innovation in them.

6.6.5 Social and culture

The social and cultural pillar is aimed at preserving the socio-cultural identity of the residents in addition to the social and cultural challenges identified from the data analysis. Firstly, it addresses the cultural challenges identified in the qualitative analysis including tough mindsets of workers and resistance to change. These challenges are addressed by targeting younger generations of workers to learn and gain the required skills to adopt MMC. These aspects are interrelated with the provision of training facilities and training incentives from the SHMFF and education providers. It will help in reducing the effect of the negative perception of prefabricated houses as previously documented which would act as a barrier to MMC implementation in addition to raising the awareness and knowledge of MMC. Furthermore, the resistance to change is also addressed by requiring change management agents to assist in the transition to MMC approaches from the traditional approach. This develops an interrelationship

between the project managers, SHMFF and SHC to manage the change from the senior management and decision makers to the workers.

The socio-cultural factors of the residents are also considered where the safety and privacy factors scored the highest ratings according to Table 5.3 in the quantitative findings in Chapter Five. Designers need to give careful consideration of these aspects during the design process with the residents. Involvement of the residents in the early design stage is crucial to the success of MMC adoption to ensure it satisfies the specific socio-cultural aspects in the design. It will also contribute to reducing the negative perception of MMC, increase its knowledge among the residents and increase the awareness of MMC technology. In addition, SHMFF and SHC to ensure strong supervision in the manufacturing and assembly of the units to improve the quality of units and users' satisfaction to achieve successful adoption of MMC units.

6.6.6 Technology

The lack of technological readiness is the main factor to deal with in this pillar. To avoid resistance to implementation of MMC, the framework considers gradual technology transfer for the adoption of MMC in social housing projects. The main activity is to implement BIM in social housing projects to overcome the coordination challenges that would arise between the factories and construction sites. This requires the full coordination between manufacturers, designers and SHC to utilise BIM when adopting MMC in their projects. the lack of technology interrelates with the construction industry capabilities which requires strong project management skills to manage the technological adaptation within social housing projects.

6.6.7 Manufacturing industry

The current manufacturing capabilities of Egypt and the improvement in the physical infrastructure are the main critical success factors. The aim of this pillar is to benefit from the availability of precast factories and upgrade them to adopt MMC technology for social housing projects. This would be less expensive to establish new factories, therefore, it would overcome the initial funding and high capital barriers for MMC adoption. Manufacturers and SHC would be encouraged to invest in MMC through financial incentives that could be potentially provided by SHMFF to adopt MMC in social housing projects. As previously mentioned, governmental support is crucial to manufacturers and SHC to adopt and implement MMC through the financial benefits available by law to invest in innovation and sustainable approaches in the construction of social housing.

Benefiting from the improvement of the road infrastructure and the availability of industrial cities, the framework addresses this success factor by launching new social housing projects close to industrial cities to limit the transportation issues. It will be easier to manufacturers and SHC to have the manufacturing facilities close to construction sites to improve coordination and management of projects. Furthermore, the pillar considers the social and cultural factors in the manufacturing industry represented in poor quality control and lack of coordination by addressing the need for strong project management skills and leadership. Supervision and project management skills are essential to successful MMC implementation to minimize coordination issues that would arise from the complex manufacturing and assembly requirements of MMC.

The relationships between the pillars and the factors including the overlapping of various activities are summarized and presented in Figure 6.2. the figure illustrates the pillars, critical success factors, challenges, barriers, involved stakeholders and the required skills to implement the framework. It shows the interrelationships between the pillars and the corresponding factors that influences its objectives and activities. In addition, it represents the involved stakeholders and the relationships between them and the pillars and what factors affects their responsibilities.

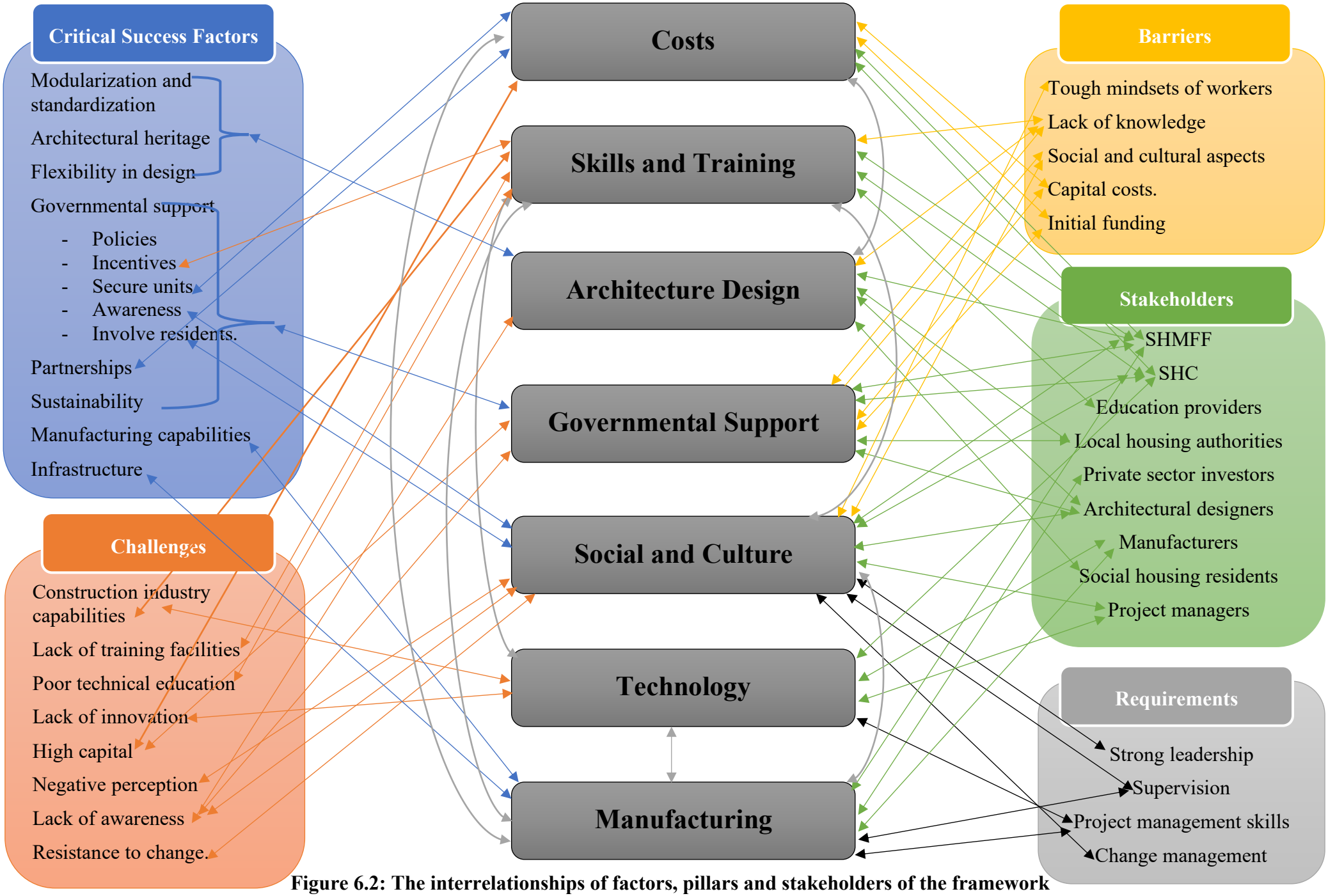

Figure 6.2: The interrelationships of factors, pillars and stakeholders of the framework

The framework provides an understanding of the specific nature of the Egyptian construction and housing sectors, where its main target is to integrate MMC systematically. To implement this framework, the activities must be executed sequentially to ensure a successful adoption process. Thus, the framework considered a multi-phase approach to achieve successful implementation by combining certain activities from the seven pillars. Table 6.2 illustrates the phases of implementation of the framework by presenting the activities in order of execution, and the stakeholders involve in each activity.

