

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

**CRITICAL SUCCESS FACTORS OF PRECAST CONCRETE
PRODUCTION**

ERSİN METİN

A THESIS OF MASTER OF SCIENCE
DEPARTMENT OF CIVIL ENGINEERING

ADVISOR: ASSOC. PROF. SEVİLAY DEMİRKESEN ÇAKIR

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I'd like to dedicate this thesis to my wife Kevser, who has always supported me, helped me with everything and inspired me along the way. And I'd also like to dedicate it to our son Mert, who always asks us, "Are you studying?" even if he doesn't remember these days in the future. Their endless love and sacrifice have been a guiding light on this path.

ABSTRACT

The precast concrete industry plays a pivotal role in modern construction due to its productivity, efficiency, cost-effectiveness, and sustainability. In addition to its fundamental role in modern construction, the precast concrete industry continues to develop, driven by innovations in materials science, construction techniques and design innovation. Oct. With an increasing emphasis on sustainable practices and the integration of digital technologies such as Lean Management, Building Information Modeling (BIM), Virtual Reality (VR), Artificial Intelligence (AI), Robotics and Automation, the industry is trying to further increase its efficiency; besides, it is also open to reducing environmental impact and developing new opportunities for growth and innovation. This thesis explores the critical success factors (CSFs) that affect the production of precast concrete aimed at increasing operational excellence and performance in the industry. To determine these CSFs, it includes an extensive literature review, which leads to the development of a structured questionnaire. The questionnaire was distributed among Decast concrete professionals to assess the relevance and implementation success of the identified CSFs. Then, using SPSS software, a factor analysis was performed on the collected survey data to determine the impact of each success factor on overall performance. Through this experimental research, it is aimed to clarify the weaknesses and opportunities in precast production and provide valuable insights for industry stakeholders. The findings emphasize the importance of factors such as quality control, efficient production processes, labor force skills and technological integration in achieving success in precast concrete production. The findings from this multi-faceted research shed light on the fundamental importance of various factors, including, but not limited to, quality control measures, streamlined production processes, skilled workforce skills, and seamless technological integration. This study contributes to the knowledge base by providing evidence-based insights that can inform strategic decision-making and operational improvements in the precast concrete industry.

Keywords: Precast Concrete Production, Critical Success Factors, Building Information Modelling, Lean Management, Factor Analysis, Survey Analysis

ÖZET

Prefabrik beton endüstrisi, verimliliği, üretkenliği, maliyet etkinliği ve sürdürülebilirliği nedeniyle modern inşaatın önemli bir rolünü oynamaktadır. Modern inşaatteki temel rolüne ek olarak, prekast beton endüstrisi, malzeme bilimi, inşaat teknikleri ve tasarım inovasyonundaki yeniliklerin yönlendirmesiyle gelişmeye devam etmektedir. Sürdürülebilir uygulamalara ve Lean Yönetimi, Bina Bilgi Modellemesi (BIM), Sanal Gerçeklik (VR), Yapay Zeka (AI), robotik ve otomasyon gibi dijital teknolojilerin entegrasyonuna giderek daha fazla vurgu yapılmasıyla, endüstri etkinliğini artırmaya, çevresel etkiyi azaltmaya ve yenilik ve büyüme için yeni fırsatlar yaratmaya hazırlanmıştır. Bu tez, prefabrik beton üretimini etkileyen kritik başarı faktörlerini (KBF) inceleyerek, sektör içinde operasyonel mükemmelliği ve performansı artırmayı amaçlamaktadır. Bu KBF'leri belirlemek için kapsamlı bir literatür taraması yapılmış ve yapılandırılmış bir anket geliştirilmiştir. Anket, prefabrik beton profesyonelleri arasında dağıtılarak belirlenen KBF'lerin ilgili olup olmadığını ve uygulama başarısını değerlendirmek amacıyla kullanılmıştır. Ardından, toplanan anket verileri üzerinde SPSS yazılımı kullanılarak faktör analizi yapılarak her başarı faktörünün genel performans üzerindeki etkisi belirlenmiştir. Bu ampirik araştırma yoluyla, prefabrik üretimdeki zayıflıklar ve fırsatlar aydınlatılmış, endüstri paydaşları için değerli bilgiler sunulmuştur. Bulgular, kalite kontrol, verimli üretim süreçleri, işgücü becerileri ve teknolojik entegrasyon gibi faktörlerin prefabrik beton üretiminde başarı elde etmede önemini vurgulamaktadır. Bu çok yönlü araştırmadan elde edilen bulgular, katı kalite kontrol önlemleri, akıcı üretim süreçleri, uzman işgücü becerileri ve sorunsuz teknolojik entegrasyon gibi çeşitli faktörlerin önemini aydınlatmaktadır. Bu çalışma, prefabrik beton endüstrisinde stratejik karar almayı ve operasyonel iyileştirmeleri bilgiye dayalı içgörülerle bilgi birikimine katkıda bulunmaktadır.

Anahtar Kelimeler: Prefabrik Beton Üretimi, Kritik Başarı Faktörleri, Bina Bilgi Modellemesi, Lean Yönetimi, Faktör Analizi, Anket Analizi

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LIST OF SYMBOLS AND ABBREVIATIONS

df	: Number of Data
Sig.	: Significance
p	: Level of Reliability
AI	: Artificial Intelligence
BIM	: Building Information Modelling
CFA	: Explanatory Factor Analysis
CSF	: Critical Success Factor
EFA	: Explanatory Factor Analysis
FR	: Factor Researching
HSE	: Healthy-Safety-Enviromental
JIT	: Just-In-Time
KMO	: The Kaiser-Meyer-Olkin
LE	: Large Enterprises
QA/QC	: Quality Assurance / Quality Control
SME	: Small-Medium Enterprises
VR	: Virtual Reality

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1. INTRODUCTION

In the construction sector, the prefabricated concrete industry holds great importance due to its versatile contributions. Recognized for its efficiency, ease of production, cost-effectiveness, and commitment to sustainability, prefabricated concrete plays an indispensable role in shaping the infrastructure of our cities and communities. Prefabrication, the application of industrial processes to construction, dates back to ancient Rome, where simple forms were used in underground tunnel networks. However, modern prefabricated concrete as we understand it today emerged in the early 18th century. The Industrial Revolution significantly influenced architecture and prefabrication, introducing new materials like steel and glass, leading to production methods based on different design approaches.

