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# Modern Construction Methods (MMC) in Saudi Arabia: Evaluation Aspects and Barriers

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## Abstract

Several modern methods of construction (MMC) are implemented to construct houses in Saudi Arabia to close the gap between the demand and supply of housing units. This study aims to evaluate the MMC based on various features, and to identify hindering factors of implementing MMC. The required data were gathered from MMC contractors, through a questionnaire survey. MMC are found to share encouraging and undesirable features in produced housing units and differ in several others. The high initial and operating costs, dominance of the traditional building method, lack of professionals are the highest critical factors affecting the implementation of MMC.

**Keywords:** Factors, Modern of Methods of Construction, Saudi Arabia

## Introduction

Saudi Arabia's population has been increasing sharply over the last few decades, increased from 7 million in 1974 to 31 million in 2020, in which 67% aged below 34 years (Mulliner and Algrnas, 2018). Furthermore, the population is expected to overgrow with an annual rate of 1.9% and is predicted to rise to 37 Million capita in 2025 (Santoso et al. 2017). The rapidly growing and young population, aggravated by the inflow of expatriate workers, leads to a rapid increase in demand for affordable housing, which increasingly tilts the government focus to housing shortages and, hence, places an enormous pressure on the government to provide about 300.000 housing units per year. The Ministry of Investment (MISA) expects Saudi Arabia to witness a sharp increase in demand for new housing units over the next couple of years and about 1.5 million new housing units by 2030. This level of demand is currently two times above the market supply, mostly signifying the inability of the currently used traditional construction methods to meet the expanding housing demand. The current supply of housing is nearly 150,000 units per year (Kerr, 2016). Besides, the traditional method results in reduced productivity, questionable quality, vast use of energy and materials, accidents on sites, and environmental pollution (Navarro-Rubio, 2019; Ministry of Housing, 2020). Over the years, several proposals have been contemplated inside the government to help Saudi Arabia's vibrant population attain homeownership and encouraging qualified observers to predict growth throughout the real estate sector (Weetas, 2019). The government has established the Ministry of Housing to deal with housing issues. Lately, the Ministry initiated the Building Technology Stimulus Program to transform the Saudi construction industry from an industry that relies on traditional construction methods to utilize advanced construction methods. That is the program aims to promote the adaptation of modern construction methods (MMC) to the Saudi building sector based on five announced criteria: 1) Cost Reduction, 2) Time Reduction, 3) Increased Quality and productivity, 4) Diversity and 5) Local Content including jobs creation to Saudi. The Ministry was successful under this program to attract, evaluate against the announced criteria, and approved several structural and modular MMC to overcome the problems encountered with the traditional construction method. Besides, the Ministry assists the MMC providers in obtaining up to 75% of the initial investment cost (factories, training, land, etc.) and working capital for the first six months of operation from the Saudi Industrial Fund (SIF). The approved MMCs, as presented in the public domain, are listed in Table 1.

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Table1:The Ministry of Housing Approved MMCs

| Technology | Category |
|---|---|
| Insulated Precast (IP)<br>Autoclaved Aerated Concrete (AAC)<br>Insulated Concrete Forms (ICF)<br>Tunnel Formwork (TF)<br>Structural Light Gauge Steel (SLGS) | Structural |
| Concrete Modular (CM)<br>Modular Light Gauge Steel (MLGS) | Modular |

Nevertheless, What are MMC shares in the housing market? What are MMC salient features? What are the success/barrier factors? This paper addresses these issues and attempt to answer the above questions. To the authors' best knowledge, there has not been a study to evaluate and compare the qualification aspects of the MMC besides identifying the reasons for their level of contribution to the housing industry. This paper contributes to the body of knowledge of MMC and assesses owners to select the most appropriate MMC that satisfies their needs. Besides, it contributes to assess government in setting the proper policies for balancing housing supply and demand.

**The objectives of the Study**

This study's main objectives are to evaluate the performance of available modern methods of construction (MMC) and to determine the success/barrier factors of implementing MMC in the Eastern Province of Saudi Arabia.

**Literature Review**

### Background

Construction industries of different counties have used MMC at times of high demands for housing units caused by wars, population growth, and clients' change of tastes. The United Kingdom, Germany, Netherland, Sweden, Japan, and many others faced urgent housing after World War II and at different intervals of time. The United Kingdom and Japan had a housing crisis with over 200,000 and 4.2 million housing units, respectively, to accommodate their citizens who lost their houses during the war (Mulliner and Algrnas, 2018). Sweden needed to supply one million apartment units during 1965-1975 (Navarro-Rubio et al. 2019), and Malaysia needed to supply 800,000 housing units in 1996 to cope with new population growth (Badir et al. 2002). The governments developed programs of innovative construction methods alongside the traditional methods to meet the rising demands. The innovative construction methods depended on manufacturing and prefabricating parts of the building in factories offsite to supply the housing units at a lower cost, a shorter time, and a better quality. In 1944, the United Kingdom government developed and deployed the emergency factory-made program (EFM), which delivered 153,000 'temporary' prefabricated homes and terminated because of the quality issue (NHBC Foundation, 2016).

The innovative construction methods have been given a wide array of labels, including Offsite construction in the UK, Australia and China; Pre-Fabrication in Singapore and Hongkong; Industrial Building System in Sweden, Japan and Malaysia; and Modern Method of Construction (MMC) in the US. In this study, MMC is used because it is the most prevailing label in many countries. Many researchers and organizations have been trying to find a proper definition of MMC to incapsulate new construction approaches for policy purposes. Most of the definitions are limited to offsite and prefabrication construction processes or products, and the definitions of MMC have varied over the years. Trikha (1999), Adebayo et al. (2006), Mesároš and Mandičák (2015), and Marti (2017) define MMC as methods of construction that use parts manufactured and assembled offsite, or components manufactured offsite and brought together onsite for assembly. Sardén and Engström (2010) argue that this definition should comprise "one evident process owner and a clear product goal of repetition in housing design and production," NHBC Foundation (2016) defines (MMC) as a term "embraces several approaches involving offsite manufacture or assembly." However, two years later, it redefined MMC "is a broad term, embracing a range of offsite manufacturing and onsite techniques that provide alternatives to traditional house building. MMC ranges from whole homes being constructed from factory-built volumetric modules to innovative techniques for laying concrete blockwork onsite (NHBC Foundation (2018).

The House of Commons Housing, Communities and Local Government Committee in the UK (2019) developed a definitional framework into which all modern construction techniques can be categorized into Pre-Manufacturing and Traditional building product leading to site labor reduction/productivity improvements. The former includes 3D primary structural systems, 2D primary structural systems, Non systemized structural components, Additive Manufacturing, and Non-structural assemblies and sub-assemblies. The latter includes the Site process led to labor reduction/productivity improvements.