Table 6.2: Phases of the implementation of the framework

Phase	Activity	Stakeholders
Phase 1 Strategy planning	- Establish partnerships with the private sector to build social housing units.	- SHMFF - SHC
	- Provide technical education incentives to SHC.	- SHMFF - SHC - Education providers
	- Include MMC in social housing policies.	- SHMFF
	- Provide financial incentives to the private sector and SHC implementing MMC.	- SHMFF
	- Develop policies that consider cultural and social aspects of the residents, including diversity.	- SHMFF - Local housing authorities
Phase 2 Strategy implementation	- Secure contracts with a large number of units.	- SHMFF - SHC
	- Launch new social housing projects close to current industrial cities.	- SHMFF - Local authorities
	- Increase knowledge and awareness of MMC.	- SHMFF - Education providers
	- Attract the younger generation of workers to learn MMC methods.	- SHC - Education providers - SHMFF
	- Ensure gradual technology transfer.	- Manufacturers - Private sector investors
Phase 3 Operational strategy	- Design social housing units to be MMC-friendly.	- SHMFF - Architectural designers - Manufacturers
	- Improve the architectural design of interiors and exteriors	- Architectural designers - SHMFF
	- Increase the variations and flexibility of unit designs	- Architectural designers - SHMFF
	- Ensure sustainability and cost efficiency through MMC in social housing.	- SHMFF - SHC
	- Increase the safety and privacy aspects of social housing units	- Architectural designers - SHMFF
Phase 4 Execution strategy	- Employ available prefabrication manufacturing capabilities and modernise them.	- SHMFF - Manufacturers - SHC
	- Utilise the current precast factories to adopt MMC in social housing.	- SHMFF - Manufacturers - SHC
	- Provide strong project management and leadership.	- Local authorities - Project managers - SHC
	- Ensure robust supervision and monitoring locally.	- Local authorities - Project managers - SHC

6.7 Phases of implementation of the framework

To ensure the successful implementation of the framework, it needed to be divided into a series of phases where each phase contains several activities to be performed by the relevant stakeholders. As shown in Table 6.2, the framework's activities are divided into four phases. The first phase is the strategy planning stage, where the main stakeholder involved is the SHMFF, the authority responsible for setting the policies and planning social housing projects. The SHMFF will work with SHC and local housing authorities to develop policies that encourage the adoption of MMC in social housing projects. SHMFF will need to establish partnerships with the private sector to build social housing units using MMC. The goal of these partnerships is for the private sector will benefit from the financial incentives SHMFF could bring according to Law 93 in 2018. These incentives include education incentives for the private sector to invest in technical education and training facilities to train unskilled workers to teach and learn the required MMC skills.

In phase 2, the strategy implementation is formulated by setting the next series of steps to achieve the goals of phase 1. Through Public-Private Partnerships (PPP), the main target is to secure contracts with a large number of units to help absorb the high initial costs of MMC and reduce the cost of units. This could be achieved by implementing new social housing projects close to industrial zones, which could be coordinated between SHMFF and local authorities. Simultaneously, SHMFF will need to increase the knowledge and awareness of MMC, including its benefits and improvements it could bring to the construction sector and the housing sector as well. This will require collaboration between SHMFF, technical education providers and SHC to prompt MMC adoption and implementation. Furthermore, manufacturers and the private sector will be working to ensure the gradual technology transfer of MMC to the manufacturing sector.

The SHMFF will collaborate with architectural designers in the third phase to work on the current social housing sector's current challenges. The design of social housing projects implemented under this framework must consider MMC approaches for its construction. Architectural designs would focus on reviving the Egyptian architectural heritage by benefiting from the standardisation nature of social housing units and the advantage of MMC technology that could introduce specific architectural styles relevant to the Egyptian heritage. This includes improvements to the architectural designs of the units to provide more flexibility and better interior and exterior designs. In addition, the safety and privacy factors require more focus from

SHMFF and architectural designers as they were the highest-rated factors from the quantitative analysis.

Moreover, in this phase, SHMFF and SHC need to ensure the sustainability and cost efficiency of the construction of social housing projects. Stakeholders should ensure a more sustainable construction process by utilising more sustainable materials, reducing onsite work and reducing construction waste which can be achieved by MMC approaches. In addition, prompt environmental performance and energy efficiency in social housing units are one of the main drivers of adopting MMC, as previously mentioned in Chapter 2.

The purpose of the fourth phase, the execution strategy, is to establish the manufacturing facilities for social housing projects and to start production. Collaboration between SHMFF, manufacturers and SHC is required to explore how the current precast manufacturing facilities can be developed to employ MMC in social housing projects. SHC and manufacturers to identify the appropriate MMC method to be implemented to ensure that it meets their capabilities. In the beginning, panel systems or sub-assemblies could be adopted to manufacture specific components of the units that can be standardised. This is to ensure that it can be easily integrated within the current practices of the construction sector and could be taught to the current workforce. With the steady progress of adopting MMC in social housing, developing training facilities, and understanding MMC approaches, more complex prefabrication methods could be adopted, such as volumetric units that can be used as bathroom and kitchen pods with the goal of manufacturing fully functional housing units offsite.

Eventually, strong leadership skills and project management knowledge are required to adopt MMC successfully in social housing projects. This is required due to the complexity of the process and the large number of stakeholders involved; in addition, the need to satisfy the requirements of each stage provides adequate coordination between them. Moreover, during the execution of projects, robust supervision and monitoring are crucial for successful implementation from local authorities due to the social and cultural differences between various locations.

6.8 Utilisation of the framework

The framework is proposed to assist decision-makers in adopting MMC in social housing units as an innovative construction method that can increase the supply rate of units. The framework offers decision-makers a structured approach to assess the benefits, challenges, and implications of implementing MMC in social housing. It presents a clear roadmap to guide

decisions from policy formulation to project implementation. Decision-makers can use the framework to create policies that support and incentivize MMC adoption. This includes offering financial incentives and establishing partnerships with various stakeholders. The framework helps decision-makers allocate resources more effectively. It identifies key areas such as training, research, quality assurance, and public engagement, ensuring that resources are directed where they are most needed.

The framework emphasizes collaboration with various stakeholders, including government agencies, the private sector, designers, and residents. Decision-makers can use these collaboration opportunities to garner support, gather diverse perspectives, and ensure successful implementation. Decision-makers can use the framework's long-term planning component to align MMC adoption with broader development goals, ensuring sustainable housing solutions for the future. The framework's public awareness and engagement component can help decision-makers build public support for MMC-based projects. Informed communities are more likely to embrace new construction methods and contribute to their success.

Decision-makers can use the framework to design pilot projects that demonstrate the feasibility and benefits of MMC. Successful pilot projects can then be scaled up to address larger social housing needs. Decision-makers can align MMC adoption with Egypt's sustainability goals using the environmental considerations component of the framework. This ensures that housing projects contribute to broader environmental and social objectives. The framework serves as a strategic guide for decision-makers in Egypt. It empowers them to make well-informed choices, engage stakeholders effectively, allocate resources efficiently, and ultimately enhance the quality, efficiency, and sustainability of social housing projects through the adoption of Modern Methods of Construction.

Adopting this framework enables stakeholders to take serious steps into improving the performance of the construction of social housing units and its utilisation according to the noted benefits of MMC discussed in the literature. Consistent coordination and collaboration between involved stakeholders are crucial for the successful implementation of the framework due to the complex interrelations between its objectives and activities. The framework provides a management strategy for the technology transfer of MMC into the social housing sector and the construction industry.

To implement the framework, a project manager should be employed at the beginning to coordinate the relationships within each phase and between the phases. This is required due to the interactions between the participants, where each element of the framework involves several stakeholders. They will need to keep in mind the critical success factors, challenges and barriers to ensure they are associated with the progress of the adoption process. It will support the project manager and participants in tackling the problems that may arise by analysing them against the identified factors. Although adopting MMC will be through the private sector in terms of manufacturers and SHC, governmental authorities, represented in SHMFF and local authorities, strongly influence the implementation of the framework. Governmental support is crucial to successfully implement the framework by initiating social housing projects according to its requirements and following its phases.