The introduction of prefabricated concrete in the United Kingdom occurred with Weaver's Mill in Swansea in 1897-98. However, modern prefabricated concrete production began with the innovations of British engineer John Alexander Brodie in the early 1900s. Brodie obtained the first patent for erecting precast concrete panel buildings and pioneered efficient construction methods. A significant milestone in the prefabricated concrete industry occurred in the 1950s with the construction of the Walnut Lane Memorial Bridge in Philadelphia, marking the formal establishment of the industry. This led to the need for standardization, prompting the establishment of the Precast Concrete Institute to set standards. In Malaysia, prefabricated concrete was first introduced in 1964 with the construction of flat houses in Kuala Lumpur. In 1891, the Coignet company from Paris built prefabricated reinforced concrete beams for the Biarritz Casino. Later, in the U.S. in 1900, the first reinforced concrete elements for large building decks were remodeled using prefabricated slabs. The early 20th century witnessed an increase in housing demand, especially in industrialized countries like England and the U.S., leading to construction projects based on industrial processes like concrete prefabrication. In 1928, Eugene Freyssinet presented the first prestressing patent, revolutionizing concrete construction by enhancing its tensile strength. The period between 1945-1970 was characterized by mass production, enthusiasm, and business concepts. Closed systems based on large panels were dominant in Eastern Europe and became significant in today's European Union countries, prioritizing economy and speed over architectural considerations.

Prefabricated concrete is produced by pouring concrete into molds, usually reinforced with wire mesh or steel bars, and may include prestressed cables if needed. After curing in a controlled environment, prefabricated concrete is transported to the construction site for installation. Particularly, prestressed reinforcement through cables or steel bars enhances concrete strength, especially in structures requiring maximum durability. Once the reinforcements have been cured, they release all that built-up stress, which gives the concrete its strength and makes it a solid, reliable material.

This research aims to conduct a detailed analysis of the factors affecting operational excellence and performance in the industry. This study, conducted using SPSS software, includes a research survey and statistical analysis shared with stakeholders. It aims to shed light on the ways to success in the prefabricated concrete sector and the challenges ahead. By examining aspects such as quality control, production efficiency, workforce skills and technological integration, it aims to provide informative data to help industry stakeholders have foresight and look ahead confidently in constantly changing conditions.

The precast concrete industry is currently undergoing a significant evolution driven by advances in material science, construction techniques and design innovations. By embracing sustainability principles and utilizing the potential of digital technologies such as Lean Management, Building Information Modeling (BIM), Virtual Reality (VR), Artificial Intelligence (AI), Robotics and Automation, the precast concrete industry is well positioned for increased productivity, reduced environmental impact and increased innovation. Against this backdrop of transformation, this thesis aims to conduct a research to explore the critical success factors (CSFs) underlying precast concrete production. Overall, this study emphasizes the fundamental role of the precast concrete sector in modern construction, emphasizing its efficiency, cost-effectiveness and sustainability. It investigates the evolution of the industry driven by advances in material science, construction techniques and digital technologies. A comprehensive literature review and empirical research were conducted using SPSS software to identify the critical success factors (CSFs) affecting precast concrete production. These factors include quality control, efficient production processes, workforce skills and technological integration. The findings highlight the importance of these CSFs in

achieving operational excellence and seek to explain strategic decision making and operational improvements in the industry through factor analysis.

1.1. Purpose of the Study

The aim of this thesis is to investigate the critical success factors (CSFs) that impact operational excellence and performance in precast concrete production. This involved conducting an extensive literature review to identify these CSFs and developing a structured questionnaire. The questionnaire was circulated among precast concrete production professionals to assess the level of interest and implementation success of the identified CSFs. Factor analysis was then performed on the collected survey data using SPSS software to determine the influence of each success factor on overall performance. Through this empirical research, weaknesses and opportunities in precast production were anticipated and valuable insights were provided for industry stakeholders. The findings highlight the importance of factors such as quality control, efficient production processes, labour skills and technological integration in achieving success in precast concrete production. This study contributes to the body of knowledge by providing evidence-based insights that can inform strategic decision-making and operational improvements in the precast concrete industry.

1.2. Scope of the Study

The scope of this thesis examines the main success factors (CSFs) affecting performance and operational excellence in precast concrete production. It does so by conducting a comprehensive literature analysis and empirical research with precast concrete experts. The aim is to identify, measure, and evaluate these CSFs. The research also considers factors such as workforce capabilities, technology integration, efficient production processes, and quality control. This will provide valuable information to improve the efficiency and productivity of precast concrete production. The scope of this study encompasses the application of factor analysis using SPSS software to determine the impact of each identified success component on overall performance. The findings of this research will expand the body of knowledge by providing fact-based perspectives that help guide tactical choices and operational improvements in the precast concrete industry.

1.3. Literature Review

This section aims to synthesize and summarize the wide range of research completed in the field of precast concrete production by conducting a thorough analysis of the literature in this area. This paper clarifies the importance, difficulties, and developments in precast concrete-related current construction techniques.

Polat and Damcı (2007) focused on the factors affecting the use of elements in the prefabricated reinforced concrete structure in Turkish construction industry. This study aims to analyze why these systems aren't widely adopted in the Turkish construction sector and propose solutions to address sectoral issues, including a comprehensive examination of their pros and cons and the current state of the Turkish prefabrication sector. The study reported that several measures are necessary to promote the widespread adoption of precast construction systems in the Turkish construction sector. These include providing incentives to increase the number of precast element manufacturing firms, legally allowing the accounting of both material and labor costs in the invoicing of precast elements used in projects, enabling the use of precast systems in public projects, tightening specifications for seismic loads in precast system design, adding elective courses on precast system design and management to the curriculum of civil engineering and architecture departments in universities at both undergraduate and graduate levels, initiating certification programs to train qualified workforce specialized in precast system assembly, enhancing the role of the Turkish Prefabrication Association to address compatibility issues arising from weak standardization and establish national standards, and supporting the use of information systems to improve managerial and organizational skills of construction companies intending to use precast systems.