Alternative forms of MMC have been developed in response to demand for housing post wars, demand for new houses exceeding supply due to population growth, and/or lifestyle changes. However, some alternatives promoted a negative image towards their use for poor success in terms of design and quality (Gitonga, 2019). Besides, negative public perception towards MMC, low mass production, lack of support from financial and insurance sectors (Mesároš and Mandičák, 2015), political context, and lack of construction skills (MacEachrane, 2006) contributed to the limited use of MMC in the construction industry. However, for fear and obsession with shortages of housing units, governments keep the exploration for MMCs alive. In the U.K, Latham and Egan's report raised concerns about the efficiency and productivity of the housebuilding industry, and in 2000 the Barker report and the National Audit study, November 2005, encouraged the use of MMC to build homes more quickly and efficiently (Building Solution, No date). Consequently, Many MCC have been developed over the years, and include many innovations, most of which are offsite technologies, moving work from the construction site to the factory (Pan et al. 2007). They include modular building, preassembly, prefabrication, offsite production, offsite manufacturing, industrialized building, and also a range of onsite and offsite construction methods (Motiar Rahman, 2014). Table 2 presents some of the developed MMC with a brief description.

| Table 2: List of developed MMC **Building System** | **Description** |
|---|---|
| Light Clay (LC) | Clay is a material that occurs naturally almost on the entire surface of the Earth. It is plastic due to particle size and geometry, as well as water content, and with adequate humidity, it allows for any forming. Clays become non–plastic upon drying or firing and an impermeable material that provides good anti-water and excellent thermal insulations. |
| Cement Bamboo Frames (CBF) | A light frame made of bamboo. Three centimeters of plaster with metal mesh in mortar cement is applied to isolate and fortify the structure. |
| Oil-Cement Blocks (OCB) | Cement blocks that are used to build structures with local material |
| Coconut Board-Based (CBB) | Wallboards that are made of processed coconut shells. |
| Insulated Precast Systems (IP) | A concrete wall manufacturing technique by applying offsite production using pre-engineered casts. |
| Autoclaved Aerated Concrete (AAC) | Manufactured by adding in a calculated quantity of aluminum powder and various other materials into sand, cement, or lime and water to produce, through a chemical reaction, bubbles that contribute to the lightness of the product |
| Insulated Concrete Forms (ICF) | This construction method is applied by placing two high-density foam layers with a cavity in between them that is filled with concrete to create a wall. |
| Tunnel Formwork (TF) | TF system using a steel formwork that gives the ability to cast walls and slabs at a site in one operation. |
| Structural Light Gauge Steel (SLGS) | Cold-formed steel panels produced at the factory and shipped for installation onsite. |
| Concrete Modular (CM) | Factory-produced, pre-engineered building modules that could be assembled directly onsite. |
| Modular Light Gauge Steel (MLGS) | Steel columns that are set vertically along with horizontal beams to form a reliable construction skeleton. |

***MMC benefits***

MMC has many benefits over the traditional construction methods which include time reduction (Handby, et al 2019; Marti, 2017; Motiar Rahman, 2014; Building Solution, no date; Gitonga, 2019); Weathertight envelope which is achieved quicker with the use of MMC (NHBC Foundation, 2016; Motiar Rahman, 2014;

Gitonga, 2019, BuildingSolution, No date); Occupational accidents reduction (Marti, 2017; Motiar Rahman, 2014; BuildingSolution, No date; Gitonga, 2019); quality improvement in construction (NHBC Foundation, 2016; BuildingSolution, No date; Gitonga, 2019); costs reduction (NHBC Foundation, 2016; Motiar Rahman, 2014); profitability improvement (NHBC Foundation, 2016; Motiar Rahman, 2014); waste reduction (Motiar Rahman, 2014; BuildingSolution, No date); overcoming shortages in the availability of skilled labor for the traditional method (NHBC Foundation, 2016); water and electricity saving during manufacturing (Marti, 2017); mitigating environmental impact (Motiar Rahman, 2014); predictability (Motiar Rahman, 2014); significant reduction of the impact on the community surrounding the construction site (BuildingSolution, No date); elimination of weather effects on construction of buildings (Marti, 2017).

***Barriers to MMC implementation***

MMC are still largely lagging behind the traditional approach and represent a small fraction of the construction market. Many researchers have investigated the factors promoting/hindering MMC implementation in the construction industry. Table 3 presents the cited success/barrier factors for the use of MMC.

| Table 3: Barriers/success Factors of MMC Implementation<br>**Factor** | **Author(s)** |
|---|---|
| **Cost Related** | |
| The initial cost of the construction method: high start-up costs to set up a factory, purchase all relevant materials at the start of the project | Zhou et al., 2019; Nawi& Lee 2011; Du et al. 2014; Gan et al. 2018; Chan et al. 2018; Darko et al. 2017; Han & Wang, 2018; Mao et al. 2015 |
| Public awareness: public perception of MMC in terms of reliance and quality | Zhou et al., 2019; Nawi& Lee 2011; Gan et al. 2018; Chan et al. 2018; Darko et al. 2017; Mao et al. 2015 |
| Skills and technical knowledgeof a project personnel | Nawi& Lee 2011; Du et al. 2014; Darko et al. 2017; Han & Wang, 2018; Mao et al. 2015 |
| Standards and codes for MMC | Zhou et al., 2019; Nawi& Lee 2011; Gan et al. 2018; Han & Wang, 2018; Chan et al. 2018 |
| Lack of professionals: Lack of trained and experienced professionals in the local market | Du et al. 2014; Chan et al. 2018; Han & Wang, 2018; Mao et al. 2015 |
| Low market demand | Du et al. 2014; Gan et al. 2018; Han & Wang, 2018; Mao et al. 2015 |
| Supporting industrial supply chain: associated with MMC that begins with raw materials until the end product is delivered | Zhou et al., 2019; Nawi& Lee 2011; Gan et al. 2018; |
| Lack of government incentives: Incentives and support from the government that motivate the adoption of MMC, such as tax exemption or ease of acquiring permits | Nawi& Lee 2011; Chan et al. 2018; Han & Wang, 2018 |
| Dominance of traditional construction method: The dominance of the cast-on-site method in the market | Gan et al. 2018; Han & Wang, 2018; Mao et al. 2015 |
| Resistance to change: Resistance to adopting MMC by the public | Darko et al. 2017; Mao et al. 2015 |
| Transportation capability: Weight and other dimensions of the building elements | Zhou et al., 2019; Han & Wang, 2018 |
| Quality problems: poor insulation of water and heat or sound | Gan et al. 2018; Han & Wang, 2018 |
| Storage difficulty: Element of housing units are large in size, heavy in weight, and require machinery to handle, hence storage is difficult and costly | Han & Wang, 2018; Mao et al. 2015 |
| Lack of local R&D: Lack of institutions that support the sector by researching better, cheaper, and more efficient materials | Mao et al. 2015; Chan et al. 2018 |
| Low profitability: Low margin of profit | Du et al. 2014 |
| Poor Manufacturing capability: Lack of overall manufacturing knowledge | Gan et al. 2018 |
| Poor aesthetic performances: Typical and bland façade | Gan et al. 2018 |

