BEYOND ROADS AND BUILDINGS: ADAPTING AUTOMOTIVE STRATEGIES TO CONSTRUCTION

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ABSTRACT

BEYOND ROADS AND BUILDINGS: ADAPTING AUTOMOTIVE STRATEGIES TO CONSTRUCTION

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The construction industry, despite its significant economic importance, continues to face challenges such as inefficiency and low productivity. While industries like automotive have made remarkable advancements in mass production and platform-based design, construction remains reliant on traditional methods and encounters obstacles in adopting modernization, particularly in prefabrication and modularization.

This research examines the success of the automotive industry in platform-based design to identify strategies for enhancing efficiency in modular and prefabricated construction. Using a qualitative approach, primary data was collected through semi-structured interviews designed with two international modular construction companies. The findings indicate that platform-based design can offer cost reduction, increased product variety, and improved process efficiency, providing significant advantages for the construction sector. However, challenges such as regulatory complexities and the need for workforce transformation remain key barriers to widespread adoption.

The insights from this research contribute to the development of effective strategies for improving productivity and fostering innovation in construction, paving the way for broader acceptance of modular and prefabricated methods.

Keywords: Construction Industry, Platform-Based Design, Automation, Prefabrication, Modularization

ÖZ

YOLLAR VE BİNALARIN ÖTESİNDE: OTOMOTİV STRATEJİLERİNİN İNŞAATA UYARLANMASI

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İnşaat sektörü, önemli ekonomik önemine rağmen, verimsizlik ve düşük üretkenlik gibi zorluklarla karşılaşmaya devam etmektedir. Otomotiv gibi sektörler, seri üretim ve platform tabanlı tasarım alanında kayda değer ilerlemeler kaydetmişken, inşaat sektörü hâlâ geleneksel yöntemlere bağımlı olup, özellikle prefabrikasyon ve modülerleşme süreçlerinde modernleşmeyi benimseme konusunda engellerle karşılaşmaktadır.

Bu araştırma, otomotiv sektörünün platform tabanlı tasarım konusundaki başarısını inceleyerek, modüler ve prefabrik inşaat süreçlerinde verimliliği artırmaya yönelik stratejileri belirlemeyi amaçlamaktadır. Nitel bir yaklaşım kullanılarak, iki uluslararası modüler inşaat şirketiyle gerçekleştirilen yarı yapılandırılmış mülakatlar yoluyla birincil veriler toplanmıştır. Bulgular, platform tabanlı tasarımın maliyetleri düşürme, ürün çeşitliliğini artırma ve süreç verimliliğini iyileştirme gibi önemli avantajlar sağlayabileceğini ortaya koymaktadır. Ancak, düzenleyici karmaşıklıklar ve iş gücü dönüşümüne duyulan ihtiyaç gibi zorluklar, yaygın benimsenmenin önündeki temel engeller olarak öne çıkmaktadır.

Bu araştırmadan elde edilen bulgular, inşaat sektöründe üretkenliği artırmaya ve inovasyonu teşvik etmeye yönelik etkili stratejilerin geliştirilmesine katkıda bulunarak, modüler ve prefabrik yöntemlerin daha geniş çapta benimsenmesinin önünü açmaktadır.

Anahtar Kelimeler: İnşaat Sektörü, Platform Tabanlı Tasarım, Otomasyon, Prefabrikasyon, Modülerleşme

To my beloved parents, whose unwavering support and encouragement have been my greatest strength. Thank you for believing in me every step of the way.

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TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

ABBREVIATIONS

AEC	Architecture, Engineering, and Construction
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AI	Artificial Intelligence
AR	Augmented Reality
BIM	Building Information Modeling
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	Computer-Aided Design
CIM	Computer Integrated Manufacturing
CMF	Common Module Family
CNC	Computer Numerical Control
DFMA	Design for Manufacturing and Assembly
ENR	Engineering News-Record
ERP	Enterprise Resource Planning
IFS	Industrial and Financial Systems
JIT	Just-in-Time Manufacturing
KAZ	Kazakhstan
LEED	Leadership in Energy and Environmental Design

MC	Mass Customization
MMC	Modern Methods of Construction
MQB	Modularer Querbaukasten
OSM	Off-Site Manufacturing
PBD	Platform-Based Design
PDM	Product Data Management
PPVC	Prefabricated Prefinished Volumetric Construction
PSA	Peugeot Société Anonyme
SAP	Systems, Applications, and Products in Data Processing
SPC	Statistical Process Control
TS EN ISO	Turkish Standards, European Norms, International Organization for Standardization
UK	United Kingdom
USA	United States of America
VW	Volkswagen
WGP	World Green Building Partnership
WRAP	Waste and Resources Action Programme

CHAPTER 1

1. INTRODUCTION

While technology rapidly transforms industries, the construction sector lags in adopting innovations like mass production and prefabrication, unlike the automotive industry. This study investigates this gap, drawing insights from success of automotive sector to pioneer solutions for the problem of slow construction adoption. Through key success factor identification and comprehensive analysis, we aim to facilitate the integration of prefabrication and modularization in construction.

1.1.Background and Motivation

The construction industry plays a vital role in economic development and societal progress. However, it faces persistent challenges such as inefficiency, high costs, and prolonged project timelines. While other industries, such as automotive manufacturing, have adopted advanced techniques like platform-based product design and mass production to improve scalability and efficiency, construction sector has been slow to innovate. This gap provides a significant opportunity to explore cross-industry strategies to enhance productivity and sustainability in construction. The growing demand for affordable, high-quality buildings and the urgent need to address global housing shortages further underscore the importance of adopting modular and prefabrication methods. By drawing inspiration from the automotive industry's success, this research seeks to bridge the gap for the construction sector.

The construction industry has evolved over time, with advancements in methods, materials and technology driving its development (Barbosa, Woetzel & Mischke., 2017). Historically, construction projects were labour-intensive and timeconsuming, and often required human labour in all stages of construction due to the lack of facilities and machinery (Ruggiero, Salvo & St Laurent., 2016), who were required to perform difficult tasks such as scaffolding, lifting, bricklaying, and plastering and many other works were in the construction environment (Ebekozien, Aigbavboa, Thwala, Aigbedion & Ogbaini., 2023). Doing these things repeatedly caused serious injuries and even fatalities of workers (Aghimien, Aigbavboa, Oke & Aliu., 2022; Aghimien, Ikuabe, Aliu, Aigbavboa, Oke & Edwards., 2023; Oke, Aliu, Fadamiro, Akanni & Stephen., 2023). However, the introduction of machinery, new materials, and new methods along with scientific progress, has revolutionized the field (Ruggiero et al., 2016). By referring to larger-scale projects, such as bridges with long spans in the 19th century, we can point at the efforts of the engineering community to automate construction processes and increase the efficiency of new machines (Malakhov, Shutin & Marfin., 2020).

Furthermore, by referring to the history of construction, it can be observed that there are primarily three construction methods that utilize machinery and labour: traditional and conventional methods, post-traditional methods, and industrial systems (Riley, 2002).

One of these methods which is part of industrial systems and has entered the construction industry since the 19th century is prefabricated construction. Prefabrication refers to any part of the building that is produced before transportation and assembly at the final location of the building. These prefabricates can be of different materials and sizes, from prefab parts to entire buildings. Prefabrication is usually done off-site, such as in a factory or controlled construction site. Off-site construction or modular construction can also be known as another meaning or concept of prefabricated. Other terms commonly associated with this approach include off-site manufacturing (OSM), modern construction methods (MMC), and industrial construction. Other terms that are related to prefabrication can be preassembled, pre-programmed, and predesigned. The term prefab mainly refers to a process rather than a product and is based on a construction approach or system and does not necessarily lead to the production of an integrated product (Noguchi, 2016).

Prefabrication method is claimed to have many advantages, disadvantages and risks since 20th century. The advantages of prefabrication could be classified into three groups: a) economic or cost-effectiveness, b) environmental or sustainability, and c) social viability or time efficiency (Bhattacharjee, Pishdad-Bozorgi & Ganapathy., 2016). The advantages of modular construction approaches over traditional construction are clear and significant (Jaillon and Poon, 2008). High cost, lack of time, and low quality are among the main challenges in the traditional construction methods that architecture engineering and construction (AEC) have been dealing with for decades. And all these choices affect the development and exploitation of a project. Therefore, efficient and durable solutions should be provided to deal with these challenges. Mass customization, modernization, and industrialization of construction processes are some of the solutions to increase productivity in the construction industry (van der Ham & Opdenakker., 2023). In addition, the modular construction method reduces waste at the construction site (Tam & Hao., 2014).

Based on project location, client needs and planning, modular construction technique and form factor may be a superior option (Gorgolewski, Grubb & Lawson, 2001). Among the important cases and advantages that make prefabricated and modular construction preferable to traditional construction are (Gorgolewski et al. 2001; Luh, Pan & Su., 2007; Jaillon & Poon. 2009, Bhattacharjee et al. 2016,):

1) Fabrication of cellular or regular shapes with such a higher degree of repetition allows for economical scale construction and design.

2) In construction workshops where noise pollution and various other pollutions must be carefully controlled during the construction phase, in prefabricated factories this pollution is controlled and limited.

3) New parts can be added to existing structures.

4) The possibility of moving and transferring construction projects to the desired location.

5) Construction in crowded cities.

This is why the Construction Industry Council (2018) defines modular construction systems as “independent integrated modules that are manufactured in a controlled, prefabricated factory and then transported to the construction site for installation.” In fact, in the modular system, 80-95% of a construction project is built in the factory environment and transferred to the site (Wuni, Shen & Mahmud.,2022; Hwang, Shan & Looi., 2018).

Modular structures have many challenges and obstacles. For instance, we can mention cost and new ways of building, equipment and standards, skills, experience, and adaptability. Furthermore, for a project to be executed successfully, it must possess the following characteristics:

1) Need for a substantial initial investment (Pan, Yang & Yang., 2018; Choi, Chen & Kim.,2019);

2) Requirement of high level of skilled labour (Pan et al. 2018; Choi et al. 2019,);

3) Lack of standardization in design (Pan et al. 2018; Nadim and Goulding 2011);

4) Limited demand in the market (Pan et al. 2018);

5) Demands effective communication among all involved parties (Salama and Said., 2023);

6) Suffers from a shortage of experienced contractors applying modularization concepts (Salama and Said., 2023);

7) Necessitates the early design and manufacturing of parts and modules in the process (Wong and Chan., 2010); and

8) Incurs significant transportation costs for delivering larger modules to the job site (Pan et al. 2018; Poon & Jaillon 2010).

One of the key industries that leverages the idea of prefabrication and modular production along with state-of-the-art technology is the automotive manufacturing industry (Crowley, 1998). At first glance, the automotive industry may seem distant from construction, but its impact on entire societies, where the construction industry is also a part, goes far beyond production. Twice in the present century, revolutions in this industry have fundamentally altered our ideas about how things are made. These changes have influenced the way we work, purchase, think, and ultimately, how we live our lives as human beings (Crowley, 1998).

About a century ago, the automotive industry transitioned from craft-based production to mass production. However, despite this shift in the automotive industry that occurred over the past 100 years, the construction industry still adheres to traditional production methods. In fact, customers and engineers involved in the construction processes are reluctant to embrace industrial production methods. As mentioned above, one of the primary reasons for this reluctance is the uniqueness and project-oriented nature of construction. They consider this aspect as a significant factor that prevents the application of industrial techniques and principles in construction (Crowley, 1998). In contrast, many automotive companies aspire to increase their productivity to compete on a global scale. However, achieving this goal is not solely possible through an increase in automation due to the high volume of production and complexity in this industry (Westkämper, 2007). Approximately one-third of the companies that have invested in high-scale automation have acknowledged that this solution lacks sufficient flexibility (Bley and Bossmann, 2006). As a result, a certain amount of manual labour has been employed to perform tasks such as controlling the assembly line and setting it up. Alongside manual labour, they have also utilized newly developed and advanced robots capable of overcoming challenges through physical collaboration with humans. In fact, one of the primary challenges in the automotive manufacturing industry is mass customization, and efforts are made within the assembly system to overcome this challenge by combining the human workforce with new technology and automation (Michalos 2011). Automotive manufacturers, in order to maintain their competitiveness, are exploring future-oriented concepts to simultaneously reduce costs and enhance the performance of assembly lines (Müller, Vette & Scholer, 2016).

A proven answer to this challenge is to adopt the principles of platform-based product development. This approach to product development revolves around a simple key challenge: balancing the trade-off between customer perceived distinctiveness in product offerings and the commonality of these product offerings from the perspective of the company (Simpson, Siddique, and Jiao., 2006; Pirmoradi, Wang, and Simpson., 2013; Meyer and Lehnerd., 1997). This may be achieved through product platforms, which are designed so that derivative products, each targeting a specific market segment, can be efficiently produced from a common base of assets (Meyer and Lehnerd 1997; Ulrich and Eppinger., 2016). In platform-based product development, the product architecture determines how individual product elements are structured and interact (Meyer and Lehnerd 1997). Typically, product architectures are composed of modules, each of which seeks to encompass an entire function (Ulrich and Yang 2016). Such architectures facilitate the modification of modules to meet different customer needs through standardized interfaces that govern the interaction between modules. Based on these concepts, product platforms and product families are formed.

1.2.Research Problem

The construction industry has struggled to embrace innovations like prefabrication and modularization as effectively as the automotive sector. The use of platform-based product design in the automotive industry has revolutionized production efficiency, product variety, and cost savings, but its implementation in construction remains limited. This study explores how platform-based design principles, applied to construction, could improve process efficiency, reduce costs, and enhance product variety.

Research Questions

1. How can platform-based product design influence production economy in construction projects?
2. What can be the impact of platform-based product design on product variety in the construction industry?
3. How can platform-based product design improve process efficiency in construction?

1.3. Aim and Objectives

The aim of this research is to evaluate the potential of platform-based product design to enhance production economy, increase product variety, and improve process efficiency in the construction industry by drawing lessons from its successful application in the automotive sector.

The first research question aims to examine the cost benefits of using platform-based designs, particularly in reducing material and labour costs through standardization and modularity. Hence, it focuses on the economic benefits of adopting platform-based product design in construction projects. The goal is to understand how the modular nature of platform-based designs can allow for customization while maintaining cost-effectiveness.

The second research question explores how the flexibility and modularity of platform-based designs can accommodate varying customer needs and preferences without increasing complexity or cost. This includes examining cost reductions in terms of materials, labour, and operational expenses, and comparing them to traditional methods. We would identify the process efficiencies gained through the use of platform-based design in construction projects.

The third research question focuses on how platform-based designs streamline manufacturing and construction processes, improving overall workflow, reducing errors, and cutting down project completion time. It analyses how platform-based design can increase product variety in construction without compromising efficiency. This involves evaluating workflow improvements, reductions in construction time, and decreases in error rates or waste through standardized processes.

1.4. Material and Methodology

This research employs a qualitative approach, combining insights from primary and secondary sources to comprehensively address the research problem. The primary sources include planned semi-structured interviews with industry professionals, while the secondary sources encompass an extensive review of existing literature, industry reports, and academic studies.

A thorough exploration of existing literature forms the foundational aspect of this research. This involves an in-depth review of scholarly articles, industry publications, and relevant books, focusing on pre-fabrication and modularization in both the construction and automotive sectors. By critically analysing the existing body of knowledge, the study aims to identify key trends, challenges, and success factors in the adoption of these technologies. The insights gained from the literature review will provide a contextual understanding of the current state of modular and prefabricated construction, as well as lessons that can be learned from the automotive industry's application of similar strategies.

To gather first hand perspectives from professionals within the construction industry, semi-structured interviews are planned. These interviews will target experts from international companies active in modular and prefabricated construction. The semi-structured interview format will allow for flexibility, enabling participants to freely share their experiences while addressing key research questions. Each interview will begin with a brief presentation by the researcher, explaining the research objectives and ensuring clarity in the process. The collected data will undergo thematic analysis to identify recurring patterns and themes, enabling a detailed understanding of the challenges and strategies related to modular and prefabricated construction projects.

Based on insights from the literature review and planned data analysis, the research aims to provide practical recommendations for overcoming challenges in the construction industry. These strategies will draw on lessons from the automotive sector to facilitate the adoption of prefabrication and modularization.

CHAPTER 2

LITERATURE REVIEW

2.1.Modular Construction and Prefabrication in Construction

The construction industry has evolved significantly, transitioning from labour-intensive traditional methods to more advanced techniques. Modular construction and prefabrication have emerged as innovative solutions to address challenges like efficiency, sustainability, and cost management. Rooted in historical practices of creating portable shelters, these methods now utilize modern technology to streamline construction processes. The following section delves into their definitions and key characteristics, highlighting their transformative potential in the industry.

2.1.1. Definition and key characteristics

Since the distant past, humankind has sought a different and safe structure to shelter from the outside world. Development in methods and equipment, making changes in the form of materials, and updating all kinds of structures have led to the construction industry's building (Barbosa and et al., 2017). Over time, man's perspective and desires have also changed, and wanted to create bigger buildings, such as the Egyptian pyramids and the Great Wall in China. In fact, construction has been one of the human endeavours throughout history. The construction of each project also took a lot of time and required labour on a very large scale. And for this reason, in the construction process, due to the lack of facilities and the lack of machinery, many workers lost their lives in the past while constructing a building. Now construction methods have changed a lot. Today, many machines and additional tools can help human workers. Also, with the progress of science and the introduction of new materials, there have been significant changes in the construction field (Ruggiero, and et al., 2016). Significant efforts to automate the construction process and enhance efficiency in the industry have been prevalent since the 19th century, as seen in the various manifestations of large and technologically formidable construction like long-span bridges (Malakhov and et al., 2020).

Although there has been rapid global progress in technology adoption and evolution in recent years, many construction processes still face delays due to reliance on traditional and old technologies. The distinctions between the construction industry and other sectors suggest ample opportunities for modernizing construction methods. One innovative strategy in this regard is prefabrication, commonly referred to as prefab. Prefabrication has demonstrated its potential to revolutionize existing construction practices. It has proven particularly impactful in economical mass housing initiatives, offering advantages such as precise time management, cost-effectiveness, improved quality, heightened productivity, and enhanced safety protocols (Deluxe Modular News Updates, 2020).

Prefabrication involves gathering structural components through a manufacturing process or assembling site and then transporting entire assemblies or sub-assemblies to the construction site where the structure will be erected (Limthongtang, 2005). The inception of this technology dates back to the mid-1880s, gaining significant traction during World War II. Nations with a limited workforce and robust manufacturing industries have embraced prefab technology, departing from conventional construction practices. Additionally, countries with colder climates have found appeal in this approach due to the constraints of outdoor working time. For instance, Sweden stands out with an impressive 84% of its construction being prefabricated (Deluxe Modular News Updates, 2020). Furthermore, economically advanced countries like the United States, Netherlands, Germany, United Kingdom, Portugal, and Japan have effectively implemented prefab technology within their construction sectors (Deluxe Modular News Updates, 2020; Smith, 2009; Smith & Narayanamurthy, 2009).

Looking at the past, the history of the use of prefab construction technology can be seen as related to nomadic life, as well as the times when people were forced to move to another place due to environmental conditions and external threats. The need of these people for houses and shelters made them think of creating houses that could be easily assembled, disassembled, and transported (Herbers, 2004). The primary material of these early prefabricated shelters was usually made of wood, which were connected to each other by making holes in the wood with pre-cut ropes and finally covered by woollen fabric, leather, and any kind of natural material. The prototypes of these shelters can be found in the civilization of early Iranians, Mongolians, and American Indians, who were known as black tents, yurts, and Tipi (Giller, 2011).

Moreover, with the onset of migration to British colonies before World War I, people became more inclined towards prefabricated houses. Because people in this period again needed houses that could be easily assembled in the place of their choice and could be collected and moved to another place if needed. The material used for these houses was also wood, which was covered with canvas, and was later covered with air boards (Smith, 2009). Unskilled homeowners could easily assemble these houses. As the immediate housing requirements were met and building expertise developed in the burgeoning colonies, the urgency to transport prefabricated houses diminished. As a result, the firms specializing in prefabricated houses faced constraints or limitations in their operations.

During the World Wars, many factories changed their operations to support the war effort. In Britain and other countries, the availability of men for restarting factories or construction-related matters decreased, leading to a significant shortage of housing, because the emphasis on the production of war goods resulted in a scarcity of construction materials (Clapson & Larkham, 2013). Especially during World War II, there was a need for construction methods with less on-site labour and more efficient use of materials (Harrison, Whiting, & Albery, 1945). This needs motivated prefabrication because this method was able to reduce the consumption of raw materials by 50% and reduce the construction time by 57% (Phillipson, Scotland, & Lane, 2001; Gorgolewski and et al., 2005; Britto, DeJonghe, DuBuisson, &

Schmandt, 2008). One of the most important prefabricated structures during World War I was the Nissen Hut, designed by Canadian engineer Peter Nissen. This building was made of corrugated metal sheet in the shape of a semi-cylinder and was placed on brick foundations. The Nissen Hut was known as a cheap and portable shelter for British Army troops and could be used for a variety of functions including shelter, hospital or armoury (Urban, 2013; Decker & Chiei, 2005).

This cottage is considered to be the first mass-produced prefabricated building (Mallory & Ottar, 1973). It was easy and quick to transport and install by unskilled workers, but one of its weaknesses was the lack of thermal insulation, which made the hut cold in winter and hot in summer (George, 1937).

Figure 2.1. Nissen Hut under construction (College of Arms, n.d.)

During World War II, the concept of the Nissen hut underwent optimization, and improved insulation was incorporated (Decker, 2005). The scarcity of housing during both World Wars, compounded by material shortages during and after the conflicts, played a pivotal role in highlighting the advantages of prefabrication. In the last year of World War II, an estimated 475,000 houses in the United Kingdom lay in ruins or were deemed uninhabitable (Barr, 1958). In 1944, Prime Minister

Winston Churchill unveiled a strategy aiming to construct around 300,000 permanent residences and 500,000 temporary homes without escalating the demand for traditional building resources and skilled workforce (Heritage, 2011; Finnimore, 1989). By transitioning manufacturing to the factory, prefabrication had the potential to enhance material and labour efficiency by 50%, utilizing 40% fewer work hours (Chiu, 2012).

The consequence was the emergence of non-traditional residences, many of which drew inspiration from the construction methods employed in wartime huts and similar structures. This gave rise to challenges related to sound and thermal insulation, as well as the fire resistance of these houses (Hayes, 1999; McIntyre & Stevens, 1995; Nash, Hird, & Tonkin, 1954). Significant concerns also arose about the quality of prefabricated houses, reflecting a prevalent mindset that prioritized quantity over quality in their design and construction (Hashemi, 2013). Moreover, the temporary houses built in the UK in 1944 were intended to have a lifespan of approximately 10-15 years, but in reality, most exceeded this timeframe, resulting in structural defects and leaks (BRE [Building Research Establishment], 2004). Interestingly, in the UK despite the production of "some 156,623 temporary bungalows for rent under the 1944 temporary housing program [in the UK]" (Vale, 1995), the initiative was terminated due to its perceived high cost. The prefabricated temporary houses incurred expenses beyond the initial estimates.