Yıldız (2017) developed a total project management model in prefabricated concrete production. In the study the concept of Total Project Management (TPM) has been integrated under the umbrella of prefabricated concrete production for the first time. The study utilized prefabricated concrete production facilities in the civil engineering sector as benchmarks. Through this approach, studies on optimizing the costs of colored concrete were conducted, resulting in substantial savings.

Sacks R. Et al (2004) This study illuminates management, engineering design, and production operations within the industry through comprehensive information and

process flow modeling undertaken by 14 member companies of the North American Precast Concrete Software Consortium. The article initiates with an economic appraisal of precast construction on a global and North American scale. The examination of models uncovers diverse management procedures, encompassing contracting arrangements, cost estimation, design outsourcing, engineering design communication, mold design, product diversity, and quality control. The findings indicate potential areas for re-engineering prefabricated management processes through the adoption of information technology.

Pasquire and Connolly (2002) discusses how lean production methods enhance off-site manufacturing of integrated mechanical services modules and suggests off-site manufacturing as a way to integrate lean theory into construction. It uses a manufacturing case study to illustrate implemented techniques, lessons learned, and key process improvements. It also identifies major failures in current construction practices, hindering lean project delivery. Finally, it connects lean enterprise with lean construction, emphasizing that realizing benefits is the main driver for change.

Sacks et. al. (2003) in their article, it has seen the effectiveness of applying lean production principles in the precast concrete industry, as highlighted in previous research, emphasizing the importance of engineering and process control information for construction production. However, in current practice, precast producers in the US often fabricate pieces well ahead of their on-site erection, leading to large product inventories stored in yards. While clients typically pay a significant portion of the precast product cost upon production, various factors such as inadequate numbering methods and information systems, high costs of real-time feedback, and producer unreliability in timely shipping have been observed to hinder inventory reduction. The paper suggests that addressing these challenges requires the concerted application of lean principles, advanced information technology, and real-time monitoring technologies. In relation to these issues, the potential of information systems and monitoring data to support lean production and delivery cycles in prefabricated construction has been interpreted.

Soemardi (2000) concentrated on the visualisation of the construction process, assisting designers in exploring different construction schemes and comprehending their impact on cost and schedule. The study described the development of a virtual reality (VR)-based system that aims to equip designers and contractors with such

information to assess the feasibility of construction methods. This system integrates virtual reality 3D graphic animation with a database of constructability assessment information. Its prototype implementation is proposed for practical applications in low-rise precast concrete building structures. The Virtual Reality (VR) system has provided users with interactive visualisations of predefined construction methods.

Ahmed and Almarri (2017) investigated the factors hindering the adoption of Building Information Modeling (BIM) in the UAE's construction sector and shed light on the slow adoption rate of the region caused by the lack of localized research. He examined the difficulties associated with the application of BIM, especially for prefabricated buildings, and identified the main success factors affecting project execution in construction. The study emphasized the importance of time, quality and cost elements in the use of BIM and in the project delivery of prefabricated structures and offered guidance to decision makers and project managers on effective BIM implementation. While addressing the challenges encountered both at the project-specific and strategic levels, it also emphasizes the importance of choosing the appropriate BIM software.

Wu and Low (2012), apart from the benefits that the use of lean manufacturing philosophy can provide in addressing sustainability challenges such as waste reduction, lead time reduction, inventory reduction and increased productivity, this article aims to determine the contribution of CO₂ emissions to environmental sustainability in prefabricated concrete factories using CO₂ emissions as an indicator given the increasing recognition of global climate change. The study focuses on construction site management and delivery management. The results show that many non-value-added activities in the prefabricated concrete production process contribute to an increase in carbon emission levels. The study provides practical guidance and a checklist for precasters to identify and reduce non-value-adding activities to achieve low-carbon production. Additionally, the findings serve as an important guide for regulatory agencies in providing recommendations to reduce carbon emissions.

Holton (2009) has focused on to develop a sector sustainability strategy for the precast concrete industry in the UK and addressed challenges faced by industry trade associations like British Precast in adopting such strategies. While the research contributes to understanding sector sustainability strategies, it also highlights the limitations of trade associations in influencing member actions. It emphasizes the

importance of management systems and continuous improvement cultures in promoting sustainability, while suggesting that more effort is needed to increase industry support, especially among small and medium-sized enterprises, and enhance downstream supply chain sustainability.

Pheng and Chuan (2001) have investigated the potential of the just-in-time (JIT) philosophy for managing the movement of precast concrete components within the construction site. They assessed whether industry stakeholders were ready to adopt JIT for receiving and installing these components on-site. The findings indicate that stakeholders often overlook total costs and only a minority show interest in JIT deliveries for cost savings. However, precasters are more willing to provide logistical support for JIT deliveries. The study suggests that reimbursing costs or sharing savings could motivate precasters to commit to JIT deliveries.

Polat (2010) has examined the limited adoption of precast concrete systems in Turkey and the U.S. despite their advantages. He investigated the factors hindering widespread use through a comprehensive survey. The study revealed significant differences in perceptions between American and Turkish participants regarding the factors influencing the use of precast concrete systems. While American participants identified size and load restrictions in transportation, poor communication between parties, and a lack of specialized contractors as key barriers, Turkish participants emphasized communication issues and the shortage of specialized engineers and contractors. In this regard, the study highlights the importance of recognizing that the reasons for the low utilization of precast concrete systems are closely tied to the specific conditions of each country.

Ray et al. (2006) focuses on providing a comprehensive assessment of lean manufacturing applied in precast concrete plants to reduce waste and enhance production operations. It identifies seven types of waste that can be eliminated and seven principles to improve success in lean manufacturing implementation. Industry examples are provided to demonstrate waste reduction and operational improvements. Although the implementation of lean manufacturing is not universal, those companies that have adopted these techniques have reported a number of benefits, including a reduction in production costs, a decrease in the number of reworks, and an increase in production capacity.

Nasrun et al. (2015) posited that the adoption of prefabricated systems in Malaysia's construction industry is significantly influenced by factors pertaining to demand and the market. Typically, projects in Malaysia utilising prefabricated systems are classified as collective projects involving thousands of residential units or high-rise buildings with a minimum of ten floors. Alternatively, projects may be funded through governmental sources, such as schools, government housing, or commercial buildings for specific purposes.