| | |
|---|---|
| and exterior design | |
| Complicated management: A method that requires effective management of production, installation, and supply chain management | Gan et al. 2018 |
| Inappropriate business model: Applying a business model that is unsuitable for the product | Gan et al. 2018 |
| Lack of financing schemes: Support from financial institutions such as bank loans | Gan et al. 2018 |
| Increased design fees: Due to the complexity and novelty of the construction method, an increase in the design fee occurs | Han & Wang, 2018 |
| Longer pre-construction stage: Since manufacturing of the part requires precise measurements, longer time is required to produce designs and drawing details | Han & Wang, 2018 |
| Design change difficulty during construction: Difficulty to change after manufacturing since it is costly because a revision of the design process and remanufacturing is required | Han & Wang, 2018 |
| Limitations on transportation: Width and weight of load restriction from the ministry of transportation | Han & Wang, 2018 |
| Condensed site environment: Compacted site that hinders the productivity of labor and machinery | Han & Wang, 2018 |
| Reluctance to innovation: Following the same work process without any update or changes that lead to lower cost and a more efficient process | Mao et al. 2015 |
| Shortage of Capable Consultants and Designers: Lack of trained professionals in the design and supervision areas | Mao et al. 2015 |
| Shortages of capable contractors on prefabrication activities: Lack of contractors for the installation activities of prefabricated elements | Mao et al. 2015 |
| Shortages of vendors that supply prefabricated parts: Lack of suppliers for the manufacturing supporting prefabricated elements | Mao et al. 2015 |
| Critical success factors | Mukhtar et al. 2016 |

***MMC Salient Features***

Unfortunately, researchers have not addressed the salient features associated with MMC. End-users may still contemplate issues related to maintainability, service life, compatibility with other systems, architectural features, and many others. The authors extrapolated building features from literature published on buildings constructed using the traditional method. Many features characterizing buildings were found and presented in table 4.

Table 4: Potential MMC salient features

| **Building Features** | **Author** |
|---|---|
| Price | Chan &Adabre, 2019; Pawluk, 2018; Ahadzie at al. 2008; Alrashed& Asif, 2014; Al-Hammad &Hassanain, 1996; Building Technology Stimulus Program |
| Operating and Maintenance Costs | Wong & Li, 2008; Chan &Adabre, 2019; Al-Hammad &Hassanain, 1996 |
| Delivery time | Chan &Adabre, 2019; Pawluk, 2018; Ahadzie at al. 2008; Alrashed& Asif, 2014; Al-Hammad &Hassanain, 1996; Building Technology Stimulus Program |
| Life span (Service life) | Wong & Li, 2008; Salzer et al. 2017 |
| Quality | Chan &Adabre, 2019; Ahadzie et al. 2008; Mulliner&Algrnas, 2018; Alrashed& Asif, 2014; Building Technology Stimulus Program |

| | |
|---|---|
| Fire Safety | Ahadzie et al. 2008; Alrashed& Asif, 2014; (Al-Hammad &Hassanain, 1996 |
| Environmental Friendliness | Ahadzie et al. 2008; Mulliner & Algrnas, 2018 |
| Risk Containment | Ahadzie et al. 2008; |
| Customer Satisfaction | Ahadzie et al. 2008; |
| Stakeholder Satisfaction | Ahadzie et al. 2008; |
| Durability | Salzer et al. 2017; Alrashed & Asif, 2014; Al-Hammad & Hassanain, 1996 |
| External Support | Yusof & Shafiei, 2011 |
| Market Readiness | Yusof & Shafiei, 2011 |
| Number of stories | Mulliner & Algrnas, 2018 |
| Quality of exterior finishing | Mulliner & Algrnas, 2018; Alrashed & Asif, 2014; Al-Hammad & Hassanain, 1996 |
| Functional and spacious layout | Mulliner & Algrnas, 2018 |
| Insulation | Mulliner & Algrnas, 2018); Al-Hammad & Hassanain, 1996 |
| Modernity | Alrashed& Asif, 2014 |
| Acoustical properties | Al-Hammad & Hassanain, 1996 |
| Exclusion of rain and water | Al-Hammad & Hassanain, 1996 |
| Availability | Al-Hammad & Hassanain, 1996 |
| Strength | Al-Hammad & Hassanain, 1996 |
| Compatibility | Al-Hammad & Hassanain, 1996 |
| Security | Al-Hammad & Hassanain, 1996 |
| Flexibility | Al-Hammad & Hassanain, 1996 |

This study intends to close the literature gap by investigating and comparing the salient features of several MMC that are used in Saudi Arabia and addressing the success/barriers factors for/against the use of MMC.

**Research Methodology**

This section presents the steps that were followed to achieve the set objective of the study. The first step involved reviewing the published relevant literature to become more familiar with the theoretical perspective on MMC. The second step was to collect the necessary data from MMC contractors through a questionnaire, which the literature review guided its development. The questionnaire consists of four sections. The first section contains questions seeking information on the respondents' characteristics i.e., education, experience in the construction industry, familiarity with MMC and their implementations. The second section contains questions seeking information on the organization i.e., age, type of MMC specialization. The third section contains questions seeking information on the salient features of MMC i.e., initial costs, delivery time, sustainability, etc. The fourth section was devoted to collecting information on the success/barriers that promote/hinder the implementation of MMC in Saudi Arabia. Eleven in-depth interviews were held with experts and key personnel with more than 10 years of experience in the development of building projects in Saudi Arabia to evaluate the contents and clarity of the questionnaire. The experts suggested some modifications to make the questionnaire more focused on local issues, especially to the MMC features and barriers. The questionnaire was emailed to 87 contractors who were in the list of attendees of a symposium on MMC organized by the Ministry of Housing during the execution of this study. There is no source for the number and identity of MMC contractors, making it difficult to define the study population. The authors asked several attendees, including the symposium organizer, on the number of MMC contractors in the Eastern Province in Saudi Arabia. The answers range from 50 to 60 contractors. The assumption is that all MMC contractors attend the symposium. Since their identities were known, we decided to send the questionnaire to all the attendees. The third step was to analyze the collected data using simple statistical tools such as frequency, mean, and standard deviation. Besides,

Terrell's transformation index (TS) is employed to compute the critical barriers to the implementation of MMC and rank them based on their influence levels. TSs were calculate using the following equation:

$$TS = [(ARS - LPRS)/PRSR] \times 100 \qquad (1)$$

where TS is the transformed score, ARS the actual raw score, LPRS the lowest possible raw score, and PRSR the possible raw score range. The formula above is adopted to convert ordinal data collected in this study into indices so that all the items for each factor could be consolidated into a single index that has values ranging from 0 – 100. After the conversion, the ordinal data become interval data, which allow the ranking of cost factors based on their indices. According to Elhag et al. (2005), barriers with the indices of 65% and above are considered critical factors influencing the implementation of MMC, while barriers that have indices below 65% are regarded as less critical.