Nevertheless, it is expected that there will be challenges when the framework is implemented. Due to the complexity of the process and the diversity of the stakeholders, several hindrances and uncertainties might arise during its implementation. Robust coordination, collaboration and transparency are required between all stakeholders to achieve implementation success. Moreover, completing all the framework phases will consume much time bringing uncertainty to the process; however, this can be tackled by employing a dedicated committee responsible for supervising and monitoring all phases of the framework.

6.9 Validation of the framework

To ensure the practicality of the proposed framework, it is significant to validate its practicality in social housing projects in Egypt. Validation helps ensure that the data collected accurately represents the intended constructs or concepts being studied. It improves the understanding of what is being measured in the research (Paredes, et al. 2021). By validating the interview questions and protocols, researchers can enhance the reliability of the data collected. Validation strengthens the trustworthiness of the study from the perspective of the researcher, the informant, and the reader. It helps address ethical concerns and ensures that the research findings are credible and trustworthy (Lindheim, 2022). By validation, researchers can demonstrate the rigour and validity of their research to the broader academic and professional community.

Interviews in construction management research provide an opportunity to gather qualitative data on practitioner opinions and experiences. By validating through the interview approach, researchers can ensure that they are capturing the most relevant and valuable information from

the participants (Hansen, 2021). Validation in construction management research can also contribute to quality management in the construction industry. It is crucial in construction management research as it ensures the accuracy, reliability, credibility, and trustworthiness of the data collected. It also helps gain valuable insights and perspectives from participants and contributes to quality management in the construction industry.

Validation is essential to test the effectiveness of the framework from the point of view of expert practitioners in the construction and housing sectors. This ensures that the identified factors in this research correspond practically to their intended use and influence on the adoption of MMC in social housing projects. Validation is a process that assures that a process or a system accomplishes its intended requirements and realistically meets the stakeholders' needs. In this section, the validation of the framework is presented and discussed from the validation interviews performed to validate the framework.

The framework was validated by conducting seven interviews with construction management experts and academics to provide their opinions. The participants were selected according to their knowledge of the Egyptian construction and social housing sectors, with their experiences ranging between 10-25 years, combining academic and practical experience. Academics are often familiar with the research process and can provide valuable feedback on the design and methodology of a study, which can help to ensure its validity and reliability (Rozali *et al*., 2022). Academics are often chosen for research validation due to their expertise and experience in the field being studied, and their feedback can help to ensure the validity and reliability of a study. Their deep understanding of the subject matter allows them to critically evaluate the research methodology, data analysis, and conclusions presented in a study. The participants are based in Egypt and have been working in the Egyptian construction industry for more than 15 years. They have been chosen for their involvement in the Egyptian housing and construction sectors. Four participants are professors, senior lecturers and assistant lecturers of construction management in Egyptian universities. The other three – one is the CEO of an architectural and project management firm with a Doctorate specialising in public housing. The other two are senior architects in urban design and technical office managers.

6.9.1 Discussion of Feedbacks

The interviews were performed face-to-face with each participant individually at their chosen venue, which has been their workplace. Each interview lasted between thirty minutes to one hour, depending on the length of the discussion and the information provided by the

interviewee. The interviews started with the researcher introducing himself and the background of the research, research aim and methodology. The framework was presented and explained, emphasising the factors that influenced it, how it will be used and the involved stakeholders. The critical success factors, barriers and challenges influencing the adoption of MMC in social housing projects were presented to the participants to provide their opinions about them and their relationships to the utilisation of the framework. Lastly, the participants were asked to provide their recommendations and suggestion for any improvements to the framework and its application.

6.9.1.1 Discussion of success factors

Starting with describing the critical success factors of adopting MMC identified in this research, the researcher explained them and their expected influence on implementing MMC in social housing projects. The interviews included a discussion of how the critical success factors have been recognised and how each factor could affect the implementation of MMC. All participants agreed that the critical success factors presented are comprehensive, and each factor significantly influences the adoption of MMC. The participants were asked to select the most critical success factor in adopting MMC; five participants stated that governmental support is the most important, one mentioned quality, and one said standardisation.

As stated by the five participants, governmental support is the critical success factor for MMC to be adopted in social housing projects in Egypt. They said that without it, it is going to be very difficult for the private sector to implement MMC solely without the support of the public sector. According to the participants, governmental support could be in various forms, including providing lands for MMC factories and social housing projects close to them, emphasising employing MMC in social housing projects by providing extra financial support and prioritising SHC who employ them in the bidding processes. It was agreed among the participants that SHC does not have the capacity to adopt MMC solely without governmental support.

One participant illustrated that the improvements in quality that MMC can bring are the most critical success factor due to the poor quality of the current social housing units. They stated that increasing the reliance on machines instead of human skills in construction will improve the quality and efficiency of buildings and increase their life span. This will help in a long time saving for the government as the leading funder of social housing units and the users by decreasing utilisation and maintenance costs. On the other hand, the last participant argued that

the nature of social housing projects is building identical unit designs all over the country; therefore, if these units are manufactured, then it will be of remarkable benefit to the housing and construction sector. They mentioned that standardisation is a substantial success factor for adopting MMC in social housing projects because of the benefits it could bring to them.

As previously discussed in the discussion chapter, governmental support is the critical success factor in MMC adoption in social housing projects. For MMC to be successfully implemented, the central government and housing authorities must be willing to adopt it. The government can provide the required support to the private sector to adopt MMC. The validation interviews have agreed with this assumption, as five out of seven experts have indicated that governmental support is the critical success factor for MMC adoption. Moreover, the participants highlighted other critical success factors that correspond to the research findings. Standard unit design and poor quality of units have been highlighted as crucial success factors that need to be stressed during the strategic planning of MMC adoption.

6.9.1.2 Discussion of challenges and barriers

The second section of the interviews discussed the challenges and barriers expected to affect the adoption of MMC. The discussions involved the experts expressing their views on the possible challenges and barriers hindering MMC implementation and comparing them to the factors already illustrated in this research. The participants confirmed that the challenges and barriers in this research are inclusive and provide a comprehensive overview of the problems hindering MMC adoption in social housing projects.

When asked about the most severe challenge to implementing MMC, all participants confirmed that the high capital costs are the leading factor creating a significant hindrance to the adoption process. They emphasised that with the current economic circumstances, it is going to be very challenging to adopt MMC due to its initial high costs and the expected reluctance from investors due to the current economic circumstances. In addition, it has been noted that the unit cost should meet the current traditionally built unit cost as it is going to be rejected by any means for any increase in the construction costs. Afterwards, the participants were asked their opinion about the second most significant challenge. Their responses fluctuated between the other challenges; three stated a lack of technical education and training facilities, two mentioned a lack of innovation, and the last two mentioned a lack of MMC awareness. The variation in their responses indicated that the expected challenges have much the same influence on the adoption of MMC in social housing projects. The influence of each challenge

should be identified and dealt with carefully because it can negatively affect the implementation of MMC in social housing projects.

Furthermore, the barriers to MMC implementation were argued with the participants. Four participants indicated that social and cultural factors could represent a significant barrier to MMC adoption other than the capital costs. These factors include the resistance from various stakeholders to employ a different construction practice other than the traditional method they are familiar with. The participants emphasised that the Egyptian decision-makers are stubborn and do not easily accept innovation. These results comply with the qualitative data analysis findings that resistance to change could be one of the main barriers to adopting MMC in the Egyptian housing sector.

Moreover, two participants mentioned that poor coordination between different stakeholders is one of the Egyptian construction sector's main issues. They agreed that MMC requires a top-level coordination competency from inception to completion to ensure projects' success. The last participant stated that the social housing contractors would be the main barrier to MMC implementation. This is due to their lack of MMC knowledge and limited resources and capabilities. They argued that social housing projects are executed only by these contractors, who are just small enterprises utilising old construction methods, simple tools and unskilled workers. Due to the considerable knowledge and capabilities gap, these organisations would be the main barrier to MMC adoption in social housing projects.