Between World War I and World War II (1918-1939), the shortage of housing and materials prompted a significant rise in prefabrication. In 1927, over 20,000 non-traditional houses employing prefabricated systems were constructed in Scotland (Scottish Office Building Directorate, 2001). Notable systems, such as featured walls made of steel plates, utilized shipbuilding skills developed during the war (Ministry of Works, 1944). However, these houses faced challenges due to poor joint quality, ventilation issues, and insufficient thermal properties, which required extensive heating.

Concrete emerged as a prominent material in prefabrication, exemplified by Atterbury's 1918 standardized prefabricated hollow concrete slab houses at Forest Hills Gardens (Pennoyer & Walker, 2009). In the USA, concrete dominated prefabrication, constituting 50% of the 1934 reviewed systems, with 38% steel, 10% wood, and 1% plastic (Moradibistouni, Isaacs, & Vale, 2018). These concrete advancements laid the foundation for panel-based systems in apartment housing, emphasizing speed of construction, albeit with challenges related to poor indoor environments and comfort. Additionally, the demand for temporary accommodation for workers on major infrastructure projects, such as dams under the Tennessee Valley Authority in the USA, further propelled prefabrication. Demountable houses made of wood, transportable in sections on public highways, became associated with temporary and trailer-based housing (Huxley, 1943).

These developments mark a pivotal era in the evolution of prefabrication between the two World Wars.

Post-World War II, the UK urgently sought faster and more efficient construction methods due to material and labour shortages (Moradibistouni et al., 2018; Waskett, 2001). This need, driven by a desire to quickly build houses with non-traditional materials and unskilled labour, was accentuated by post-war concerns like unemployment and Ministry of Works' support for prefabrication (Gay, 1987). Between 1945 and 1947, the UK government subsidized non-traditional construction methods (Hayes, 1999). Along with the emergence of prefabricated construction techniques (system building), it led to the popularity of high-rise apartments, with the aim of accommodating large populations, optimizing land use, and speeding up construction. Ronan Point apartment tower is an example of this trend. The building's system employed factory-built, precast concrete components, minimizing on-site construction work (Eng. News-Rec, 1968). However, after subsidy cuts in 1947, prefabricated buildings struggled economically against traditional methods, facing challenges in adapting to new technologies. Prefabrication, while efficient for larger projects, incurred higher initial costs than conventional construction, posing ongoing financial challenges (Hayes, 1999). Stakeholders contended with post-war financial crises, shortages (Finnimore, 1989; Hayes, 1999), and 1950s challenges such as on-site delays and estimating man-hours accurately (Hayes, 1999). These challenges, coupled with events like the 1968 collapse of Ronan Point because of the gas stove leak on the 18th floor in apartment, impacted prefabrication's success and acceptance (Pearson, 2005).

In contemporary times, the current scarcity of affordable housing, emphasizes the renewed importance of employing prefabrication construction methods. However, there are additional compelling factors prompting a reconsideration of prefabrication. Presently, humanity is depleting energy and environmental resources at a pace equivalent to the resources of 1.6 planets, a projection that anticipates a rise to 2.0 planets by 2050 without intervention (Global Footprint Network, 2016). Conti, Holtberg, Diefenderfer, LaRose, Turnure, and Westfall (2016) anticipate a substantial 48% increase in world energy consumption by 2040. Furthermore, in 2015, the average concentration of CO_2 in the atmosphere (399 ppm) experienced a 40% surge compared to the mid-1800s, marking the highest level in the last 800,000 years (Hong Kong Observatory, 2016). Recognizing the critical impact of construction methods, the buildings sector and people's activities within buildings collectively contribute to approximately 31% of global final energy demand and roughly one-third of energy-related CO_2 emissions (GEA Writing Team, 2012).

Given the pivotal role of the construction industry in energy consumption and environmental impact, it is imperative to adopt construction methods that utilize resources more efficiently and environmentally responsibly. Theoretically, prefabrication could serve as a viable alternative to traditional methods, potentially utilizing energy and water resources 50-55% and 30-50% more efficiently, respectively, with the potential to reduce CO_2 emissions by 35% (Britto et al., 2008; Phillipson et al., 2001). However, the current negative perceptions of stakeholders toward prefabrication, likely stemming from past experiences as mentioned above, constitute a significant obstacle to its broader adoption. "People have developed the notion that prefabrication signifies jerry-building, dilapidated shacks, caravans, substandard work, unplanned development, drafts, leaks, and all unfavourable aspects of construction. The Government itself appears to maintain a perplexed viewpoint, associating prefabrication with something temporary" (Vale, 1995). While the term prefabricated means: elements (from a component to a complete building) that are made in a factory at a distance from the final location. The parts are then sold and shipped as a kit (or complete building), and the final result of assembling the kit (or attaching the complete building to its foundation), the resulting building is usually detached, one story or more, and can be eco-efficient. Because these prefab houses have the potential to be designed in a way that prioritizes ecological efficiency such as incorporating environmentally friendly materials, energy-efficient systems, and sustainable design practices to minimize the environmental impact of the constructed buildings (Serrats, 2012).

2.1.2. Advantages of modular construction and prefabrication

Prefabrication has the potential to provide enhanced value: heightened quality within a reduced on-site time frame, more predictable outcomes with fewer uncertainties, and potentially improved energy efficiency with minimized resource consumption. The significance of tangible results in terms of cost, quality, and timeframe becomes evident as consumers engage in the process of exploring show homes, selecting materials, observing factory manufacturing, and witnessing the assembly of the house at the construction site. Therefore, prefabricated construction has many advantages, but among the most important advantages, we can mention time efficiency, cost-effectiveness, and paying more attention to the environment to improve sustainability (Noguchi, 2016).

2.1.2.1. Time efficiency: One of the most significant advantages of modular and prefabricated construction over traditional on-site methods is the considerable reduction in construction time. While the design phase in modular construction may take longer due to the need for precise designs and early decision-making, the construction phase is markedly faster. The manufacturing of modules can proceed simultaneously with foundation work, and because this takes place in a controlled environment with increasing automation, it is significantly quicker than on-site construction. On-site assembly is also streamlined, with modules simply being put together and utilities connected, resulting in faster and cheaper labour.

The factory setting enhances quality control, minimizing the risk of rework and ensuring that mistakes are identified and rectified early, unlike in traditional construction, where errors may go unnoticed until long after project completion. This comprehensive approach can reduce construction time by 20-50% (Patel & Kaushal, 2024) (Below it is figure 2.2).

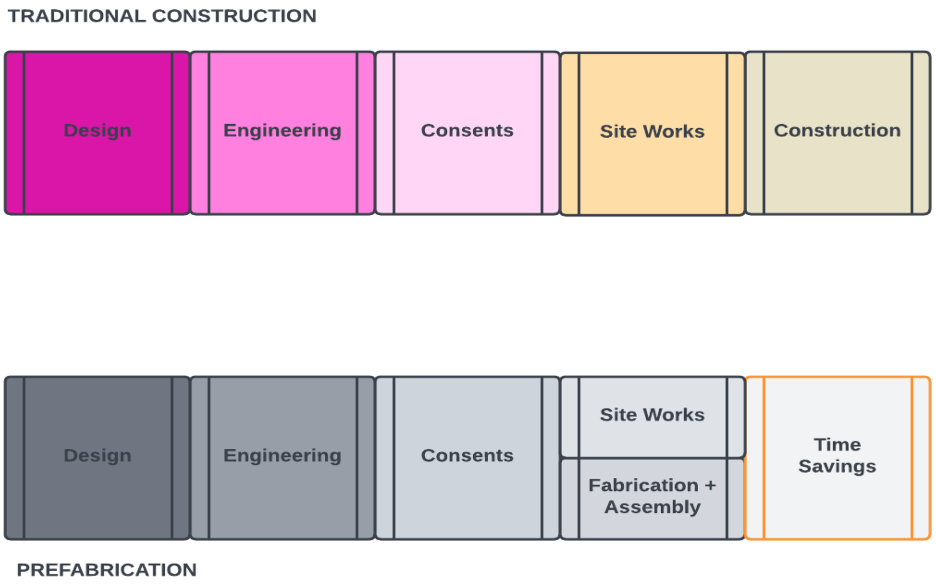


Figure 2.2. Time Savings in Prefabrication delivery compared with traditional construction

Prefabrication further enhances time efficiency by allowing construction to proceed concurrently with site preparation. By integrating prefabricated panels or modules, the construction process is simplified, reducing reliance on external contractors and wet trades, and leading to faster project delivery (Poon, Yu, & Ng, 2003). Additionally, building in a factory environment mitigates delays caused by adverse weather conditions, which is particularly beneficial in climates with frequent inclement weather (Bildsten, 2011). This can reduce project time by 30-60% compared to traditional methods, effectively controlling costs associated with new material development and extensive pre-construction planning (Aburas, 2011; Bildsten, 2011). However, this approach requires meticulous planning, as alterations are difficult once the fabrication process begins, representing a shift away from traditional linear construction processes.

2.1.2.2. Cost-effectiveness: Financial benefits encompass the cost savings for both customers and developers achieved through faster delivery, reduced correction periods, and a shorter duration of financial borrowing. As noted by Buchanan (2004), "Considering the inherent cost savings in the construction technique, a prefabricated shell is generally more cost-effective than a site-built structure with identical specifications, configuration, and quality."

The reduction of timeframes and costs can be achieved by mitigating reliance on weather conditions for site-based construction, enhancing the in-house coordination of sub-trades, minimizing transportation expenses, and capitalizing on price advantages through bulk ordering (Noguchi, 2016).

2.1.2.3. Sustainability: Sustainability benefits involve the reduction of material waste through effective ordering, indoor protection, meticulous pre-planning, and precise cutting. For example, in New Zealand, the construction sector is labelled as the ‘forty percent industry’ because buildings are responsible for 40% of energy consumption, 40% of the waste flow, 35% of carbon emissions, and 40% of raw material usage. The Waste and Resources Action Programme (WRAP) in the United Kingdom disclosed that adopting various prefabricated manufacturing methods could potentially lead to a 90% reduction in waste. Likewise, in the United States, there are optimistic projections indicating a potential 50% decrease in energy consumption within the construction industry through the adoption of prefabrication methods (Noguchi, 2016).

The final construction benefits from minimizing defects, and enhanced precision for improved thermal and acoustic performance, resulting in heightened energy efficiency and decreased heating expenses. Prefabricated structures play a role in diminishing the overall carbon footprint by reducing transportation needs to the site and promoting lower energy consumption throughout their lifecycle. Through the implementation of modular construction, delivery to the construction site can be reduced by 60%. Process advantages include a safe, healthy, and controlled environment for workers, increasing labour productivity and material efficiency. Traditionally, on-site work can be up to 50% below its potential, with an estimated 13-18% of delivered materials being wasted due to misuse (Gorgolewski, 2005).

In its most environmentally conscious form, certain prefab buildings are designed for disassembly, facilitating the potential future reuse of materials and components. One of the sustainability drawbacks lies in the over-engineering and resulting extra material used to brace the modular units for transport. However, this over-engineering can also enhance the durability and resilience of the house once assembled on-site. Prefabrication processes can also effectively tackle challenges in the construction industry, such as a shortage of skilled construction workers, growing market demands for higher-quality housing, and the increasing regulations within the industry (Noguchi, 2016).

2.1.3. Examples of successful modular construction projects

As prefabrication evolved over time to address various housing needs, we now witness its modern applications, as seen in projects like The Clement Canopy. Unlike early nomadic shelters and colonial-era prefabricated houses, today's prefabrication technology reflects a more sophisticated and efficient approach. The Clement Canopy stands as a testament to the continued relevance of prefabrication in contemporary construction. While the historical context underscores the necessity of easily assembled and transportable structures, this case study exemplifies how modern prefabrication techniques go beyond mere convenience. The use of Prefabricated Prefinished Volumetric Construction (PPVC) at The Clement Canopy not only addresses logistical challenges but also presents a paradigm shift in construction efficiency and quality (Seng, Huat, Mui, Hooi, Chuan & Lin, 2021).

Figure 2.3: The Clement Canopy. (Adapted from SRX, 2024)

The use of Prefabricated Prefinished Volumetric Construction (PPVC) appears as a defining feature in Clement Canopy. Unlike historical prefabrication endeavours that relied on raw materials and assembly methods, The Clement Canopy uses complex six-sided concrete PPVC modules. Weighing between 26 to 31 tons, these modules, installed using two 48-ton capacity tower cranes, represent a departure from traditional prefabricated structures. One notable feature is the strategic utilization of PPVC for typical floors from levels 2 to 40, which demonstrates a commitment to innovation and efficiency. The astonishing height of The Clement Canopy, which holds the title of the tallest PPVC concrete building in the world, emphasizes the structural integrity and feasibility of this modern construction approach.

Figure 2.4. Tower Crane Hoisting of PPVC module (Seng and et al., 2021).

The learning points from The Clement Canopy extend beyond the construction site and permeating the entire project lifecycle. Early decisions in the design phase, such as confirming drawings and materials, proved critical in ensuring a seamless production cycle. Challenges in site control and discipline were met with improved work, as the majority of architectural activities occurred in a controlled factory environment.

This case study not only highlights the evolution of prefabrication from historical roots but also highlights its contemporary features. The integration of advanced materials, engineering, and construction methodologies at The Clement Canopy exemplifies how prefabrication has evolved to address current challenges, offering a blueprint for the future of efficient and quality-driven construction practices (Seng and et al., 2021).

Another case study is Fleetwood Prefabricated Homes: Fleetwood stands out as a prominent supplier of prefabricated homes in Australia, boasting an annual capacity to deliver over 600 housing units across the West and East Coast. The prefabricated homes provided by Fleetwood are meticulously crafted, with 99% completion achieved within a controlled factory environment (Figure 5). The entire construction timeline spans seven weeks, encompassing six weeks within the factory and an additional week for delivery and on-site installation.

Figure 2.5. Fleetwood Homes. (Adapted from Fleetwood Homes, 2024).

Early collaboration with clients plays a pivotal role in enhancing the optimization of design and construction processes, leading to a reduction in overall construction costs through minimized material waste and increased labour efficiency.

The factory production line mirrors the dynamics of a typical construction site, with various housing types concurrently under construction. Throughout the construction process, teams work collaboratively, completing specific tasks at designated stations before transitioning to the next phase. Commencing with the placement of a chassis on the factory floor, each chassis is purposefully designed to facilitate the manufacturing and transportation of homes, allowing occasional relocation from one site to another.

Fleetwood employs two distinct chassis systems:

(a) a precast concrete slab chassis that minimizes the threshold height and achieves finishes resembling in situ construction,

and (b) a steel chassis combining floor structure and retractable lifters. The number of chassis elements required for a house depends on its size and floor plan layout. Single dwellings typically range from 90 to 120 m2 in area, featuring regular square shapes. The dimensions of each chassis are typically 4.2 m wide × 14.4 m long, aiming to minimize construction and transportation costs.

All homes fully comply with Australian national construction codes and standards. The building structure has been precisely optimized to withstand winds of up to 61 meters per second (Noguchi, 2016).

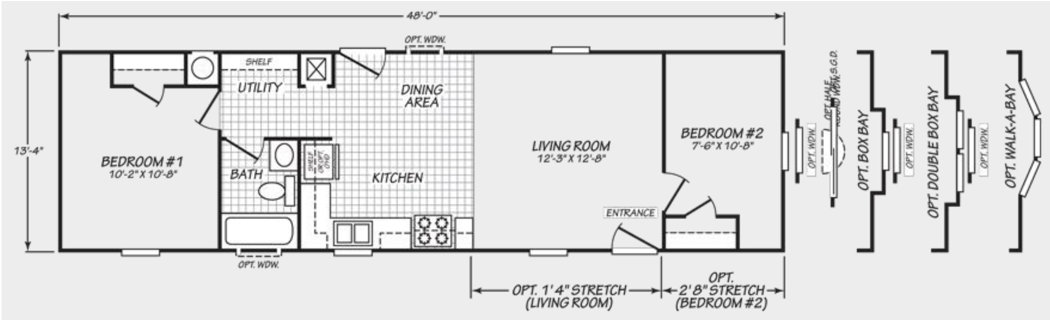


Figure 2.6. Plan of prefabricated home. (Adapted from Fleetwood Homes, 2024).

By examining the history of prefabricated construction in the construction industry until today, it can be seen that today, with the advancement of science and technology in all fields, which is also evident in the construction industry, traditional and on-site construction techniques in the housing sector face technical limitations. For this purpose, many efforts have been made in the construction industry for the industrialization of the construction industry in the last few decades (Bock, 2015). In fact, with industrialization and the use of construction automation techniques, construction time can be shortened and unit costs can be reduced, and some challenges caused by conventional construction methods such as product and process waste can be overcome. Nowadays, prefabricated housing and off-site construction are no longer just a theoretical option but have become a real-world practice (Leiner and Bock, 2012). However, prefabricated construction may negatively affect the quality of housing products and may not achieve sufficient customer satisfaction due to its high standardization for lower unit costs and uniform design (Giebler and Tivima, 2014; Larsen, Lindhard, Brunoe, Nielsen, & Larsen, 2019).

Customer satisfaction in the housing industry is not measured by the success of a project alone, meaning that the on-time delivery of a project consistent with high quality and within budget constraints defines it (Du, Jiao & Tseng, 2006). have argued that an organization's ability to provide a customized product tailored to customer demand is positively related to the overall level of customer satisfaction. On the other hand, compared to mass construction with a uniform design, it has been observed that home builders who offer more design options have problems with more quality problems, reduced productivity, increased inventory, increased construction costs, and even fewer satisfied buyers (Nahmens, 2007). This emphasizes the urgent need to find an appropriate balance between mass efficiency and product diversity in the realm of housing goods. The goal is to allow extensive customization while maintaining a delicate balance between low unit cost and high product quality. That is, mass customization (MC) continues to be facilitated in the industrial housing industry (Andújar-Montoya, Gilart-Iglesias, Montoyo, & Marcos-Jorquera, 2015).

Mass customization (MS) is a strategy that aims to meet customer demand through efficient and rapid mass production with high competition (Kotha, 1995). Customer participation during product development is included in the MC strategy, where customers can participate in the design process of their final product to better define their needs (Lee and Chang, 2011). Efforts to swiftly respond to customer needs have led to the implementation of information systems and lean production principles in mass customization environment (MC) (Farr, Piroozfar & Robinson, 2014; Fettermann and Echeveste, 2014; Ahmad, Tichadou & Hascoet, 2017; Piroozfar, Farr, Hvam, Robinson & Shafiee, 2019). The main functions of MC information systems usually focus on creating collaborative environments for product development, gathering customer insights, and supporting customized product design in a virtual platform that isn't restricted by location or time constraints (Frutos and Borenstein, 2004). These technologies play a crucial role in speeding up responses, refining product variety, and enhancing flexibility (Yan, Gupta, Schoefer & Licsandru, 2020).

However, the subject of mass production has not found its place in the construction industry, which is contrary to this principle, which is very well-known and popular in the car manufacturing industry. To understand better this issue, it will be good to first examine the automotive manufacturing process and find the similarities between construction and automotive manufacturing.

2.2. The Automotive Industry as a Model

The automotive industry has evolved from handcrafted cars to mass production and, more recently, mass customization. Innovations like Ford's assembly line and Toyota's lean production have shaped its success, focusing on efficiency, scalability, and customer demand. These advancements provide valuable lessons for improving productivity and customization in other industries, including construction.

2.2.1. Overview of the automotive manufacturing process

The automotive industry has a rich history dating back to the late 19th century when the first gasoline-powered car was built by Karl Benz in Germany in 1886, an invention widely considered to be the first true automobile (Samani, 2023). Initially, automobiles were crafted by skilled artisans who meticulously assembled each vehicle, essentially creating "horseless carriages." This hand-crafted approach meant that early cars were luxury items for the wealthy. The Daimler Stahlradwagen of 1896 marked the first mass-produced car in Germany, a significant step toward making cars more accessible to the general public (Samani, 2023).

Henry Ford revolutionized automotive production in 1908 with the introduction of the Model T, utilizing assembly line techniques to make automobiles affordable for middle-class Americans. By adopting and expanding Frederick Taylor's "scientific management" philosophy, Ford enabled the mass production of vehicles. This shift was transformative, moving the industry from the artisanal, hand-crafted models of the past into the era of mass production (Crowley, 1998). The rapid expansion of the automotive industry in the 1920s, especially in the United States, further cemented its place as a key economic force, with cars becoming symbols of social status. Companies like General Motors and Chrysler emerged during this time, contributing to the industry's growth (Samani, 2023).

The period following World War I saw Henry Ford and Alfred Sloan of General Motors lead a significant shift in manufacturing, moving away from European craft-based production methods and heralding the era of global mass production, primarily driven by the U.S. market (Crowley, 1998). However, the Great Depression of the 1930s had a major negative impact on the industry, with many companies failing due to plummeting sales (Samani, 2023).

After World War II, Eiji Toyoda and Taiichi Ohno introduced the concept of lean production at the Toyota Motor Company in Japan, which focused on reducing waste and optimizing efficiency. As other Japanese companies adopted this system, Japan quickly rose to economic prominence. Today, lean production is a dominant manufacturing philosophy, enabling manufacturers to produce vehicles in response to customer demand, rather than their production capabilities or preferences. In Japan, customers can often place orders for custom vehicles and receive delivery in less than two weeks, showcasing the flexibility of this system (Crowley, 1998).

As the automotive industry continued to evolve, the oil crisis of the 1970s marked a shift from large, V8-powered cars to smaller, more fuel-efficient models. This transition was in response to rising fuel prices, leading to the increased popularity of compact cars (Samani, 2023). The industry's ability to adapt to external challenges, such as economic downturns and environmental concerns, has been one of its defining features.

The post-war boom of the 1950s led to increased demand for automobiles, signalling the beginning of a new era of growth and prosperity. In the 1960s, "muscle cars" like the Ford Mustang and Chevrolet Camaro became hugely popular, appealing to a new generation of consumers (Samani, 2023). Meanwhile, the adoption of advanced manufacturing technologies in the 1980s, such as fuel injection and computer-aided design, further fuelled growth in the industry.

The advances in mass production during the 20th century were driven by continuous improvements in manufacturing processes, which significantly boosted productivity. These advancements were fuelled by technological innovations, including the development of superior engineering materials, the use of mechanical power, the introduction of new tools for mechanization, precision measurement techniques, and the interchangeability of parts, which eliminated the need for "fitting." These developments laid the foundation for the modern automotive industry (Crowley, 1998).

By the 1990s, Japanese automakers had established a strong global presence, especially in the U.S. market. Globalization had a profound impact on the automotive industry, leading to increased competition and innovation. Despite the setbacks caused by the global financial crisis of 2008, the automotive industry has shown resilience, continuing to grow and evolve in the years that followed. Today, it is a major driver of global economic growth, with new trends and technologies shaping its future (Samani, 2023).

The evolution of the automotive industry can be better understood through a chronological overview of its key milestones and transformative events. The following timeline highlights these significant developments, showcasing the industry's progress and resilience over the decades.

