# DEVELOPMENT OF PREFABRICATED BUILDING IMPLEMENTATION FRAMEWORK FOR ADDRESSING HOUSING NEEDS IN LIBYA

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by

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بِسْمِكَ اللّٰهُمَّ

**In the name of Allah, we start**

## DEDICATION

*To the soul of my father, who had dreamt to witness these moments ...*

*To my kind-hearted mother, for her unlimited love, inspirations, supports, protections, sacrifices, and prayers ...*

*To my wife, and my daughter, for their sacrifices in this academic pursuit...*

*Khaled M. Amtered El-Abidi*

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| | |
|---|---|
| ACA | Acceleration Capital Allowance |
| BSRIA | Building Services Research and Information Association |
| BURA | British Urban Regeneration Association (United Kingdom) |
| CIA | Central Intelligence Agency |
| CIB | International Council for Research and Innovation in Building and Construction |
| CII | Construction Industry Institute (United States) |
| CIDB | Construction Industry Development Board |
| CIMP | Construction Industry Master Plan 2006-2015 |
| CIRC | Construction Industry Review Committee |
| CREAM | Construction Research Institute of Malaysia |
| COMET | Committee for Middle East Trade |
| CSFs | Critical Success Factors |
| ETF | European Training Foundation |
| £L | Libyan Pounds (Previous currency of Libya) |
| GAE | General Authority for Environmental |
| GAI | General Authority for Information |
| GDP | Gross Domestic Product |
| GOH | General Organization for Housing |
| IBS | Industrialized Building System |
| IMF | International Monetary Fund |
| LYD | Libyan Dinar |
| MIDA | Malaysian Investment Development Authority |
| NAO | National Audit Office |

| | |
|---|---|
| NCID | National Corporation for Information and Documentation |
| R&D | Research and Development |
| SMEs | Small and Medium-size companies |
| UNECE | United Nations Economic Commission for Europe |
| UNEP | United Nations Environment Programme |
| US$ | United States Dollars |

# PEMBANGUNAN RANGKA KERJA UNTUK IMPLEMENTASI PRA-FABRIKASI BANGUNAN BAGI MENANGANI KEPERLUAN PERUMAHAN DI LIBYA

## ABSTRAK

Memenuhi keperluan perumahan amat dititikberatkan dikebanyakkan negara di dunia dengan lebih banyak tuntutan keperluan di negara membangun dan Libya tidak terkecuali. Kajian-kajian yang berkaitan telah membuktikan bangunan pra-fabrikasi dapat membantu meningkatkan usaha penyediaan perumahan dari segi kecepatan, kuantiti, dan kualiti serta pembinaan semula pasca-konflik. Kajian ini adalah tentang pra-fabrikasi bangunan di Libya, yang masih belum dikaji sebelum ini. Kaedah-kaedah campuran telah dibangunkan untuk tujuan ini, dengan penekanan diberikan kepada teknik penyelidikan kualitatif. Kaedah-kaedah yang digunakan terdiri daripada: data sekunder, temubual separa berstruktur, tinjauan kuantitatif, tinjauan AHP, dan perbincangan kumpulan fokus. Kaedah penyelidikan kualitatif menawarkan penerokaan pada peringkat pertama. Manakala kaedah penyelidikan kuantitatif menyumbang kepada proses pentafsiran yang lebih jelas di peringkat kedua, kaedah penyelidikan kualitatif menawarkan penerangan yang kukuh kepada peringkat sebelumnya. Dapatan awal kajian ini berdasarkan temubual separa struktur bersama pekerja yang terlibat mendapati pra-fabrikasi memberi faedah kepada keperluan perumahan walaupun kaedahnya masih belum dikenal pasti. Oleh itu, kajian ini memberi tumpuan untuk membangunkan satu kerangka konseptual berkenaan Faktor Kejayaan Kritikal (CSF) berdasarkan garis panduan untuk meningkatkan peluang kejayaan transformasi ke prafabrikasi bangunan, yang boleh berkembang untuk disesuaikan dengan keadaan perumahan di Libya. Bagi mewujudkan kefahaman tentang CSF untuk pelaksanaan bangunan pra-fabrikasi, kajian di negara yang mempunyai industri yang kukuh seperti Malaysia adalah perlu. Berdasarkan dapatan CSF, kajian ini mencadangkan rangka kerja yang dibangunkan sesuai dengan amalan industri pembinaan di Libya melalui kumpulan tumpuan. Sepuluh faktor kejayaan kritikal telah dikenal pasti di bawah tiga elemen utama: strategi, proses, dan pekerja, diikuti oleh tiga sumber dana yang penting dan tiga faktor pemangkin utama. Keputusan daripada kajian ini bersesuaian dengan kajian-kajian terdahulu mengenai kepentingan kestabilan politik sesebuah negara dan dasar negara tersebut terhadap pelaburan dan infrastruktur baru.