Rangrao Chougule (2016) has studied Quality Assurance and Quality Control in precast concrete elements for construction in the Pune region of India. It is focused on developing Quality Control and Quality Assurance programs for precast concrete elements used in construction, including the formulation of Quality Control Policies (QCP) and Quality Assurance Plans (QA Plans). The focus of the study is aimed at understanding Quality Assurance in precast concrete elements, investigating the role of precast technique in the construction sector, analyzing how quality is achieved at both stages and finding solutions to minimize deficiencies.

Badraddin et al. (2022) conducted a study to identify the success factors of concrete recycling in construction projects in Malaysia. By identifying the critical success factors, they compared them between large enterprises (LE) and small-medium enterprises (SME) and grouped them into structures. They identified ten critical success factors for concrete recycling, which included standards, stakeholder awareness, waste management plans, government support, marketing strategy, communication, sub-industry practices, method Decrees, legislation and infrastructure. The degree of consensus among SMEs and LE's on these factors has been observed to be low. This study, which divides the factors into external and internal groups, provides important insights to promote concrete recycling in research and practice.

2. CRITICAL SUCCESS FACTORS (CSFs) OF PRECAST CONCRETE PRODUCTION

The main components that determine the success or failure of precast concrete production processes are known as critical success factors or CSFs. In this context, achieving operational excellence, guaranteeing quality control and promoting competition in the construction sector require a comprehensive understanding of these variables. By recognizing and addressing the critical components, precast concrete manufacturers can manage the process and management of their operations more effectively and ultimately achieve greater productivity, profitability and customer satisfaction.

2.1. Critical Success Factors (CSFs)

Critical Success Factors (CSFs) are the basic criteria or activities that must be performed effectively for an organization or project to achieve its goals. These factors vary depending on the industry, organization, or specific project. But it is usually a small number of essential elements that are necessary for success. Identifying and focusing on CSFs allows organizations to efficiently allocate resources and prioritize their efforts on the most critical aspects of their operations. CSFs serve as a strategic tool to enable organizations to focus on their most critical aspects. By identifying these key factors, organizations can streamline their efforts, allocate resources effectively, and increase their chances of achieving success. Determining CSFs requires a comprehensive understanding of the organization's goals, objectives and the external environment in which it operates. This often requires the application of extensive analytical techniques, including SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis, Sunday research and stakeholder consultations. Through these processes, organizations can identify the most important areas to achieve the desired results. Once the CSFs have been identified, it is extremely important for organizations to prioritize these core areas and focus their efforts on these areas. This may require the allocation of resources such as time, budget and manpower to initiatives that directly contribute to the success of CSFs, and the reduction of priorities for less critical activities. CSFs should be measurable so that progress can be monitored and evaluated over time. This requires the identification of key performance indicators

(KPIs) or metrics that are compatible with each CSF. Regular monitoring allows organizations to evaluate their performance, identify areas for improvement, and make informed decisions to move forward on the path to achieving their goals. As business environments evolve, CSFs may also change. Organizations need to remain compliant and flexible by constantly re-evaluating their CSFs in light of changing Sunday dynamics, technological developments, regulatory changes and other external factors. This agility allows organizations to adjust their strategies and priorities to stay competitive and achieve long-term success. CSFs should be clearly communicated throughout the organization to ensure compliance and understanding by all stakeholders. This helps to create a common sense of purpose and direction and allows employees to contribute effectively to the goals of the organization. CSFs should be closely aligned with the overall strategy and vision of the organization. It should reflect the basic values, priorities and long-term goals of the organization and guide decision-making at all levels.

Investigating Critical Success Factors (CSFs) in Precast Concrete Production provides an in-depth look into the complex elements that determine the effectiveness and efficiency of this important sector within the construction industry. It is crucial to understand the factors contributing to the success of precast concrete, which plays a vital role in modern construction projects. This understanding is vital for ensuring optimal outcomes and sustainable practices. It is of vital importance for operational performance optimisation, promoting innovation, and ensuring long-term sustainability in the construction industry. Quality control, efficiency, workforce development, and technological integration are the keys to success for precast concrete manufacturers. By prioritising these factors, manufacturers can overcome challenges, capitalise on opportunities, and achieve excellence in production processes.

2.2. Critical Success Factors (CSFs) of Precast Concrete Production

Critical success factors (CSFs) for precast concrete production are often positioned around operational excellence, quality assurance and various aspects that are critical to achieving competitiveness in the Sunday. By focusing on these critical success factors, precast concrete manufacturers can increase their competitiveness, offer high-

quality products and achieve sustainable growth in the construction industry. One of the basic CSFs in precast concrete production is quality control. In order to produce durable, safe and reliable precast concrete elements, it is extremely important to ensure that the highest quality standards are maintained throughout the production process. Strict quality control measures cover material selection, production processes, improvement techniques and final inspection procedures. Compliance with these quality standards reduces the risk of errors, minimizes rework and maintains customer satisfaction.

Another crucial success factor in precast concrete production is the implementation of efficient production processes. Optimising production operations, improving workflow, and maximising resource utilisation are necessary to increase productivity and reduce delivery times. The implementation of lean principles such as just-in-time production and continuous improvement initiatives can help minimise waste, enhance efficiency, and optimise overall productivity.

The success of the workforce plays an important role in the production of precast concrete. The availability of qualified and knowledgeable personnel is extremely important for the effective operation of machines, the fulfillment of production tasks and the maintenance of quality standards. The implementation of workforce training and development programs ensures that employees have the necessary skills, expertise and competencies to effectively fulfill their roles. In addition, the promotion of a culture of teamwork, cooperation and accountability encourages employee participation and improves overall operational performance.

Technological integration is described as a critical success factor in the production of modern precast concrete. The use of advanced technologies, including Building Information Modeling (BIM), automation, robotics and digital production tools, has the potential to revolutionize production processes, improve accuracy and speed up project delivery. The integration of digital technologies into Decast concrete production has the capacity to increase design accuracy, facilitate coordination between stakeholders and provide real-time monitoring of production measurements.