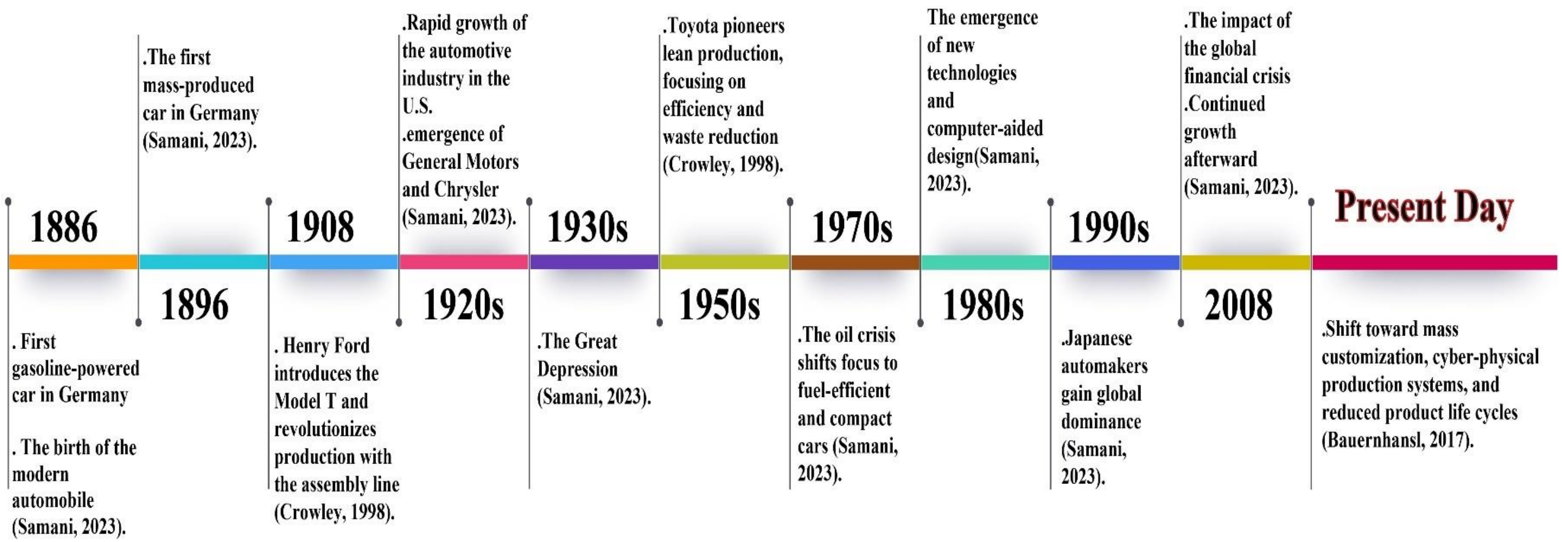


Figure2.7. Overview of the automotive manufacturing process

In today’s automotive manufacturing process, the focus has shifted from mass production to mass customization and personalized production. In the era of mass production, the customer's role was significantly limited, with only the ability to choose from the offerings of manufacturers. Contrastingly, in contemporary times, the role of the customer about manufacturers and product providers is undergoing constant transformation.

To understand this, it is better to take a brief look at the alternatives to assembly line production in the automotive industry from the beginning until now.

Assembly line production, a cornerstone in the automotive industry for over a century since its debut at the Ford Motor Company, has gained widespread acceptance globally. Initially designed for efficiently manufacturing a specific car model, assembly lines played a pivotal role in enabling mass production. However, in recent decades, the automotive market has shifted from being dominated by sellers to being influenced by buyers, transforming manufacturers into global players (Schuh, 2014; Herlyn, 2012). As a consequence of prioritizing customer preferences and expanding into international markets, automobile manufacturers have diversified their range of products and product variants (Holweg,2008). This evolution has shifted the landscape from simple and homogeneous products to highly sophisticated and customized ones. Consequently, the traditional approach of mass production has transformed into the era of mass customization (Piller, 2013). Due to the introduction of new materials and alternative drive concepts, along with the growing trend towards personalization and personalization of automobiles, this trend is expected to continue. This trajectory is expected to lead to greater product differentiation and subsequently fewer cars per variant (Holweg, 2008). Moreover, this development is associated with a shorter life cycle of products and production technologies (Landherr & Westkämper, 2014). This increasing complexity fundamentally changes the requirements regarding the assembly of automobiles. Consequently, adjustments are imperative for the assembly systems of automobile manufacturers to accommodate the rising complexity and guarantee the efficient production of automobiles (Bauernhansl, 2017). Simultaneously, emerging technologies and the evolution of cyber-physical production systems present novel opportunities for the design of assembly systems, potentially empowering car manufacturers to effectively navigate the growing complexity. Therefore, this process led to the development from single model assembly lines to mixed model.

The assembly line concept was originally introduced to efficiently assemble a uniform model in large quantities, which revolutionized automobile manufacturing through mass production (Holweg, 2008). In this framework, the individual workstations of an assembly system are arranged along an assembly line and connected by a fixed transportation system, facilitating continuous or intermittent flow (Boysen,2005). As a result, each workstation follows the same time schedule for its assembly process. Therefore, the strategic allocation of assembly tasks to individual workstations along the assembly line, referred to as assembly line balancing, is a critical aspect of achieving high productivity in an assembly system (Scholl and Scholl, 1999; Boysen, Fliedner & Scholl, 2007).

However, the increasing variety in products and their versions, particularly over the last decade and the subsequent reduction of cars per type made it impossible to implement a single model assembly line for each product type (Hüttenrauch and Baum, 2007). This led to the emergence and current prevalence of mixed-model assembly lines in all medium- and high-scale automotive assembly systems (Boysen, 2005). Unlike single- or multi-model assembly lines, mixed-model assembly lines can produce multiple car models without organizing them into predefined batches, doing so in a random, mixed sequence (Scholl and et al., 1999).

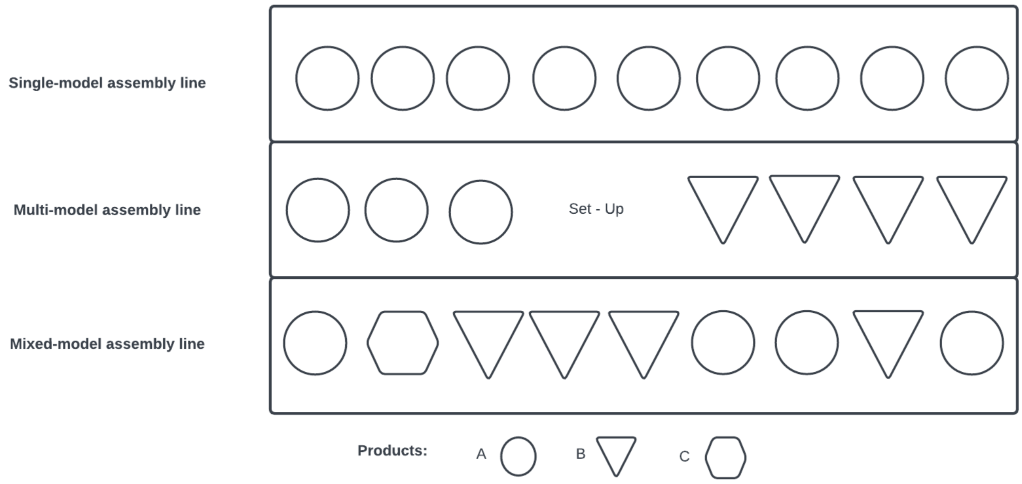


Figure 2.8. Types of assembly line

2.2.2. Similarities and differences between construction and automotive manufacturing

A clear similarity emerges when taking a closer look at modular unit housing production systems, with particular emphasis on Toyota. Toyota, which manufactures cars and houses, has actively pursued cross-industry learning. The manufacturing processes of the Toyota and Sekisui Heim systems (which is a renowned and trusted housing brand in Japan that is owned by Sekisui Chemical Group.) have similar characteristics that extend throughout the manufacturing process to final assembly. Toyota Homes and Sekisui Heim specialize in the production of modular unit housing and employ comparable manufacturing methods. These systems, which are at the top of the hierarchy of industrial and semi-industrial housing, use methods similar to the different stages of car production (Gann, 1996).

A fundamental consideration in housing and automotive manufacturing revolves around striking a delicate balance between standardization, facilitating efficient use of the product line, and flexibility, ensuring market appeal by accommodating consumer preferences for a wide range of custom options. This balance is achieved in both areas through a combination of standard subsets and "platform" design approaches complemented by computer component optimization techniques (Ward, Liker, Cristiano & Sobek 1995). Moreover, the modular unit housing industry has adopted production methodologies inspired by car manufacturing, incorporating practices such as Just-in-Time (JIT), quality circles, the utilization of Computer Numerical Control (CNC) machine tools where applicable, and automation of transfer and storage of parts (Gann, 1996).

However, notable distinctions exist between the processes of car manufacturing and industrialized housing. The following table summarizes the key differences between construction and automotive manufacturing processes for better clarity and comparison:

Table 2.1. Differences in Construction and Automotive Manufacturing

Section	Construction Industry	Automotive Manufacturing
Chances of IT convergence	Rather difficult to organize the construction	Organizing electronics production is relatively easy
Complexity in Customer Choice	Several unexpected requirements originated throughout the process	Project planning phase (especially on market research)
Space Allocation	More space	Small space
Approach to Design and Sales	Frequent	Rare
Seller Concentration	Fewer sales per year	More sales per year
Manpower Costs	Reduces on-site construction costs	Increased costs for design/sales staff

As shown in the table, the distinctions highlight the unique challenges in the construction industry compared to automotive manufacturing. Compared to construction industry, car manufacturers have excelled in automating a broader range of activities within their factories. They have also successfully implemented Computer Integrated Manufacturing (CIM) techniques, which housing manufacturers have yet to achieve.

One significant challenge in the construction industry is the complexity of customer choice, particularly in components like interior finishes and door types, where options can exceed 300 variations. Furthermore, housing factories allocate a larger area of floor space for warehousing and storage compared to automotive facilities. This is partly due to the larger size of housing materials and partly because of the greater number of parts and replacement requirements in residential units.

Industrial housing manufacturers differ in their approach to design and sales compared to their counterparts in the automotive industry. Sekisui company employs in-house design/sales specialists who also act as market researchers, ensuring a closer relationship between manufacturers and users. These specialized teams exhibit the ability to navigate trade-offs between customer requirements and engineering solutions for production, facilitating the satisfaction of a broader spectrum of preferences in customized products. Furthermore, the concentration of sellers per unit sale is more pronounced in the housing sector than in the automotive sector. Sales staff at the four largest steel-frame housing producers averaged 14 sales per year in 1993, highlighting a higher degree of seller concentration. In contrast, Toyota franchise sales staff were only selling five or six houses each, a significantly lower figure compared to the automotive industry where car sales staff typically aim for much higher sales volumes. The impact of reduced on-site construction activities in modular unit housing production has led to a decrease in manpower costs. However, this is offset by increased costs for design/sales staff and promotional efforts. Housing manufacturers must deal with greater degrees of flexibility related to customer choice, regulatory environments, and local site conditions. The total number of parts and replacement of assembly options in the production of housing is more than that of cars. While a car is typically assembled from approximately 20,000 items, a house may involve the construction of up to 200,000 components. For instance, Sekisui House manages a staggering inventory of around 2 million parts for one of their housing systems (Ota, Matsumura, Mori, & Kamo, n.d). However, further investigation is necessary to discern the balance between customized and standardized components in housing, especially in relation to the flexibility of the final product. Similarly, research is needed to explore the technical complexity associated with the number of permutations of connections between different components in industrial residential systems and the importance of this for design flexibility (Gann, 1996).

Housing companies add more value to their factories than auto manufacturing, where a significant portion of the work is outsourced to suppliers and component makers. In-depth research in this area is necessary to gain a comprehensive understanding. In terms of the proportion of value added, construction sites share similarities with final assembly plants in automobile production. The challenge confronting housing producers lies in discovering innovative approaches to enhance performance during the final on-site assembly stages, potentially through the adoption of novel project management methodologies (Gann, 1996).

2.3. Platforms in the Automotive Industry

In the automotive industry, platforms refer to shared architectures that allow manufacturers to produce a variety of vehicle models using common components and processes. This approach helps companies reduce costs, improve production efficiency, and accelerate the introduction of new models. By leveraging platforms, automakers can create diverse products while maintaining economies of scale and flexibility to meet market demands.

2.3.1. Definition and role of platforms in car manufacturing

Since the mid-20th century, with the rise of mass production, markets have increasingly emphasized a wider variety of products with shorter life cycles to satisfy evolving consumer demands, resulting in greater market saturation (Koren, 2010). This trend affects numerous sectors, impacting not only those that manufacture assembled products like automobiles (Simpson et al., 2006), but also industries producing non-assembled goods such as food products (Fuller, 2016). As a result, manufacturers face growing external complexity and must regularly introduce new product variations while operating in an increasingly global marketplace (Vogel and Lasch, 2016; Seifert et al., 2013). In response to this pressure, manufacturers have been increasing internal complexity to stay competitive and meet diverse customer needs (Vogel and Lasch, 2016). However, this often leads to higher operational costs, inefficiencies (Piya, Shamsuzzoha, Khadem, & Al-Kindi, 2017), and a loss of competitive edge. A recognized solution to address these challenges is the adoption of platform-based product development strategies which have been extensively adopted in discrete manufacturing industries to address changing market demands. However, the process industries, despite facing similar pressures, have seen much less research and application of platform-based strategies (Andersen, Brunoe & Nielsen, 2023). This approach hinges on addressing a core challenge: finding the balance between offering distinctive products as perceived by customers and maintaining product commonality from the company's perspective (Meyer and Lehnerd, 1997; Pirmoradi, Wang, & Simpson, 2013; Simpson et al., 2006). This can be accomplished through product platforms, which are structured so that various derivative products, each aimed at a specific market segment, can be produced efficiently using a shared pool of resources (Meyer and Lehnerd 1997; Ulrich, Eppinger, and Yang 2020). In platform-based product development, the architecture of the product dictates how its individual components are organized and interact with each other (Meyer and Lehnerd 1997). Typically, product architectures consist of modules, each designed to cover a complete function (Ulrich et al. 2020). These architectures allow for the flexible swapping of modules to meet different customer demands, using standardized interfaces to control interactions between the modules. Through these principles, product platforms and product families are established.

In recent years, many companies have increasingly developed product platforms and designed product families around these platforms to achieve both variety in the marketplace and efficiency in their manufacturing processes. A product family typically consists of a series of related products derived from a shared platform, allowing companies to meet diverse market needs while benefiting from economies of scale and scope (Simpson et al. 2006).

The definition of a product platform can vary depending on the industry and market. Some view a product platform as a collection of assets—including components, processes, knowledge, people, and relationships—that are shared across multiple products (Robertson and Ulrich, 1998). Others define it as a set of shared components, modules, or parts from which various derivative products can be efficiently developed and launched (Meyer and Lehnerd, 1997). Additionally, it can be seen as a set of common elements, especially core technologies, applied across a range of products (McGrath, 1995).

Today, the automotive sector is one of the industries that uses the platform thinking strategy. Manufacturers of automobiles utilize a common base, referred to as a platform, for constructing the entirety of a vehicle. This platform is shared among diverse models to attain increased production volumes and benefit from economies of scale. Major car manufacturers use common platforms for constructing various brands under their ownership, thereby facilitating the production of larger quantities (Mike, Mats, Javier & Oriol, 2007). Also, other sectors and industries derive their innovations from product platforms. The term "product platform" refers to a common design for a variety of final products. The objective behind employing product platforms in automotive industry is to optimize commonalities and effectively recycle investments in the development of new products. The figure will help visually demonstrate the idea of a shared platform across multiple models, reinforcing the concept of platform thinking in the automotive industry.

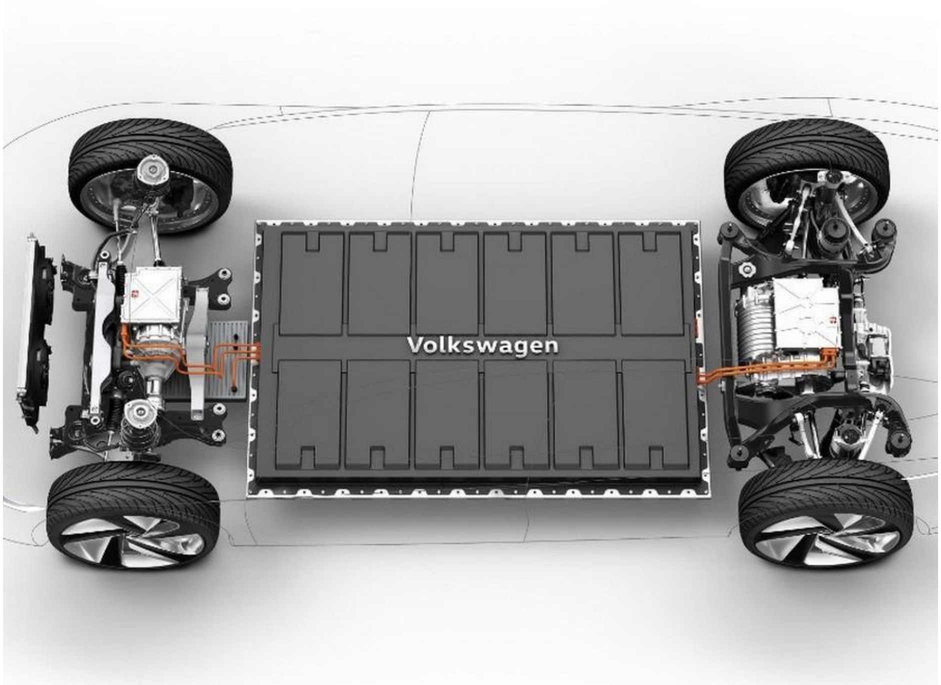


Figure 2.9. The Concept of Product Platforms in the Automotive Industry.
(Retrieved from https://www.volkswagen-newsroom.com)

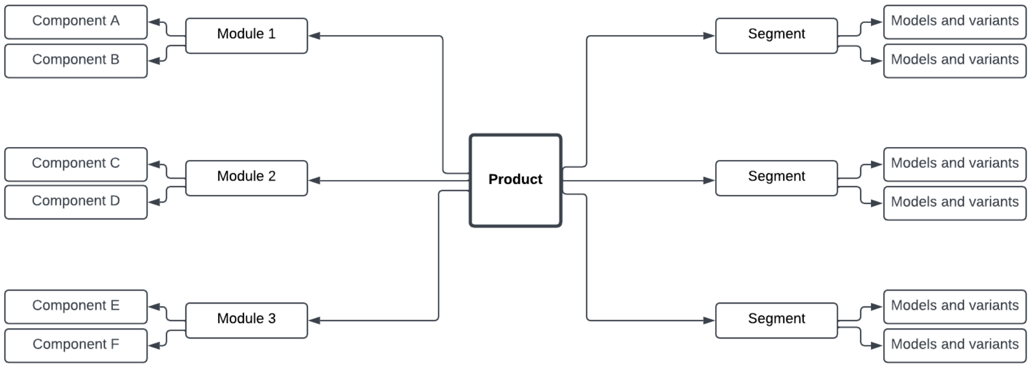
Within consumer products, these platforms are often linked with modularity and standardized connections among physical components. This brings about benefits not only in the realm of new product development but also in the efficient management of operations (Alblas, Wortmann, 2014). However, platform thinking involves not only the sharing of platforms but also a whole philosophy of process, especially within groups. At its core, this approach aims to promote collaboration, involving the shared utilization of components, tools, processes, development, workers, and strategy (Mike et al. 2007).

A product platform is not an independent product; rather, it is a set of common elements, specifically the underlying definition of technology, that is implemented across a range of products (McGrath, 2001). Essentially, the platform embodies the most basic technological aspects shared among products within a product line. These common elements may not be complete in a form that can be sold directly to the customer. Therefore, the guiding principle associated with platforms is the concept of "invest one, reuse over and over again" (Kuczmarski, Middlebrooks & Swaddling 2000). Considering that a product platform is more than physical, its main function is to provide a framework for strategic planning, decision-making, and thinking. Consequently, companies using a product platform must carefully evaluate how the product family meets diverse customer needs and which markets or customer segments are involved (McGrath, 2001).

All this collaborative effort aims to achieve a more cost-effective approach to automobile production. However, managing this collaboration requires meticulous attention, presenting a considerable challenge. Companies need to coordinate different aspects, and using global platforms adds complexity to their development and makes it more difficult to meet the diverse requirements and constraints for the wide variety of models they have to consider. In addition, the complexity of product planning increases due to the large number of vehicles involved. At the same time, the coordination of different production processes becomes very complicated. Working with people from different brands, cultures, and often locations add another layer of difficulty to collaboration. Additionally, too much commonality between models makes it more challenging to maintain a good level of diversity across these different models based on a single platform (Mike et al., 2007).

Although product platforms are used in various industries, their importance is most prominent in the fields of automotive, consumer electronics, and engineering sectors. The challenge facing companies in these industries is to create favourable economic diversification (Sundgren, 1999). Figure 1.1 below, shows a representation of the platform concept in the automotive industry (Danilovic, Börjesson, 2001; Sundgren, 1999).

Table 2.2. Product Platform



2.3.2. Types of platforms used in the automotive sector

The concept of platforms in the automotive industry is not new. Since the 1960s, many automakers have sought to achieve economies of scale and scope by increasing the sharing of parts across a larger number of models (Jetin, 2018). This approach led to the development of platform-based strategies. Which, refers to a collection of shared assets used across various products (Simpson et al., 2006) that remain compatible with manufacturing processes (Muffatto and Roveda, 2000).

A major development in platform strategies occurred in the 1990s when reduction and standardization became key objectives (Siddique and Rosen, 1998; Whitney, 2004). This shift resulted in the creation of a standardized platform for multiple models within the same product segment (Holweg, 2008). By adopting this approach, manufacturers were able to use the same components and systems across many models built on the same platform (García Vázquez, Lampón Caride & Vázquez, 2005). Standardization focused on improving product development by simplifying engineering and design processes, reducing both costs and development time (Muffatto, 1999; Suh, De Weck, Kim & Chang, 2007). Another significant benefit was the realization of economies of scale through the production of more shared components per platform, leading to cost savings on parts (Korth, 2003).

In recent years, the platform strategy has evolved, with modular platforms being introduced into the industry (Sehgal and Gorai, 2012). Standard platforms allowed automakers to design and produce multiple models within the same segment, a concept known as horizontal variety, where differences among models were mainly confined to aesthetic and non-structural elements. This means that while the models share the same basic structure, their features might vary in design or trim. Modular platforms, however, aim to combine this horizontal variety with vertical variety, which enables the design and production of models across different segments and sizes (Buiga, 2012; Schuh et al., 2013). Vertical variety allows manufacturers to create entirely different models that cater to varying market needs, such as compact cars, sedans, and SUVs, all from the same modular platform.