The discussions with the experts have confirmed the challenges and barriers factors previously identified from the qualitative and quantitative data analysis and the literature review. They agreed that these factors would have a negative impact on the adoption of MMC if they had not been seriously considered during the implementation of the framework. It is understood that there are variations in the responses of the participants regarding the most critical factors imposing a challenge or a barrier to the adoption of MMC. This indicates the importance of all the factors and how each can affect MMC adoption. The specific nature of the Egyptian construction industry and housing sector required careful consideration of all the associated factors that could hinder the implementation of MMC. Social and cultural factors strongly influence the adoption of new approaches, as agreed between the validation interviews and the qualitative data findings.

6.9.1.3 Discussion of the framework

Following the abovementioned discussions, the framework was discussed with the participants to express their opinions and views about its context, presentation and implementation. The interviews started by describing the presentation of the framework showcasing the purpose of each column and row and their relationships. The participants agreed that the seven pillars are comprehensive, covering the main influencing factors on adopting MMC. Under each pillar, the objectives and activities were discussed and the role of each stakeholder as well. Moreover, the four phases of implementation were confirmed with the participants by providing their views on each activity and their order. The experts agreed that the framework provides a clear strategy for successfully adopting MMC in social housing by creating a roadmap for implementation.

Firstly, the objectives and activities of the framework were discussed by going through each objective and the activity related to it. The participants confirmed that the objectives and activities of the framework are inclusive of the needed steps to implement MMC in social housing projects. They agreed that it covers the success factors, challenges and barriers expected to influence the adoption of MMC within the Egyptian context. In addition, they confirmed that the framework is logical and that the relationships between the objectives and activities are straightforward to follow. The participants emphasised that full coordination between stakeholders is required to successfully implement the framework due to the interrelationships between the objectives and activities. This has been confirmed by the researcher that to implement this framework, as previously mentioned, a project manager needs to be appointed to ensure full coordination between different stakeholders and to ensure the achievement of each objective through the assigned activities.

The role of the stakeholders was also discussed with the experts, and which would be the key stakeholder to achieve success in MMC adoption. Five participants agreed that the government represented in SHMFF is the key stakeholder in adopting and implementing MMC. Their point of view was that SHMFF is the authority responsible for planning, executing and supervising social housing projects, so they have the power to promote MMC adoption and implementation by providing their full support to make it work. On the other hand, two participants argued that the private sector represented in SHC would be the key stakeholder. According to them, the private sector would be the initiator to adopt MMC instead of traditional construction, and this is because the private sector is responsible for constructing social housing units. The

government procures social housing projects with fixed prices without imposing a specific construction method. From this debate, full cooperation and coordination are required to adopt MMC as the private and public sectors strongly influence the framework's successful implementation, as previously discussed.

Lastly, the participants were asked to provide suggestions or recommendations to improve the framework and identify any missing factors. One of the participants stated that to ensure robust coordination, Building Information Modelling (BIM) approaches must be utilised in implementing the framework. They argued that using BIM with MMC would ensure better coordination between different stakeholders, which is required with an innovative method such as MMC. BIM needs to be used from the early design stage for more accessible communication between manufacturers and contractors to gain projects' success. Furthermore, another participant indicated that the health and safety factor need to be mentioned in the implementation of the framework for its importance due to the poor health and safety performance of the current practices. They stated that MMC could bring more significant improvements to the health and safety performance of the construction phase of social housing projects by reducing onsite work and site hazards. These two factors have been included in the framework and the phases of implementation, as shown in Tables 6.3 and 6.4.

From the interview analysis, it has been confirmed that the framework can provide a clear strategy for adopting MMC in social housing projects. The critical success factors, challenges and barriers have been confirmed with the experts, and the key influencing factors have been identified. The participants agreed that the framework is clear and logical by providing a practical strategy to integrate MMC in the social housing and construction sectors gradually.

Table 6.3: Amended framework for adopting MMC in social housing projects.

Influencing Factors	Objective	Activity	Key stakeholders
Costs	- Ensure the cost of prefabricated units is ≤ traditional methods. - Absorb capital costs by securing contracts with a large number of units	- Establish partnerships with the private sector to build social housing units. - Secure contracts with a large number of units	- SHMFF - Social housing contractors (SHC)
Skills and training	- Increase training facilities for SHC. - Train and develop unskilled workers available in abundance. - Modernise current construction methods	- Provide training support to SHC. - Provide technical education incentives to SHC.	- SHC - SHMFF - Education providers
Architecture design	- To restore the architectural heritage. - Provide more flexibility for expansions and modifications. - Increase the users' satisfaction.	- Improve the architectural design of interiors and exteriors. - Work on more flexible design of units - Increase the variations of designs. - Involve the residents in the early design stage	- Designers - Social housing residents - Local councils - SHMFF
Governmental support and policies	- Increase knowledge and awareness of MMC.	- Include MMC in social housing policies.	- Housing authorities. - SHC

	- Encourage SHC and the private sector to invest in MMC. - Improve the sustainability of the social housing projects in the construction and utilisation phases. - Improve the health and safety performance of social housing projects. - Ensure addressing the specific needs of the residents in each area according to their local environment and culture.	- Provide financial incentives to the private sector and SHC implementing MMC. - Ensure sustainability and cost efficiency through MMC in social housing. - Ensure health and safety aspects in the construction of social housing projects through MMC. - Develop policies that consider cultural and social aspects of the residents, including diversity.	- SHMFF
Social and culture	- To reduce resistance to change. - To ensure good quality in manufacturing or assembly. - To increase the adaptability and satisfaction of residents and workers.	Residents: - Increase the safety and privacy aspects of social housing units. - Increase knowledge and awareness of MMC.	- Project managers - Designers - SHC - SHMFF
		Workers:	

		- Attract the younger generation of workers to learn MMC methods. - Ensure strong local leadership and supervision.	
Technology	- Ensure full coordination between stakeholders through BIM approaches. - To cope with poor technological readiness. - Gradual adaptation to MMC approaches.	- Utilise BIM software from the design stage in social housing projects. - Ensure gradual technology transfer. - Employ available prefabrication manufacturing capabilities and modernise them.	- Manufacturers. - SHC - Designers - Project managers
Manufacturing industry	- Gradual adaptation to MMC approaches and upgrading of current manufacturing facilities. - Encourage manufacturers and SHCs to invest and implement MMC in social housing. - Improve quality control measures and ensure robust coordination between factories and construction sites.	- Utilise the current precast factories to adopt MMC in social housing. - Launch new social housing projects close to current industrial cities. - Provide strong project management and leadership.	- Manufacturers - SHC - Private sector investors. - SHMFF

Table 6.4: Amended phases of the implementation of the framework

Phase	Activity	Stakeholders
Phase 1 Strategy planning	- Establish partnerships with the private sector to build social housing units.	- SHMFF - SHC
	- Provide technical education incentives to SHC.	- SHMFF - SHC - Education providers
	- Include MMC in social housing policies.	- SHMFF
	- Provide financial incentives to the private sector and SHC implementing MMC.	- SHMFF
	- Develop policies that consider cultural and social aspects of the residents, including diversity.	- SHMFF - Local housing authorities
Phase 2 Strategy implementation	- Secure contracts with a large number of units.	- SHMFF - SHC
	- Launch new social housing projects close to current industrial cities.	- SHMFF - Local authorities
	- Increase knowledge and awareness of MMC.	- SHMFF - Education providers
	- Attract the younger generation of workers to learn MMC methods.	- SHC - Education providers - SHMFF
	- Ensure gradual technology transfer.	- Manufacturers - Private sector investors
Phase 3 Operational strategy	- Design social housing units to be MMC-friendly.	- SHMFF - Architectural designers - Manufacturers
	- Improve the architectural design of interiors and exteriors	- Architectural designers - SHMFF
	- Increase the variations and flexibility of unit designs	- Architectural designers - SHMFF
	- Ensure sustainability, health and safety and cost efficiency through MMC in social housing.	- SHMFF - SHC
	- Increase the safety and privacy aspects of social housing units	- Architectural designers - SHMFF
Phase 4 Execution strategy	- Employ available prefabrication manufacturing capabilities and modernise them.	- SHMFF - Manufacturers - SHC
	- Utilise BIM software from the design stage in social housing projects.	- SHC - Architectural designers - Manufacturers
	- Utilise the current precast factories to adopt MMC in social housing.	- SHMFF - Manufacturers - SHC
	- Provide strong project management and leadership.	- Local authorities - Project managers - SHC
	- Ensure robust supervision and monitoring locally.	- Local authorities - Project managers - SHC

6.10 Chapter summery

This chapter presented the key critical success factors, challenges and barriers to MMC adoption in social housing projects in Egypt. The influencing factors were discussed, showing how each affects the implementation of MMC, how the critical success factors are to be exploited and how the challenges and barriers are mitigated. The framework to adopt MMC in social housing projects has been presented, with each of the seven pillars explained. The framework consists of a series of objectives and activities to be performed by the relevant stakeholders to ensure a successful implementation of MMC in social housing projects. After that, the framework's implementation phases were presented by describing the four main implementation phases. Each phase consisted of several activities to be implemented by the relevant stakeholders. How the framework can be used was discussed alongside the expected challenges when implementing it.