**DEVELOPMENT OF PREFABRICATED BUILDING IMPLEMENTATION FRAMEWORK FOR ADDRESSING HOUSING NEEDS IN LIBYA**

## ABSTRACT

Addressing housing needs is of great concern in many countries of the world with more predominance in developing countries and Libya is not an exception. Related literature has proven that prefabricated building can help improve housing delivery efforts in terms of speed, quantity, and quality as well as post-conflict reconstruction. This research is concerned with prefabricated building in Libya, which has not been investigated before. A mixed methods approach was developed for this purpose, with emphasis given to qualitative research techniques. Methods used comprised: secondary data, semi-structured interviews, quantitative survey, AHP survey, and focus group discussions. Qualitative research methods offered an exploration in the first stage. Whereas quantitative research methods contributed to a more rigorous interpretation process in the second stage, qualitative research methods offered a solid description of the former. The findings of the early stages of this study have shown that the participants of semi-structured interviews' have recognized prefabricated building benefits on addressing housing needs, eventhough they are not entirely sure about the method of implementation. In order to establish a comprehensive understanding on CSFs for prefabricated building implementation, exploring another country with an established industry, such as Malaysia, is necessary. From the identified CSFs, a conceptual framework that is able to comply with the construction industry needs in Libya is developed via focus group. Ten CSFs were identified under three main elements: strategy, process, and people, followed by three important sources of funding factors and three major enabling factors. Results from this study concur with previous studies regarding the importance of the country's political stability and its policies towards new investment and infrastructure.

# CHAPTER ONE
# INTRODUCTION

## 1.1 Background

"The term prefabricated brings to mind a building system in which the essential pieces of structure are sent to the site on which the finished edifice will be constructed partially or completely assembled" (Bahamón, 2002). Although a crude form of prefabricated building began before the iron age, there had been no substantial prefabrication in housing construction until the time of two World Wars (Pan, 2006). Meanwhile, many former colonies of Europe in Africa and Asia became independent during postwar years; these countries must immediately acquire and apply technology to expedite their development (Akubue, 2002). In the early 1960s, prefabricated building was transferred to many independent countries, including Libya, by developed countries. However, many countries demonstrated limited success in using this technology due to tarnishing its reputation by previous design as well as construction mistakes. Consequently, conventional construction methods still prevailed in housing construction.

In the late twentieth century, prefabricated building processes were enhanced by advances in design, information technology, and machinery as well as the current emphasis within the industry to reduce waste materials, energy consumption, labor requirements, project duration, and costs. These situations have validated that using prefabricated building is now more practical than ever (CII, 2002 and Song et al., 2005).

During the late 1990s and 2000s, governments of many countries and regions, such as the United Kingdom (UK), South Africa, Singapore, Hong Kong, Malaysia, Province of Quebec in Canada, Australia, and Germany, rethought adopting prefabricated building, they introduced policies to enhance mechanization in their industries through long-term visions or strategies (CIDB, 2003; CIRC, 2001; Construction 21 Steering Committee, 1999; DPW, 1998; Egan, 1998; Hampson and Brandon, 2004; Venables and Courtney, 2004; and Leabue and Vinâls, 2003). Significant differences in local emphasis were noted despite several similarities among these initiatives (Green et al., 2011). Since the intensity of influence of these aspects may differ from country to country, as may the nature of the construction industry, targeting any attempt to develop a policy or strategy to enhance prefabricated building adoption or integration is needed (Zakaria et al., 2017). Efficient processes and step-by-step advances can direct prefabricated building to achieve its optimal extent in countries that have not yet developed enhanced mechanization.

However, the Libyan government has the additional burden of dealing with domestic conditions, which place it in a serious situation and perhaps insurmountable disadvantage. The construction industry needs to learn from the experiences and good policy that support transformation and knowledge acquisition, which can be realized in improvements on a continuous basis. Thus, countries can learn from each other's experience (Ofori, 2006), by analyzing their experiences. The focus on the factors that are really critical to the success of prefabricated building implementation in another country is useful for the Libyan construction industry to formulate future strategies to transform from conventional practice into prefabricated building. It can be used as a complementary, alternative building method that can incrementally offer advantages to the overall housing industry.

## 1.2 Research Context

With a focus on the increasing demand for housing, this section presents the policy context of the previous housing supply. This context suggests a need to address the use of prefabricated building for housing construction. The current stakeholders' low familiarity with the concept of its processes indicates the need for Malaysia's experience in prefabricated building application as a case study.

### 1.2.1 Housing Supply Context

After its adoption of the socialist philosophy in 1977, the Libyan government assumed full responsibility and control over the provision and allocation of housing. According to The Secretariat of Utilities (1985) 750,000 dwelling units should have been developed during the planning period 1980 to 2000 in consideration of the housing requirements and the elimination of the present deficit. However, this number was not achieved due to a general decline in government spending as a result of successive shocks to the Libyan economy, which lasted until 2004 (see section 3.4.3). On the other hand, the growing housing demand is a product of change in the country's demographic structure from having 24.2% of its population in cities and towns in 1954 to over 88% in 2006.

In the early 2000s, to correct its previous policies, the Libyan government implemented a large-scale privatization program, it allocated US dollars (US$) 123.4 billion for infrastructure projects, including the construction of 530,000 dwelling units throughout the country. Despite the strong demand for housing, most new estates remained unfinished because of significant delays in construction, which were aggravated by the onset of political turmoil in February 17, 2011 that escalated into a civil war. Many housing contracts were suspended or canceled as a result. On the other hand, 70,000 people were internally displaced after the civil war, and they urgently required new permanent accommodation (UNHCR, 2013). In addition, the damaged areas due to political violence escalation by 2014 require rebuilding. Despite the upgrading, the total capacity of the Libyan housing market could not immediately meet the new short-term demands for buildings, and could not respond to the totality of new needs. It is estimated that 50,000 dwelling units should be constructed annually during the period (2014-2033).