During the extensive literature study conducted for the thesis, effective CSFs in the field of precast concrete production were meticulously determined. These CSFs cover various aspects that are critical for achieving operational excellence, ensuring strict

quality control measures and ensuring a competitive advantage in the construction industry. By studying these CSFs better, valuable insights and suggestions are being sought to determine decision-making processes and ensure continuous improvement in this dynamic sector. **(Table 2.1).**

Table 2.1: Critical success factors of precast concrete production

FACTORS	EXPLANATION	REFERENCES
Labor Force	Skilled and knowledgeable personnel are essential for precast concrete production, ensuring efficient operation of machinery and maintaining quality standards	Peñaloza, G. A., Formoso, C. T., & Saurin, T. A. (2017); Benjaoran, V., & Dawood, N. (2005); Adinyira, Ayarkwa, & Aidoo (2014); Warszawski, A. (1982); Sacks, Eastman, & Lee (2004)
Automation	Automating certain production processes streamlines operations, reduces manual labor, and enhances efficiency in precast concrete manufacturing.	Wang, Z., Hu, H., & Gong, J. (2018); Nmai, Ko, Vickers, Bury, & Lianopoulos (2022); Skrzypczak (2023); Xiong, Chu, Li, Du, & Wang (2021); Adinyira, Ayarkwa, & Aidoo (2014)
Just-in Time	Implementing just-in-time production methods minimizes inventory holding costs, reduces waste, and optimizes resource utilization in precast concrete production.	H. W., Chen, J. H., Cheng, J. Y., Wei, H. H., Hsu, S. C., & Liu, H. C. (2021); Benjaoran, V., & Dawood, N. (2005); Pan, M., & Pan, W. (2019); Holton, 2009; Peng & Pheng (2011)
QA/QC Management	Rigorous quality assurance and quality control management ensure that precast concrete elements meet or exceed required standards, ensuring durability and safety.	Bock, 2017; Reichenbach & Kromoser, 2021; Warszawski, A. (1982); Sacks, Eastman, & Lee (2004); Skrzypczak (2023)
Robotics & AI	Integration of robotics and artificial intelligence enhances precision, speed, and consistency in precast concrete manufacturing, improving overall production efficiency.	Wang, Z., Hu, H., & Gong, J. (2018); Kong, Li, Luo, Ding, & Zhang (2018); Xiong, Chu, Li, Du, & Wang (2021); Pan, M., & Pan, W. (2019); Nmai, Ko, Vickers, Bury, & Lianopoulos (2022)
Visual Management	Visual management techniques, such as signage and labeling, facilitate communication, enhance workflow, and improve safety in precast concrete production facilities.	Low, S. P., & Chan, Y. M. (1996); Tai, H. W., Chen, J. H., Cheng, J. Y., Wei, H. H., Hsu, S. C., & Liu, H. C. (2021); Benjaoran, V., & Dawood, N. (2005); Peñaloza, G. A., Formoso, C. T., & Saurin, T. A. (2017); Xiong, Chu, Li, Du, & Wang (2021)

Table 2.1: Continue		
Virtual Reality	Virtual reality simulations aid in design validation, process optimization, and training, enhancing efficiency and accuracy in precast concrete production.	Kong, Li, Luo, Ding, & Zhang (2018); Low Sui Pheng & Joo Chuan, n.d.; Sui Pheng & Joo Chuan, 2001, n.d.; Xiong, Chu, Li, Du, & Wang (2021); Pan, M., & Pan, W. (2019)
Transportation	Efficient transportation logistics ensure timely delivery of precast concrete elements to construction sites, minimizing delays and optimizing project schedules.	Chen et al., 2017; Tai, H. W., Chen, J. H., Cheng, J. Y., Wei, H. H., Hsu, S. C., & Liu, H. C. (2021); Benjaoran, V., & Dawood, N. (2005); Sacks, Eastman, & Lee (2004); Nmai, Ko, Vickers, Bury, & Lianopoulos (2022)
Market Conditions	Monitoring and adapting to market conditions, such as demand fluctuations and regulatory changes, are crucial for the success of precast concrete manufacturers.	Warszawski, A. (1982); Adinyira, Ayarkwa, & Aidoo (2014); Holton (2009); Peng & Pheng (2011); Reichenbach & Kromoser (2021)
Inventory Management	Effective inventory management practices minimize excess inventory, reduce storage costs, and ensure timely availability of materials for precast concrete production.	Sacks, Eastman, & Lee (2004); Tai, H. W., Chen, J. H., Cheng, J. Y., Wei, H. H., Hsu, S. C., & Liu, H. C. (2021); Nmai, Ko, Vickers, Bury, & Lianopoulos (2022); Pan, M., & Pan, W. (2019); Xiong, Chu, Li, Du, & Wang (2021)
Resource (Material) Management	Optimizing material usage and minimizing waste are essential for sustainable and cost-effective precast concrete production.	Nmai, Ko, Vickers, Bury, & Lianopoulos (2022); Adinyira, Ayarkwa, & Aidoo (2014); Bock, 2017; Reichenbach & Kromoser (2021); Benjaoran, V., & Dawood, N. (2005)
Schedule Planning	Effective scheduling ensures efficient allocation of resources, minimizes downtime, and optimizes production output in precast concrete manufacturing.	Rangrao Chougule, n.d.; Tai, H. W., Chen, J. H., Cheng, J. Y., Wei, H. H., Hsu, S. C., & Liu, H. C. (2021); Xiong, Chu, Li, Du, & Wang (2021); Peñaloza, G. A., Formoso, C. T., & Saurin, T. A. (2017); Warszawski, A. (1982)
Lean Construction	Applying lean construction principles, such as value stream mapping and continuous improvement, enhances efficiency and reduces waste in precast concrete production processes.	Adinyira, Ayarkwa, & Aidoo (2014); Tai, H. W., Chen, J. H., Cheng, J. Y., Wei, H. H., Hsu, S. C., & Liu, H. C. (2021); Wang, Z., Hu, H., & Gong, J. (2018); Benjaoran, V., & Dawood, N. (2005); Sacks, Eastman, & Lee (2004)