The framework was validated by conducting interviews with seven experts in construction management. The interviews included discussions about the critical success factors, challenges and barriers identified in the research and their expected influence. In addition, the framework, the phases of implementation, the relevant stakeholders, and their roles were discussed. From the analysis of the interviews, it was confirmed that the framework could provide an implementation strategy for MMC to be adopted in social housing projects. The participants of the interviews stated that the framework is logical and can be practically implemented. There were two minor modifications to the framework, according to the interviews. The next chapter will discuss the conclusion and recommendations of the research.

7 Chapter 7: Conclusions and recommendations

7.1 Introduction

This chapter presents the conclusions of the research based on its findings. It describes how the aim and objectives of the research have been achieved and the answers to the research questions. The chapter also discusses the contribution of the research to existing knowledge and the recommendations for future research.

7.2 Achievement of the research aim

The literature has documented the benefits of MMC and offsite prefabrication to the construction industry. It has been sought after as a solution to the drawbacks of the construction industry, including poor quality, unsustainability, health and safety issues…etc. The aim of this research is to bring offsite prefabrication technology to the Egyptian housing sector. It has been proved in several studies the improvements MMC brings to the construction sector and that it has been adopted in many developed countries to increase the supply of decent housing to the least advantaged. Although, the transfer of MMC technology requires exploring and identifying the critical success factors, challenges and barriers to its implementation within the Egyptian context. This research explored the influencing factors to adopt MMC in Egypt's construction and housing sectors to recognise their impact on developing a framework for the successful adoption of MMC in social housing projects.

Upon identification of the influencing factors, the aim of the research was achieved by developing an adoption framework for the successful implementation of MMC in social housing projects. It was developed by understanding the main success factors contributing to MMC adoption in developed countries, how they can be exploited in the Egyptian context, the main challenges and barriers, and how they can be mitigated. The framework consists of seven pillars covering the main aspects of the successful adoption of MMC, which was discussed in detail in Chapter 6, including its implementation phases. It is presented as a series of activities to be performed by their relevant stakeholders simultaneously by keeping in mind the challenges that might arise during the implementation process.

The framework does not just transfer the prefabrication technology by importing it from developing countries. It develops an implementation strategy to integrate MMC innovation into the current construction practices in social housing projects where traditional construction is

the only practice. Traditional construction has been proved in the research as insufficient to provide the needed supply of social housing in Egypt, where the shortage is kept on increasing through the decades.

7.3 Achievement of the research objectives

a) *Identify the critical success factors for adopting MMC in housing projects in developed countries and the MENA region.*

The first objective of the research has been achieved from the literature review findings in Chapter 2. The review chronologically analysed the adoption of MMC in developed countries to understand the factors associated with its growth and development and identify the hindrances and challenges to its implementation. It also reviewed the adoption of MMC in several countries in the MENA region that face comparable characteristics and challenges as the Egyptian construction and housing sectors. From the literature, it was recognised that certain factors could support the adoption of MMC in low-income housing. Governmental support is one of the main critical success factors, where it can be in different forms, such as governmental insistence to adopt MMC in developed countries, developing policies and legislations to encourage MMC utilisation and generating building codes that support employing innovative and non-traditional construction methods. Moreover, other success factors include integrating the private sector, enhancing socio-cultural aspects, and utilising industrial capabilities.

On the other hand, the adoption of the MMC in developing countries has been investigated. However, there were minimal cases of MMC adoption in housing projects, although it has been documented in the literature that there is a high potential for MMC adoption driven by the growing demand for low-income housing. Several factors were identified that prevented wider implementation of MMC, including lack of awareness, technological readiness, high capital costs, and resistance to change. There were trials to adopt MMC in housing projects in developing countries, but they did not widely spread due to cultural inconsistency, unwillingness from different stakeholders and financial difficulties.

From the literature review analysis, the critical success factors of MMC adoption in developed countries have been explored and understood. Besides, the challenges and barriers were recognised by the developed and developing countries. These factors have been reflected in the Egyptian context to recognise their influence on adopting MMC in low-income housing

projects. They have enriched the understanding of the different factors and challenges that can impact the implementation of MMC.

b) Analyse the drivers for MMC in Egypt and the factors associated with it.

Several drivers have been identified to adopt MMC, such as shortage in housing, shortage in skills, improved quality and health and safety and achieving sustainability. These drivers directly influenced the decision to introduce MMC to the construction industry in developed countries. By looking at the Egyptian construction industry and the low-income housing sector, both sectors are struggling from many of these factors. It has been noted in Chapter 2 and confirmed in Chapters 4 and 5 that Egypt's construction industry faces performance-related challenges, including poor quality, unsustainable practices, poor health and safety and an abundance of unskilled workers. Besides, the shortage of low-income housing has been documented where the gap between supply and demand keeps widening despite governmental efforts throughout the last seven decades.

This objective has been achieved by analysing the literature on the Egyptian housing and construction sector. In addition, the problems currently facing both sectors have been confirmed from the interviews. As one of the largest African developing countries, these problems Egypt is struggling with are common within developing countries; however, due to its large population, they have severe impacts. The housing sector's main struggles are mainly due to policy fluctuations and legislation changes. In addition, the government has taken sole responsibility for the housing supply, which has been proven insufficient. The traditional construction method was also considered inadequate to provide the needed supply of social housing. However, MMC has never been introduced as a method to increase housing supply, although several studies have investigated it as a possible solution to the housing shortage in other developing countries.

c) Identify the critical factors likely to hinder the acceptance of MMC adoption in housing in Egypt

The findings from the literature review, semi-structured interviews and questionnaire survey indicated the factors likely to impose hindrances to the adoption of MMC in housing projects. These factors have been discussed in Chapters 2, 5 and 6, illustrating their relationships. The literature review pointed out the factors that hindered the implementation of MMC in developed and developing countries. The main conclusion of the literature review is that capital costs would be the main barrier to MMC implementation, especially in developing countries.

Although it is documented in the literature that MMC could result in cost savings over the long term, the initial capital costs for setting up its manufacturing facilities are the major hindrance to its adoption. Regarding the Egyptian context, it is concluded that a partnership is required between the private and public sectors to absorb the capital costs through securing contracts with a large number of units and the government providing financial incentives to decrease costs.

Other factors identified from the data analysis include the need for intensive training to prepare unskilled workers to work with MMC. Per the semi-structured interviews, technical education in Egypt is considered inadequate, and scarcely any training facilities are available in the private sector. The government, the private sector and education providers need to collaborate to increase training facilities and improve technical education to benefit from the abundance of unskilled workers. Furthermore, lack of awareness of MMC is one of the factors that could hinder its implementation. It has been illustrated from the questionnaires that (94%) of the respondents do not know what MMC or offsite prefabrication is. It shows that there is a lack of public awareness of MMC, which has been a significant barrier in developed countries, as per the literature. In the UK, the negative perception of MMC since World War 2 is still a documented barrier in the literature.