The coefficient of variation (CV) is used to measure the contractors' agreement trough measuring the relative variation for distributions with different means, which expresses standard deviation as a percentage of the mean. The coefficient of variation for sample data is computed as follows:

$$CV = (\text{Standard deviation}/\text{Mean}) \times 100 \qquad (2)$$

**Result Analysis and Discussion**

Because the population sizes are small, the structured questionnaire was distributed in the third quarter of 2019 via email to the 87 contractors. The questionnaire was followed up with emails, telephone calls, and personal visits to invite and encourage constructability experts to participate in the study. Thirty-four experts from contracting organizations completed and returned the questionnaires. Improving the reliability of the collected data mandated restoring questionnaires that had at least 80 percent of their contents duly completed, and the data were provided by constructability experienced experts. All received responses met the abovementioned criteria and, hence accepted. Therefore, the rate of return is measured 57% (assuming the population size is 60 MMC contractors), which is considered way above the typical norm of 20-30% response rate in most postal questionnaire surveying of the construction industry (Akintoye and Fitzgerald, 2000).

***Characteristics of Respondents***

The results indicate that the respondents hold college degrees, mostly in civil engineering and architecture. The majority (53%) of the respondents are Operation managers, and most of the remaining are engineers. Besides, the majority (70%) have more than 10 years of experience in the Saudi construction industry in which the majority (65%) have gained part of the experience (less than 5 years) working with their current employers. The respondents indicated that they have experience in MMC, but with varying exposures, about 32% have between 5 and 10 years, and the remaining have less than 5 years. They gained these experiences through their participation in at least 2 projects built using MMCs. Table 5 presents a summary of the characteristics of respondents. The characteristics of the respondents indicate that the majority of the respondents are highly experienced in their fields, which adds to the quality of the responses.

The participants are employed in organizations in which the majority (65%) of them have been in the market for more than 10 years. The majority (61%) of the organizations have annual revenue between SR50-80 million, with an average of SR65 million per year. The organizations adopt different MMC to build projects: 15 use IP, 12 use SLGS, four use AAC, one uses ICF, one uses CM, and one uses MLGS. The majority (75%) of the organizations employ less than 100 people. The organizations use MMC to build housing units, residential buildings, commercial buildings, infrastructure, plants, pump stations, schools, treatment plants, and lift stations. About 59% of the contractors indicated that the housing units comprise 50%-75% of their annual sales, where they build less than 500 housing units per year.

In summary, it is with confidence that the participants are well informed in MMC, and their organizations are considered a qualified and trustworthy source of information related to MMC. Hence, obtaining information from such talents increases the reliability of the obtained results.

Table 5: The Characteristics of Respondents

| **Inquiry** | **Majority of response** | **Total percentage** |
|---|---|---|
| Job Title | Operation Manager 53% | 74 % |
| | Engineer 21% | |
| Experience in Construction | More than 15 years 44% | 70 % |
| | From 11 to 15 years 26 % | |
| Number of years with the current employer | Less than 5 years 65% | 86 % |
| | From 6 to 10 years 21% | |
| Educational Level | Bachelor 65% | 97 % |
| | Master 32 % | |
| Area of education | Civil 56% | 80 % |
| | Architecture 24% | |
| Experience in MMCs | Less than 5 years 32% | 64 % |

| | | |
|---|---|---|
| | From 6 to 10 years 32% | |
| Participation in building technologies | 6 or more times 44% | 70 % |
| | Less than 2 times 26% | |

***MMC Types***

The results reveal that SLGS, MLGS, ICF, AAC, IP, and CM are the available MMC in the Eastern Province of Saudi Arabia. SLGS is made by a cold-forming process where sheets of steel are passed through a series of roll forming dies to create their desired shape. AAC is manufactured by adding in a calculated quantity of aluminum powder and various other materials into sand, cement, or lime and water to produce, through a chemical reaction, bubbles that contribute to the lightness of the product. This system gives excellent thermal insulation, excellent firing resisting abilities, and reduced structure weight, which implies lower costs. This construction method is applied by placing two high-density foam layers with a cavity in between them that is filled with concrete to create a wall. The advantages of this system are energy savings, noise reduction, wall strength, high thermal insulation, and low construction time. However, the cost of building material is high. CM is a factory-produced, pre-engineered building module that could be assembled directly onsite. MLGS is steel columns that are set vertically along with horizontal beams to form a reliable construction skeleton. Adlakha and Puri (2003) discussed prefabrication for low-cost housing and mentioned that the skill level of the local workforce must be kept in mind to ensure sustainability. IP, as a construction method, is advantageous over the conventional method, as the cladding materials of the precast are more fire-resistant, durable, and overall better quality.

***MMC Salient Features***

The respondents were asked to provide the information on MMC features based on a hypothetical typical housing unit, that is being built using MMC other than the traditional construction method with the following details:

1. Scope of work: Build the skeleton of the house with interior and exterior walls only. Plastering, finishing, mechanical, electrical, and plumping are not part of the scope.
2. Land characteristics: Lot size is 500 m2 located in an area with normal conditions (typical soil, normal weather, low water table, and accessible),
3. Architectural program: The house consists of ground, first, and roof floors. The area for each floor is 300m. The ground floor consists of a reception area, living room, dining area, and two bathrooms. The first floor consists of four bedrooms with bathrooms. The total rooms area is 150m. The roof consists of two 16m2 rooms and a 6m2 shared bathroom.

The respondents provided qualitative and quantitative information about the features of their MMC, which are described through seven categories: owner costs, delivery time, sustainability, housing unit characteristics, future modifications, technology characteristics, and manufacturing capacity. Table 6 presents the salient features of the existing MMC in Saudi Arabia.

*Owning Costs*

An owner, as in investor, has significant concerns with the price and maintenance costs at the start of his journey to own a housing unit. The results indicate that SLGS has the lowest price for delivering the hypothetical housing unit, the average price of SR 362/m2, and annual maintenance cost, an average of SR 1475. On the other hand, IP has the highest price, the average price of 735 SR/m2, and the second-highest in annual maintenance cost, an average of SR 2833. This variation reflects the cost of used resources (e.g., materials, labors, equipment). Interestingly, the square meter produced by MMC, excluding the SLGS, is more expensive than that produced by the traditional construction method.

*Delivery Time*

The results indicate that all the existing MMC erect the hypothetical housing unit within two months. CM has the shortest delivery time (about 0.25 months), and IP has the longest (about 2 months). AAC has the second shortest delivery time, and ICF has the second-highest delivery time. This feature shows the superiority of MMC over the traditional method.

*Sustainability*

The average life span of the existing MMC ranges from 33 years to 47 years, with an average of 38 years. SLGS has the longest average life span out of all the MMC, with an average life span of 47 years. AAC has the least life span of 33 years.