### 1.2.2 The Need to Address the Use of Prefabricated Building in Housing Industry

Many developing countries prefer conventional construction methods over adopting innovative construction methods. It is very comfortable for them to use labor intensive and low technology methods of construction, believing that they are an efficient means of producing a house. However, "*the construction industry in most developing countries operates with low productivity and relatively high overall costs, despite low labor costs*" (Ofori, 1994a: p.44). This statement is also valid for the Libyan case, which is currently characterized by traditional procurement systems, paper-based and verbal communication systems, and cement- and intensive-labor process (Grifa, 2006).

Although Libya is facing acute shortage of water supply, the construction industry operations are currently cement based and designed around mixing methods on site in which water is an important issue in terms of quantity, quality, and management (Grifa, 2006). In addition, the output quality in the conventional construction methods is highly dependent on the professional skill of workers. However, the required quality cannot be achieved, because of poor quality control at the site (Badir et al., 2002). The poor image of the industry is caused by high incidence of accidents, absence of job security, poor management, and low wages for high-risk jobs and lack of opportunity for career development (Abdul Razak et al., 2010). These methods require lengthy construction periods (Thomas and Sakarcan, 1994), which are even unable to cope with the huge demand for houses.

Libya is a large country in terms of area but small in population, thus human resource is the main obstacle for development. Consequently, expatriate workforce is indispensable in the Libyan domestic market. In the late 1980s and 1990s, the Libyan foreign policy encouraged the entry of irregular workers from African and Arab countries into the country and allowed their presence (Abuhadra and Ajaali, 2014). This step has dire consequences on the construction industry since foreign workers have little or no skills. Grifa (2006) argued that labor is one of the biggest issues and key challenges of the Libyan construction industry. Ile Housing Forum (2004) skills report claims that the housebuilding sector experiences a more acute skills supply problem than construction in general. In fact, recent labor shortage in the industry mainly in the troubled areas have resulted in insufficient workers being available to undertake conventional construction projects.

Pressured by the skills shortage, the declining number of new workforce entrants and the need for faster housing completion, the construction industry is seeking innovative technology based on prefabricated building to maximize productivity. Also the water usage in construction can be reduced via reducing wet trades through using prefabricated building. With the government incentives and encouragement, there is a high possibility that prefabricated building could flourish. Any increased activity of the private sector in the housing building for the purpose of sale or lease is likely to create significant new market opportunities for prefabricated building.

### 1.2.3 Research Gap

Construction is a process-based industry and thus researchers need to understand the process to innovate and improve the industry (Abeysinghe and Urand, 1999; Finnemore et al., 2000; and Halpin, 1993). Within the housing system, prefabricated building is considered a radical innovation as the dominant methods for implementing a project are completely restructured. Policies that advocate strictly for prefabricated building uptake, without due consideration to or engagement with the wider industry, were proved to be unsuccessful in changing construction practices. As Slaughter (1998: p.227) notes: "*all previous linkages and interactions may be irrelevant for a radical innovation, not only with respect to the systems, but also the ties among organizations*". There has also been a lack of regulation and policies specifically concerning prefabricated building of housing, and little rigorous assessment of the few instated policies (Steinhardt et al., 2014). Such understanding of the problems related to prefabricated building uptake has often been particular to specific contexts, with ignorance of the wider influences on the housing industry, and lack of clear theoretical direction which can drive future research or policy development (Steinhardt et al., 2013a).

It is argued that if there is a need for the development of a framework, measures, and broader policy context, etc. for prefabricated building emergence then there is also a need for a prevalent business framework that can fulfill for the specific needs of prefabricated building companies. Beatham (2003) concludes that it is the human component that is critical for the successful implementation and use of any improvement system. The general consensus is that the best handling of prefabricated building is a holistic process, and the total synchronization of design, construction, and manufacturing is required (Hamid et al., 2008). It is argued that the way an organization identifies process improvement opportunities may need to be specialized to the technology context. Therefore, there is a need to conduct research on organizational aspects, to 'soft' concerns such as management and process issues of prefabricated building implementation strategies for industry stakeholders. The key and obvious research gaps involve:

- Lack of specific conceptual framework, regulatory bodies, management, processes, and practices that focus on the organizational strategy and soft issues. This can be achieved by proposing a lightweight framework from scratch to cater for managing the industry's transition to prefabricated building appropriately suited to Libya.
- Lack of knowledge about the factors and indicators that play a part in the successful implementation of prefabricated building in the Libyan construction industry. A factor is an element that contributes to a particular result or situation (Runeson and Höst, 2009). These factors can play a major role in helping the industry in adopting and making prefabricated building initiatives successful. This research gap can be filled by identifying the success factors from another country with an established industry.

### 1.2.4 The Need for Malaysia's Experience in Prefabricated Building Implementation as Case Study

The government and practitioners should be well informed about the factors that affect the use of prefabricated building if these systems are to be a solution to the Libyan housing issues. Prefabricated building uptake in the future is dependent on many factors, essentially, a better understanding of the holistic process and it requires a total synchronization of design, manufacturing, and construction as well as the government role. Prefabricated building also needs long-range planning on the national scale. This involves consideration of the strategic organization and assessment systems in the various stages of technology acquisition.