These modular platforms feature flexible configurations based on a single scalable design, composed of interchangeable modules. This flexibility allows for structural variations such as changes in front and rear overhang, wheelbase, and track width. As a result, modular platforms not only support the assembly of multiple models within the same segment (same size), as standard platforms do, but also enable the production of models from different segments (varying sizes) on a single platform (Lampón, Cabanelas & González-Benito, 2017).

The flexibility of modular platforms is further enhanced by the varying utilization of components, with manufacturers choosing to incorporate more or fewer elements based on their brand preferences. Some brands opt for a more basic and simpler platform that consists of fewer components, facilitating easier assembly and reduced costs. In contrast, other manufacturers may utilize more intricate platforms with a larger number of components, allowing for greater customization and enhanced features across diverse model ranges. Differences in the components utilized are caused by various factors. One contributing factor is that, for a specific company, it may prove more beneficial to integrate a particular element into the platform, facilitating its shared use across different models. Conversely, another company might opt to have a unique component for each model derived from the same platform, deliberately excluding it from the shared platform (Mike et al., 2007).

Another influencing factor is the diverse set of production technologies available to each company. Car manufacturers employ distinct production processes, and these methods play a crucial role in determining the choice of components integrated into the platform. Due to technological limitations, there are cases where a manufacturer would like to include certain components on the platform, but is unable to due to limitations in their manufacturing process.

However, the distinction between components belonging to the same platform is not the only difference. The approach in engaging with platforms also differs among brands. While some companies have seamlessly integrated the platform concept into their organizational structure, others use it predominantly for cost-saving purposes without a complete alignment with their overall strategy. Adopting a platform strategy requires not only a change in mindset, but also a significant financial investment to implement the changes. The group must allocate a budget to cover the costs associated with the transformation of its factories, which makes the process financially demanding (Mike et al., 2007).

A deeper analysis of the platform concept across various brands in the market illustrates that the components of a platform are not fixed. For instance, Volkswagen's platform includes a wide range of components such as front axles, rear axles, front ends, rear ends, exhaust systems, brake systems, and many others (Sudjianto and Otto, 2001). In contrast, General Motors defines its platform as an integration of the steering system, suspension, brakes, engine, and exhaust. Notably, GM also designs its engines to be compatible with its platforms, allowing multiple engine options to be utilized within a single vehicle platform (Scott, 1995).

Fundamentally, the platform serves as the foundational framework of automobiles, incorporating key elements like the floorpan, drivetrain, and axles (Ghosh and Morita, 2004). Typically, this platform encompasses the underbody and the suspension system, with the underbody comprising the front floor, underfloor, engine compartment, and frame. Based on this foundational definition of a platform, Japanese manufacturers have identified three variations: narrow, broad, and flexible (Muffato and Rowda, 2000).

Within a narrow definition, a platform is composed of the front floor, underfloor, engine compartment, and suspensions, with the option to include steering equipment to this basic narrow definition. On the contrary, in a broad definition, a platform encompasses the front floor, underfloor, engine compartment, suspensions, engine, transmission, fuel tank, and exhaust system. A broad definition indicates a more assertive approach or an advanced platform strategy that significantly impacts product development performance and organizational structure. Finally, in a flexible definition, a platform is outlined as floor panels (core, front, and end), suspensions, powertrain, and engine. A single platform can exhibit various lengths, contingent on the wheelbase. It is necessary to use the same stamping dies or with minimal changes to produce the same platform. Within these limitations, a platform may integrate a mix of components, such as core under-floor B, front suspension A, rear suspension B, and so forth. However, this adaptability also involves certain trade-offs. For example, if the same platform is intended for use with different engines, considerations must be given to the chassis weight and engine size, as a larger engine requires a more robust structure and vice versa. Another critical aspect is whether the platform permits the use of the same production line without substantial adjustments (Mike et al., 2007).

Different brands on the same platform with small differences in technology, perceived quality and features make it difficult to convince customers that a particular car offers a unique experience. The question arises: why choose an Audi or a Volkswagen when the Skoda is equal in terms of features, performance and comfort? The platform technology is designed for the car model with the highest production volume. Nevertheless, it can be stated that, on average, the development timeline for a platform is approximately 24 months, while model development typically spans around 18 months.

Another crucial aspect of the platform concept is the number of models that share a common platform. Historically, the count of models per platform used to be lower, but the prevailing and future trend is to maximize the creation of models with the same platform. The rationale behind this tendency is straightforward: the higher the number of models derived from a unique platform, the more efficiently the platform itself is utilized and its effectiveness increases (Muffatto, Roveda, 2000). Concurrently, automobile manufacturers endeavor to minimize the number of platforms they work with, thus fostering an ongoing increase in the number of models based on a single platform over the years.

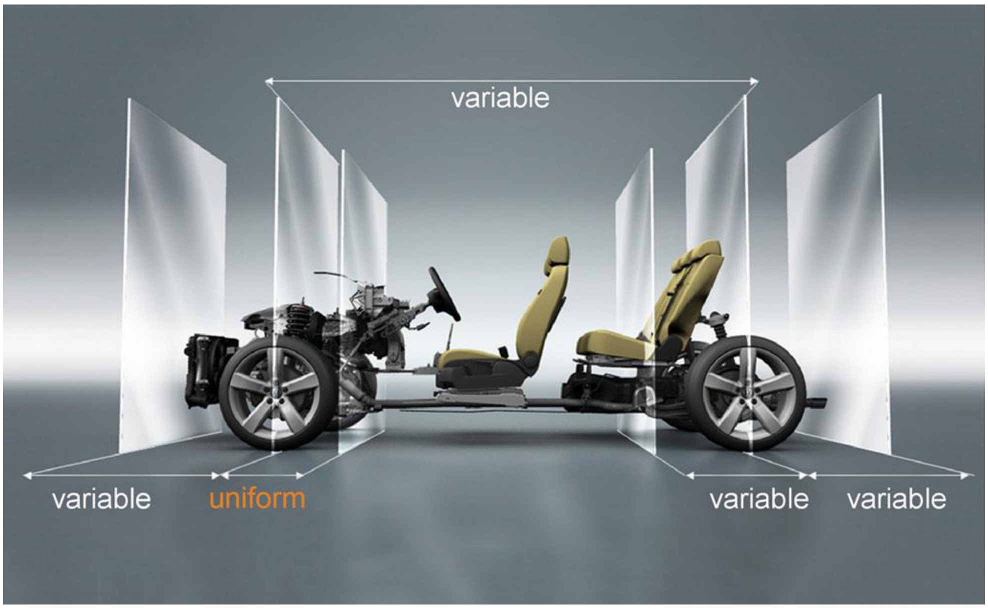


Figure 2.10. Volkswagen's new MQB platform (Colwell, 2012)

For a better understanding, a subset of three well-known platforms used in the automotive industry, which lead to the production of various car models, are briefly described below:

Volkswagen MQB (Modularer Querbaukasten) Platform

The MQB platform, introduced by Volkswagen in 2012, marked a significant evolution in automotive manufacturing. It began its production in the Ingolstadt plant in Germany, initially with the Audi A3, followed by the Volkswagen Golf in 2013 and 2014. This modular platform is designed to accommodate vehicles across four Volkswagen brands: VW, Audi, Seat, and Skoda, effectively replacing the older PQ25, PQ35, and PQ46 platforms that were used for models in segments B (compact), C (mid-size), and D (full-size) (Lampón, Cabanelas & Frigant, 2017). The MQB platform is structured around three primary modules that allow for extensive customization. It includes options for three different front and under-body chassis, five front floor configurations, and four rear floor configurations. The platform facilitates variations in track width and longitudinal dimensions, with the sole exception being the fixed distance from the pedals to the front axle. This flexibility enables the MQB to support the production of 24 different models across the aforementioned segments, catering to diverse consumer needs (Lampón, Frigant & Cabanelas, 2019).

Volkswagen's manufacturing network encompasses 22 plants across nine countries, with a production capacity exceeding 5 million units annually, translating to an average of 0.755 million cars produced per segment. The MQB platform is integral to this extensive network, which includes 14 plants dedicated to assembling 24 models with a combined annual capacity of 3.91 million units. The platform's design allows for multi-brand production, enhancing coordination and knowledge transfer among different facilities (Lampón, Cabanelas & González-Benito, 2017). Furthermore, the modularity of the MQB facilitates the production of segment C and D vehicles in new locations, such as Kaluga, Russia, which brings production closer to evolving markets and customer bases. The platform has also streamlined operations across the value chain by integrating processes such as stamping, body-in-white, painting, and final assembly at various plants (Lampón, Cabanelas & Benito, 2015). The MQB platform exemplifies Volkswagen's strategic approach to automotive production, combining flexibility in design with an extensive manufacturing network. This integration aims to reduce development costs while maximizing the use of common components across multiple models, thereby enhancing efficiency and responsiveness to market demands.

PSA Peugeot-Citroën's EMP2 (Efficient Modular Platform)

The PSA was first implemented in 2013, starting with the production of the Citroën C4 Picasso in Vigo, Spain, and the Peugeot 308 in Sochaux, France. The EMP2 platform allows for flexibility in production due to its modular nature, enabling variations in structural dimensions such as track width, rear overhang, and wheelbase (Lampón et al., 2017). This platform supports the assembly of 13 different models in segments C and D of Peugeot and Citroën, previously manufactured on the PF2 and PF3 platforms (Lampón et al., 2019). EMP2's architecture includes two structural modules—the front-end chassis and rear unit—as well as non-structural modules like the cockpit and suspension systems, which enhance production flexibility. This modularity allows the assembly of vehicles ranging from compact cars to larger family vehicles, effectively reducing production costs and improving operational efficiency (Lampón et al., 2015). By 2016, PSA began manufacturing the Peugeot 5008 on the EMP2 platform at its Rennes plant, showcasing the platform's ability to support segment C vehicles, which were previously limited to segment D production at the plant (Lampón et al., 2017). In total, six of PSA's European plants will assemble cars using the EMP2 platform, with an annual production capacity of 1.87 million units. This platform is projected to serve as the basis for 50% of PSA's vehicle production (Lampón et al., 2019).

The Renault-Nissan alliance introduced the CMF (Common Module Family) platform

The CMF at the end of 2013, starting with the production of the new Nissan Qashqai in Sunderland, UK. By late 2014, Renault adopted this platform for the assembly of the Espace in its Douai plant, France (Lampón et al., 2017). The number of models assembled on this platform is projected to increase to 14 worldwide once the platform is fully implemented (Lampón et al., 2015).

The CMF platform's design features a modular system with two main structural components: the front and rear under-body modules. This structure is further enhanced by non-structural modules, such as the engine bay, cockpit, and electronic architecture. These modular configurations allow for flexibility in key structural dimensions like track width, rear overhang, and wheelbase. As a result, the CMF platform replaces the former X84/C-platform and D-platform in Europe, enabling the production of 14 models from both Nissan and Renault across the C and D segments (Lampón et al., 2019).

In terms of manufacturing, the introduction of the CMF platform has allowed for multi-brand production across Renault-Nissan's European plants. Seven plants are expected to integrate this platform, with a total production capacity of 1.48 million vehicles per year. Although Turkey's manufacturing plant initially remained aligned with the former standard platform, it is anticipated that this facility will eventually contribute to the production of new segments in the region. Once fully operational, the seven plants will be capable of transferring production between them, further enhancing manufacturing flexibility (Lampón et al., 2017).

2.3.3. Benefits of platform-based manufacturing

Platform-based manufacturing has emerged as a transformative strategy in modern production systems, significantly enhancing operational efficiency and cost-effectiveness through the reuse of components across diverse product lines. This methodology allows manufacturers to leverage a unified platform to produce multiple product variants, yielding substantial economic benefits and competitive advantages in today's dynamic market landscape (Andersen, Brunoe & Nielsen, 2023).

2.3.3.1.Economies of Scope and Standardization

A crucial aspect of platform-based manufacturing is its ability to harness economies of scope, which arise from synergies in production processes. This approach allows for the simultaneous production of various products in smaller batches, rather than the less efficient method of manufacturing individual products in larger quantities (Panzar & Willig, 1977; Goldhar & Jelinek, 1983; Kogut, 2013). In the automotive sector, for instance, manufacturing networks are increasingly organized around standardized platforms, where factories can assemble multiple vehicle models using common components. This standardization has not only enhanced production efficiency but has also facilitated quicker adaptations to market changes, enabling manufacturers to introduce new models with reduced lead times (MacDuffie, Sethuraman, & Fisher, 1996).

2.3.3.2.Accelerated New Product Launches

One of the most significant advantages of platform-based manufacturing is the acceleration of new product launches. By leveraging established platforms, manufacturers can significantly shorten development cycles for new products, allowing them to respond swiftly to market demands and outpace competitors (Vickery, Bolumole, Castel & Calantone, 2015). In an environment where being first to market can confer substantial advantages, the capacity for rapid product introduction is essential.

2.3.3.3.Cost Reduction and Improved Efficiency

The cost advantages of platform-based manufacturing are substantial. By sharing components and processes among different products, companies can achieve economies of scale, leading to lower unit costs and reduced manufacturing expenses. Research has shown that firms employing platform strategies can realize cost savings of up to 30% (Cameron & Crawley, 2013), which significantly enhances their profitability. Additionally, the standardization of processes improves production quality and minimizes waste, further supporting cost reduction (Pirmoradi et al., 2014).

2.3.3.4.Enhanced Flexibility and Customization

Flexibility in production is another critical benefit. Platform-based strategies allow manufacturers to adapt their production processes easily, catering to diverse customer needs and preferences. This adaptability is vital in addressing the growing demand for customized products, enabling rapid reconfiguration of production lines to serve various market segments effectively (Simpson et al., 2006). The ability to offer tailored solutions while maintaining efficiency is a significant competitive advantage.

2.3.3.5. Reduced Capital Investments and Enhanced Collaboration

Implementing platform-based manufacturing also leads to considerable reductions in capital investments. By reusing components across multiple products, companies can lower their initial investment requirements by up to 50% (Muffatto, 1999). This reduction not only improves financial performance but also enhances a company's agility to invest in new technologies and innovations. Furthermore, platform-based approaches foster improved collaboration between suppliers and manufacturers. The shared use of components streamlines supply chain operations, reduces lead times, and enhances overall operational efficiency (Ulrich, Eppinger, & Yang, 2016). This collaborative environment enables companies to respond more readily to changes in demand and supply, further solidifying their competitive position.

Therefore, platform-based manufacturing offers a multitude of benefits, including increased speed in product launches, significant cost reductions, improved product quality, and enhanced flexibility. By standardizing processes and leveraging economies of scope, manufacturers can not only achieve higher efficiency but also position themselves favourably in the competitive marketplace. The ability to adapt quickly to changing market conditions while maintaining cost-effectiveness is essential for sustaining long-term success in today’s dynamic business environment (Andersen t al., 2023).

CHAPTER 3

Material and Methodology

This thesis explores the challenges and solutions in design processes within modular and prefabricated construction projects. Given the growing significance of this construction method in international industries, the aim of this research is to investigate how design processes are managed and optimized in modular and prefabricated projects. The research data was collected through semi-structured interviews with experts in the field who work for two international companies. In this chapter, the methods used to collect and analyse data are explained in detail to provide an accurate picture of how the research was conducted.

3.1 Research Design

The present research is based on a qualitative approach. A qualitative approach was chosen due to the complex and interpretative nature of the topic, which requires a deep understanding of the design processes and various interactions within modular and prefabricated construction projects. The primary aim of this research is to identify and analyse design challenges and strategies for improvement from the perspective of industry experts.

To achieve this goal, the research was designed to involve a detailed and comprehensive examination of two international companies active in modular and prefabricated construction. In each of these companies, interviews were conducted with design specialists and managers to gather their insights and experiences regarding existing challenges and solutions.

The interviews were semi-structured, consisting of a series of key questions that served as the main focus of the conversations. These questions were formulated in a way that allowed interviewees to share their experiences freely, with the flexibility to pose additional, follow-up questions based on their responses. This approach provided the necessary flexibility for collecting qualitative data and interpreting the details.

To ensure clarity and transparency in the interviewees' responses, each interview began with a brief presentation by the researcher. This presentation included explanations about the research objectives and subject matter, helping the interviewees to have a clear understanding of the questions and the research process.

Overall, the qualitative research design and the use of semi-structured interviews enabled the researcher to gather rich and qualitative data, essential for an in-depth analysis of the challenges and suggestions related to the design of modular and prefabricated projects.

3.2 Data Collection

In this study, primary and secondary sources were used to gather data. Each will be explained in the following sections.

3.2.1 Primary Data

Interviews as a primary source of data collection were conducted with two modular construction companies based in Turkey that have international operations:

At Dorçe, an online interview was held with a design team member. The interview centered on integrating prefabricated design into production, strategies for enhancing efficiency and sustainability, and digital technology usage in design processes.

At DMT, an in-person interview was conducted with the experienced managing director department, covering similar topics. The company has a global presence, including factories and construction companies in the Netherlands and Kazakhstan, allowing for insights from diverse markets.

Table 3.1. Comparison of Key Characteristics of Interviewed Companies

Company	**Company A (Dorçe)**	**Company B (DMT)**
Industry Sector	Modular and prefabricated construction	Advanced modular system production
Countries	Kazakhstan, Middle East, Europe	Netherlands, Kazakhstan, Europe, Asia, Africa
Key Projects	Health, education, housing, hotel, warehouse, and water treatment	Advanced building projects in Europe
Number of Interviewees	1 person	1 person
Role of Main Interviewee	Design Director, 21 years of experience	Managing Director, 14 years of experience
Main Technologies	BIM and limited automation	BIM and AI usage

Interview questions addressed the following key areas:

- Integration of prefabricated design and production processes.

- Impact of design on production efficiency.

- Strategies for cost reduction and productivity enhancement.

- Utilization of previous design data for new projects.

- Importance of design in sustainability.

- Role of digital tools in design and production.

- Quality control measures in prefabrication.

- Incorporating customer feedback in new designs.

- Encouraging innovation in design.

- Enhancing communication between design and production teams.

Each company was asked to describe a successful modular project, offering practical examples from start to finish. While Dorçe provided a detailed description of a complete project from its inception to completion, DMT showcased multiple examples of modular projects undertaken in various countries. However, DMT did not provide specific details or in-depth information about individual projects during the interview.

The content validity of the interview questions was approved by two experts at building science.

3.2.2 Secondary Data

A thorough literature review of academic papers, industry reports, and books was conducted to gather insights on modular construction, platform use in the automotive sector, and the benefits of platform-based product design.

These secondary sources provided benchmarks for assessing the potential and challenges of adopting platform-based approaches in the construction industry.

3.3 Data Analysis

The data collected from interviews underwent thematic analysis, focusing on identifying recurring patterns and themes related to efficiency, cost, sustainability, and innovation in modular construction.

Secondary data were cross-checked with primary findings, using metrics like time efficiency, cost reduction, and environmental impact for comparative analysis.

Graphs, tables, and charts will be employed to visually represent the similarities and differences between the construction and automotive sectors.

3.4. Research Framework

This study employs the Platform-Based Product Design Framework as a theoretical foundation, emphasizing the benefits of standardized components and processes. This framework serves as a lens to compare the modular construction method with the automotive industry's use of platforms, where standardization enhances efficiency and flexibility in production.

In modular construction, the application of platform-based design principles can lead to improved efficiency by standardizing components and processes across different building projects. Similar to the automotive industry, where platforms serve as a base for various vehicle models, modular construction platforms can streamline production, reduce costs, and accelerate timelines by reusing standardized components in different configurations.

By examining these principles in the realm of modular construction, this study aims to show how platform-based strategies can improve design, manufacturing, and operational efficiency, offering valuable insights into scalability and increased productivity within the industry.

3.5. Sampling Method

In the current study, convenience sampling was conducted in a way that the choice of interviewees was guided by accessibility, relevance, and international operations. While initial outreach to companies in the US, Canada, and China did not receive positive responses, the selected companies in Turkey have a significant international footprint:

Dorçe Prefabricated Building and Construction Industry Trade Inc. is one of Turkey's global leaders in prefabricated modular steel structures. With over 40 years of experience, Dorçe is a pioneer in the sector, completing modular structures that address a wide range of needs, from engineering and supply to logistics and assembly, all on a turnkey basis. The company operates its own large-scale production facilities in Ankara, which are among the largest for light steel structures in Europe. Dorçe has a global presence, completing projects in over 60 countries across various industries, including oil, natural gas, energy, mining, and defence. It has also been consistently recognized as one of the top 250 global contractors in the field by ENR (Engineering News-Record) for the past nine years. The company emphasizes the use of advanced methodologies such as Building Information Modeling (BIM), Design for Manufacturing and Assembly (DFMA), and other modern construction methods to efficiently manage the full lifecycle of projects.

DMT Modular, based in Ankara, has established itself as a key player in the modular and prefabricated building sector, serving the European and African markets. The company's 35,000 m^2 facility is equipped with the latest machinery and employs a well-organized team of experts. DMT is dedicated to sustainability, separating waste in compliance with environmental regulations and focusing on minimizing its ecological footprint. The company follows rigorous quality standards, adhering to international norms and European regulations. With a commitment to high-quality, cost-effective production, DMT Modular aims to continually improve its products and services, working within the framework of TS EN ISO 9001 Quality Management System.

This selection allows for a regionally focused study with broader international implications, considering their engagement in diverse markets and extensive experience in the modular construction industry.

3.6. Procedure

The research process for this thesis began with the formulation of ten essential questions, each aimed at exploring critical aspects of modular construction and platform-based product design. These questions were carefully crafted to cover a wide range of topics, from the integration of processes to the impact of design on overall efficiency. The focus was on understanding how companies optimize costs, increase efficiency, reuse previous designs in new developments, and address sustainability. Furthermore, attention was given to their use of digital technologies in design and production, quality control, safety measures, customer satisfaction strategies, and approaches to fostering innovation. Finally, the examination included how companies strengthen the collaboration between design and production in modular construction projects.

These questions served as a foundation for understanding the practical applications of platform-based design in modular construction, guiding the subsequent research phase.

3.6.1. Ethical Considerations and Permissions

Prior to conducting the interviews, the necessary approvals were obtained from the Human Subjects Ethics Committee at the Middle East Technical University. Additionally, an Informed Consent Form was provided to all participants, outlining the study's objectives, interview procedures, data usage, confidentiality assurances, voluntary participation, and contact information. Verbal explanations of the research goals were given to participants before each interview to ensure full transparency, and the confidentiality of all responses was guaranteed. These ethical measures, approved by both the Human Subjects Ethics Committee and the Applied Ethics Research Centre of METU, were essential in maintaining the integrity of the research process.

3.6.2. Identifying Relevant Companies

With a clear set of questions, the next step involved identifying relevant companies within the global modular construction industry. The focus was on companies specializing in modular construction and utilizing platform-based design principles, as this alignment was crucial for the scope of the research. Initially, a comprehensive search was conducted to identify key players worldwide, particularly in countries like the United States, Canada, and China, which are known for advancements in modular construction. Despite sending detailed emails outlining the research goals and interview requests, no responses were received from companies in these regions.