Table 6: MMC Features Matrix

| **Category** | **Features** | **MMC** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **SLGS** | **MLGS** | **ICF** | **AAC** | **IP** | **CM** |
| **Owning Costs** | Price, SR per square meter | 362 | 550 | 490 | 573 | 735 | 600 |
| | Maintenance, SR | 1475 | 1800 | 2200 | 2250 | 2833 | 3000 |
| **Time** | Delivery, Months | 0.98 | 1.50 | 1.77 | 0.50 | 2.00 | 0.25 |
| **Sustainability** | Life Span, Years | 47 | 35 | 35 | 33 | 43 | 35 |
| **Housing Units Characteristics** | Fire Rating, Hours | 4 | 2 | 2 | 4 | 4 | 5 hrs |
| | Fire Safety: Approved by Civil Defence | Yes | Yes | Yes | Yes | Yes | Yes |
| | Structure Safety: Approved by Civil Defence | Yes | Yes | Yes | Yes | Yes | Yes |
| | Certified as environmentally friendly | Yes | Yes | Yes | Yes | Yes | Yes |
| | Conform to the thermal insulation requirements of the Saudi building code | Yes | Yes | Yes | Yes | Yes | Yes |
| | High sound insulation | Yes | Yes | Yes | Yes | Yes | Yes |
| **Future Modifications** | Possibility of wall breaking | Yes | Yes | No | Yes | Yes | No |
| | Allow socket addition | Yes | Yes | No | Yes | Yes | No |
| | Allow water pipe removal | Yes | Yes | No | Yes | Yes | No |
| | Allow for the addition of floors in the future | No | No | No | No | No | No |
| **Technology Features** | Compatibility with other building systems e.g. windows, doors, HVAC, mechanical, or electrical systems | No | Yes | No | No | Yes | Yes |
| | Number of Floors, No | Up to 7 | Up to 7 | Up to 7 | Up to 7 | Up to 7 | Up to 20 |
| | Allow for a large number of rooms | Yes | Yes | Yes | Yes | Yes | Yes |
| | Floor heights, meters | 3-6 | 3-6 | 3-6 | 3-6 | 3-6 | 3-6 |
| | Limitations on room sizes | No | Yes | No | Yes | No | Yes |
| | Limitations on number of bathrooms | No | No | No | No | No | No |
| | Limitations layout design | No | No | No | No | No | No |
| | Constraints on the shape of the building | Yes | Yes | No | Yes | No | Yes |
| | Allow exterior design options | Yes | Yes | Yes | Yes | Yes | Yes |
| | Addition of separate buildings | Yes | Yes | Yes | Yes | Yes | Yes |
| | Addition of elements such as elevators | Yes | Yes | Yes | Yes | Yes | Yes |
| | Allow for basement additions | No | No | No | No | No | No |
| **Production Capacity** | Minimum Number of Houses per year to business survival | 40-200 (AVG 87) | 100 | 150 | 200-300 (AVG 250) | 100-500 (AVG 280) | 1000 |
| | Minimum Production Capacity Achievement | Yes | Yes | Yes | Yes | Yes | Yes |

*Characteristics of produced Housing units*

The MMC contractors claim that the housing unit that they build are safe in term of structure, fire, soundproof, and thermal insulation. The Civil Defense, the authorized government party for building safety, approves the structures' safety and attests to the compliance of the housing units to the fire code requirements. The contractors claim that the housing units built using CM have a 5-hours fire rating, the MLGS and the ICF have a 2-hours fire rating, and the remaining MMC have a 4-hours fire rating. All MMC produce housing units with high sound insulation and complying with Saudi building code thermal insulation requirements.

*Future Modifications*

The results indicate that MC and the ICF are inflexible for future changes and alterations. These limitations may have a negative influence on clients to implement the above MMC.

On the other hand, SLGS, MLGS, AAC, and IP are flexible for future modifications, including socket addition, water pipe removing, and wall breaking as the walls are not being load-bearing. All MMC do not allow adding additional floors in the future.

*Technology features*

The results indicate that MMC share several technical features and differ in a few others. They are flexible in the housing design layouts, the sizes and number of rooms, the number of bathrooms, the exterior design options, the floor heights (ranging from 3 m to 6 m), and the addition of separate buildings and other elements such as elevators. Besides, all MMC are environmentally-friendly certified. However, MMC do not allow for the inclusion of basements.

On the other hand, they differ in a few other technical features. CM, IP, and MLGS are not compatible with other available building systems, including HVAC, mechanical, electrical, while AAC, SLGS, and ICF are compatible. CM is the only MMC that can construct up to twenty floors buildings, while the other MMC are limited to seven floors. All MMC, except ICF and IP, do not have constraints on the shape of the building.

*Production and Capacity*

The results indicate that all MMC contractors achieve the minimum annual quantity of housing units that are needed to survive economically. The minimum annual number of housing units ranges from 40-200, an average of 87 for SLGS; 200-300, an average 250 for AAC; and 100-500, an average 280 for IP. This variation indicates the sizes of the MMC factories and, hence, their capacities. The annual minimums number of housing units for MLGS, the ICF, and CM are 100, 150, and 1000. The nature of these MMC requires continuous production of housing units to be economically feasible, as it would not be logical to operate a manufacturing facility for one single or very few housing units.

### *Factors Hindering the Implementation of MMC*

The participants provided numerical scoring expressing the level of severity of several barriers to the implementation of MMC in Saudi Arabia. The TS for each barrier was calculated, presented in Table 7, to measure its influence on MMC implementation. Besides, the mean, standard of deviation, and coefficient of variation (CV) for each barrier were calculated and presented in Table 8.

The results indicate that there are many barriers to the implementation of MMC in Saudi Arabia. The results indicate that 10 factors have obtained a transformed score higher than 65%, and the remaining 19 factors have obtained a transformed score of less than 65%. These results show that out of 29 factors identified from the literature review, only 10 factors are regarded by the MMC contractors as highly relevant for the implementation of MMC in Saudi Arabia. Besides, the results show that the variation of responses on success/barrier factors to MMC implementation is relatively low, as measured by the coefficient of variation (CV), which is regarded as a good indication implying that there is a relatively high level of agreement among contractors in rating the factors. All the 10 critical factors have coefficient of variations ranging from 12% to 25%. Comparatively, the remaining 19 factors have higher coefficients of variation, ranging from 23% to 51%.

The factors are classified into seven categories: Supply Chain, Market, Customers, Government, Technology, Cost, and Contractors.

*Supply Chain*

The results indicate that the lack of skilled technicians, expert architects, and experienced engineers in MMC is the only critical factor in this category affecting the implementation of MMC. The unavailability of such professionals is not surprising where the MMC require new skills that are not available in the market. This issue is not limited to Saudi Arabia but is common in many other countries. On the other hand, the MMC contractors consider the other factors not critical, indicating that they find all necessary raw materials and common interior design elements available in the local market for their MMC.