Table 2.1: Continue

Assembly& Testing	Efficient assembly and thorough testing of precast concrete elements ensure quality and reliability, meeting project requirements and specifications.	Skrzypczak (2023); Tai, H. W., Chen, J. H., Cheng, J. Y., Wei, H. H., Hsu, S. C., & Liu, H. C. (2021); Wang, Z., Hu, H., & Gong, J. (2018); Reichenbach & Kromoser (2021); Pan, M., & Pan, W. (2019)
Climate Changing	Adapting production processes to mitigate the impact of climate change, such as reducing carbon emissions and conserving resources, is essential for sustainable precast concrete manufacturing.	Aidoo & Technology, 2014; Nmai, Ko, Vickers, Bury, & Lianopoulos (2022); Reichenbach & Kromoser (2021); Holton (2009); Peng & Pheng (2011)
Durability& Sustainability	Prioritizing durability and sustainability in material selection and production processes ensures the longevity and environmental friendliness of precast concrete elements.	Holton, 2009; Peng & Pheng, 2011; Nmai, Ko, Vickers, Bury, & Lianopoulos (2022); Reichenbach & Kromoser (2021); Benjaoran, V., & Dawood, N. (2005)
Re-cycling	Incorporating recycled materials into precast concrete production reduces environmental impact, conserves natural resources, and supports sustainable manufacturing practices.	Benjaoran, V., & Dawood, N. (2005); Nmai, Ko, Vickers, Bury, & Lianopoulos (2022); Pan, M., & Pan, W. (2019); Xiong, Chu, Li, Du, & Wang (2021); Adinyira, Ayarkwa, & Aidoo (2014)
BIM	Utilizing Building Information Modeling (BIM) enhances collaboration, coordination, and efficiency in precast concrete design, fabrication, and construction processes.	Pan, M., & Pan, W. (2019); Tai, H. W., Chen, J. H., Cheng, J. Y., Wei, H. H., Hsu, S. C., & Liu, H. C. (2021); Wang, Z., Hu, H., & Gong, J. (2018); Xiong, Chu, Li, Du, & Wang (2021); Nmai, Ko, Vickers, Bury, & Lianopoulos (2022)
HSE Training	Providing comprehensive health, safety, and environmental (HSE) training ensures a safe work environment and compliance with regulations in precast concrete production facilities.	Pan & Pan, 2016; Tai, H. W., Chen, J. H., Cheng, J. Y., Wei, H. H., Hsu, S. C., & Liu, H. C. (2021); Sacks, Eastman, & Lee (2004); Benjaoran, V., & Dawood, N. (2005); Xiong, Chu, Li, Du, & Wang (2021)

3. METHODOLOGY

As part of this comprehensive study to investigate the critical success factors associated with precast concrete manufacturing, a rigorous examination is conducted through the application of a structured questionnaire designed to explain the comprehensive dynamics of precast concrete manufacturing. The main objective of this research is to gain valuable insights into the factors that significantly influence operational excellence, quality assurance and overall competitiveness in the precast concrete industry.

The methodology used in this study is based on a representative sample of stakeholders and industry professionals, systematic data collection through the implementation of a well-designed survey. This survey has been prepared to capture a comprehensive range of perspectives and experiences covering the critical success factors common in precast concrete production. Through the survey, participants are invited to share their views, experiences and thoughts on various aspects related to precast concrete production, including, but not limited to, quality control measures, production efficiency, workforce capabilities and technological integration.

The structured survey approach represents a powerful methodology for collecting quantitative data from a diverse and representative sample of participants in the precast concrete industry. By involving a wide range of stakeholders, including manufacturers, engineers, contractors and industry experts, the survey aims to capture a rich range of perspectives and experiences that reflect the diversity and experiences of precast concrete production. It should also be noted that the survey tool is designed to ensure the anonymity and confidentiality of participants. This commitment to confidentiality encourages participants to give open and sincere answers about the results. The privacy environment created in this way encourages participants to give open and sincere answers about the results.

The data collected through the survey will be subjected to an analysis using advanced statistical techniques to Decipher patterns, trends and relationships between various factors. Therefore, the study aims to reveal detailed insights into the critical success factors affecting operational excellence and competitiveness in the precast concrete industry.

In addition, it is thought that the findings of this study will provide actionable recommendations and best practices that can inform and direct interest in continuous improvement processes in the precast concrete production sector. These recommendations may include strategies such as improving quality control measures, optimizing production processes, taking advantage of technological developments and investing in workforce development initiatives.

In summary, this study represents a detailed process to explore the critical success factors associated with precast concrete production. The research uses a structured survey methodology and rigorous data analysis techniques to provide valuable forecasts and recommendations to the precast concrete industry.

3.1. Questionnaire Design

The design of the questionnaire should be the result of a rigorous process that draws on opinions and experiences collected from a large number of sources. These include a comprehensive review of the relevant literature, insights from the experiences of industry professionals, and inputs from subject matter experts. The survey has been prepared through the synthesis of these two sources in order to address the important aspects of precast concrete production. The survey draws on both academic research and practical applications to gain insights into the latest trends and practices in the precast concrete industry.

The questions were carefully included using the important findings obtained from the creation and organisation of the survey, the insights obtained from industry practices and the existing literature. The purpose of the survey is to collect a wide range of information about precast concrete production by comprehensively revealing the participants' perspectives and experiences, with the aim of understanding the main industry challenges. Consequently, respondents are anticipated to furnish comprehensive and valuable feedback by responding to the questionnaire.

The survey was devised using an approach that incorporates both structured questions and open-ended inquiries, which permit respondents to express their diverse experiences and perspectives. This methodology enables respondents to engage with the subject matter from multiple vantages, thereby facilitating the expression of their views in a clear and coherent manner. Furthermore, efforts have been made to ensure

the survey's accessibility and transparency by providing explanatory notes when necessary to assist respondents in comprehending and responding to the questions effectively.

3.2. Description of the Participants

Participants are encouraged to provide detailed information about their professional background in the construction industry, including their roles related to precast concrete production, years of experience and areas of expertise. In addition, they will be able to share their views on their current corporate affiliations, which may include information about the type and size of companies they work for. These details will help to correlate the responses and provide valuable insights into the perspectives presented. By understanding the demographic and professional profiles of the participants, it is aimed to draw meaningful conclusions about the critical success factors in precast concrete production from the collected data. Participants will be assured that all information provided will be kept confidential and will be used only for research purposes. His contributions are extremely valuable and his views will play an important role in advancing knowledge in the field of precast concrete production.