Due to the time constraints of the project, the focus shifted to Turkey, where two significant companies with a strong international presence were identified: Dorçe and DMT. Both companies met the research criteria, operating on a global scale and undertaking modular construction projects of substantial size and complexity. Establishing contact with these companies required persistent follow-ups through emails, LinkedIn messages, and phone calls.

3.6.3. Securing Interviews

After several attempts, interviews were successfully arranged with experts from both Dorçe and DMT. For Dorçe, a member of the design team with 21 years of professional experience participated in the interview. Despite being abroad, the interview was scheduled with meticulous coordination to accommodate time zone differences and the interviewee's availability. Given the time constraints, the interview was conducted online and lasted approximately two hours. For DMT, an in-person interview was conducted with a representative from the managing director department, who had 14 years of professional experience. This expert provided valuable insights, drawing on extensive involvement in international projects across Europe, Africa, and the Middle East. Their perspectives offered a comprehensive understanding of modular construction practices in diverse regions. The interview with DMT was slightly longer due to logistical challenges, as the company's location outside the city and the difficulty of access for individuals not working on-site resulted in a one-hour commute. Additionally, the interview was delayed while waiting for the expert to conclude a prior meeting, and once the interview commenced, it lasted for approximately 3.5 hours.

3.6.4. Preparation for the Interviews

To ensure that the interviewees fully understood the scope and objectives of the research, a brief yet informative PowerPoint presentation was prepared, outlining the key aspects of the thesis. This presentation, lasting 2-3 minutes, served as an introduction at the beginning of each interview, allowing the participants to gain a clear understanding of the research objectives and the specific information being sought. By clarifying the purpose of the inquiries, more precise and focused responses were encouraged from the interviewees.

3.6.5. Conducting the Interviews

Each interview was conducted in a semi-structured format, allowing the experts to elaborate on their experiences while still addressing my key questions. The interview with Dorçe covered various aspects of their design and production processes, focusing on their application of platform-based design principles. The interviewee provided detailed insights into how Dorçe standardizes components across different projects, which led to a discussion about the integration of digital technologies, sustainability considerations, and how these approaches have enhanced efficiency.

The DMT interview took place in person, which allowed for a more dynamic and interactive discussion. The interviewee not only answered my prepared questions but also provided a guided overview of specific projects. These examples illustrated the unique challenges and solutions DMT employs, particularly in regions with diverse environmental and regulatory requirements. The discussion included details about the use of previous design templates in new projects, efforts to meet international quality standards, and their innovative strategies for optimizing costs and timelines.

3.6.6. Data Collection

Throughout both interviews, extensive notes were taken, documenting the interviewees' responses and noting any specific projects or examples referenced. In some instances, both Dorçe and DMT showcased completed projects that exemplified their modular construction practices, providing a direct insight into the practical application of the concepts discussed. This insight into their work proved invaluable for understanding the complexities and nuances of modular construction, particularly in relation to platform-based product design.

3.6.7. Data Analysis

The information gathered during these interviews formed the basis for the analysis phase of the research. By categorizing the responses according to the key themes—such as efficiency, standardization, digital integration, and sustainability—it was possible to identify common practices and trends within the modular construction industry. This analysis enabled the drawing of meaningful conclusions regarding the role of platform-based design in enhancing productivity and scalability within the sector.

The process, from initial outreach to the completion of the interviews, required a balance of persistence, coordination, and careful preparation, ultimately facilitating the collection of high-quality, relevant data from leading companies in the modular construction field.

CHAPTER 4

Findings and Discussion

This chapter presents the findings derived from the interviews conducted with experts from two international companies, Dorçe and DMT. The findings are based on insights gained through semi-structured interviews, which focused on various aspects of modular and prefabricated construction, including efficiency, sustainability, and the integration of digital technologies. These findings are discussed in detail, with reference to both primary data from the interviews and secondary data from the literature review. The discussion section interprets these findings in the context of existing research, providing a deeper understanding of the challenges, strategies, and potential improvements in modular construction processes.

4.1 Introduction

This chapter presents a comprehensive analysis of data gathered from interviews with two leading companies in the modular construction industry, Dorçe and DMT. Both companies, known for their extensive experience in prefabricated construction, provided valuable insights into the current state and potential of modular construction practices. The interviews were structured around ten key questions focusing on aspects such as cost, design, production efficiency, sustainability, and digital tools. These questions were thematically grouped based on the research objectives and analysed accordingly.

The findings from the interviews are organized around major themes that emerged during the analysis. Comparisons are drawn between the approaches of Dorçe and DMT, providing a detailed exploration of the strategies they employ to address challenges and optimize processes in the modular construction sector. These insights are contextualized within the framework of platform-based product design, emphasizing the role of modularity and standardization in improving efficiency, reducing costs, and increasing flexibility. This framework, rooted in the automotive industry, is increasingly relevant to the construction sector.

By analysing the experiences of Dorçe and DMT, this chapter aims to identify patterns, best practices, and unique challenges in implementing platform-based strategies in construction. The findings are also compared to broader trends observed in the literature review, revealing areas of innovation as well as ongoing challenges. Ultimately, the discussion synthesizes both the interview data and existing academic knowledge to provide a more nuanced understanding of how platform-based design principles can be applied to modular construction, contributing to the industry's ability to adapt and thrive in a competitive market.

4.2. Results

To address the overarching research questions, the ten interview questions were categorized into three major themes:

(A) The impact of platform-based product design on production economy: Questions 3, 7, and 9 focused on how Dorçe and DMT adopt strategies for cost-effective production. The aim was to investigate measures for reducing costs, maintaining quality control, and fostering innovation in design and production processes to ensure economic efficiency.

(B) The influence of platform-based product design on product variety: Questions 4 and 8 explored how the companies use previous design experiences, existing data, and customer feedback to expand their product offerings and adapt designs to meet diverse market demands, thereby enhancing product variety.

(C) The role of platform-based product design in improving process efficiency: Questions 1, 2, 5, 6, and 10 focused on how Dorçe and DMT integrate design and production stages to optimize efficiency. This included leveraging prefabrication processes, utilizing digital technologies, addressing sustainability, and fostering collaboration between design and production teams.

Table 4.1. Categorization of Interview Questions by Thematic Focus

Theme	Interview Questions
(A) The impact of platform-based product design on production economy	3. What measures do you take for economical production? What strategies do you implement to reduce costs and increase efficiency in production processes? 7. How are quality control and safety measures ensured in prefabricated design and production processes?
(B) The influence of platform-based product design on product variety	4. How do you benefit from old designs in developing new design improvements? How are past experiences and existing design data used in the development of new designs? 8. How do you take customer feedback into account in new design projects? What strategies do you follow to meet customer expectations?
(C) The role of platform-based product design in improving process efficiency	1. How does your company integrate prefabricated design and production processes? 2. How do you evaluate the impact of design on production efficiency in the prefabrication process? 5. What is the importance of design in prefabrication processes in terms of sustainability and environmental impact? What steps are you taking in this regard? 6. How important is the use of digital technologies in design and production processes for your company? Which digital tools do you use and how? 9. What strategies does your company implement to encourage innovative design and production methods in prefabrication processes? 10. How do you strengthen communication and collaboration between design and production in prefabrication processes?

The discussion is organized around these major themes, with comparisons drawn between Dorçe and DMT's approaches. This thematic analysis provides an in-depth exploration of the strategies employed by the companies to address challenges, optimize design processes, and maintain a competitive edge in the international construction market. The insights gathered are framed within the context of platform-based product design, which serves as the theoretical foundation for this research. This framework emphasizes the potential of modularity and standardization to improve efficiency, reduce costs, and increase flexibility—concepts that are well-established in the automotive industry but are still being gradually adopted in the construction sector.

4.2.1 Impact of Platform-Based Product Design on Production Economy

Having categorized the interview questions into three major themes, the first theme focuses on the impact of platform-based product design on production economy. This section delves into how Dorçe and DMT leverage platform-based design strategies to achieve economic efficiency in their production processes. Through insights gained from the interviews, it is clear that both companies employ a variety of measures to reduce costs, optimize production, ensure high-quality standards, and foster innovation, all of which contribute to the economic success of their modular construction practices.

By exploring cost reduction strategies, quality control measures, innovation, and long-term economic sustainability, this section illustrates how platform-based product design principles play a crucial role in enhancing production economy. These strategies, though tailored to each company's unique context, highlight the broader potential for modular construction to benefit from the same efficiency improvements and cost savings that have driven success in the automotive industry. The findings of the interview sessions will be organized under the following topics which will be explained completely: (A) Cost Reduction Strategies, (B) Quality Control Measures, (C) Innovation in Design and Production, and (D) Impact on Long-term Sustainability.

4.2.1.1 Cost Reduction Strategies

Cost reduction is a key factor for both Dorçe and DMT in maintaining competitiveness within the modular construction sector. By adopting platform-based product design, both companies standardize components and processes, leading to economies of scale and significant cost savings across various projects. This approach also ensures that their production processes remain efficient, flexible, and cost-effective, even in the face of changing market demands.

Both companies have adopted similar strategies to reduce costs, albeit with slight differences in implementation. For example, Dorçe emphasizes the reuse of standard components across various projects, which allows the company to avoid reinventing designs for each new project. This standardization creates efficiencies by using the same parts and processes for multiple clients, capitalizing on economies of scale. Additionally, optimizing the supply chain and collaborating closely with suppliers helps Dorçe reduce transportation delays and material shortages, further contributing to cost savings.

On the other hand, DMT focuses on mass production of standardized modules, creating a pool of interchangeable components. This enables the company to reduce unit costs by producing components at scale, minimizing the complexity of production and eliminating the need for custom components. DMT also uses advanced production planning tools to optimize material usage, reduce waste, and streamline logistics, ensuring timely and coordinated delivery of materials to production sites.

Both companies also implement lean manufacturing techniques to reduce waste and enhance efficiency throughout the production cycle. This approach ensures that resources are used optimally, contributing to long-term cost reduction.

4.2.1.2 Quality Control Measures

Maintaining high-quality standards is essential for both Dorçe and DMT, as both companies are committed to ensuring that their cost reduction strategies do not come at the expense of product quality. The adoption of platform-based product design provides a strong foundation for quality control by enabling the standardization of components and processes. However, both companies go beyond mere standardization to implement robust quality control measures throughout their production processes, ensuring that every modular unit meets the necessary performance and durability standards.

For instance, Dorçe places a strong emphasis on quality assurance (QA) as an integral part of its platform-based design model. As the company standardizes components and processes across multiple projects, it ensures consistency in the quality of materials and workmanship. Given that the same components are often used across various projects, this company's strict quality control measures ensure that each component meets high-performance standards and adheres to regulatory requirements before being incorporated into the final product.

One of the key aspects of Dorçe's quality control process is the regular inspections and testing at every stage of production. These inspections begin as early as the design phase and continue through the procurement, manufacturing, and final assembly stages. Commitment to rigorous quality checks helps identify potential issues early in the process, reducing the likelihood of defects in the final product and ensuring that all components meet the required standards for safety, durability, and performance.

Moreover, Dorçe's platform-based approach enables continuous improvements in both design and manufacturing processes. As the company collects feedback from completed projects, it can apply lessons learned to refine its designs and production methods. This iterative process of improvement enhances the overall reliability and performance of the final product, ensuring that each new iteration of the modular design is more robust and reliable than the last. The feedback loop from previous projects helps this company adjust its quality control protocols, making the system more efficient over time.

Another significant aspect of quality control in this company is its focus on material selection. By using standardized materials across different projects, they can establish strong supplier relationships and ensure that only high-quality materials are procured for production. This consistency in material quality plays a crucial role in maintaining product integrity, especially as the same components are used repeatedly across multiple projects.

Similarly, DMT integrates stringent quality control measures within its platform-based production system to ensure the consistency and performance of its modular units. Similar to Dorçe, DMT emphasizes the importance of standardization by ensuring that each component used in the prefabricated systems meets predefined quality standards. This consistent approach ensures that no matter how many times a component is used across projects, it will meet the same high-quality specifications.

One of the standout features of DMT's quality control strategy is its use of real-time monitoring systems and automated inspections. By employing advanced technologies such as IoT (Internet of Things) sensors and automated inspection systems, the company can continuously monitor production and detect any defects in real time. This real-time approach allows for immediate corrective actions, which ensures that defects are caught early before they escalate into larger problems that could compromise the integrity of the final product. This proactive system of real-time defect detection significantly enhances the company's ability to maintain high quality while minimizing the risk of costly rework or delays.

In addition to automated inspections, DMT integrates Statistical Process Control (SPC) techniques to track and monitor variations in the production process. By analyzing data from production, the company can identify any deviations from the desired specifications and make necessary adjustments before they affect the quality of the final product. This data-driven approach allows DMT to ensure that each modular unit adheres to strict performance criteria, reducing the likelihood of defects and ensuring that products meet or exceed client expectations.

Furthermore, DMT's quality control team conducts extensive pre-shipment inspections before any modular units are delivered to construction sites. This step ensures that the modules meet all design specifications and are ready for installation, further safeguarding the company's reputation for delivering high-quality products.

4.2.1.3 Innovation in Design and Production

Innovation is a driving force behind both companies' ability to achieve cost-effective production while keeping their offerings competitive in the market. Platform-based design principles inherently support innovation by providing a flexible structure that can accommodate new materials, technologies, and design ideas.

Dorçe places a strong emphasis on innovative design solutions to meet market demands while reducing production costs. The company frequently updates its modular platform to incorporate the latest advancements in construction materials and techniques. For instance, the integration of sustainable building materials and energy-efficient technologies into their modular designs allows them to meet the growing demand for environmentally friendly buildings without incurring excessive costs. This focus on innovation also leads to a faster time-to-market, as the standardized platform enables quicker adaptation to new trends in the construction industry.

DMT also drives innovation through its platform-based design approach. By adopting cutting-edge digital technologies, such as BIM (Building Information Modeling) and virtual prototyping, DMT enhances its ability to create complex designs that are both cost-effective and adaptable. The use of digital tools helps streamline the design and manufacturing processes, reducing the need for costly revisions and rework. Furthermore, this company is constantly exploring new construction techniques, such as 3D printing and robotics, to enhance its modular systems and offer more innovative and cost-efficient solutions to clients.

4.2.1.4 Impact on Long-Term Economic Sustainability

In the modular construction sector, long-term economic sustainability is a key factor for survival and growth. Both Dorçe and DMT recognize that a platform-based design approach offers significant advantages in maintaining economic resilience over extended periods, even during times of market volatility. By adopting flexible, scalable, and standardized systems, both companies have positioned themselves to withstand market fluctuations, reduce operational risks, and ensure steady profitability.

Platform-based design is Dorçe's strategic approach to long-term economic sustainability. The ability to replicate successful modular designs across various projects without the need for major modifications provides a significant advantage. This standardization enables the company to maintain consistent production levels, even when external economic factors create fluctuations in demand.

Because Dorçe relies heavily on standardized components, it can streamline its production process, cutting down on the time and resources typically required for custom design work. This reduction in custom work helps the company remain financially stable during economic downturns, as the company is less exposed to the risks associated with volatile demand for custom-designed projects. By minimizing the costs associated with continuous design development, Dorçe can offer cost-effective solutions to clients without sacrificing quality or efficiency.

Moreover, the use of a modular platform allows the company to scale its operations quickly and efficiently, responding to shifts in market demand without the need for major capital investments or infrastructure changes. The standardized nature of the company's design systems enables it to maintain a steady flow of production, ensuring that Dorçe can meet market demands while keeping costs under control. As a result, this company can withstand economic fluctuations and position itself for long-term success.

Similarly, DMT has adopted a similar approach to economic sustainability, focusing on the ability of its platform-based design to provide flexibility and scalability. The company's modular approach allows it to build projects more efficiently, with a clear focus on reducing operational costs over time. By standardizing key components, the company can streamline production and procurement processes, eliminating inefficiencies that would otherwise arise from custom design work.

The key benefit for DMT is its scalability. By leveraging modular systems that can be easily adapted to a wide variety of projects, the company can adjust production capacity in response to changing market demands. This scalability ensures that this company can meet client requirements while keeping costs low, and it allows the company to ramp up production during periods of high demand or scale back during slower periods without incurring excessive costs. This agility helps DMT maintain profitability and economic resilience throughout market cycles.

Moreover, the company's use of a modular design enables it to work with a wide range of clients across different regions and industries. This diversity in projects and clients helps to mitigate the risks associated with dependency on a single market sector, further contributing to long-term sustainability. By adjusting its production volumes according to market conditions, DMT ensures that it can weather economic downturns without significantly affecting its bottom line.

4.2.1.5 Summary of the Findings Related to the Platform-based Product Desing on Production Economy

To answer the first research question, we combined the relevant questions of the interview under the major themes of our research questions. The first one focused on the impact of the Platform-based Product Desing on Production Economy. Next comes the summary of the findings.

Considering cost reduction strategies, while both Dorçe and DMT adopt platform-based product design to reduce costs, their approaches differ in the specifics of how they manage production and logistics:

Dorçe places a strong emphasis on the reuse of components and the implementation of lean manufacturing practices to reduce waste and optimize resource utilization. DMT, on the other hand, focuses on advanced production planning tools and logistical coordination to minimize production downtime and ensure the efficient flow of materials to production sites. Both companies effectively leverage logistics as an integral part of their cost reduction strategies. By optimizing supply chains, improving transportation efficiency, and ensuring timely material delivery, Dorçe and DMT reduce operational costs and improve their competitiveness in the modular construction sector. Moreover, their ability to standardize components and processes through platform-based design enables them to further capitalize on economies of scale, making modular construction a cost-effective solution for the future.

Regarding Quality Control Approaches, both Dorçe and DMT have integrated comprehensive quality control measures within their platform-based design systems. While their approaches share similarities—such as using standardized components, ongoing inspections, and material consistency—they also feature unique strategies:

Dorçe relies on regular inspections at each stage of production and continuous feedback loops to improve product design and manufacturing processes. This ensures the consistency and reliability of components used across multiple projects.

DMT, on the other hand, integrates real-time monitoring systems and automated inspections to proactively detect defects during production. Additionally, DMT employs advanced statistical process control to fine-tune its manufacturing processes and guarantee quality.

Both companies' commitment to quality control ensures that they deliver high-performance, reliable products while adhering to cost-reduction strategies. By leveraging platform-based design, Dorçe and DMT manage to achieve a balance between maintaining stringent quality standards and implementing cost-saving measures, securing their competitiveness in the modular construction industry.

Considering Innovation through Platform-Based Design, Innovation is a driving force behind the ability of both Dorçe and DMT to produce cost-effective, high-quality modular construction solutions. By adopting platform-based design principles, these companies have created flexible structures that can easily accommodate new materials, digital technologies, and innovative construction techniques. Whether through the integration of sustainable materials, the adoption of BIM and virtual prototyping, or the exploration of robotics and 3D printing, both companies are leveraging innovation to enhance their production efficiency, meet market demands, and maintain a competitive edge.

These innovations ensure that Dorçe and DMT can not only meet current industry demands but also anticipate future trends, positioning them for continued success in the rapidly evolving modular construction sector.

With regard to Long-Term Sustainability through Platform-Based Design, both Dorçe and DMT were able to ensure economic sustainability over the long term. The standardization and scalability of their systems provide these companies with the ability to maintain stable production levels, reduce operational costs, and quickly adapt to market changes. This resilience is crucial in an industry as dynamic as modular construction, where market conditions can fluctuate rapidly.

Both companies' strategies highlight how platform-based design can provide a robust foundation for long-term economic success. Whether through cost efficiency, rapid adaptability, or standardization, Dorçe and DMT are able to achieve profitability and sustain their operations in the face of changing market conditions, ensuring their continued success in the evolving construction sector.

4.2.2 Influence of Platform-Based Product Design on Product Variety

This section examines how platform-based product design impacts the ability of companies to offer a wide variety of products while maintaining efficiency. By leveraging modular components and a shared platform, companies can achieve a balance between standardization and customization, which is critical for addressing diverse customer needs and market demands. To organize the data gathered from interview questions related to the second research question, we merged question 4 and 8 and put them under major topics of reusing past designs and data as well as customer feedback and adaptation. each will be explained in detail next.

4.2.2.1 Reusing Past Designs and Data

The reuse of past designs and existing data is a hallmark of platform-based product design, offering significant benefits for efficiency, cost reduction, and innovation. By building on a shared base of modular components and design templates, companies can optimize workflows while maintaining high-quality standards.

Dorçe exemplifies this principle by utilizing a modular platform strategy that includes a catalog of standardized components, such as prefabricated wall panels, roof structures, and foundation modules. These components can be mixed and matched to fit the specific needs of different projects. This approach not only reduces design time but also minimizes manufacturing errors by relying on components that have been thoroughly tested in previous applications.

Scalability: For large-scale projects, Dorçe can upscale or downscale designs with ease, ensuring that the core components remain consistent while configurations vary to meet unique project requirements.

Learning from Past Projects: For instance, in projects requiring seismic-resilient construction, Dorçe may reuse its previously validated designs, incorporating minor adjustments based on regional regulations or client-specific preferences.

On the other hand, DMT goes a step further by utilizing advanced digital tools and data repositories. The company archives data from previous projects, including design blueprints, material specifications, and performance metrics, in a centralized database. This enables rapid prototyping by allowing the design team to reference and adapt successful elements from similar past projects.

Iterative Prototyping: With digital modelling, DMT can test new configurations virtually, iterating designs based on customer feedback or market trends without incurring significant physical costs.

Global Adaptation: For instance, DMT's ability to use modular design data to adapt building layouts for different climates and cultural requirements highlights the versatility of this approach.

By reusing designs and data, both companies achieve a balance between standardization and flexibility, reducing lead times while expanding the variety of products they can offer. This approach fosters innovation as designers spend less time on redundant tasks and more time refining new ideas.

4.2.2.2 Customer Feedback and Adaptation

Customer feedback is pivotal in ensuring that platform-based designs remain relevant and competitive. Modular components inherently offer the flexibility needed to incorporate feedback and meet dynamic market demands.

Dorçe's reliance on modularity makes it particularly adept at integrating customer feedback.

Rapid Customization: For instance, if a client requests additional facilities, such as an annex to a prefabricated building, Dorçe can easily integrate the requirement by adding standardized modules without affecting the overall structural integrity.

Feedback Loops: Dorçe frequently collects post-project evaluations from clients, which helps identify areas for improvement in design or production. This feedback often leads to updates in the modular component catalog, ensuring that lessons learned from one project benefit future designs.

DMT places a strong emphasis on engaging customers throughout the design and construction process.

Cultural Adaptation: For example, in markets with specific architectural aesthetics, such as traditional European or modern minimalist designs, DMT adjusts its modular components to reflect these preferences while retaining core structural elements.

Real-Time Adjustments: Using advanced Building Information Modeling (BIM) systems, DMT integrates customer feedback during the design phase, allowing clients to visualize changes instantly. This interactive process ensures alignment with client expectations before manufacturing begins.