*Market*

The MMC contractors consider the dominance of the traditional construction method a critical factor affecting the implementation of MMC in Saudi Arabia, coupled with low market demand for MMC. The contractors do not believe that MMC's public awareness is a critical factor affecting the implementation of MMC but rather due to customers' resistance to using MMC.

*Customers*

The results indicate that the MMC contractors trust customers do not have any problem with the exterior design or secure mortgages from financial institutes for purchasing or building their houses using MMC. However, they consider the customers' resistance to MMC the only critical factor in this category affecting the implementation of MMC.

*Government*

The results indicate that MMC contractors consider the lack of government support and the Ministry of Housing approval process critical factors affecting the implementation of MMC in Saudi Arabia. Commonly, the government provides unlimited supports for MMC, but it seems not enough. It is probably that MMC contractors demand that the government enforce MMC on more significant percentages of housing units and relax some bureaucracy in the evaluation processes inside the Ministry of Housing. The MMC contractors indicate that other logistics such as obtaining construction permits from municipalities and the Civil Defense, availability of building standards/code, and customs clearance of imported items are not critical factors to the implementation of MMC.

*MMC Technology Issues*

Although the results indicate that none of the factors in this category is critical, the size and load restrictions on transportation are near critical and ranked the 11th factor affecting the implementation of MMC. These restrictions limit the number of manufactured heavy elements per transport, driving the cost of a housing unit upward through increased transportation costs.

*Cost Issues*

The contractors consider the high initial cost for building a manufacturing factory is the most critical factor that has a severe impact on the implementation of MMC. Many MMC require offsite manufacturing facilities that require a substantial initial investment and operating costs. The government supports MMC contractors with up to 75% of the initial cost and the finance of the first six months operations. The government has signed contracts to fund two MMC factories with a value of SR 186 million ($ 50 million) (Ministry of Housing, 2018). Seemingly, MMC either face significant difficulties in obtaining the necessary fund, or the number of secured housing units does not encourage investors in MMC. The shifting building work from onsite to offsite mandates sustainable production to recover the initial investment in a reasonable payback period and to finance the factory operating costs. As shown below, the contractors consider the number of housing units critical to the implementation of MMC.

*MMC Contractors*

Three factors in this category are considered critical imposing severe impacts on the implementation of MMC. The contractors admit the improper marketing plan and the low skills and knowledge of local staff contribute heavily to the high/low implementation of MMC. Besides, the vagueness in the number of housing units awarded and constructed using MMC is a critical factor affecting the implementation of MMC. Recovery of initial investment and operating costs and having competitive service prices mandate the acquisition of a continuous large number of housing projects.

Table 7: Terrell's transformation index (TS)

| Factors | ARS | LPRS | PRSP | TS | Rank | Decision |
|---|---|---|---|---|---|---|
| **Supply Chain** | | | | | | |
| Availability of raw materials | 106 | 34 | 136 | 59 | 19 | Not Critical |
| Compatibility with common local interior design elements such as paint, gypsum, or flooring | 88 | 34 | 136 | 45 | 28 | Not Critical |
| Compatibility with local common systems of windows, doors, HVAC, mechanical, or electrical | 92 | 34 | 136 | 48 | 25 | Not Critical |
| Lack of experienced design consultancy and designers | 115 | 34 | 136 | 63 | 12 | Not Critical |
| Lack of local R&D | 91 | 34 | 136 | 49 | 24 | Not Critical |
| Lack of professionals (skilled technicians, | 140 | 34 | 136 | 79 | 5 | **Critical** |

| | | | | | | |
|---|---|---|---|---|---|---|
| expert architects, experienced site engineers) | | | | | | |
| **Market** | | | | | | |
| The dominance of the traditional construction method | 143 | 34 | 136 | 82 | 4 | **Critical** |
| Low market demand for MMC | 136 | 34 | 136 | 77 | 6 | **Critical** |
| Public awareness of MMC | 112 | 34 | 136 | 62 | 13 | Not Critical |
| **MMC Customers** | | | | | | |
| Financial institution: Difficulty in obtaining mortgage from banks for a house built using MMC | 105 | 34 | 136 | 59 | 16 | Not Critical |
| Acceptance of exterior design | 100 | 34 | 136 | 54 | 21 | Not Critical |
| Resistance to adopt MMC | 151 | 34 | 136 | 88 | 2 | **Critical** |
| **Government** | | | | | | |
| Lack of construction standards for MMC | 85 | 34 | 136 | 46 | 27 | Not Critical |
| Lack of government support | 129 | 34 | 136 | 71 | 8 | **Critical** |
| Ministry of housing approval | 129 | 34 | 136 | 73 | 7 | **Critical** |
| Municipality permits | 98 | 34 | 136 | 52 | 22 | Not Critical |
| Delay in customs clearance for imported items | 106 | 34 | 136 | 57 | 18 | Not Critical |
| Conformance with existing building code/regulations | 109 | 34 | 136 | 60 | 14 | Not Critical |
| Civil Defence Permits | 100 | 34 | 136 | 54 | 20 | Not Critical |
| **MMC Technology Issues** | | | | | | |
| Design change difficulty during construction | 107 | 34 | 136 | 58 | 17 | Not Critical |
| Longer pre-construction stage | 88 | 34 | 136 | 46 | 26 | Not Critical |
| Size and load restrictions on transportation | 117 | 34 | 136 | 64 | 11 | Not Critical |
| **Cost Issues** | | | | | | |
| High design fees | 93 | 34 | 136 | 50 | 23 | Not Critical |
| High initial cost | 154 | 34 | 13 | 90 | 1 | **Critical** |
| **MMC Contractors** | | | | | | |
| Improper marketing plan | 147 | 34 | 136 | 85 | 3 | **Critical** |
| Low profitability | 109 | 34 | 136 | 60 | 14 | Not Critical |
| Skills and knowledge of local staff | 123 | 34 | 136 | 69 | 9 | **Critical** |
| Number of units to be constructed | 122 | 34 | 136 | 67 | 10 | **Critical** |
| Site location distance from the main office | 84 | 34 | 136 | 44 | 29 | Not Critical |