Social and cultural factors have been concluded to be the influencing factors in MMC adoption. Resistance to change from SHC and the workers could impede MMC implementation because of the difference from the traditional method they are used to. The findings concluded that the decision-makers and governmental officials have rigid mindsets that are difficult to change, requiring change management skills to deal with. From the residents' point of view, resistance to change would be a manageable issue for construction practitioners as their primary concern is the affordability of units regardless of the construction method. However, the social and cultural aspects from the residents' side are crucial to the success of MMC. Several social issues have been identified that can impose barriers to its implementation and utilisation. Negligence of social and cultural aspects during the design stage of social housing projects could lead to difficulties during utilisation and prevent the wider spread of MMC in social housing projects. On the other hand, it can lead to greater success if it satisfies the residents' needs and avoids the drawbacks of the current housing units.

The abovementioned factors summarise the achievement of the third objective from the analysis of the literature review, semi-structured interviews and questionnaires. This objective

showcased all the factors that can hinder the adoption and implementation of MMC from different aspects related to the Egyptian construction and housing contexts.

d) Establish and validate a framework for the successful implementation of MMC in low-income housing projects in Egypt.

After a critical analysis of all the factors associated with adopting and implementing MMC and exploring implementation strategies, a framework for adopting MMC in social housing projects has been developed. This has been achieved from the analysis of the literature in Chapter 2, the data analysis in Chapter 4 and discussions in Chapters 5 and 6.

The framework consists of seven pillars that present the main factors influencing the adoption process of MMC in social housing projects. As shown in Chapter 6, the framework presents an implementation strategy through a series of activities to achieve a set of objectives by the relevant stakeholders. The seven pillars strongly influence the implementation of MMC in social housing projects in Egypt concerning the previously identified success factors, challenges and barriers. To implement the framework, the activities were combined into four phases in order of implementation, creating a roadmap for the successful adoption of MMC.

Interviews with construction management experts have validated the framework to confirm its usefulness and practicality. It has been confirmed that the framework alongside its phases of implementation provides a comprehensive strategy for the successful adoption of MMC by taking into consideration all relevant factors that may impact it. The framework enables the stakeholders to identify the expected challenges to MMC implementation and the areas required to cover prior to its adoption. As discussed in Chapter 6, to implement this framework, strong project management skills are required to fulfil its objectives to ensure consistent coordination and collaboration between different stakeholders due to the expected challenges that might arise during implementation. The framework provides guidance on how to adopt MMC to tackle the housing shortage and offers insights into the characteristics of the Egyptian construction and housing sectors.

7.4 Contribution to knowledge

This research contributed to the body of knowledge of construction management in several aspects. The main contribution to knowledge is shown in the following points:

- The research has developed a framework to adopt MMC in the Egyptian low-income housing sector, where the dominant construction method is traditional construction. All

previous research has explored housing policies and their drawbacks without introducing a different construction method. On the other hand, previous construction-related research was mainly concerned with performance-related issues and presenting recommendations for improving the currently utilised methods. This research is the first to present an adoption framework for MMC to address all related issues in Egypt's social housing and construction sectors.

- The framework presents a strategic solution to increase the supply of decent housing to the least advantaged households besides introducing innovative construction methods that can help improve the performance of the construction sector. The framework provides new insights into implementing MMC in developing countries where its basis can be adopted in similar communities that face comparable circumstances. Egypt is one of the largest countries in terms of population and economy.
- The literature review has identified the lack of an adoption framework on MMC that encompasses all the relevant factors to its implementation. It also considered the socio-cultural aspects and revealed its interrelation with other influencing factors for MMC adoption. The identified factors can be applied to different countries to provide an understanding of the influencing factors and their impact on the adoption of MMC.

The research has provided an understanding of how MMC can be adopted in the construction sector by highlighting the factors affecting its implementation and how they would impact it.

7.5 Limitation of the research

Like any research, there have been a few limitations while conducting it. In the literature, the information about adopting MMC in developing countries, especially Middle Eastern countries, was very limited. Reliable publications on social and low-income housing projects in the Middle East were rare to provide enough information to compare similar trials in similar countries. However, this limitation did not affect the research findings as the primary data provided adequate information to achieve the aim and objectives of the research.

On the other hand, the outbreak of the Covid-19 pandemic has affected the data collection process. The travel restrictions and social distancing measures have been in effect during the primary data collection stage resulting in a long and stressful process. The interviews and questionnaire surveys were planned to be performed in person; however, they were done remotely to ensure all the precautionary measures were in place, as previously discussed in

Chapter 3. Nevertheless, all the required information was gathered, and the needed data was analysed to provide comprehensive research.

The survey approach was performed within the limited sample and in two specific projects in Cairo. The results were used to generalise, although it might generate different information if done in different governorates. However, the validation interviews were performed to ensure all information and to validate the results.

7.6 Recommendations for future research

This research has established a framework for adopting MMC in low-income housing projects in Egypt. Further research could be conducted based on the research findings as follows:

- Further investigation is required for the cost analysis of adopting MMC in social housing projects and to compare it to the current practices to explore its cost-effectiveness in detail.
- Risk analysis research is recommended to identify the relevant risks to MMC implementation in developing countries and explore their mitigation methods.
- Further research about procurement methods and types of partnerships between the private and public sectors is recommended to investigate the optimum route to adopt MMC in developing countries.
- Housing and sustainability policies could be investigated further to promote the utilisation of MMC in wider sectors and not only limited to social and low-income housing.
- Further research could investigate different MMC methods in-depth and identify the most suitable approach to implement in social housing projects.

7.7 Recommendations for the industry

Several recommendations for the construction industry have been concluded based on the findings of this research:

- To implement MMC in housing projects, start with small-scale pilot projects to test different MMC methods and techniques.
- Invest in training and education for construction teams about the principles and benefits of MMC to help them understand new techniques, technologies, and safety protocols associated with MMC.

- While adopting MMC, consider local factors such as climate, materials availability, and regulations. Adapt MMC methods to suit the local context while maintaining efficiency and quality.
- Embrace Building Information Modelling (BIM), prefabrication, and modular construction technologies. These tools can enhance collaboration, streamline design processes, and improve project scheduling.
- Develop robust quality control processes to ensure that MMC projects meet or exceed traditional construction standards. Implement regular inspections and testing to maintain high-quality results.
- Highlight the environmental benefits of MMC, such as reduced waste and energy consumption. Incorporate sustainable design principles into MMC projects to align with global and local sustainability goals.

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9 Appendices

Appendix I: Interview questions

London South Bank University	PhD Research Project **Framework for Adopting Modern Methods of Construction in Low-income Housing Projects in Egypt**		
Name of Interviewee		Date of Interview	
Case Study No:		Reference No:	

Interviewee's Information	
Job title	☐ Senior Manager ☐ Mid-level Manager ☐ Technical Staff ☐ Other
Years of experience	☐ < 5 years ☐ 5-10 years ☐ 11-15 ☐ >15
The nature of the current company	☐ Governmental Official ☐ Contractor ☐ Architect/designer
Knowledge of MMC/Prefabrication	☐ high ☐Low ☐ None
How many projects you completed using MMC?	☐ None ☐ 1-5 ☐ >5

BARRIERS	
Cost	• How the high capital cost of MMC would be absorbed in low-income housing projects? • To what extent do you think the initial cost of MMC will hinder its implementation in housing projects? • How the high cost risk might be mitigated?
Skills	• Do construction companies have the training facilities required to implement MMC? • Do you think the Egyptian workers have the skills and ability to learn a totally new and innovative construction methods?
Cultural perception	• How do you think the residents will accept building their homes with a new prefabricated method rather than the traditional methods? • How do you think is the best way to avoid negative public perception of MMC methods to be implemented in housing projects?
Technical issues	• Do you think the Egyptian construction industry has the capabilities to deal with technical difficulties associated with MMC such as early design freeze, coordination and communication, vertical transportation and storage? • What technical difficulties that will act as a major barrier to implement MMC in housing projects?

- What are the barriers preventing MMC implementation in Egypt?
- What will be the barriers to use MMC in housing projects in Egypt?