3.3. Data Collection

The thesis questionnaire was distributed to industry representatives via e-mail and other digital communication channels. In this process, approximately 310 stakeholders were reached, and the survey was announced. Various communication channels were used to reach the relevant people and encourage their participation. A total of 106 responses were collected and the survey was completed, resulting in a participation rate of 34%. The participants' data were collected and stored using online platforms such as Google Doc. This platform facilitates the organization and accessibility of survey responses. Participants entered their responses and recorded their data using this special platform to complete the survey. The results were used to analyze the collected data and to prepare the relevant sections of the thesis. This process has been meticulously managed to ensure the effective implementation of the survey and the collection of data.

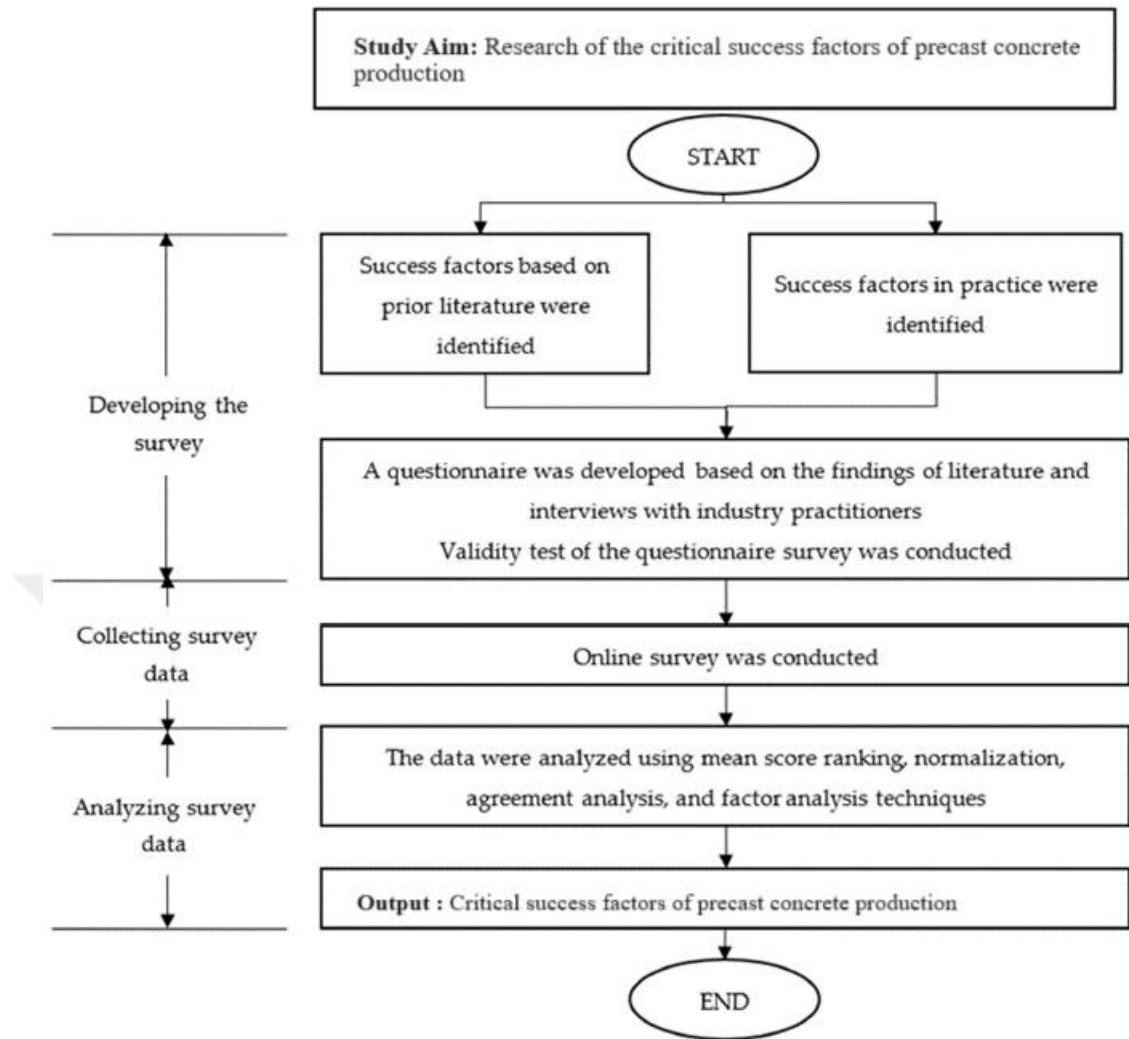


Figure 3.1: Conduct of the research.

4. RESULTS

The results of the questionnaire, completed by 106 participants via online channels, were analysed using the SPSS program. The objective of this analysis was to determine the relationships between variables in the survey data and to group these variables under a smaller number of factors.

4.1. Demographic Data Analysis

The descriptive statistics obtained after analyzing the data obtained as a result of the questionnaire in the SPSS program are given below. The analysis of the questions asked for the demographic structure research of our questionnaire is explained with figures.

4.1.1. Age Statement of Respondents

Table 4.1: Age statistics of respondents.

Total Response	106,00
Mean	40,90
Median	40,00
Mode	42,00
Minimum	24,00
Maximum	70,00

According to the **Table 4.2**, the average age of 106 participants was found to be 40.9 years. The oldest participant was 70 years old and the youngest participant was 24 years old.

4.1.2. Gender of Respondents

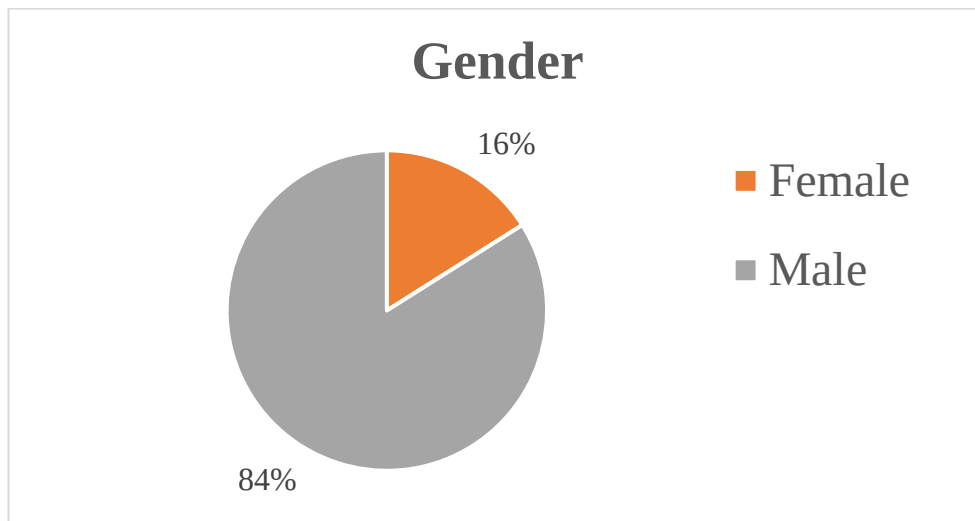


Figure 4.5: Gender of survey participants.