Table 8: Factors Hindering the Implementation of MMC

| Category | Sr | Factors | Level of Severity | | | | | Mean | SD | CV |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | | | |
| Supply Chain | 1 | Availability of raw materials | 9 | 2 | 8 | 2 | 13 | 3.24 | 1.65 | 0.51 |
| | 2 | Compatibility with common local interior design elements such as paint, gypsum, or flooring | 8 | 5 | 12 | 4 | 5 | 2.79 | 1.34 | 0.48 |
| | 3 | Compatibility with local common systems of windows, doors, HVAC, mechanical, or electrical | 6 | 5 | 14 | 4 | 5 | 2.91 | 1.26 | 0.43 |
| | 4 | Lack of experienced design consultancy and designers | 0 | 3 | 17 | 7 | 7 | 3.53 | 0.93 | 0.26 |
| | 5 | Lack of local R&D | 0 | 8 | 19 | 7 | 0 | 2.97 | 0.67 | 0.23 |
| | 6 | Lack of professionals (skilled technicians, expert architects, experienced site engineers) | 0 | 0 | 9 | 10 | 15 | 4.18 | 0.83 | 0.20 |
| Market | 1 | The dominance of the traditional construction method | 0 | 0 | 5 | 15 | 14 | 4.26 | 0.71 | 0.17 |
| | 2 | Low market demand for MMC | 0 | 1 | 7 | 14 | 12 | 4.09 | 0.83 | 0.20 |
| | 3 | Public awareness of MMC | 2 | 4 | 12 | 8 | 8 | 3.47 | 1.16 | 0.33 |
| Customer | 1 | Financial institution: Difficulty in obtaining mortgage from banks for a house built using MMC | 3 | 7 | 8 | 7 | 9 | 3.35 | 1.32 | 0.39 |
| | 2 | Acceptance of exterior design | 3 | 5 | 13 | 10 | 3 | 3.15 | 1.08 | 0.34 |
| | 3 | Resistance to adopt MMC | 0 | 0 | 1 | 15 | 18 | 4.50 | 0.56 | 0.12 |
| Government | 1 | Lack of construction standards for MMC | 3 | 9 | 15 | 5 | 2 | 2.82 | 1.00 | 0.35 |
| | 2 | Lack of government support | 0 | 0 | 14 | 11 | 9 | 3.85 | 0.82 | 0.21 |
| | 3 | Ministry of housing approval | 0 | 2 | 11 | 9 | 12 | 3.91 | 0.97 | 0.25 |
| | 4 | Municipality permits | 2 | 5 | 18 | 6 | 3 | 3.09 | 0.97 | 0.31 |
| | 5 | Delay in customs clearance for imported items | 4 | 4 | 11 | 8 | 7 | 3.29 | 1.27 | 0.39 |
| | 6 | Conformance with existing building code/regulations | 4 | 4 | 12 | 3 | 11 | 3.38 | 1.37 | 0.41 |
| | 7 | Civil Defence Permits | 1 | 6 | 15 | 10 | 2 | 3.18 | 0.90 | 0.28 |
| MMC Technology Issues | 1 | Design change difficulty during construction | 2 | 4 | 14 | 9 | 5 | 3.32 | 1.07 | 0.32 |
| | 2 | Longer pre-construction stage | 6 | 7 | 12 | 4 | 5 | 2.85 | 1.28 | 0.45 |
| | 3 | Size and load restrictions on transportation | 0 | 2 | 15 | 13 | 4 | 3.56 | 0.79 | 0.34 |
| Cost Issues | 1 | High design fees | 4 | 7 | 13 | 5 | 5 | 3.00 | 1.21 | 0.40 |
| | 2 | High initial cost | 0 | 0 | 2 | 10 | 22 | 4.59 | 0.61 | 0.13 |
| MMC Contractors | 1 | Improper marketing plan | 0 | 0 | 2 | 17 | 15 | 4.38 | 0.60 | 0.14 |
| | 2 | Low profitability | 1 | 5 | 12 | 11 | 5 | 3.41 | 1.02 | 0.30 |
| | 3 | Skills and knowledge of local staff | 0 | 3 | 11 | 11 | 9 | 3.76 | 0.96 | 0.26 |
| | 4 | Number of units to be constructed | 0 | 1 | 18 | 6 | 9 | 3.68 | 0.91 | 0.25 |
| | 5 | Site location distance from the main office | 8 | 8 | 8 | 4 | 6 | 2.76 | 1.42 | 0.51 |

*SD = Standard of Deviation, Level of Severity = (1) Not very severe, (2) Not sever, (3) Severe, (4) Very severe, (5) Extremely severe

The contractors were asked to indicate the success and obstacles factors of their MMC in the Saudi market. Contractors related their success to the Ministry of Housing support, low cost, sound insulation, strength and durability of the structure, speed of delivery, success with residential complexes, repetitive designs, long life span, and light structure.

Contractors indicated that their MMC face significant obstacles, including production capacity, fear of experience, low budget, slow to award projects, improper understanding of the system, resistance from vendors and traditional contractors, and lack of support from authorities due to fear of responsibilities.

**Conclusion**

The use of modern methods of construction (MMC) in Saudi Arabia is still very moderate and securing a minimal share of the housing market despite the massive financial and logistical support of the Ministry of Housing. Structural Light Gauge Steel, Modular Light Gauge Steel, Insulated Concrete Forms, Autoclaved Aerated Concrete, Insulated Precast, and Concrete Modular are the used MMC in the Eastern Province of Saudi Arabia. These MMC share encouraging and undesirable features in produced housing units and differ in several others. The produced housing units are structurally sound, environmentally friendly, soundproof, allowing exterior design options, the addition of separate buildings, the addition of building elements such as elevators, and complying with the Saudi thermal and fire codes, which are all encouraging. Besides, MMC do not allow for basements and additional future floors, which are considered undesirable. They differ in the selling price of housing units and the flexibility to future modifications. The weaknesses and limitations inherent in the available MMC, including renovation capabilities, aesthetics, creativity, and limitation in design options are attributed to the low share of these MMC in the housing market. The high initial and operating costs, customers' resistance to MMC, improper marketing strategies, the dominance of the traditional building method, lack of professionals (skilled technicians, expert architects, experienced site engineers), low market demand for MMC, lack of government support, skills and knowledge of local staff, and the number of units to be constructed contribute immensely to the use of MMC.

MMC providers are advised to develop effective marketing plans to ease customers' resistance toward MMC. They are also encouraged to develop concentrated training plans for new hires to solve the lack of professionals.

The government is advised to set a regulation dictating the percentage of government-supplied housing units to be delivered using MMC. The government is advised to encourage and fund local research and development (R&D) institutions to develop materials, technologies, and MMC that suit the local market and environment.

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**References**

Adlakha, Shri P. K., & Puri Shri, H. C. (2003). Prefabrication building methodologies for low cost housing. *Journal of The Institution of Engineers, 84*.

Ahadzie, P., Proverbs, D., & Olomolaiye, P. (2008). Critical success criteria for mass house building projects in developing countries. *International Journal of Project Management, 26*(6), 675–687. doi: 10.1016/j.ijproman.2007.09.006.

Al-Hammad, A., & Hassanain, M. A. (1996). Value engineering in the assessment of exterior building wall systems. *Journal of Architectural Engineering, 2*(3), 115–119. doi: 10.1061/(asce)1076-0431(1996)2:3(115).

Badir, Y., Kadir, M. , and Hashim, (2002). Industrialized Building Systems Construction in Malaysia. *Journal of Architectural Engineering,* vol. 8, no. 1, pp. 19-23, 2002.

Building Solution. (No date). An Introduction to Modern Methods of Construction (MMC) and Offsite Fabrication. Hertfordshire.