Since the early stages of this study, it was apparent that the first and most important point to consider was: how should tentative guidelines be provided to embrace prefabricated building, but their provision did not succeed. Exploring the factors that are truly critical to the success of prefabricated building implementation of another country with an established industry; would allow for most parties in the Libyan construction process to gain better understanding of the prefabricated building operations. Furthermore, this can be useful to assist them in providing tentative guidelines, which aim to present a conceptual framework that will be developed to guide future research.

Despite the extensive literature that relates to change initiatives in many countries, only four countries and a region namely, UK, Australia, Malaysia, Singapore, and Hong Kong are evidently the biggest contributors of involved articles. Also, change initiatives are driven by governments in these countries. Nevertheless, these initiatives advocating significantly different institutional arrangements to implement the desired changes (Green et al., 2011). UK and Australia are similar in terms of the prefabricated building patterns with a considerable evolution, whereas Malaysia adapted an advanced approach practiced in other countries (Azman et al., 2013). The transfer of construction technology is one of the similar approaches that are used for development in developing countries. Thus, these countries should exchange information and expertise on matters such as the modernization of the indigenous building materials sectors; research and manpower training; policy formulation for the construction sector; and growth strategies (Ofori, 2000). Considering impediments to using prefabricated building of developing countries (see 2.6), it is clear that Malaysia is the closest to the situation in Libya, However, similarities and differences between these two countries were taken into consideration (see sections 2.7 and 3.6).

Malaysia and Libya depend on foreign expertise and laborers in the construction sector, they also rely on imported technology as mentioned above. Another similarity is low labor costs, which is a key issue that will inhibit the growth of prefabricated building in both countries. Malaysia is emerging from periods of regulation and has developed certain sectors of their economies. It has reached a marked stage in the development of its construction industry, while Libya still suffers from lack of organization in the industry. There is also a difference between the two countries in the stages of privatization, which can be used by the Libyan side to accelerate the dependence on the local private sector in the field of construction industry. The mature stages of prefabricated building practice and experiences from Malaysia are deemed the most appropriate that Libya can learn from. Understanding this issue is important for both the industry and academia and this study will assist in clearing the confusions and expectations surrounding prefabricated building implementation within the Libyan context.

## 1.3 Research Questions

Bearing background and research context above in mind, the core research question of this doctoral thesis is: *What type of framework and guidelines are needed for the successful transformation to prefabricated building in Libya?*

This question is imposed in order to develop a strategy to optimize the use of prefabricated building for responding to housing needs. However, answering this question requires preliminary knowledge of local construction experts' perspectives and current practices on the use of prefabricated building. Therefore, stage I sets three significant secondary research questions:

*1) What is the current situation of prefabricated building in Libya?*

2) *What are the key drivers and main challenges affecting the use of prefabricated building in the Libyan construction sector?*

3) *How can prefabricated building improve its exploitation towards the housing industry?*

Stakeholders need guidance to re-localize prefabricated building by steady steps rather than leaps over a long time. The discussion with interview respondents during the first field trip in Libya in April 2013 (see 6.2.3), showed that crafting a vision or strategy for achieving the optimal extent of prefabricated building implementation is far from satisfactory. Thus, it was decided to conduct this study to fill in the gaps in stakeholders' knowledge based on the experiences and good policies of other countries, this will support them to craft a conceptual framework that is considered a starting point for development and much-needed prefabricated building drives. Bearing this in mind, stage II sets significant secondary research question:

*What are the key factors of success for prefabricated building implementation in Malaysia?*

The secondary research question indicates that the research takes into consideration the existing literature on the topic; attempts to find the relationships between prefabricated building success factors, if any, such that the combined effect of one or more factors on such technology success can be identified. Then attempts were made to find critical success factors (CSFs) of prefabricated building implementation in Malaysia. From the survey results, identified CSFs can be used to give a clearer sight of view of the overall development in the Libyan industry, which can provide information to guide stakeholders to develop the conceptual framework. Bearing this in mind, stage III significant secondary research question is:

*What are the Libyan stakeholders' perceptions to further develop and validate the framework that fits with the industry practice in Libya?*

## 1.4 Aim and Objectives

The need to address the use of prefabricated building in the Libyan housing sector is coupled with the lack of previous research in the specific context of prefabricated building. The idea of this research is to address the under-supply of housing and the industry needs in improving quality performance through the implementation and use of prefabricated building. The aim is thus to develop a conceptual framework that provides guidelines on the transformation to prefabricated building to be used in the Libyan housing industry. Also establishing an understanding of CSFs for prefabricated building implementation necessitates exploring another country with an established industry, such as Malaysia. By having the guidelines, the stakeholders can be able to evaluate and understand their readiness in terms of prefabricated building implementation requirements that need to be satisfied. The specific objectives devised in order to help achieve the aim were as follows:

1. To explore the current situation and the potential for using prefabricated building to addressing the under-supply of housing and quality improvement in Libya.
2. To determine the CSFs of prefabricated building implementation in the Malaysian construction industry; and
3. To develop framework for prefabricated building implementation that fits with the construction industry practice in Libya; and
4. To make recommendations for the implementation of the framework in Libya and further work.