4.2.2.3 Summary of the Findings Related to the Platform-based Product Desing on Product Variety

After analysing the data related to the second question, we could summarize the findings as follows. While both companies excel in adapting to customer needs, their approaches highlight different strengths: Dorçe: Leverages modularity for quick turnarounds, making it ideal for projects requiring fast delivery, such as disaster relief housing. On the other hand, DMT focuses on precision and customization, making it more suitable for high-end projects with unique design requirements.

Platform-based design not only improves adaptability but also enhances the ability to cater to a wide range of customer preferences. By maintaining a robust foundation of modular components, companies can achieve the following:

Cost Efficiency: The ability to reuse designs and integrate feedback reduces material waste, design errors, and manufacturing inefficiencies.

Global Reach: The flexibility of modular platforms enables companies to enter diverse markets, adapting their products to local needs without fundamentally altering production processes.

Scalability: Whether it’s a single-family prefabricated home or a multi-story modular office building, platform-based designs can be scaled up or down with ease.

This adaptability not only improves customer satisfaction but also allows companies to position themselves as versatile, customer-centric leaders in the modular construction industry. The strategic use of feedback and data enables them to innovate continuously, staying ahead of competitors in a rapidly evolving market.

4.2.3. Role of Platform-Based Product Design in Improving Process Efficiency

Platform-based product design provides a strong system that connects the separate processes of design and production, making them more efficient. By integrating these processes, leveraging advanced technologies, and prioritizing sustainability, companies like Dorçe and DMT can optimize workflows, reduce errors, and deliver higher-quality prefabricated structures. This section explores the mechanisms through which platform-based product design enhances the efficiency of modular construction projects based on the data obtained from the interview questions 1, 2, 5, 6, and 10.

4.2.3.1 Integration of Design and Production

The integration of design and production ensures that modular components are not only aesthetically and functionally robust but also manufacturable and easy to assemble. This synergy reduces inefficiencies that stem from misalignment between design intent and production realities.

Dorçe’s integrated design-to-production workflow revolves around a proactive approach that addresses manufacturing constraints during the design phase. They include (A) Standardization and Modularization; (B) Early Involvement of Production Teams; (C) Feedback Loops for Continuous Improvement; (D) Simulation-Driven Design; (E) Pre-Planned Modular Configurations, and (F) Flexibility in Design Adjustments. Each will be explained in detail in the following paragraphs.

Standardization and Modularization: Dorçe employs a modular approach where components share standardized dimensions and connections. This standardization simplifies production, enabling the use of automated manufacturing processes and reducing variability. Modularization also facilitates parallel production of components, where multiple parts of a project are manufactured simultaneously and later assembled onsite, significantly reducing lead times.

Early Involvement of Production Teams: In Dorçe's methodology, production engineers are involved from the early stages of design. This collaborative approach ensures that potential challenges, such as material availability, manufacturing limitations, or assembly complexities, are identified and addressed early, avoiding costly redesigns.

Feedback Loops for Continuous Improvement: Dorçe uses iterative feedback loops, where real-time feedback from production teams helps refine designs for better manufacturability. For example, if a prototype exhibits assembly difficulties, the design team can modify it before mass production begins, saving both time and resources. DMT focuses on dynamic and real-time synchronization between design and production processes, utilizing digital technologies to streamline operations.

Simulation-Driven Design: DMT employs simulation tools to evaluate the manufacturability of designs before production begins. This allows the company to predict and resolve potential issues, such as structural weaknesses or inefficient assembly sequences. Simulations also enable DMT to test multiple configurations quickly, ensuring that the chosen design aligns with both customer requirements and production capabilities.

Pre-Planned Modular Configurations: DMT's approach to prefabrication involves creating modular components with pre-defined configurations. By planning assembly workflows in advance, the company ensures that components fit together seamlessly during onsite construction.

Flexibility in Design Adjustments: When production challenges arise, DMT leverages real-time data to make immediate design adjustments. For instance, if a specific material becomes unavailable or a production machine encounters limitations, the design can be adapted without delaying the project.

4.2.3.2 Digital Technologies and Tools

Digital technologies are revolutionizing the design and production processes in platform-based modular construction, improving efficiency, enhancing quality control, and streamlining workflows. However, the adoption and integration of these tools come with challenges and opportunities, as highlighted by Dorçe and DMT.

Dorçe recognizes the importance of digital tools like Building Information Modeling (BIM) and other software solutions, though they acknowledge the current limitations and the ongoing process of improvement.

Hence, digital technology and tools used by these two companies could be organized under the following topics which will be explained in detail: (A) Integration of AEC and Production Tools; (B) Challenges and Continuous Development; (C) Design and Production Alignment; (D) Use of Digital Twins; (E) Augmented Reality, and (F) Critical Perspective on Technology.

Integration of AEC and Production Tools: Dorçe strives to combine Architecture, Engineering, and Construction (AEC) tools with Product Data Management (PDM) systems to address the dual needs of architectural design and manufacturing. While ready-made solutions for such integration are still evolving, Dorçe supplements these gaps by using custom tools like Dynamo for visual programming.

Challenges and Continuous Development: Dorçe faces difficulties in integrating BIM systems with Enterprise Resource Planning (ERP) tools like IFS, but the company is actively working towards achieving a seamless connection. This integration is expected to enhance coordination between departments such as design, inventory, and production.

Design and Production Alignment: Although not yet fully effective in utilizing BIM, Dorçe employs it to simulate project workflows and improve production planning. For instance, clash detection within BIM aids in identifying design inconsistencies early, reducing the risk of errors during assembly.DMT emphasizes the significance of leveraging digital tools while maintaining a cautious approach to over-reliance on technology. Their strategy highlights a balanced use of cutting-edge tools to enhance production efficiency and ensure safety.

Use of Digital Twins: By creating virtual replicas of modular components, DMT can conduct simulations to test functionality and resolve potential issues before production begins. This preemptive approach ensures that designs are refined, reducing waste and errors.

Augmented Reality (AR): DMT incorporates AR in its workflows to assist production teams in visualizing complex assemblies. This enhances precision during manufacturing and onsite assembly, improving overall quality control.

Critical Perspective on Technology: DMT also acknowledges the potential downsides of digital tools, such as over-dependence leading to diminished critical thinking. They advocate for a thoughtful application of technology to complement, rather than replace, human expertise and decision-making.

4.2.3.3 Sustainability and Environmental Impact

Sustainability is increasingly becoming a key driver in the construction industry. Platform-based product design facilitates eco-friendly practices by enabling resource optimization, reducing waste, and promoting the use of sustainable materials. Dorçe incorporates environmentally-friendly practices into its prefabrication processes by taking some measures.

Using Eco-friendly materials is the first one. The company prioritizes using recyclable and renewable materials in its modular components, such as steel frames and composite panels with low environmental impact.Second is the energy efficiency considerations. Dorçe's designs often include energy-saving features, such as thermal insulation and renewable energy systems, aligning with global sustainability goals. Third one is the *Waste Reduction.* By standardizing modular components, Dorçe minimizes material waste during production. DMT actively integrates sustainability into its modular construction processes, leveraging innovative strategies and materials to reduce environmental impact and promote eco-friendly practices which are presented under the following headings: (A) *Low-Carbon Manufacturing Practices; (B) Sustainable Material Selection; (C) Eco-Friendly Supply Chain; (D)Innovative Waste Management Systems, and (E) Sustainability in Design.*

Low-Carbon Manufacturing Practices: DMT optimizes its production facilities to minimize energy consumption and greenhouse gas emissions. This includes:

(A) *Efficient Energy Use:* Implementing energy-efficient machinery and renewable energy sources, such as solar panels, in its factories to reduce reliance on fossil fuels; (B) *Process Optimization:* Streamlining workflows to ensure minimal energy usage and avoiding redundant processes during production.

Sustainable Material Selection: DMT prioritizes the use of materials that have a low environmental footprint while maintaining structural integrity and performance standards, by taking the next strategies:

(A) *Recyclable Materials:* The company often uses steel and aluminum, which are fully recyclable and can be repurposed at the end of a building's lifecycle;

(B) *Renewable Resources:* Incorporating wood or engineered timber from certified sustainable forests into its modular designs where feasible;

(C) Composite Materials: Opting for composite panels that offer durability and energy efficiency while reducing environmental degradation.

Eco-Friendly Supply Chain: DMT carefully selects suppliers that align with its sustainability objectives. This involves:

(A) Partnering with vendors who provide eco-certified materials and adhere to sustainable production standards and

(B) Encouraging transparency in the supply chain to ensure all raw materials meet green building criteria, such as those certified by organizations like LEED or BREEAM.

Innovative Waste Management Systems: DMT integrates waste reduction strategies throughout its operations by first

Modular Standardization which is designing components with standard dimensions to reduce offcuts and material wastage during production and by

Recycling Initiatives which is establishing recycling programs within its facilities to repurpose leftover materials, such as scraps from steel cutting or unused insulation.

*Sustainability in Design:*DMT incorporates energy-saving and eco-friendly features directly into its modular designs by taking insulation techniques. That is, High-performance insulation materials improve thermal efficiency and reduce energy consumption for heating and cooling. In addition, Roofs designed for solar panel installations or rainwater harvesting systems enable clients to adopt greener practices in building operations.

By embedding these strategies, DMT demonstrates how sustainability can be seamlessly integrated into platform-based modular construction. Their focus on environmentally-responsible materials and processes ensures that their practices not only align with global sustainability goals but also add value for clients seeking sustainable building solutions.

4.2.3.4 Summary of the Findings Related to the Role of Platform-Based Product Design in Improving Process Efficiency

This section has examined the role of platform-based product design in enhancing process efficiency within the modular construction industry, with specific reference to Dorçe and DMT's practices. The integration of design and production processes emerges as a central factor, enabling both companies to streamline workflows, reduce production errors, and ensure timely delivery. Dorçe's approach emphasizes standardization, early production involvement, and iterative feedback loops, which improve the manufacturability and assembly of components. In contrast, DMT utilizes advanced digital tools such as simulation-driven design and real-time data integration, ensuring that design and production are dynamically synchronized.

The adoption of digital technologies, including Building Information Modeling (BIM), Digital Twins, and Augmented Reality (AR), plays a pivotal role in optimizing production efficiency and quality control, with both companies leveraging these tools to enhance design accuracy and manufacturing precision. Despite these advances, Dorçe and DMT also highlight the challenges of integrating these technologies, particularly in terms of system compatibility and over-reliance on digital tools.

Sustainability practices are another key component discussed in this section, with both companies adopting eco-friendly strategies in production and materials selection. Dorçe's focus on using recyclable materials and minimizing waste through modular standardization complements DMT's commitment to low-carbon manufacturing and sustainable material sourcing.

Overall, platform-based product design serves as a catalyst for improving process efficiency by enabling companies to integrate design and production more effectively, adopt innovative technologies, and prioritize sustainability. Both Dorçe and DMT demonstrate the potential of this approach to optimize workflows, reduce costs, and meet evolving market demands in the modular construction sector.

4.3. Summary Table: Comparative Analysis of Dorçe vs. DMT's Findings

The table below provides a comparative analysis of the key findings from Dorçe and DMT, highlighting the similarities and differences in their approaches to platform-based product design.

Table 4.2. Summary Table: Comparative Analysis of Dorçe vs. DMT

Aspect	Dorçe	DMT
Cost Efficiency	Focuses on component reuse, lean manufacturing, and eco-friendly materials to reduce waste and optimize resource utilization.	Emphasizes advanced production planning, logistics coordination, and digital tools (e.g., BIM) to minimize production downtime and waste.
Product Variety	Offers flexibility in design adaptation within a standardized framework. Modifications based on customer feedback are done within the limits of standard components.	Provides higher design flexibility using modular platforms, digital tools (e.g., digital twins, AR) to customize solutions based on customer feedback.
Operational Efficiency	Prioritizes lean manufacturing, prefabrication, and regular collaborative reviews to optimize workflows and reduce material waste.	Uses interdisciplinary teams, real-time monitoring, automated inspections, and digital technologies to ensure operational efficiency.

4.4.Discussion

This section discusses the findings of the research in relation to the existing literature and industry practices. The study aimed to examine the inefficiencies and productivity challenges in the construction industry, while exploring the potential of adopting prefabrication and modularization practices, inspired by the success of the automotive industry. The findings from the interviews with Dorçe and DMT, alongside the literature review, reveal both the opportunities and obstacles associated with the integration of modern manufacturing techniques into construction.

The research has shown that while the construction industry has made progress in incorporating some aspects of prefabrication, it is still significantly behind the automotive sector in terms of mass production, automation, and modular design. This delay can largely be attributed to the industry's reluctance to depart from traditional practices and the high initial investment required for implementing new technologies. However, the findings also suggest that there are substantial benefits to adopting these practices, particularly when integrated with modern digital tools, standardized processes, and enhanced collaboration between design and production teams.

4.4.1 Comparing Automotive and Construction Industry Practices

As highlighted in the findings from interviews with Dorçe and DMT Modular, the automotive and construction industries approach standardization and customization differently. While the automotive sector thrives on modularity and shared platforms, construction often faces challenges in achieving similar efficiency due to its bespoke designs and site-specific requirements. This contrast is summarized in Table 4.4 below:

Table 4.3. Comparison of Key Aspects Between the Automotive and Construction Industries

Aspect	Automotive Industry	Construction Industry
Platform-Based Product Design (PBD)	Extensive use of PBD for shared components and architectures, leading to efficiency, cost savings, and variety.	Adoption of PBD principles is in its early stages. Offers potential for improved efficiency and customization in modularization and prefabrication.
Standardization vs. Customization	High level of standardization enables shared platforms across multiple models with minimal redesign.	Bespoke designs are common, adapting to site-specific conditions, regulations, and client preferences, which limits standardization.
Integrated Production vs. Fragmented Processes	Integrated and automated production systems optimize manufacturing processes.	Fragmented processes involve multiple independent stakeholders, causing inefficiencies. Collaboration among stakeholders is critical for improved modular adoption.
Regulatory Challenges	Global standards simplify compliance across markets.	Regional variability in codes complicates scalability. Adapting prefabricated components to diverse standards increases costs and delays.
Technological Advancements	Advanced technologies like robotics, digital twins, and CAD ensure precision and efficiency.	Slower adoption of new technologies. BIM is used in some cases, but traditional methods are still dominant. Wider digital adoption could streamline processes.
Economies of Scale	Produces large volumes of standardized components, reducing unit costs.	Economies of scale are limited to large-scale projects with repetitive designs. Prefabrication is economically viable for worker accommodations or large residential complexes.
Using Past Designs and Data	Extensive reliance on design databases and historical data (e.g., Volkswagen’s MQB platform). Facilitates optimization of costs, timelines, and innovation.	Past designs and data are used to streamline production and improve processes, but customization and client-specific variables limit full reuse. Standardized designs often serve as starting points rather than final solutions.

Platform-based product design (PBD), a concept extensively employed in the automotive industry, has revolutionized vehicle manufacturing by enabling companies to share common components and architectures across different models. This strategy has led to significant improvements in efficiency, cost savings, and product variety (Meyer & Lehnerd, 1997; Bridi, Ceolin, Granja & Formoso, 2019). Considering the construction industry's persistent challenges of inefficiency and low productivity, the adoption of similar platform-based strategies could provide transformative solutions, especially in the domains of modularization and prefabrication. This research examines how lessons from the automotive industry's application of PBD can be leveraged to enhance construction practices.

In the automotive sector, platform-based design is celebrated for its flexibility in product development. By standardizing a set of modular components, manufacturers can develop diverse vehicle models with minimal redesign efforts (Muffatto, 1999). This approach reduces development time and costs while enabling rapid responses to market demands. Translating this concept to construction, modular platforms could streamline repetitive building processes, enhancing efficiency in design and delivery without compromising on client customization.

Another critical advantage of PBD in the automotive industry is its role in achieving economies of scale. Common platforms enable manufacturers to produce components in bulk, significantly reducing production costs and improving profitability (Sako, 2002). For the construction sector, adopting prefabricated systems built on modular principles could achieve similar cost efficiencies. Prefabrication minimizes material wastage and enables resource optimization, contributing to both economic and environmental sustainability (Bridi et al., 2019).

Production efficiency is another hallmark of platform-based product design in the automotive sector. By employing modular production lines, automakers maintain high levels of customization while ensuring consistent quality (Muffatto, 1999). In construction, off-site prefabrication using modular systems could similarly enhance efficiency by reducing on-site labour requirements and mitigating project delays caused by weather and other site conditions. This approach aligns with the growing emphasis on sustainable construction practices that prioritize resource conservation and time efficiency.

Furthermore, the automotive industry’s ability to maintain diversity in its product offerings through platform-based design provides an important lesson for construction. By reusing core components while customizing external features, automakers have successfully balanced standardization with differentiation (Meyer & Lehnerd, 1997). For construction, modular platforms could allow for varied building designs while maintaining a standard framework, thereby addressing diverse client needs without escalating complexity or costs.

The collaborative ecosystem fostered by the automotive industry is another notable success factor. Through close partnerships between manufacturers and suppliers, the industry has optimized component development and delivery processes (Sako, 2002). A similar collaborative approach in construction, particularly involving prefabrication specialists and contractors, could streamline supply chains, reduce lead times, and enhance overall project outcomes.

In conclusion, the automotive industry’s adoption of platform-based product design demonstrates its potential to transform sectors characterized by inefficiencies and high costs. By adopting modular and prefabricated approaches inspired by PBD principles, the construction industry could realize significant advancements in efficiency, cost-effectiveness, and sustainability. However, addressing challenges specific to the construction sector, such as regulatory constraints and the need for technical expertise, remains crucial for successful implementation.

By adopting modular and prefabricated approaches inspired by PBD principles, the construction industry could realize significant advancements in efficiency, cost-effectiveness, and sustainability.

Translating this concept to construction, modular platforms could streamline repetitive building processes, enhancing efficiency in design and delivery without compromising on client customization. However, while the automotive industry thrives on this approach, the construction industry faces its own set of challenges.

4.4.1.1. Standardization vs. Customization

As highlighted in the findings from interviews with Dorçe and DMT Modular, while both industries aim to balance efficiency with customization, the implementation of modular and prefabricated systems in construction remains in its infancy compared to the automotive sector.

The automotive industry thrives on standardization (Knapp, Šimon, 2023). Modular components allow automakers to produce multiple models with shared underlying platforms, minimizing design changes and reducing production times (Lampón, et al., 2019). In construction, however, this level of standardization is challenging due to the unique nature of each project. The interviews revealed that clients in the construction sector often demand bespoke designs tailored to specific site conditions and regulations.

The construction sector's focus on client-specific needs often limits standardization, as evidenced by Dorçe's experience in projects like the Aktogay Accommodation Complex. The Aktogay Accommodation Complex project, located in Aktogay, Kazakhstan, is a prefabricated building designed to provide housing facilities. Covering an area of 54,000 m^2, the project was initiated on March 18, 2019, and completed by October 1, 2020. Developed by KAZ Minerals Aktogay LLC, it was constructed by Dorçe Prefabricated Building and Construction Industry Trade Inc., who also handled the steelwork, mechanical, electrical, and engineering aspects. The project involved 3,100 tons of steel and was designed by KAZGOR Design Academy. The complex is part of a larger infrastructure effort to support mining operations in the region.

Figure 4.1. Photograph of the Aktogay Accommodation Complex

Figure 4.2. Photograph of the Aktogay Accommodation Complex

While modular units were standardized in dimensions and materials, the design had to be adapted to local environmental conditions, including extreme temperatures. DMT Modular echoed similar challenges, emphasizing that achieving full standardization is particularly difficult for diverse building projects. This contrasts sharply with the automotive industry's ability to standardize platforms across multiple vehicle models.

In contrast, the DMT Modular seems that while the general structure or chassis of the buildings may remain consistent, the types and specific requirements for each project can vary. This implies that the basic framework or platform is standardized, but customization is still necessary to adapt to different site conditions, client requirements, and regulatory standards.

Both companies believe they have succeeded in standardizing certain components for mass housing projects, but they also emphasized the need for flexibility to meet specific client requirements, which often jeopardizes the potential for full modularization.

In the construction industry, standardization may be possible for core components or systems, but the final design often needs to be adjusted based on factors like location, local building codes, environmental conditions, and client preferences (Chippagiri, Bras, Sharma & Ralegaonkar, 2022). Thus, the standards for each project could indeed change depending on these factors, making the process more flexible but less rigidly standardized compared to industries like automotive manufacturing.

4.4.1.2. Integrated Production vs. Fragmented Processes

Automotive production benefits from integrated, automated systems where every stage of manufacturing is optimized for efficiency (Knapp & Šimon, 2023). By contrast, construction projects are inherently fragmented, involving multiple stakeholders—architects, contractors, and suppliers—who often operate independently (Chippagiri, et al, 2022). Both Dorçe and DMT Modular identified this fragmentation as a key barrier to adopting streamlined, modular approaches.

For instance, Dorçe's design team noted that a lack of collaboration among project participants often leads to inefficiencies, miscommunication, and increased costs. DMT Modular also pointed out that without an integrated ecosystem, scaling modular practices becomes increasingly challenging, particularly in international projects where coordination across borders is essential. The fragmented nature of construction complicates the integration of design, manufacturing, and assembly processes.

Dorçe's use of Design for Manufacturability and Assembly (DFMA) principles in the Aktogay project helped mitigate inefficiencies by streamlining production and ensuring that modular components were easy to assemble on-site. However, both companies noted that such integration is not yet the norm in construction, often leading to coordination issues and increased costs.

To address these challenges, collaboration among stakeholders—including owners, clients, contractors, designers, engineers, and policymakers—is critical. These key players must understand the gaps in current processes and work together to make them more adaptable. Moreover, the development of effective codes, policies, regulations, and laws by politicians and city authorities is essential for reducing risks and supporting the transition to more efficient, modular systems in the construction and prefabrication industries (Björnfot, Sardén, 2006; Xue, Zhang, Su, & Wu, 2017; Kim, Chester, Eisenberg & Redman, 2019; Rasmussen, 1998).

4.4.1.3. Regulatory and Logistical Challenges in Modular Construction

The automotive sector operates within well-defined global standards, allowing manufacturers to produce vehicles that meet consistent regulatory requirements across markets (Gann, 1996). In contrast, the construction industry faces a much more complex regulatory environment. Local building codes and regulations can vary significantly by region, making the scalability of modular construction more challenging. For instance, modular homes, which are built in factory sections, are designed to comply with regional and local codes, with the construction process typically taking 1-2 weeks. The modular home design is often similar to that of a traditional house, with the flexibility to be customized to the owner's needs using specialized software. Despite their appearance resembling a conventional home, modular houses are more cost-efficient due to the factory-based production model, which reduces costs associated with labour and materials (Cantu, Canal & Costin, 2019).

However, adapting these prefabricated components to meet different regional standards significantly increases costs and causes delays. DMT Modular's representatives highlighted that this variation in standards presents a major obstacle, while Dorçe also shared similar experiences in international projects that required compliance with multiple, sometimes conflicting, regulatory frameworks. Moreover, logistical challenges, such as the transportation of modular components to different sites—whether urban or remote—further complicate the broader application of modular construction solutions.