CHALLENGES	
Socio-cultural needs	• Which socio-cultural needs that MMC can provide/improve that traditionally built houses do not provide? • Do you think MMC can help improve the living conditions of the residents? • What cultural factors that need to be considered when implementing MMC in housing projects for residents as well as the workers?
Infrastructure	• Does Egypt have the infrastructure capacity to implement MMC? • What infrastructure abilities required to implement MMC?
Training	
Architectural heritage	• Do you think MMC will help restore the lost architectural heritage of Egyptian houses? • How can MMC help restore this architectural heritage? • Why do you think the main reason of losing the rich Egyptian architectural heritage in the current housing stock?
Resistance to change	• How to overcome resistance to change when adopting a new construction method either from the worker or the residents?
Technological readiness	• What type of technology Egyptian construction industry needs in order to adopt MMC?

	• Do you think that Egypt is technologically ready to adopt MMC in housing projects?

- What risks that might challenge the implementation of MMC and how it will be mitigated?

SUCCESS FACTORS	
Governmental support	• Do you think the governmental housing authorities will support MMC in housing projects? • What are the critical factors the government will consider when implementing MMC in housing projects? • Are there any laws, policies, codes to encourage MMC/offsite prefabrication? • What will be the main factor that will persuade the government to adopt MMC?
Adopting building codes	• Is Modern Methods of Construction have or had been considered in any housing policy? • Do you think the current building codes can adopt the implementation of MMC in housing projects?
Private sector	• Did any private developer has considered adopting MMC in their residential projects? • What do you think are the main barriers oppose the integration of the private sector in housing projects?
Industrial capabilities	• Do you think Egypt has the industrial capabilities to adopt MMC for housing projects? • What industrial capabilities Egypt lacks for successful implementation of MMC?
Social and cultural aspects	• Do you think MMC can enhance the socio-cultural aspects of the Egyptian families? If yes, how?

- Why do you think MMC is not happening in Egypt until now?
- How MMC will improve the performance of construction industry in Egypt?

Appendix II: Questionnaire survey

	PhD Research Project		
Name of Surveyor		Date of Survey	
Case Study No:		Reference No:	

1. **Gender**

☐ Male ☐ Female

2. **Age Group**

☐ 18-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 56+

3. **Marital Status**

☐ Single ☐ Engaged ☐ Married

4. **Number of Occupants in Household**

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5+

5. **Occupation**

6. **How long have you been living in this property?**

☐ Years ☐ Months

7. **Do you know the structural system of the building?**

☐ Yes ☐ No

8. **How important to you knowing the structural system of the building?**

Very important	Important	Neutral	Not important	Not at all important

9. Do you know Offsite Prefabrication/MMC?

☐ Yes ☐ No

10. If yes, which method do you know?

☐ Modular ☐ Volumetric ☐ Panel system

☐ Hybrid ☐ sub-assemblies and components

11. If your home is built with MMC, will it raise any doubts from the following aspects?

Factor	Very high	High	Average	Low	Very low
Quality					
Affordability					
Ability to expand					
Ability to modify					
Safety					
Privacy					
Architectural design					
Ease of maintenance					
Sound insulation					
Ventilation					

Other, please specify:

12. In your current home, please rate the following factors

Factor	Excellent	Good	Average	Fair	Poor
Exterior design					
Interior design					
Quality of finishes					
Ability to expand					
Ability to modify					
Safety					
Privacy					
Ease of maintenance					
Thermal insulation					
Sound insulation					
Natural lighting					
Natural ventilation					

13. Please rate the following factors according to their importance when selecting your new home.

Factor	Very important	Important	Neutral	Not important	Not at all important
Exterior design					
Interior design					
Quality of finishes					

Affordability					
Ability to expand					
Ability to modify					
Safety					
Privacy					
Ease of maintenance					
Thermal insulation					
Sound insulation					
Natural lighting					
Natural ventilation					

14. Additional comments

Appendix III: Participant information sheet

Information Sheet

Study Title: Framework for Adopting Modern Methods of Construction in Low-income Housing Projects in

Egypt

You are being invited to take part in a research study. Before you decide whether to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please feel free to contact me for further clarification and information. Take your time to decide whether you wish or wish not to participate.

The purpose of the study

Low-income housing in Egypt is suffering from serious issues, the current supply is insufficient to the increasing demand. In addition, the construction industry in Egypt is considered lagging behind in in terms of innovation, quality and performance.

I am a Doctoral Researcher in School of Built Environment and Architecture at London South Bank University. I am developing a framework for efficient adoption of Modern Methods of Construction (MMC) in low-income housing projects in Egypt. This framework will help in successful implementation of an innovative construction approach that will increase the access to decent housing for the most disadvantaged households.

It is a three years long study, currently being in its second year. The data collected from participants will be analysed using a method called case study.

Why you have been asked to participate

You have been invited to participate in this study because you are considered one of the stakeholders in housing projects in Egypt. Stakeholders include, but not limited to, governmental decision makers, designers, contractors, quantity surveyors and occupiers. Participants will be interviewed or fill in a questionnaire from two low-income housing projects in Cairo, Egypt that will be regarded as case studies. Please note that any information collected will be for academic purposes only without affecting your benefits or entitlements.

The voluntary nature of participation

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason. You can withdraw by simply refusing to participate either verbally or written without giving any reasons. However, if you decide to withdraw after participating, you will need to contact the researcher Yamen Bakhaty (contact details below) to ensure your responses are removed from the research, please include your reference number. As a participant, you will receive an email to acknowledge your withdrawal and confirmation that you have been removed from the research.

What will happen if the participant takes part and opting in

The researcher will contact you in an appropriate communication method regarding an appropriate date, time and location to meet. In case of interview, this may be face to face, telephone or via Skype or another platform of your choice. Regarding questionnaire, you will be given a printed questionnaire to fill and return it to the researcher. Prior to start, the researcher will provide you with consent form to give confirmation of performing interview or questionnaire. The researcher will ask several questions regarding your role in low-income housing projects according to your involvement in the project. No personal, sensitive nor identifiable questions will be asked that could be used to identify your personality. Interviews will last about an hour or could be less, however, if you do not mind it may last longer depending on the amount of information you wish discuss. Questionnaires will not take longer than ten minutes to fill and may include unstructured questions regarding your answers.

Possible disadvantages/risks to participation

Performing interviews or questionnaires might cause the participant to feel exhausted or phycological intrusion. The research in this case will perform data collection at the pace of the participant, if they feel uncomfortable, the researcher will immediately stop and continue at their convenient. Any question the participant feels its psychologically intrusive, it will be eliminated, and any answer given will permanently deleted.

Possible benefits to participation

This study intends to provide an innovative method to deliver low-income housing that will increase its provision to decrease the gap between supply and demand. This approach is

intending to provide houses that overcome the current challenges and disadvantages of the current housing stock in terms of quality, performance and raise the standards of low-income housing.

Data collection and confidentiality

All the information collected about you and other participants will be kept strictly confidential (subject to legal limitations). Data generated by the study must be retained in accordance with the University's Code of Practice. All data generated in the course of the research must be kept securely in paper or electronic form for a period of 10 years after the completion of a research project. No identifiable personal data is going to be collected. All data collected will have a reference number that will only be used for subsequent analysis. Your information will only exist in a password-locked flash drive in the researcher's possession. It will be stored in the researcher's office with no access to it except the researcher himself.

What will happen to the results of the research study on completion

Upon completion of the study, the results will be used in the thesis to obtain the degree of PhD in Construction Management and Economics. Upon successfully obtaining the degree, the thesis will be published in printed and electronic forms to be added to LSBU Research Open then the British Library will harvest it to add it to ETHOS according to the university code of practice. Participants can obtain a copy of the thesis by contacting the researcher (contact details below) mentioning their reference number and method of contact.

Who is organising and funding the research

The research is organised by Yamen Bakhaty (Doctoral Research Student) and Ass. Professor Yamuna Kaluarachchi (Doctoral Supervisor) from division of Construction, Property and Surveying, the School of Built Environment and Architecture at London South Bank University. The research is not funded by any other organisations.