## 1.5 Research Hypothesis

Three hypotheses are formulated for investigation in this research:

1) The extreme shortage of housing dating back to the 1980s, furthermore, the recent political turmoil resulted in forced deportation of some towns and ruin for others. These would provide prefabricated building with an opportunity to establish itself as a trusted solution.
2) Prefabricated building allows the problems associated with the traditional shortage of skills and declining number of new labor entrants, dating from 2011, to be solved.
3) Learning from overseas experience, untapped potential can be realized for developing prefabricated building to be used more broadly within the Libyan housing industry.

## 1.6 Research Scope

This research focuses mainly on prefabricated building, especially its usage in the housing sector. The commercial, infrastructure, and industrial plants have not been considered unless some specific high-value learning point can be applied to housing sector was involved. Due to limitations of the availability of funds, time, and respondents as well as research resources, the scope of the study focused on CSFs and the development of the conceptual framework with regard to the followings:

- This study focused on the degree of the current level of utilization of prefabricated building techniques in the Libyan construction industry, and the perceptions of local construction experts of using these techniques in the housing industry.

- The research is based on the Malaysian situation with regard to CSFs for prefabricated building implementation, though the international context was mentioned where necessary. The CSFs identified in this research are on the strategic level of organizational aspects.
- One of the research objectives of this study was to develop a framework that fits with the industry practices in Libya. However, the current version of the developed framework includes studying the relationship between the importance of factors and the industry current capability to implement them. Although all these factors are equally essential, it is an impossible task to discuss all of them in depth. But each factor could be pursued as part of future research.

# CHAPTER TWO
# PREFABRICATED BUILDING DEVELOPMENT

## 2.1 Introduction

This chapter addresses the relevant literature with regard to prefabricated building. The aim of the literature review is to critically establish the extent and depth of existing knowledge on prefabricated building in terms of definitions, concepts of technologies and levels of categories and systems. The main benefits and motivations of using prefabricated building were reviewed. Also, impediments/ barriers of implementing this technology especially in developing countries were examined.

## 2.2 Prefabricated Building Categories, Definitions and Concepts

Many definitions and concepts of different terms that describe innovation in the construction industry were used throughout the literature, including: prefabrication (Prefab) (Steinhardt et al., 2013a and Steinhardt et al., 2013b); industrialized construction (Lewicki, 1966); modern methods of construction (MMC) (Rahman, 2014); and offsite manufacturing (OSM) (Hampson and Brandon, 2004), are worth examination. Prefabricated building is the term that was found by the researcher in the Libyan government late 1970s' documents and is the term that will be used in this research. Thus, the information and nomenclature presented will remain consistent with prefabricated building. According to Richard (2005: P.443), "*Prefabrication starts with pre, which means before and/or elsewhere*". The essence of off-site construction is best represented by prefabrication (Daniel and Samantha, 2016). Building has always been associated with prefabrication (Piroozfar and Farr, 2013). Prefabricated building is defined as "the manufacturing process, generally conducted at a specialized facility, in which various materials are joined to form a constituent part of final installation"

(Jaillon and Poon, 2009).

Prefabrication was closely associated with new methods of construction and, in particular, system building, but many systems were not based on the use of prefabricated components (Finnimore, 1989). Prefabrication is "*often associated with the terms 'offsite' and 'assembly' or just 'fabrication' which means to fabricate the parts of building at a factory*" (Smith, 2010: p.xi). The term Prefabrication is defined by White (1965) as production, under factory conditions, of components that may be used in a building, and the pre-assembly of such components into complete units of a building. While the term building system is defined by Warszawski (1999) as a set of interconnected elements that act joined together to enable the designated performance of the building. This may include various procedures (technological and managerial) for the production and assembling of these elements for this purpose (Sarja, 1998).

### 2.2.1 Prefabricated Building and Related Terms

Several terms have been used as synonyms to prefabricated building in different countries. Modern Methods of Construction (MMC) is the term used by the UK government to describe a number of innovations in houseduilding (BURA, 2005). The Australian construction industry has identified Offsite Manufacturing as the future of the industry (Blismas and Wakefield, 2009 and Hampson and Brandon, 2004). Industrialized Building System (IBS) is the term used by the industry and government in Malaysia to represent the adoption of construction industrialisation and the use of prefabrication of components in building construction (Din et al., 2012).

Similarly, in the European Union (EU) increasing Industrialized Building with Standardised Modules and Prefabrication are used to improve the productivity and performance in the construction industry (Gurdjian and Andonan, 2003). Likewise, prefabrication is the term used by both Hong Kong and Singapore. National Research Council (2009) identified that the US uses terms of prefabrication, preassembly, modularization, off-site fabrication techniques and processes as one of the five interrelated sets of activities.

Although the terms are often interchangeably used, their precise definitions depend on the users' experience and understanding, which vary from country to country (Wong et al., 2003). The key concept of using prefabricated building and related terminologies is shifting a large quantum of building activities from on-site to off-site under a controlled manufacturing environment in order to save cost and achieve better quality as well as shorter construction time (Gibb and Isack, 2003 and Tatum et al., 1987).

### 2.2.2 Classifications of Prefabricated Building

In early stages, Majzub (1977) explained that the relative weight of the components should be used as a basis for classifying the building systems that consist of "Frame System", "Panel System" and "Box System". Majzub added, the weight has a significant impact on the transportability of components, it also has an influence on the production method of components and their erection method on site. Table 2.1 shows the building system classification according to the relative weight of components.