For example, Dorçe had to adapt the Aktogay project's design to comply with a combination of EN and SNiP standards, which added complexity and extended the project timeline. Similarly, they focused on optimizing the transportation of modules to the project site, considering factors such as cost control and the logistics of using roads and highways.

4.4.1.4. Technological Advancements

The building industry is slow to change or adapt to newer technologies and ways of doing things, unlike the automotive industry. The automotive industry is efficient, lean, and focused on reducing waste, with companies like Toyota adopting practices that add value and minimize unnecessary efforts (Duggan, 2015). Automation and digital technologies, such as robotic assembly, digital twins, and advanced CAD systems, are integral to the automotive sector, ensuring high precision and efficiency (Scholer, Müller, 2017). In contrast, the construction industry remains behind in adopting these technologies. While companies like DMT Modular have introduced Building Information Modeling (BIM) to improve project coordination, many construction firms still rely on traditional, labour-intensive methods. Dorçe's team highlighted that wider adoption of digital tools and automation could help the construction industry move closer to the streamlined processes seen in automotive manufacturing.

4.4.1.5. Economies of Scale

Automotive manufacturers capitalize on economies of scale by producing large volumes of standardized components, significantly reducing unit costs. This is exemplified by companies like Toyota and Volkswagen, which use a common base design for multiple models, leading to reduced lead times and development costs (Mike et al., 2007; Ben Mahmoud-Jouini, Lenfle, 2010). In contrast, the construction industry’s project-based nature limits such opportunities. Modular construction offers the potential for economies of scale, particularly when large quantities of standardized modules are produced simultaneously. However, as DMT Modular highlighted, prefabrication becomes economically viable primarily in large-scale projects with repetitive designs, such as worker accommodations or large residential complexes.

For example, a company could achieve economies of scale by adopting an offsite modular construction approach, allowing for continuous, standardized production of modules. A shift from the traditional make-to-order model to an engineer-to-order (platform concept) model would enable companies to gain economies of scale through the repeated use of components and large-volume orders (Jansson, 2013). This approach is achieved by increasing production volumes, leveraging common designs, and working with a select few suppliers, which reduces the need for upskilling staff. However, a key challenge in this model is that many customers desire unique homes. Therefore, the value created through modular construction must be high enough to offset the downsides of standardization.

In the case of Dorçe’s Aktogay project, the company successfully standardized modules, which led to cost efficiencies. This example demonstrates how larger projects with consistent design requirements can benefit from economies of scale. However, as DMT Modular observed, smaller projects often lack the scale necessary to justify such approaches. This illustrates a significant difference between construction and the automotive industry, where mass production of standardized components remains a core advantage.

4.4.1.6 Using past Designs and Data

The ability to reuse past designs and data is a hallmark of efficiency and innovation in manufacturing industries. In the automotive sector, manufacturers rely heavily on design databases and historical production data to optimize costs, reduce development time, and refine processes for new models (Mike et al., 2007). Platform-based product design is a prime example of this strategy, allowing manufacturers to build multiple vehicle models on shared foundations. For instance, in the automotive sector, the Volkswagen Group provides a compelling example with its Modularer Querbaukasten (MQB) platform strategy. Introduced in 2012, this system rationalized the number of parts and assemblies across the conglomerate's extensive vehicle ranges. By isolating highly variable components into specific plug-in parts while maintaining shared subplatforms, Volkswagen achieved significant standardization. Approximately 90% of the components within the platform are identical across models, leaving the remaining 10% for relatively superficial customizations, such as body styling, interior finishes, and engine power. This approach allowed for economies of scale while catering to customer preferences with a limited degree of personalization (Lampón et al., 2019). Lessons learned from earlier iterations often guide the integration of new technologies or the adaptation to regulatory changes, showcasing how past knowledge informs future advancements (Steinberg, 2022).

In modular construction, this approach also holds promise, as demonstrated by projects at Dorçe and DMT Modular. Both companies leverage past designs and data to streamline production processes and ensure efficiency in delivering modular units. For instance, DMT maintains a repository of standardized designs that are adapted for different regions and regulatory requirements, similar to how automotive companies refine platforms for diverse market demands. Likewise, Dorçe employs digital tools such as Building Information Modeling (BIM) to archive and reuse data from previous projects, enabling quick identification of proven solutions for new builds.

However, during interviews, representatives from both companies acknowledged that the direct application of past designs in new projects is often constrained by the inherent differences between the construction and automotive sectors. Unlike the automotive industry, where customers have limited customization options and products can be more easily standardized, the construction industry is characterized by a higher degree of complexity and personalization. Each client in the construction sector typically has unique requirements, from architectural preferences to functional needs, making it challenging to fully replicate past designs without significant modifications (Barlow, Childerhouse, Gann, Hong-Minh, Naim & Ozaki, 2003; Aitchison, 2017).

Furthermore, the scope of construction projects often encompasses a broader range of variables than automotive manufacturing, including site-specific conditions, regional regulations, and a more diverse set of materials and techniques (Aitchison, 20017). As DMT pointed out, while their prefabricated modules can be adapted to meet regional demands, the extent of customization required means that standardized designs serve more as starting points than complete solutions. Similarly, Dorçe noted that although their archived designs help reduce development time, adapting these designs to fit new customer needs often requires extensive re-engineering.

The challenge is compounded by the wide array of choices available to clients in the construction industry compared to the automotive sector. While car buyers generally select from a limited set of models and options, construction clients have virtually limitless possibilities for customization, from design aesthetics to material selections and energy efficiency features. This diversity further limits the applicability of a standardized formula for reusing past designs in modular construction (Aitchison, 20017).

Despite these challenges, both Dorçe and DMT emphasized the value of historical designs and data as tools to enhance efficiency and reduce redundancies. By learning from previous projects, these companies can improve their processes and adapt faster to market demands, even if full standardization remains elusive. For example, DMT's operations in Kazakhstan and the Netherlands benefit from modular designs that have been refined through iterative use, reducing logistical costs and ensuring compliance with diverse regulations. Similarly, Dorçe leverages past data to develop modular units optimized for energy efficiency, meeting environmental standards without starting from scratch.

While the modular construction industry faces limitations in achieving the same level of standardization as the automotive sector, companies like Dorçe and DMT are laying the groundwork for more efficient practices. By combining lessons from historical data with flexible adaptation to customer needs, the industry can progress toward achieving a balance between customization and efficiency.

4.4.2 Discussion on the Influence of Platform-Based Product Design on Product Variety

Despite the challenges of adapting platform-based product design from the automotive sector to the construction industry, both Dorçe and DMT companies demonstrate practices that align with several key success factors, enabling product variety in modular construction. These factors include design standardization, early integration of production teams, advanced technologies, and quality control. By applying these practices, they can offer a broader range of modular solutions tailored to meet diverse customer needs, ensuring that customization is achieved while still benefiting from standardized production processes.

Table 4.4. Key Factors Supporting Product Variety in the Automotive and Construction Industries

Factor	Automotive Industry	Construction Industry
Design Standardization	Platforms like Volkswagen's MQB enable economies of scale with a balance of customization (Lampón et al., 2019).	Standardized modular designs (e.g., Dorçe and DMT) reduce waste, simplify production, and ensure compatibility while allowing client-specific adjustments.
Early Integration of Production Teams	Collaboration between design and engineering minimizes redesigns and supports customizable options (Duggan, 2015).	Production engineers at Dorçe and DMT provide early input during the design phase, facilitating efficient customization and reducing constraints.
Use of Advanced Technologies	Tools like CAD, simulation software, and AR enhance precision and flexibility in customization.	BIM, AR, and simulation tools at DMT and Dorçe streamline design, identify errors early, and support efficient adaptation of modular units to diverse needs.
Scalability through Modularization	Modular platforms like Volkswagen's MQB enable streamlined production of varied vehicle models (Ben Mahmoud-Jouini & Lenfle, 2010).	Modular designs at DMT and Dorçe allow for scalable production of diverse configurations, such as prefabricated units tailored to regional needs.

4.4.2.1 Design Standardization

One of the most critical success factors in achieving product variety in modular construction is the standardization of designs and components. In the automotive industry, standardized platforms like Volkswagen's MQB allow manufacturers to achieve economies of scale while maintaining a degree of customization (Lampón et al., 2019). This balance between standardization and variety is key in both sectors.

Dorçe's approach involves utilizing a repository of standardized modular designs that comply with international codes, ensuring compatibility across regions. This approach reduces material waste, simplifies production, and maintains consistent quality while allowing for flexibility in design. The standardized foundation of these designs enables Dorçe to offer a wide variety of modular solutions tailored to different customer needs and regional preferences.

DMT's strategy incorporates standardized elements in their prefabricated modules, streamlining production while allowing for client-specific adjustments. For example, in their projects in Kazakhstan and the Netherlands, DMT offers customization options, such as layout and materials, to cater to local demands, demonstrating how standardized designs can support product variety within modular construction.

4.4.2.2 Early Integration of Production Teams

Integrating production teams during the design phase is another hallmark of success, particularly in achieving product variety. This approach, common in the automotive sector, ensures that designs are manufacturable while aligning production capabilities with customer requirements, thus enabling greater flexibility in offering diverse product options.

In automotive production, early collaboration between design and engineering teams minimizes the risk of costly redesigns and allows for the inclusion of customization options from the outset (Duggan, 2015). This ensures that the final product can meet the varied preferences of customers while maintaining manufacturing efficiency.

In modular construction, Dorçe involves production engineers early in the design process, enabling the identification and resolution of potential manufacturing constraints before construction begins. This integration facilitates the incorporation of customer-specific adjustments, allowing Dorçe to offer a range of modular designs suited to different needs and preferences. Similarly, DMT integrates production feedback during the planning stage to refine modular designs, ensuring they can be customized while remaining efficient and cost-effective for a variety of projects.

4.4.2.3 Use of Advanced Technologies

The application of advanced digital tools, such as simulation software, Building Information Modeling (BIM), and augmented reality (AR), plays a transformative role in both enhancing the accuracy of designs and supporting product variety in modular construction. These technologies allow for more flexible and customized solutions, helping to adapt designs to meet diverse customer preferences while maintaining high efficiency.

DMT uses AR and simulation tools to visualize modular units during the design phase, ensuring that potential errors are identified and resolved before production begins. This not only reduces lead times and improves accuracy but also enables the customization of modular units to suit various project specifications, thereby increasing product variety.

Dorçe also employs BIM to streamline the design process, not only for initial designs but also to document past projects. This repository of data enables Dorçe to quickly adapt proven solutions to new contexts, allowing for the efficient creation of customized modular units that meet specific client needs, thus enhancing the diversity of available product options.

4.4.2.4 Scalability through Modularization

The ability to scale production while maintaining the ability to offer a variety of products is a key success factor in both the automotive and construction industries.

In the automotive sector, modular platforms like Volkswagen’s MQB support large-scale production with minimal design changes, allowing manufacturers to offer a range of vehicle models while keeping production processes streamlined and efficient (Ben Mahmoud-Jouini & Lenfle, 2010).

Similarly, in modular construction, both DMT and Dorçe leverage standardized modular designs that allow for the creation of a wide variety of product configurations to meet diverse regional needs. For example, Dorçe's prefabricated units for worker housing in Kazakhstan showcase how scalability can be achieved while accommodating local customization. DMT's modular units, designed for quick assembly on-site, also provide flexibility for a variety of applications, enhancing product variety while maintaining production efficiency.

4.4.3 Discussion on the Role of Platform-Based Product Design in Improving Process Efficiency

Platform-based product design plays a significant role in improving process efficiency in modular construction by enabling better quality control, and facilitating smoother collaboration between teams. This section explores how such platforms contribute to achieving these efficiencies in both the automotive and construction industries, drawing insights from existing literature and interviews with experts at Dorçe and DMT Modular.

Table 4.5. Comparison of Platform-Based Product Design in Enhancing Process Efficiency

Factor	Automotive Industry	Modular Construction Industry
Quality Control and Efficiency	- Advanced automation and precision engineering ensure consistent quality across mass production. - Lean manufacturing practices reduce waste and improve sustainability. - Rigorous quality checks at every production stage.	- Controlled factory environments enable automated processes, reducing human error. - Standardized designs and automated production improve quality and consistency. - Lean principles minimize waste and optimize resource use.
Collaborative Ecosystems	- Early supplier integration streamlines production and minimizes lead times. - Collaboration with suppliers ensures standardization and reduces production errors. - Integration of teams during design phases optimizes processes.	- Early engagement with clients, suppliers, and engineers ensures alignment on requirements. - Collaborative approach reduces delays and rework. - Integration with suppliers ensures availability of standardized materials.

4.4.3.1 Quality Control and Efficiency

Quality control is a critical factor in ensuring that prefabricated modules meet industry standards and customer expectations. In the automotive industry, manufacturers rely on advanced automation and precision engineering to achieve consistent quality across mass-produced components (Knapp & Šimon, 2023). These processes are essential in maintaining uniformity and meeting strict quality standards in large-scale production.

Similarly, in modular construction, companies like DMT and Dorçe benefit from operating in controlled factory environments, where they can apply rigorous quality control measures. The use of automated processes and standardized designs reduces human error, enhances consistency, and minimizes defects. These practices not only improve the quality of the final product but also contribute to the efficiency of the overall production process. By reducing the variability inherent in on-site construction, DMT and Dorçe are able to ensure higher levels of quality assurance while keeping production times manageable.

Furthermore, these practices align with Lean manufacturing principles, which focus on minimizing waste and improving sustainability (Shah & Ward, 2003). In modular construction, Lean techniques help streamline operations, reduce unnecessary costs, and ensure that resources are used effectively, ultimately leading to both enhanced quality and increased process efficiency. By focusing on process optimization and adopting high standards for quality control, modular construction companies can maintain competitive advantages in the rapidly evolving construction industry (Barlow et al., 2003).

4.4.3.2 Collaborative Ecosystems

Collaboration among designers, engineers, suppliers, and other stakeholders is a significant factor in improving process efficiency. In the automotive industry, manufacturers prioritize collaboration with suppliers to standardize components and streamline production processes. This cooperation helps minimize lead times, reduce production errors, and ensure consistent quality across large-scale manufacturing (Gann, 1996). By integrating suppliers early in the design and production phases, automotive companies can achieve a more efficient and cost-effective manufacturing process.

In modular construction, companies like DMT and Dorçe follow similar collaborative principles. Both companies prioritize early engagement with clients, suppliers, and engineers to ensure that all parties are aligned on the project’s functional and regulatory requirements. This early integration allows for the identification and resolution of potential issues before they impact the production schedule, reducing the likelihood of delays or rework. By fostering a collaborative environment, DMT and Dorçe can streamline their design processes, ensuring a more efficient production cycle and minimizing wasted resources.

Furthermore, collaboration with suppliers in modular construction contributes to process efficiency by ensuring that standardized materials and components are readily available, reducing production delays and the need for custom solutions. This interconnected approach enhances the overall efficiency of the production process, allowing modular construction companies to meet deadlines, reduce costs, and maintain quality control throughout the project.

4.4.4 Challenges to Adoption in the Construction Industry

Challenges to Adoption in the Construction Industry discusses the difficulties faced by the construction sector in implementing platform-based product design principles, particularly those successfully used in the automotive industry.

4.4.4.1. High Initial Costs and Investment Risks

The shift to prefabrication and modularization demands substantial upfront investments in manufacturing infrastructure, advanced technologies, and workforce training. Unlike traditional construction, which relies on localized, project-based practices, modular construction necessitates centralized production facilities that require significant capital outlay.

Representatives from both Dorçe and DMT Modular emphasized the financial burden associated with setting up dedicated factories and adopting digital tools like BIM and simulation software. Dorçe, for instance, noted that their transition to modular approaches for the Aktogay project required a significant allocation of resources, particularly in workforce training and equipment upgrades.

Research shows that small- to medium-sized construction firms are often deterred by these initial costs, especially in markets where demand for modular construction is uncertain (Bock, 2015).

4.4.4.2. Lack of Standardization

The inherent diversity of construction projects, coupled with varying regional regulations, complicates efforts to establish standardization—a cornerstone of modular and prefabricated methods.

DMT Modular's team pointed out that adapting modular components to comply with different building codes across regions adds complexity and costs. Similarly, Dorçe shared that, despite employing DFMA principles, achieving a high degree of standardization across international projects remains a persistent challenge.

Without standardized design and manufacturing protocols, companies face difficulties in scaling modular solutions. Unlike the automotive industry, where platforms like Volkswagen's MQB enable consistent production across markets, construction projects often require bespoke solutions that undermine standardization efforts.

4.4.4.3. Fragmentation of the Industry and Resistance to Change

The construction industry is characterized by fragmented processes and a reliance on traditional practices, making it resistant to change.

The involvement of multiple, often disconnected stakeholders—architects, contractors, engineers, and suppliers—hampers coordination and integration. As noted by Dorçe's team, this fragmentation leads to inefficiencies, miscommunication, and higher costs.

Both Dorçe and DMT Modular observed reluctance among clients and smaller contractors to adopt modular approaches, largely due to skepticism about their long-term benefits. This resistance is often rooted in a preference for established methods and concerns about the perceived risks of adopting unproven technologies.

4.4.4.4. Technological and Logistical Challenges

While digital tools like BIM, ERP, and PDM systems have proven their value, their full integration into modular construction workflows remains a significant challenge.

DMT Modular noted that while they have successfully implemented BIM and AR for project planning, ensuring seamless collaboration between departments is still a work in progress. Similarly, Dorçe highlighted logistical hurdles, such as the transportation of large modular components to remote sites, which often involves additional costs and planning.

Studies suggest that the construction industry lags behind other sectors in adopting automation and robotics, which limits the potential for efficiency gains (Scholer & Müller, 2017). The logistical complexity of transporting prefabricated modules, particularly for international projects, further complicates adoption (Pan & Goodier, 2012).

4.4.4.5. Market and Regulatory Barriers

The absence of unified regulatory frameworks across regions exacerbates the difficulty of adopting modular construction on a global scale.

Dorçe’s experience with the Aktogay project illustrates this challenge, as they had to navigate both EN and SNiP standards, leading to increased timelines and costs. DMT Modular reported similar difficulties when adapting designs for different markets, where inconsistent regulations hinder scalability.

CHAPTER 5

CONCLUSION

The construction industry faces longstanding challenges in inefficiency and low productivity, despite its critical role in economic development. By exploring the lessons and strategies from the automotive sector, particularly platform-based product design, this study offers innovative methods for modernizing construction practices through prefabrication and modularization. This chapter summarizes the key findings of the research and outlines the implications for both academia and industry, while also addressing the limitations and recommending areas for future study.

5.1 Summary of Findings

The research revealed that platform-based product design offers significant potential to transform the construction industry. Drawing upon insights from the automotive sector, the findings can be categorized into three major themes:

5.1.1 Production Economy

Platform-based designs enable cost reduction through standardization, bulk material purchasing, and streamlined production processes. Modular and prefabricated approaches lead to shorter construction timelines, thereby reducing labour costs and project overheads. Enhanced quality control in factory settings minimizes errors and waste, contributing to long-term economic sustainability. The following headings can better explain the economics of production.

(A) Cost Optimization: One of the most notable findings is the ability of platform-based designs to achieve substantial cost reductions. This is primarily due to the standardization of components, which allows for bulk purchasing of materials and more predictable manufacturing processes. This standardization minimizes variability and inefficiencies in production, leading to significant savings in both material and labour costs.

(B) Reduced Timeframes: Modular and prefabricated approaches shorten project timelines by enabling simultaneous off-site production and on-site preparation. By reducing the overall construction duration, these methods help to lower overhead costs, which include expenses for site management, equipment rentals, and labour.

(C) Enhanced Quality Control: The controlled environment of off-site manufacturing reduces the risk of errors that often occur in traditional construction settings. This not only decreases waste but also ensures higher consistency and quality in the final product, leading to fewer call-backs and repair costs over the building's lifecycle.

(D) Long-Term Financial Sustainability: The integration of prefabrication and modularization contributes to long-term cost savings by streamlining maintenance and reducing operational inefficiencies. The durability of prefabricated components, combined with reduced material wastage, ensures economic benefits extend beyond the construction phase.

5.1.2 Product Variety

Customization and Flexibility: Modular construction, inspired by automotive practices, enables extensive customization of structures to meet diverse client needs. This is achieved without compromising efficiency or escalating costs, making it a viable alternative to traditional methods.

Feedback Integration: Utilizing data-driven design processes and customer feedback ensures that modular construction meets specific requirements while maintaining structural integrity. This approach facilitates continuous improvement and innovation in design strategies.

Scalability and Reusability: The ability to reuse standardized components across multiple projects supports scalability and reduces material costs. Adaptable designs further enable the creation of innovative solutions tailored to various applications, from residential to commercial projects.

5.1.3 Process Efficiency

Advanced Digital Tools: Integration of design and production through tools like Building Information Modelling (BIM) enhances accuracy and collaboration among stakeholders. This digital integration reduces the likelihood of errors and ensures that design intentions are accurately realized during production.

Automation and Robotics: The application of automation technologies streamlines repetitive tasks, enhances precision, and improves overall safety at worksites. Combined with human oversight, these tools boost productivity and reduce labour-intensive processes.

Sustainability Efforts: Modular construction significantly reduces on-site waste and minimizes carbon emissions. By optimizing resource utilization, it aligns with global sustainability goals, making the industry more environmentally responsible.

5.2 Implications for the Construction Industry

Adopting platform-based product design can drive a paradigm shift in construction. It offers a pathway to overcome challenges of fragmentation, lack of standardization, and resistance to change. By leveraging modularization and prefabrication, companies can improve project outcomes and contribute to industry-wide modernization. Key implications include (A) Economic Viability, (B) Market Responsiveness, (C) Operational Streamlining and (D) Workforce Transformation:

(A) Economic Viability: Platform-based strategies, though requiring an initial investment, promise long-term savings through efficiency, reduced waste, and enhanced productivity. Firms that adopt these approaches are better positioned to manage costs effectively over project lifecycles.

(B) Market Responsiveness: Companies embracing platform-based modular construction can address evolving customer demands for affordable, high-quality, and sustainable solutions. This agility allows firms to remain competitive in an increasingly dynamic market.

(C) Operational Streamlining: Standardized components and processes reduce variability and complexity, enabling smoother workflows and fostering better coordination among project teams. This minimizes delays and improves overall project management.

(D) Workforce Transformation: As automation and digital tools become integral to construction, training programs must evolve to equip workers with the skills needed to operate advanced technologies. This transition creates opportunities for workforce development and upskilling.

5.3 Limitations of the Study

While the study provides valuable insights, several limitations must be acknowledged:

- The findings are based on qualitative data from interviews with two modular construction firms, which may not capture the full diversity of the industry.

- The absence of numerical data restricts the ability to perform quantitative comparisons.

- Challenges specific to certain regions, such as regulatory barriers or logistical constraints, were not deeply explored.

5.4 Recommendations for Future Research

To build upon the current study, future research should:

- Conduct large-scale quantitative studies to validate the economic and efficiency benefits of platform-based construction.

- Explore region-specific challenges and develop tailored strategies for implementing modular and prefabricated systems.

- Investigate the role of emerging technologies, such as artificial intelligence and digital twins, in further enhancing platform-based design.