Who has reviewed the study

This study has been approved by the School of Built Environment and Architecture at London South Bank University.

Who to contact for further information

If you would like further information about this study, please find below the contact details of the researcher and the doctoral supervisor:

Yamen Bakhaty, researcher
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Dr. Yamuna Kaluarachchi, doctoral supervisor
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103 Borough Road,
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Email: Yamuna.Kaluarachchi@lsbu.ac.uk

Please contact the Chair of the School of Built Environment and Architecture's Research Ethics Committee, (Yamuna.Kaluarachchi@lsbu.ac.uk) if you have any concerns about how the way in which the study has been conducted.

Thank you for taking time to read this information sheet.

Appendix IX: Ethics approval

Ethics ETH1819-0135: Mr Yamen Mohamed Badawy Sayed Bakhaty (Medium risk)

Date Academic Student ID Project School Division

Ethics application

Project details

Research project title

25 Jun 2019
Mr Yamen Mohamed Badawy Sayed Bakhaty 3701349
Doctoral Research Project
Built Environment and Architecture Construction, Property and Surveying

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FRAMEWORK FOR ADOPTING MODERN METHODS OF CONSTRUCTION IN LOW-INCOME HOUSING PROJECTS IN EGYPT

Researcher(s)

Mr Yamen Mohamed Badawy Sayed Bakhaty

Theoretical Rationale

This study tends to provide a non-traditional solution to the housing crisis in Egypt through the implementation of MMC applications as a method to increase the access to quality housing to the poorest households. The low-income housing deficit has reached 3.5 million unit in 2017 (Schwab, 2017). Moreover, the population has reached more than 97 million with increase rate about 1.7 percent with 27.8 percent of the population below the poverty line (CAPMAS, 2016) (The World Bank, 2018). On the other hand, there is a huge gap between the supply and demand where the two main housing projects implemented by the government 'Youth' and 'Future' supplied a total of 90069 units in a 10 years period during the late 1990s and 2000s (Ahmed, 2012). The latest Social Housing Program announced by the government in 2014 is planning to build one million unit, however, only 12,000 was built in the first year (Marketline, 2017). Therefore, it is expected that the gap is going to increase where traditional methods for housing projects are inadequate to fulfil the continuously increasing demand.

Procedure

Kindly find attached the ethics report outlining the research description and the proposed research methodology and methods.

Are there any beneficiaries to the proposed research project?

Yes

If yes, who are they and how will they benefit?

Housing Associations in Egypt and developing countries through implementing an innovative construction approach for building low-income housing projects in addition to providing a framework to implement MMC in Egypt and developing countries.

Does any of your research fieldwork take place outside of the UK?

Yes

If yes, please state the location(s) of your fieldwork Region
Cairo

Country

Egypt

Does any of your research take place in the USA?

Research project start date

15 Nov 2019

Anticipated research project end date

26 Jul 2021

Ethical risk

Does the research project have funding?

No

Does this research project involve other organisations?

No

Does the research project involve people as participants or in any other way?

Yes

Does the research project involve vulnerable groups?

No

Does the research project involve sensitive topics?

No

Does the research project involve secure data, or publicly available data in which individuals can be potentially identified?
No

Does the research project involve any situations where the safety of the researcher may be in question?

No

Does the research project involve recruiting participants via the internet?

No

Does your research project involve access to, or use of, material which could be classified as security sensitive?
No

Does the scope of the research project involve additional insurances over and above the University's standards?
No

Does the research project involve deceased persons, body parts, or other human elements?

No

Ethical guidelines

All research conducted by LSBU staff and students should follow the LSBU Ethics Code of Practice. You should also follow the guidelines relevant for your discipline. Please indicate which discipline guidelines you will use below.
Social Research Association: Ethical Guidelines

If you selected other, please enter details here.

Is there any special training of investigators needed to complete this research project?

No

If yes, please provide details for the training and how it will be delivered.

Human participants: Information and participation **Who will be recruited?**

1- Housing decision-makers from housing associations in Egypt. 2- Urban Planners
3- Architects
4- Construction professionals

5- House occupiers

How will recruitment take place?

Through invitations by emails and/or telephone calls. By talking to residents

Does the research project involve members of the public in a research capacity (participative research)?

Yes

How will you gain access to the research setting and research participants?

I will need a letter of confirmation from the university indicating that I am enrolled in PhD study and that I am collecting data for research purposes only.

I will select a specific housing scheme and obtain approval from participants through consent form

Will written consent be obtained?

Yes

If written consent will not be obtained please indicate why and how verbal consent will be obtained or what will be considered implied consent.

Please upload consent form and evidence of communication with participating organisations if the latter is required.
Could the research project involve the sharing of confidential information beyond the initial consent given?

No

Does the research project involve visual or vocal methods where identifiability may be a concern?
No

Does the research project involve deception?

No

Is the choice to participate likely to be a sensitive issue?

No

Does the research project involve situations which may induce stress, anxiety, humiliation or pain?
No

If yes, what safeguards will be put in place?

Please upload your participant information sheets / invitation letters.
Will incentives beyond reasonable compensation for time and travel being used in the proposed research project be offered to participants?
No

If yes, please describe the incentives and outline any strategies to mitigate ethical issues relating to the their use.

Human participants: Method

Does your research contain any possible risk to participants?

Yes

If yes, please indicate which of the following risks may be entailed by your research project.

Potential psychological intrusion from questionnaires, interview schedules, observation techniques

If other has been selected above, please indicate what this risk consists of.

How will these risks be mitigated?

Invitations will be sent prior to conduct any interview letting the interviewee select the suitable location and timings for conducting the interviews.

Questionnaires will be as short as possible and giving the participants a suitable timeframe to complete them at their convenience.

There will Participant Information Sheet providing each participant with full research information, supervisor and researcher's contact details and confirming that the data collected will be for academic purposes only without affecting their benefits.

Does the research project involve intrusive interventions or data collection?

No

Will participants be debriefed?

No

If yes, how will participants be debriefed?

If no, why is debriefing not required?

The study includes semi-structured and unstructured interviews that does not require debriefing.

Please upload any debrief sheets.

Data collection and sharing

Does the research project involve access to records of personal or sensitive information concerning identifiable individuals?
No

Which of the following data types will you be using?

Surveys/Scale based measures Interviews/Focus groups

For each data collection type please indicate how data will be collected and from what sources.
Surveys will be conducted by questionnaire performed by the residents.

Interviews will be conducted either face to face, telephone or Skype with housing projects stakeholders such as designers, contractors, site managers and housing policy decision makers.

What steps will be made to ensure the data collected will be anonymous or made anonymous?
Prior to perform an interview, a verbal consent will be requested to record the interview by audio recorder. If accepted, the interview will be recorded by the researcher's own device that is password protected, if recording permission declined, then written notes will be taken for the whole interview. Each interview will be given a reference number to anonymise the data collected. Transcribing will be performed immediately after the interview to ensure that every information is recalled and saved for analysis. Transcripts will be imported into NVIVO software with reference numbers without personal data for qualitative analysis.

Will data be stored electronically?

Yes

If yes, what steps will be taken to secure the data?

It will be stored on a flash drive locked with password only known to the researcher. This flash drive will be stored in the researcher's locked safe place.

If no, where will the data be stored?

Notes taken from interviews will be stored in the researcher's locked disk space with no unauthorised access could be obtained.

When will the data be destroyed?

After three years from research completion/degree awarded for publication purposes.

Although all forms of data analysis cannot be foreseen prior to data collection, please indicate what form of analysis is currently planned.
Quantitative data will be analysed using SPSS collected from survey questionnaire.

Qualitative data will be analysed by NVIVO collected from interviews.

Disclosure and Barring Service

Does the investigator or anyone else connected to the research project require a DBS check?

No

If no, please indicate why.

Data collection will be from participants overseas. No personal nor sensitive data required as well as no recruitment will take place.

If yes, please attach a copy of the certificate.

Has a health and safety risk assessment been carried out and, for applicants with supervisors, has the assessment been approved by a supervisory team?
No