The trend may be different today and plausibly change with the development of lightweight concrete that fulfills strength requirements (Martins et al., 2015 and Kurt et al., 2016). Moreover, due to its high compressive strength, precast concrete is used as load-bearing stabilizing systems for high-rise modular prefab (Boafo et al., 2016). For example, Prefabricated Pre-finished Construction (PPVC) is the new, advanced modular construction technology (Steel and Concrete PPVC System) introduced by Singapore

Building and Construction Authority (BCA), which is mandatory for selected non-landed residential Government Land Sale (GLS) sites to use from 1 Nov 2014 onwards (BCA, 2015).

Table 2.1: Building system classification according to the relative weight of components, (Majzub, 1977).

| No | General System | System | Production Material |
|---|---|---|---|
| 1 | Frame system | Light weight frame | Wood, light gage metals |
| | | Medium light weight frame | Metal, reinforced plastics, laminated wood |
| | | Heavy weight frame | Heavy steel, concrete |
| 2 | Panel system | Light and medium weight panel | Wood frame, metal frame and composite materials |
| | | Heavy weight panel (factory produced) | Concrete |
| | | Heavy weight panel (tilt up-produced on site) | Concrete |
| 3 | Box system (modules) | Medium weight box (mobile) | Wood frame, light gage metal, composite |
| | | Medium weight box (sectional) | Wood frame, light gage metal, composite |
| | | Heavy weight box (factory produced) | Concrete |
| | | Heavy box (tunnel produced on site) | Concrete |

The degree of prefabricated building refers to the size and complexity of prefabricated components or the configuration of the final product (Boafo et al., 2016). Goodier and Gibb (2007), Arif and Egbu (2010) stated that prefabricated building can generally be classified into five levels according to the prefabrication degree applied on the product:

- ***Zero-level*** "Basic Material" None-Off-site Manufacture
- ***First-level*** "Component Manufacturing and Sub-assembly"
- ***Second-level*** "Non-volumetric Preassembly"
- ***Third-level*** "Volumetric Pre-assembly"
- ***Fourth-level*** "Modular Building"
- ***Fifth-level*** "Hybrid System"

To clarify the classification, the original term "prework method," which consists of "prefabrication," "preassembly," and "modularization," should be initially defined.

Components of **prefabrication** often only involve the work of a single craft, they are not considered as a complete system to be prefabricated (CII, 2000). It is regarded as the first level of industrialization, which is followed by mechanization, automation, robotics, and reproduction (Richard, 2005). Prefabrication is categorized as ***Zero-level*** "Basic Material" without preinstallation assembly features (Pan et al., 2004). In this level, prefabrication can be done onsite (onsite fabrication). It is defined by CIB (2010) as building, at factory, sub-assemblies or full modules which are quite similar to what is produced on a traditional construction site, often using the same processes and the same materials. This category is intended to encompass schemes utilizing "Innovative Building Techniques" and "Structural Systems" that cannot be placed in the category of off-site manufacture (Taylor et al., 2004).

According to Mineral Products Association (mpa), typical examples of None-Off-site Manufacture category are "Frames System" (such as Tunnel form; System column formwork; Jumpform) and "Walls System" (such as Flat slabs/Slipform; masonry/blockwork; Vertical panel systems; Horizontal panel) (the Concrete Center; http://www.concretecentre.com). German efforts usually focused on enhancing plant and equipment used in concreting (IAARC, 2004). For example, a German "Platform System" for housing projects, it does not imply that "off-site manufacturing" is the most optimal production method, rather it is a matter of handling complexity (Thuesen and Hvam, 2011). The Swedish companies have organized their effort in product platforms, where housing has been striving towards mass customization using repetition of components and processes in the development of building systems (Johnsson, 2013).

**Preassembly** is "*a process by which various materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a unit*" (CII, 2000: P.4). It is generally regarded as a combination of prefabrication and modularization. Such combination is further categorized into first, second, and third levels:

- ***First-level*** "Component Manufacturing and Sub-assembly" refers to small sub-assemblies that are frequently assembled prior to installation (Pan et al., 2004). Off-site fabrication and off-site production are employed when both prefabrication and preassembly are integrated. Prefabrication can be as high as mass-production of components in a factory to as low as using onsite tunnel-form or thin-joint. In this level, prefabrication can be done offsite, it is defined by Tatum et al. (1987), Gibb (1999), and Jaillon and Poon (2009) as a manufacturing process, generally conducted at a specialized facility, in which various materials are joined to form a component part of the final installation.
- ***Second-level*** "Non-volumetric Preassembly" refers to preassembled units that do not enclose usable space. Examples of this level include parts of the structural frame, internal partition panel systems, cladding panels, parts of building services, distribution ductwork or pipe-work and so forth.
- ***Third-level*** "Volumetric Pre-assembly" refers to pre-assembled units that enclose usable space and are generally completely finished internally in a factory. However, these units do not form building structures such as toilet and bathroom.