- Assess the social implications of automation and prefabrication, including their impact on job creation and workforce dynamics.

5.5 Final Thoughts

This study highlights the transformative potential of adopting automotive-inspired platform-based product design in the construction industry. By addressing inefficiencies and embracing innovative technologies, construction firms can achieve cost savings, enhanced product variety, and improved process efficiency.

The intersection of modular construction with digital tools and automation creates new possibilities for design innovation, allowing firms to balance customization with standardization effectively. Furthermore, this method aligns with global sustainability goals by minimizing waste and resource consumption, contributing to a more environmentally conscious construction sector.

For the industry to fully realize these benefits, a collaborative effort is required. Policymakers, educators, and industry leaders must work together to create supportive regulatory frameworks, invest in workforce training, and foster an innovation-driven culture. Such initiatives will ensure that the lessons from this study are not only implemented but also expanded upon, enabling the construction sector to achieve new heights of efficiency, quality, and sustainability.

Ultimately, this research underscores the importance of looking beyond traditional practices and embracing strategies that have been proven successful in other industries. The adoption of platform-based product design is not merely a technical shift but a transformative journey toward redefining the construction industry for the better.

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A. List of Questions to be Used (English)

1. How does your company integrate prefabricated design and production processes?

2. How do you evaluate the impact of design on production efficiency in the prefabrication process?

3. What measures do you take for economical production? What strategies do you implement to reduce costs and increase efficiency in production processes?

4. How do you benefit from old designs in developing new design improvements? How are past experiences and existing design data used in the development of new designs?

5. What is the importance of design in prefabrication processes in terms of sustainability and environmental impact? What steps are you taking in this regard?

6. How important is the use of digital technologies in design and production processes for your company? Which digital tools do you use and how?

7. How are quality control and safety measures ensured in prefabricated design and production processes?

8. How do you take customer feedback into account in new design projects? What strategies do you follow to meet customer expectations?

9. What strategies does your company implement to encourage innovative design and production methods in prefabrication processes?

10. How do you strengthen communication and collaboration between design and production in prefabrication processes?

B.List of Questions to be Used (Turkish)

1. Şirketiniz, prefabrik tasarımı ve üretim süreçlerini nasıl entegre ediyor?

2. Prefabrikasyon sürecinde tasarımın üretim verimliliğine olan etkisini nasıl değerlendiriyorsunuz?

3. Ekonomik üretim için hangi önlemleri alıyorsunuz? Üretim süreçlerinde maliyetleri azaltmak ve verimliliği artırmak için hangi stratejileri uyguluyorsunuz?

4. Yeni tasarım geliştirmelerinde eski tasarımlardan nasıl faydalanıyorsunuz? Geçmiş deneyimleriniz ve mevcut tasarım verileriniz nasıl yeni tasarımların geliştirilmesinde kullanılıyor?

5. Prefabrikasyon süreçlerinde tasarımın sürdürülebilirlik ve çevresel etki açısından önemi nedir? Bu konuda hangi adımları atıyorsunuz?

6. Tasarım ve üretim süreçlerinde dijital teknolojilerin kullanımı şirketiniz için ne kadar önemli? Hangi dijital araçları kullanıyorsunuz ve nasıl kullanıyorsunuz?

7. Prefabrik tasarım ve üretim süreçlerinde kalite kontrol ve güvenlik önlemleri nasıl sağlanıyor?

8. Yeni tasarım projelerinde müşteri geri bildirimlerini nasıl dikkate alıyorsunuz? Müşteri beklentilerini karşılamak için hangi stratejileri izliyorsunuz?

9. Şirketiniz, prefabrikasyon süreçlerinde yenilikçi tasarım ve üretim yöntemlerini teşvik etmek için hangi stratejileri uyguluyor?

10. Prefabrikasyon süreçlerinde tasarım ve üretim arasındaki iletişim ve işbirliğini nasıl güçlendiriyorsunuz?

C. Raw Interview Transcript – DORÇE

Question 1: How does your company integrate prefabricated design and production processes?

In this section, one of the company's experts explained the integration of design and production processes for prefabricated structures. In general, the company uses platform logic in its work and aims to improve this process. The company, founded in 1982, has been involved with prefabricated and modular structures from the beginning. Initially, these structures were more focused on temporary and movable solutions but have gradually evolved to meet various needs. The design and production of these structures are primarily provided as turnkey solutions by the company.

In terms of design, these structures are highly flexible and configurable. The key point here is the configurability of these structures. In platform logic, our goal is to make the structures more flexible by combining similar components in different ways. This relies on a manufacturing method, a construction method, and a design method. Specifically, when it comes to production, there are certain limiting factors, with the most significant being the machinery park and the physical capabilities of a factory or production line.

Of course, if the production is customized or boutique (i.e., if a small number of units are to be produced), more options become available, and such productions can be outsourced or made on a one-time basis without efficiency calculations or feasibility studies. In these cases, all efforts can be justified as long as the required profit is achieved from that production. However, as production shifts toward mass production, a concept borrowed from the automotive industry, this involves the products initially moving through fixed operations while the products themselves move on a conveyor belt. Over time, mass production has evolved and changed.

In this context, production occurs within the limitations of the machinery park. For example, this is not only true for our company but also for many other players in the sector, especially in the cold-formed steel segment of the industry. Steel manufacturers generally use cold-formed steel for certain dimensions or spans, which are used as structural elements, and many different sections can be produced. In mass production, ready-made box profiles like H or square sections are typically used. If the company has its own production capabilities, these profiles can be shaped using bending machines or presses, or a form-giving line can be used. These profiles are then tested and proven to be effective through structural analyses, producing sections such as C, sigma, or omega profiles.

By combining these profile sections, two-dimensional elements like floor, wall, or ceiling elements are produced. These systems typically form the framework that constitutes the skeleton of a building. Over time, further discussions would include cladding over the frame systems, connectors, and joint elements that bring these frames together. The choice of cladding materials is influenced by both the designer's vision and the structure's budget, and these materials are selected accordingly.

Logistics, which can vary from project to project, also plays a determining role in how these components come together. Upon analyzing all these processes, some commonalities can be observed. We use the same tools, whether or not we are using the same parts. For example, if I look at data from previous years, I would likely find about 10-15 different types of C-section profiles. The ways these parts come together may vary, but generally, we are talking about around 20 different sizes, depending on the project. There may be slight variations, but fundamentally, we are talking about the same parts being configured in different ways.

When these data are collected and analyzed, we can identify common patterns, which simplifies decision-making. This process is similar to how the automotive industry works. In the automotive sector, efficiency and production effectiveness have always been a priority, and these analyses were carried out in a controlled environment. Initially, production lines were introduced, and later more complex platforms emerged. In the 1960s, components like C-sections were introduced to increase efficiency. Data was collected, analyzed, and areas for improvement were identified.

The biggest challenge in the construction industry is the lack of data collection. Often, the industry operates without data, making it difficult to pinpoint inefficiencies. When modular structures are used and data is analyzed (for example, by reviewing historical data from companies like Dorçe), much clearer results can be achieved. Especially with technologies like machine learning, data can be analyzed more accurately, and processes can be made more efficient. This approach provides more freedom to designers and increases variety in structures, while standardization enhances efficiency and predictability.

Question 2: How do you evaluate the impact of design on production efficiency in the prefabrication process?

In response to the question on efficiency, the company expert emphasized that the construction industry is inherently inefficient. While technology has started to play a role in addressing certain issues, such as tracking and record-keeping, the primary challenge lies in the construction method itself. The expert stated that even with the support of technology, traditional construction methods are still far from achieving the level of efficiency desired.

To improve efficiency, the expert suggested that it would be beneficial if construction methods evolved into more technologically advanced approaches, supported by various technologies. He emphasized that this evolution could lead to more widespread adoption of modular and prefabricated buildings, or potentially other types of structures. However, the expert pointed out that the industry is not yet at the desired level of technological integration. Despite the ongoing discussions around these challenges, particularly in relation to the automotive sector, the industry has yet to undergo the transformation needed to enhance efficiency.

The dynamics of the construction industry are similar to those of the automotive industry, yet there are key differences. One significant distinction is that cars are mobile products, whereas buildings are stationary and interact more with their environment. The expert likened this difference to the experience of moving houses, explaining that while cars are designed for mobility, buildings are more firmly anchored to their locations, which limits their flexibility.

Furthermore, the expert acknowledged that while automotive companies, such as Tesla, can conduct tests in extreme conditions and apply the results to similar environments, the same cannot always be said for construction projects. The construction industry is influenced by multiple external factors, including standards and regulations, which often limit flexibility and create challenges in meeting sustainability goals. Unlike car factories, which can scale production efficiently, constructing buildings in limited quantities—such as fifty houses—does not operate in the same way, leading to mismatches between supply and demand. This mismatch can cause companies to lose faith in the sustainability of the market and eventually withdraw from it.

In conclusion, while the construction industry shares similarities with the automotive industry in terms of efficiency goals, it faces unique challenges due to its dependence on various factors and the immobile nature of buildings. To improve production efficiency, the industry needs to adopt more advanced, technology-supported methods and overcome the barriers that currently hinder progress.

Question 3: What measures do you take for economical production? What strategies do you implement to reduce costs and increase efficiency in production processes?

In response to the question regarding economic production and cost-reduction strategies, the expert explained that there are several factors involved in achieving cost efficiency. He emphasized that it is not only about the shell or skeleton design of a structure, but the entire process, particularly in turnkey projects. Many of the turnkey products are produced within the company itself.

One important consideration is whether to produce certain components internally or purchase them from external suppliers. The expert noted that while there is a tendency, especially among architecture students, to believe they can make everything once they develop the necessary skills, this is not always practical or cost-effective. Some components may indeed be feasible to produce in-house, but others may be more economical to buy.

The company takes a disciplined approach to production, focusing particularly on the components it manufactures internally. A key factor in this process is logistics. The dimensions of the products need to be optimized to strike a balance between on-site labour and shipping costs, as these two factors are inversely related. Smaller components are cheaper to transport in bulk, but they may increase labour costs on-site. Conversely, larger components, while reducing labour costs, incur higher shipping expenses.

Thus, for each project, the company aims to find a balance between these two factors, which can vary depending on the project and its location. This balance is continuously adjusted throughout the production process.

The company also highlighted the importance of standardization in the production system. The company's factory is designed to be flexible, allowing it to cater to a wide range of sector demands. This flexibility enables the company to produce both mass-market products and customized designs. However, customization can lead to inefficiencies over time, as the variation in parts and designs may become difficult to manage. Therefore, finding a balance between customization and standardization is critical.

Standardization is crucial for efficient production in the factory, but customization is necessary to meet customer demands or control costs. The expert described the company's efforts to integrate both strategies, noting that this approach resembles platform production in the automotive industry. For example, cars like the Jeep Renegade share the same motor and chassis but may differ in visual design. In construction, however, the differences go beyond aesthetics and include factors like structural loads and wind resistance, which must be considered when standardizing production processes.

In conclusion, the company strives to optimize production efficiency through a combination of standardized processes, careful consideration of logistics, and the flexibility to accommodate customer demands. This approach helps to balance cost reduction with the need for high-quality, customizable products.

Question 4: How do you benefit from old designs in developing new design improvements? How are past experiences and existing design data used in the development of new designs?

The company discussed the importance of using past designs in the development of new ones, explaining that old designs serve as a starting point for new projects. This is essential for both economic and practical reasons. He elaborated that there is an ongoing tension between standardization and customization, similar to the conflict between mass production and standardization.

In the past, the company focused on creating "production libraries," which consisted of standardized production files that were constantly updated. However, as the need for customization grew, the company struggled to keep these libraries updated. The emergence of new ideas and the increasing demand for custom solutions made it difficult to maintain the libraries, and eventually, the approach became unsustainable. As a result, the company shifted towards a project-based approach.

Despite this shift, the issues of differentiation in projects persisted. Even though the projects were similar, the customization requirements led to significant variations, making it impossible to continue working with stock or semi-stock methods in the factory. To address this, the company tries to balance both approaches—continuing with a project-based approach while maintaining fixed elements that allow for customization.

Thus, while the company still uses old projects, they are updated regularly to keep pace with evolving needs. This process remains challenging but is essential for improving efficiency over time.

Question 5: What is the importance of design in prefabrication processes in terms of sustainability and environmental impact? What steps are you taking in this regard?

The expert emphasized the importance of sustainability in the company's operations, acknowledging that it is a significant issue, even though there is some debate surrounding its sincerity. He stated that sustainability is an essential criterion for their work, whether it is deeply believed in or approached more superficially. Regardless of the motivation, the company must meet sustainability standards, as they are set as requirements for their projects.

The company focuses on measuring and reducing the carbon footprint during production processes. While a fully established system for this is not yet in place in the country, they are making efforts to guide their suppliers in reducing emissions related to the raw materials they use. The focus is not only on the production phase but also on tracking the carbon and emissions throughout the entire lifecycle of the modular units, as they will serve the end users.

Although the company has not yet been able to guide its suppliers as effectively as they would like, they are working toward improvement. The company pointed out that their company is the first in the sector to measure and document carbon emissions, and they are actively working on refining this process to make it more effective over time.

Question 6: How important is the use of digital technologies in design and production processes for your company? Which digital tools do you use and how?

The expert discussed the importance of digital technologies, particularly design software, in the company's operations. While they are using Building Information Modeling (BIM) tools to their full potential in just specific projects, they are actively working to integrate them as much as possible. In the modular and prefabricated sector, which merges Architecture, Engineering, and Construction (AEC) with production activities, BIM solutions alone are insufficient. The company requires both AEC and Product Data Management (PDM) tools to effectively convert design data into production data.

The company uses both AEC and PDM software, though challenges arise due to the lack of ready-made solutions for integrating these tools. Some of these challenges cause delays, but as software developers improve their products, the company adapts and continues to evolve. When existing tools fall short, the company looks for alternative solutions, such as incorporating visual programming languages like Dynamo into their design processes.

In addition to design software, the company also uses Enterprise Resource Planning (ERP) systems for integrating production and other disciplines. ERP tools, like SAP, IFS, Oracle, and Microsoft products, are used for managing accounting, finance, inventory, and purchasing. These systems ensure that various departments communicate effectively using a common platform. The company's current focus is on integrating BIM systems with ERP software like IFS, which is still in the preparatory stages but expected to be implemented in the near future.

Question 7: How is quality control and safety ensured in the prefabricated design and production processes?

The company explained the approach to ensuring quality control and safety in prefabricated designs, emphasizing the distinction between mass production and project-based production. For projects that involve mass production, such as producing hundreds or thousands of identical modules, the process begins with the creation of a prototype or mock-up. Although the designs may be visible in 3D through design software, final details often emerge once the physical prototype is produced. The prototype is then presented to the client for approval, ensuring it aligns with their expectations.

Additionally, the company sets up a factory space for observing the production process. This observation period allows the team to identify any necessary changes, which can be incorporated into the mass production phase. If no changes are required, the production proceeds according to the approved prototype.

The testing process for prefabricated structures is generally less extensive than that for mechanical components. For example, aging tests are not conducted as in the automotive industry. Instead, static analysis is sufficient for most structures, while mobile structures undergo dynamic vibration tests using engineering software like Ansis. These tests are aimed at observing potential movements of the structure, module, or component in future operations.

When discussing waterproofing in modular construction, the expert acknowledged that water leakage had once been a bigger issue but now receives more attention in the industry. The challenge arises from the need to break up structures for transport, creating interruptions in the continuous waterproof covering. However, numerous solutions are available to address this issue, and it is no longer as prominent a concern. It is particularly important in multi-component constructions, where careful attention to waterproofing is necessary.

The company also discussed the regional differences that influence construction approaches. For instance, environmental conditions and cultural habits affect design choices, such as the type of roofing. In regions like the Netherlands, high-pitched roofs with a 30% slope are common, whereas in areas like Abu Dhabi or Saudi Arabia, flat roofs are more typical. The company adapts its designs based on these regional characteristics, ensuring that the structures meet local needs and expectations.

Question 8: How do you take customer feedback into account in new design projects? What strategies do you follow to meet customer expectations?

The firm highlighted the crucial role of the proposal department in determining what can be realistically produced, with a focus on understanding customer needs. The team is involved in this process to ensure that the right solutions are suggested based on the company's capabilities. A key strategy is balancing customer demands with the practicalities of production.

To illustrate this, the expert shared an example from a project in Kazakhstan, where a mining company required expansion of their workers' camp. The original camp, located in the eastern part of Kazakhstan near the Chinese border, included dormitory blocks, cafeterias, and other essential facilities, and was designed to serve the workers for the long term. The client wanted to expand this complex, with clear requirements for the construction of additional dormitory-type buildings and related facilities. While an architectural design was already in place, most of the buildings were modular and suitable for prefabrication.

However, a challenge arose in housing the construction workers needed for the project. The region lacked the necessary facilities for this workforce. As a result, the project had to adopt offsite construction methods, not for trend reasons but out of necessity. This example illustrates how the company listens to customer needs and adapts its approach to deliver the best possible solution within its capabilities.

Question 9: What strategies does your company implement to encourage innovative design and production methods in prefabrication processes?

The firm highlighted the importance of early-stage decision-making when adopting modular construction methods, emphasizing the need for timely engagement in order to maximize the benefits of prefabrication. He recounted an example where a company in Hong Kong approached them after the design and approvals had already been finalized, just before the construction phase began. The company sought to implement modular construction due to a drastic reduction in the project timeline—from 3 or 5 years to just 1 year. However, after reviewing the project, it became clear that the design was not suitable for modular construction, as the project would have required significant changes. Since the design was already finalized and approvals were complete, making these changes was no longer feasible. Consequently, the modular approach was not viable, and the timeline could not be shortened, leading to increased costs.

To avoid such situations, the expert emphasized the importance of early involvement with modular construction firms. He stated that their business development department works proactively, tracking projects from their inception, even before they are publicly announced. By engaging with clients early in the process, the company can provide guidance on how to incorporate modular construction effectively, ensuring the design is adaptable and capable of benefiting from the efficiency and cost savings that modular methods offer.

Question 10: How do you strengthen communication and collaboration between design and production in prefabrication processes?

The expert emphasized the integral relationship between design and production in the prefabrication process, highlighting that a design must be feasible for production. He acknowledged the challenges of designing something that cannot be produced efficiently within the available time and resources. While creative designs are important, he stressed that practicality must be at the forefront, particularly in the fast-paced construction environment.

He described how production processes can be pushed to evolve by presenting new and challenging ideas. These challenges can lead to advancements in machine technology and production methods, which, in turn, inspire further innovation. However, he pointed out that design and production must be interconnected, with constant feedback loops between the two. Designers should not insist on pursuing ideas that may lead to inefficiencies or problems in production.

He also noted that in traditional construction processes, designers often work in isolation, preparing designs that are later handed off to contractors. These designs might not be fully realized due to unforeseen challenges during the construction phase. As a result, designers typically have little insight into what happens during construction. In contrast, modular construction requires a more collaborative approach, where design and production teams work closely together.

The feedback and collaboration between these two areas are essential to the success of the project, ensuring that the design is not only feasible but also optimized for production and assembly. The firm emphasized that modular construction cannot function with the traditional divide between architectural and production design. All teams must collaborate closely for the project to succeed, ensuring that the final product aligns with the initial design vision while also meeting production capabilities.

D. Raw Interview Transcript – DMT

Question 1. How does your company integrate prefabricated design and production processes?

- The process starts with demand creation. Sometimes demand emerges naturally, and sometimes the company actively creates it. Once a sale is confirmed, the sales team collaborates with clients to define project requirements.

- The licensing process for permanent buildings follows standard municipal approval procedures, similar to traditional construction.

- A structured workflow is implemented, involving architectural, mechanical, electrical, and structural engineering teams. Designs are created in Revit and integrated into a BIM model.

- Production follows a controlled sequence, similar to automotive assembly lines, minimizing errors and ensuring efficiency.

Question 2. How do you evaluate the impact of design on production efficiency in the prefabrication process?

- Efficiency is measured through data collection, including the number of steps workers take daily. If workers take more than 4,000 steps per day, workflow adjustments are made to improve efficiency.

- The company emphasizes lean production, reducing unnecessary movement and optimizing processes.

- Prefabricated modules are designed with ease of assembly in mind, preventing rework due to misalignment between design and execution.

Question 3. What measures do you take for economical production? What strategies do you implement to reduce costs and increase efficiency in production processes?

- Cost reduction begins with precise measurement and analysis of each process.

- Standardized chassis designs allow for efficient mass production with variations in layout and finishes rather than fundamental changes.

- The company minimizes labour inefficiencies by reducing unnecessary tasks and ensuring that every action contributes to the final product.

- Logistics and transportation considerations are integrated early in the design phase to avoid additional costs.

Question 4. How do you benefit from old designs in developing new design improvements? How are past experiences and existing design data used in the development of new designs?

- The company follows an iterative approach, using past projects as a foundation for new developments.

- The automotive industry's modular design philosophy is applied, where a single core structure can be adapted for multiple product variations.

- Data from previous projects is analysed to optimize future designs, allowing for minor adjustments instead of starting from scratch.

Question 5. What is the importance of design in prefabrication processes in terms of sustainability and environmental impact? What steps are you taking in this regard?

- Environmental sustainability is a priority, with a focus on zero-energy buildings and renewable energy sources.

- Materials are selected based on their environmental impact, with preferences for sustainable, fire-resistant, and recyclable options.

- The company adapts its designs to regional environmental conditions to ensure durability and minimize waste.

Question 6. How important is the use of digital technologies in design and production processes for your company? Which digital tools do you use and how?

- Digital tools like Revit and BIM are extensively used for project visualization and coordination.

- 3D modelling integrates electrical, mechanical, and structural data, reducing errors during production and assembly.

- AI-driven production planning is utilized to optimize material usage and minimize waste.

Question 7. How are quality control and safety measures ensured in prefabricated design and production processes?

- A controlled factory environment significantly reduces construction errors compared to traditional on-site buildings.

- Fire-resistant materials and advanced insulation techniques are employed to enhance safety and durability.

- Modular structures undergo rigorous testing before assembly to ensure compliance with safety standards.

Question 8. How do you take customer feedback into account in new design projects? What strategies do you follow to meet customer expectations?

- The company actively engages with clients throughout the design and production phases to refine designs based on feedback.

- Customization options are guided within controlled parameters to balance client preferences with production feasibility.

- Regional market analysis is conducted to align design features with cultural and economic expectations.

Question 9. What strategies does your company implement to encourage innovative design and production methods in prefabrication processes?

- The company continuously studies automotive and other manufacturing industries for process improvement inspiration.

- A focus on modularity allows for flexibility in design without compromising efficiency.

- Employees are encouraged to experiment with new materials and techniques that can improve durability and sustainability.

Question 10. How do you strengthen communication and collaboration between design and production in prefabrication processes?

- The use of BIM facilitates seamless collaboration among different engineering and design teams.

- Regular meetings and direct communication between designers and production teams ensure alignment throughout the process.

- Training programs enhance workforce understanding of design intent and production constraints, fostering a cooperative approach.