Chan, A. P., & Adabre, M. A. (2019). Bridging the gap between sustainable housing and affordable housing: The required critical success criteria (CSC). *Building and Environment, 151*, 112–125. doi: 10.1016/j.buildenv.2019.01.029

Chan, A. P. C., Darko, A., Olanipekun, A. O., & Ameyaw, E. E. (2018). Critical barriers to green building technologies adoption in developing countries: The case of Ghana. *Journal of Cleaner Production, 172*, 1067–1079. doi: 10.1016/j.jclepro.2017.10.235

Du, P., Zheng, L.-Q., Xie, B.-C., & Mahalingam, A. (2014). Barriers to the adoption of energy-saving technologies in the building sector: A survey study of Jing-jin-tang, China. Energy Policy, 75, 206–216. doi: 10.1016/j.enpol.2014.09.025

Elhag TMS, Boussabaine AH, Ballal TMA. Critical determinants of construction tendering costs: quantity surveyors' standpoint. Int J Project Manage 2005;23:538-45.

*Forecast, Saudi Arabia Real Estate Price Index. Trading Economics.*

Girmscheid, G. (2005). Industrialization in Building Construction –Production Technology or Management Concept? Institute for Construction Engineering and Management, Swiss Federal Institute of Technology Zurich

Gitonga, B. (2019). Modern Methods of Construction to Build Homes More Quickly and Efficiently: A Study of the UK Industry. University of Embu.

Han, Y., & Wang, L. (2018). Identifying barriers to off-site construction using Grey Dematel Approach: case of China. Journal of Civil Engineering and Management, 24(5), 364–377. doi: 10.3846/jcem.2018.5181

Handby, C. , Salisbury, G., and Baldwin, C. (2019).The housing sector is huffing and puffing to increase productivity. Real Estate, a forum for conversation on leading Real Estate topics, with insights, ideas and knowledge from industry experts.

House of Commons Housing, Communities and Local Government Committee. (2019). Modern methods of construction. Fifteenth Report of Session 2017–19

Lam, P. T., Chan, E. H., Poon, C., Chau, C., & Chun, K. (2010). Factors affecting the implementation of green specifications in construction. *Journal of Environmental Management, 91*(3), 654–661. doi: 10.1016/j.jenvman.2009.09.029.

Laubier, R., Burfeind, A., Arnold, S., Witthöft, S., and Wunder, M. (2019). The Offsite Revolution in Construction.

Marti, S. (2017). What it means industrialised construction? New Industrialized Building Contractors. Boston Consulting Group.

Mesároš, P. and Mandičák, T. (2015). Factors affecting the use of modern methods and materials in construction. IOP Conf. Series: Materials Science and Engineering 71 (2015) 012053 doi:10.1088/1757-899X/71/1/012053.

Ministry of Investment. Housing. Retrieved from the Ministry website investsaudi.sa. Ministry of Housing. (2018, November 21). *"BTS" program signed contracts to fund the construction of two factories for modern construction technology that worth 186* million riyals. www.housing.gov.sa/en/news/997.

Ministry of Housing. (2020). *Building Technology Stimulus Program*. Retrieved from https://www.btsi.gov.sa

MohdNawi, Mohd Nasrun& Lee, A. and Nor, K. (2011). Barriers to implementation of the industrialised building system (IBS) in Malaysia. The Built and Human Environment Review, 4.

Motiar Rahman, M. (2014). Barriers of Implementing Modern Methods of Construction. Journal of Management in Engineering, Vol. 30, No. 1 pp 66-77.

Mukhtar, M. M., Amirudin, R. B., Sofield, T., & Mohamad, I. B. (2016). Critical success factors for public housing projects in developing countries: a case study of Nigeria. Environment, Development and Sustainability, 19(5), 2039–2067. doi: 10.1007/s10668-016-9843-2.

Mulliner, E., & Algrnas, M. (2018). Preferences for housing attributes in Saudi Arabia: A comparison between consumers and property practitioners' views. *Cities, 83*, 152–164. doi: 10.1016/j.cities.2018.06.018

Navarro-Rubio, J., Pineda, P., & García-Martínez, A. (2019). Sustainability, prefabrication and building optimization under different durability and re-using scenarios: Potential of dry precast structural connections. *Sustainable Cities and Society, 44*, 614–628. doi: 10.1016/j.scs.2018.10.045

NHBC Foundation (2016). Modern methods of Construction: Views from the industry. Published by IHS BRE Press on behalf of the NHBC Foundation, ISBN 978-1-84806-451-5

NHBC Foundation (2018). Modern methods of Construction: Who is doing what?. Published by IHS BRE Press on behalf of the NHBC Foundation, ISBN 978-1-9995997-1-3

*Real Estate Price Index, First Quarter 2019*, General Authority for Statistics

Salzer, C., Wallbaum, H., Ostermeyer, Y., & Kono, J. (2017). Environmental performance of social housing in emerging economies: life cycle assessment of conventional and alternative construction methods in the Philippines. The International Journal of Life Cycle Assessment, 22(11), 1785–1801. doi: 10.1007/s11367-017-1362-3.

Santoso, T., Trigunarsyah, B, Hassanain, M., Tuffaha, F. (2017). Industrialized Building Systems for the Kingdom of Saudi Arabia. The 7th International Conference on Construction Engineering and Project Management, Oct. 27-30, Chengdu, China.

Sardén, Y and Engström, S (2010) Modern methods of construction: a solution for an industry characterized by uncertainty? In: Egbu, C. (Ed) Procs 26th Annual ARCOM Conference, 6-8 September 2010, Leeds, UK, Association of Researchers in Construction Management, 1101-1110.

Susilawati, C., & Al Surf, M. (2011). *Challenges facing sustainable housing in Saudi Arabia : a current study showing the level of public awareness*. 17th Pacific Rim Real Estate Society Conference, Bond University, Gold Coast, Qld.

Taleb, H. M., & Sharples, S. (2011). Developing sustainable residential buildings in Saudi Arabia: A case study. Applied Energy, 88(1), 383–391. doi: 10.1016/j.apenergy.2010.07.029.

The KSA Real Estate Market, A Year in Review 2018, JLL

Vision 2030. (2018). *The Housing program*. Retrieved from https://vision2030.gov.sa

Weetas. (2019).*The real estate market of Saudi Arabia in 2018: A year in review*. 14 February.

Wong, J. K., & Li, H. (2008). Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems. *Building and Environment, 43*(1), 108–125. doi: 10.1016/j.buildenv.2006.11.019

Yashiro, T. (2014). Conceptual framework of the evolution and transformation of the idea of the industrialization of building in Japan. Construction Management and Economics, vol. 32, no. 1-2, pp. 16-39.

Zhou, J., He, P., Qin, Y., & Ren, D. (2019). A selection model based on SWOT analysis for determining a suitable strategy of prefabrication implementation in rural areas. *Sustainable Cities and Society, 50*, 101715. doi: 10.1016/j.scs.2019.101715