**Modularization** "*generally refers to preconstructing a complete system in a location away from the construction site, and then transporting the completed system to the site*" (CII, 2000: p.3). It is categorized as a ***Fourth-level*** "Modular Building" (Goodier and Gibb, 2007). Modular building/construction is widely used term in the UK, Australia, and North America to refer to volumetric elements constructed offsite and joined together to form a permanent structure. According to Lu (2007) modular systems are generally similar to hybrid systems; however, they typically consist of multiple rooms with 3D units. Modular systems can be complete factory-built houses or apartment blocks, which are constructed and preassembled. Trim work, as well as electrical, mechanical, and plumbing fixtures, are also installed. On the other hand, modular building for multi-storey construction in the past, provide only the structure and sometimes cladding, and are then finished on-site (Gibb,1999). Currently, the modular building is fully finished offsite as a "one-stop" system. A 40-storey conceptual design in Integer (2003), a newly concept applied to a prefabricated tower project, is a typical example of the modular building (Tam et al., 2007). Prefabricated Pre-finished Construction is one of the games changing technologies that support the Design for Manufacturing and Assembly concept to significantly speed up construction, where construction is designed such that as much work may be done off-site in a controlled manufacturing environment as possible (BCA, 2015). Complete modules have become regarded as a perfectly acceptable solution for house building in some countries, such as Hong Kong and Singapore.

***Fifth-level*** "Hybrid System" is a combination of two or more volumetric or non-volumetric systems. That is typified by two- 'semi-volumetric' and 'panelized system', which involve the factory production of three-dimensional units and two-dimensional components respectively, transported to site for assembly into dwellings. For example, "*a Prefabricated Bathroom Unit (PBU) is preassembled off-site, complete with finishes, sanitary wares, concealed pipes, conduits, ceiling, bathroom cabinets, shower screen, and fittings, in a controlled environment of a factory*" (Yit Lin, 2016: p.42). Langdon and Everst (2004) note that in addition to housing, the hybrid system could equally be applied in public infrastructure projects where urgent construction is required, such as reconstruction programs after disaster incidence.

The term "Off-site" is a generic term describing a range of construction techniques that are different from traditional onsite forms of construction (Ross, 2002). The term "Off-site Construction" is traditionally used in the UK (Gibb 1999: p.8), it includes preassembly, hybrid building systems, panelized building systems, and modular building systems (Gibb and Pendlebury, 2005). Meanwhile, the term "Off-site Manufacture" can be described as the prefabrication of the key building components or assembly of building system offsite (MBI, 2010). The term "Off-site Manufacture" is used widely in the UK and Australia as part of construction policy documents, referring to work carried out away from the building site (Blismas, 2007; Blismas and Wakefield, 2009; Gibb and Pendlebury, 2007; and Hampson and Brandon, 2004). Also, it is found in other countries such as Japan (Gann, 1996), the Nordic counties (Thuesen and Jonsson, 2009), and Germany (Venables and Courtney, 2004). "Off-site Manufacture" embraces various categories for factory manufacture of buildings including off-site fabrication, off-site assembly, off-site construction, and off site production (Kenley et al., 2012). Mbachu (2009) considered "Off-site Manufacture" as a forerunner to mechanization and robotization of the construction process. In general, construction automation and robotics can be defined as the use of mechanical and electronic means in construction to achieve automatic operation or control (Hewitt and Gambatese, 2002).

"Off-site Manufacture" term has been re-branded broadly within the term Modern Methods of Construction (Gibb, 1999). The term was first used in the United Kingdom to describe changes to improve social housing construction methods (Housing Corporation, 2003), modern methods of construction can also include onsite

"Innovative Building Techniques" and "Structural Systems". The Office of the British Deputy Prime Minister (ODPM) defines the term modern methods of construction as a process to produce more, better quality homes in less time, with the aim of improving business efficiency, customer satisfaction, environmental performance, sustainability and the predictability of delivery times (Elnaas, 2014).

**Industrialization** describes all prework forms (prefabrication, preassembly and modularization), which relatively implies the use of fully integrated and automated project processes (CII, 2000). Uttam et al. (2008) stated that industrialized building systems refer to the complete integration of all subsystems and components into a general process that fully applies industrialized production, transportation, and assembly techniques. Also including general concepts such as scheduling, efficiency, and technology improvements (Blismas, 2007). The term "Industrialization Homebuilding" is used in the United States to refer to both modular and manufactured housing as a group (Nahmens and Bindroo, 2011), but is not widely used within the industry. While Industrialized Building/Housing term is prominently used in Sweden and other European countries since the early 2000's incorporating off-site manufacturing of materials, supplier coordination, and the systematization of build processes (Lessing et al., 2015). Historically, Industrialization Building was used in the 1970s and 1980s in New Zealand (Bell, 2009), and during the 1960s and the early 1970s was used in the U.S. and UK.

The term Industrialised Building System is formally defined in Malaysia in the early 2000's encompassing the use of prefabricated, offsite, mass produced and standardized components (Yunus and Yang, 2011). It is defined as a construction technique in which components are manufactured in a controlled environment (on or off site), transported, positioned and assembled into a structure with minimal additional site works (CIDB, 2003 and CIDB, 2016).

Whilst there are different classifications of prefabricated building used in the literature, the purpose here is to develop a matrix for classifying offsite products with various degrees of manufacturing techniques on both production sites: offsite and onsite as shown in Figure 2.1.

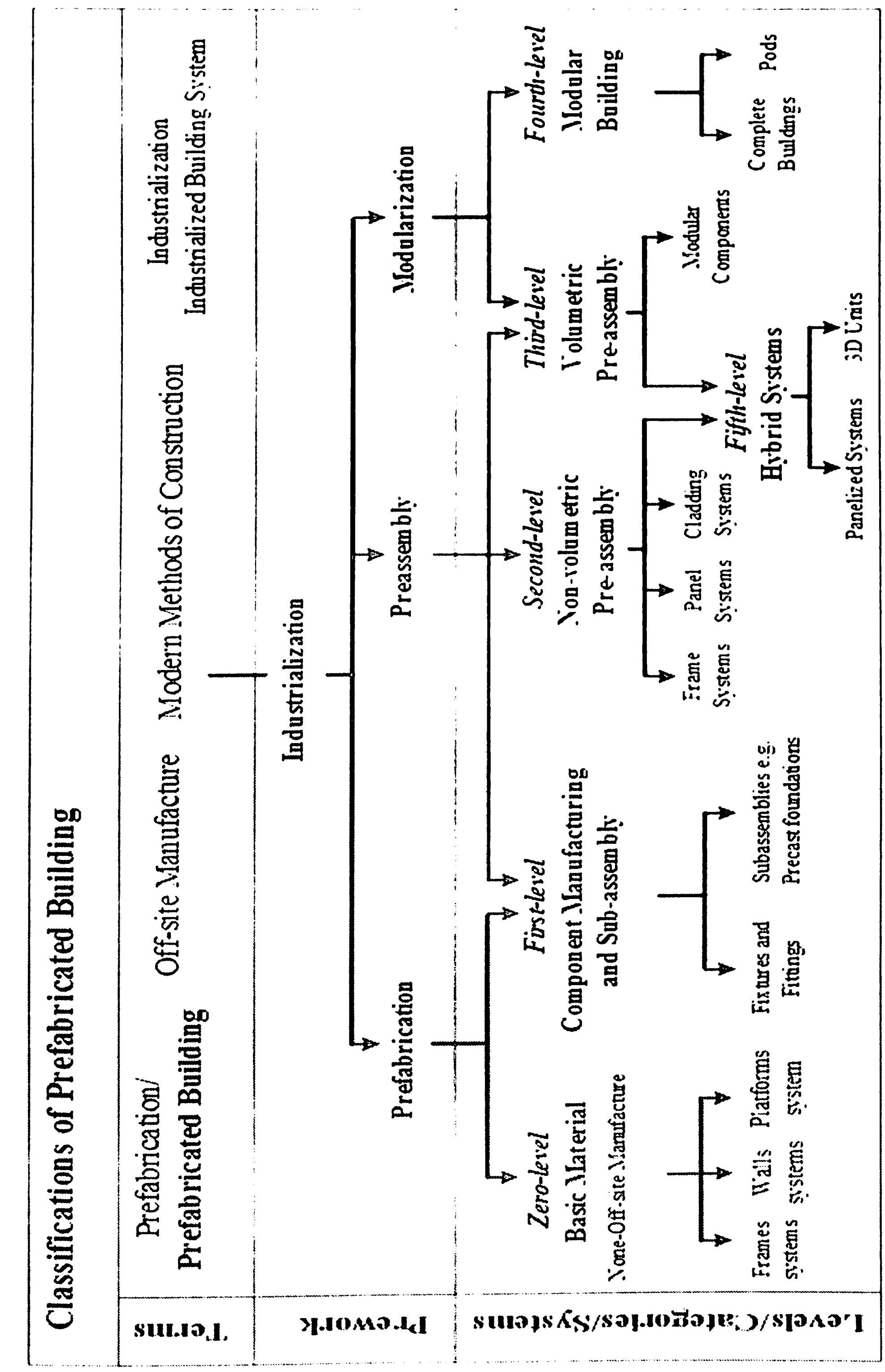

Figure 2.1: Classification of prefabricated Building

In general, cost, schedule, quality, and safety issues are the primary motivations in employing prefabrication and preassembly (Levels 1, 2 and part of 5) (CII, 2002). CII (2002) cited that project or site constraints, such as harsh weather conditions, are key motivations in using modularization "Modular Building" (Levels 3, 4 and another part of 5), which means saving time and greater productivity. For example, factories in Sweden manufacture detached single houses (Anders and Thomas, 2010). Logistics and site operations, which are more prominent in studies in the UK and the US, simplify the process and result in greater efficiency.

Modularization has been widely adopted in Province of Alberta in Canada for constructing industrial projects (Lei et al., 2013). However, transporting volumetric and modular systems has numerous underlying barriers, including transport costs, improved road capacities, special vehicles, and heavier cranes that are required in construction sites (Santiago and Jardon, 2008). These constraints are more prominent in Australia (Blismas and Wakefield, 2009). Using volumetric and modular systems is sometimes impossible under the conditions in India (Arif et al., 2012), due to population density and poor infrastructure. Moreover, the results of a study in Saudi Arabia also show the inapplicability of these two types of systems in permanent construction; however, they can be used in temporary structures such as site offices (Aburas, 2011). Temporary structures are commonly used only in oil fields in Libya.

Goodier and Gibb (2007) suggested that for the low level of manufacturing, the skill required was the same, but for the more advanced and mechanized system in prefabricated building, it requires more skills as compared with the equivalent products constructed conventionally. In general, Levels 3, 4 and part of 5, cannot be applied in developing countries because of poor civil infrastructure and lack of skilled expert labor. The main focus in developing countries should be Levels 1, 2 and the other part of 5 to