While 16% of the respondents were female, 84% of them were male. It is noteworthy that the sector has few female employees. Considering that the survey participants are in managerial/expert positions, it should be noted that the ratio is high.

4.1.3. Education Statement of Respondents

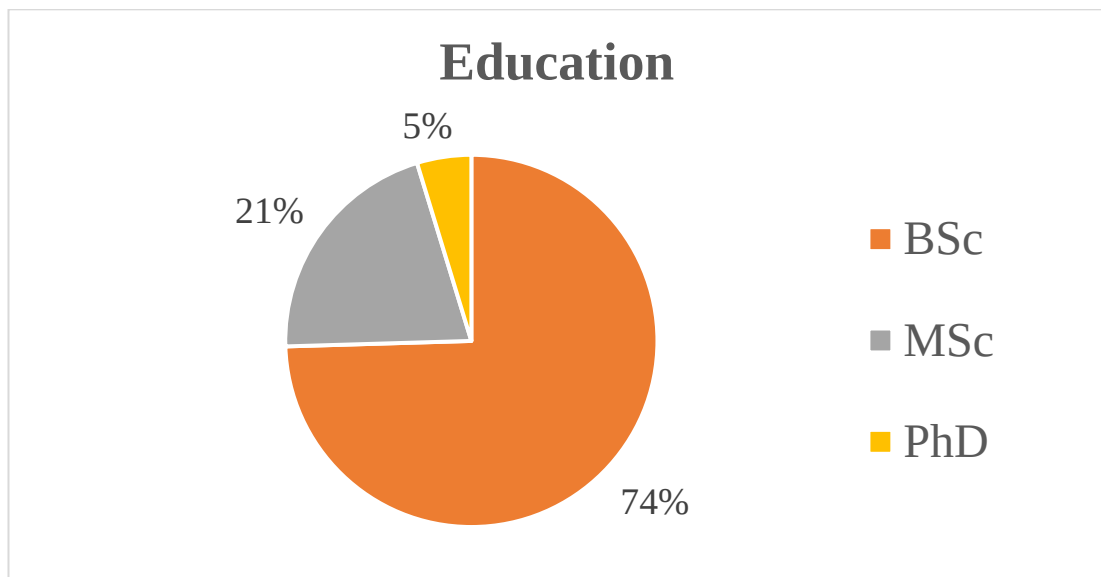


Figure 4.6: Educational State of Parpticipants

When we analyse the educational level of the survey participants, PhD graduates were the lowest with 5%. This rate was followed by MSc graduates with 21%. The majority of the respondents were bachelor's degree graduates with a rate of 74.

4.1.4. Experience Years of Respondents

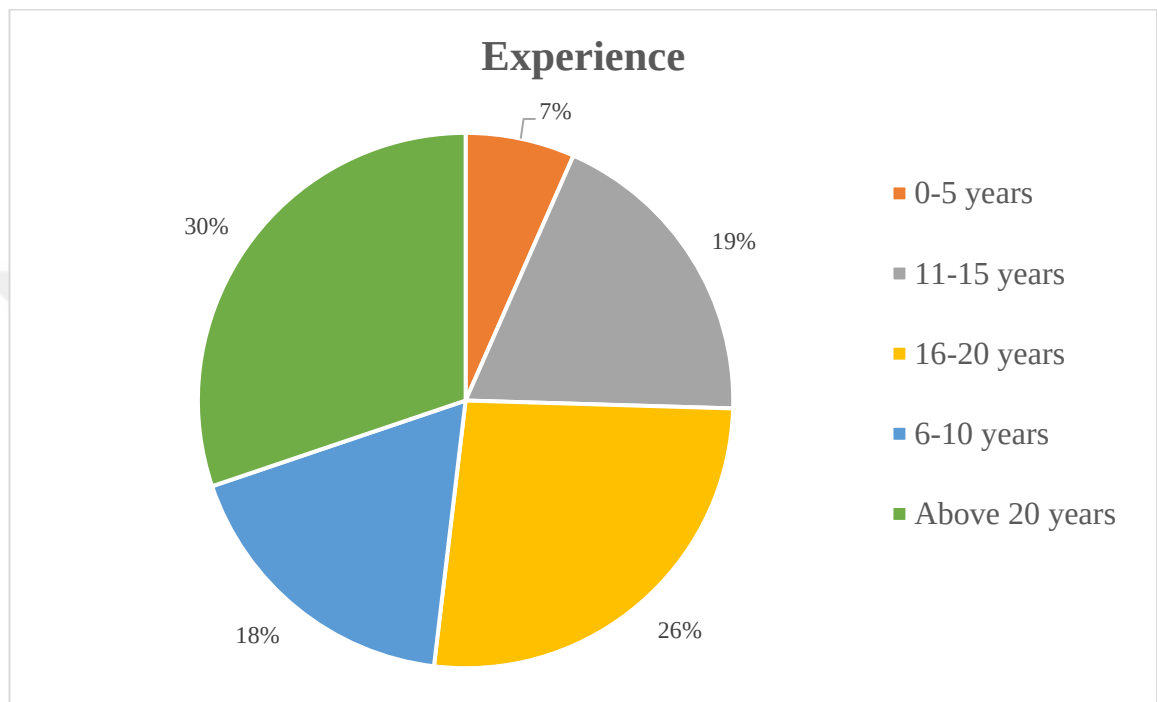


Figure 4.7: Experience Years of Participants

When the experience and experience periods of the respondents are analysed, the sum of those with 16-20 years and more than 20 years of experience is 56% higher than the other scales. In other words, more than half of the respondents have 16 years and more experience. With 44%, less than half of them have 15 years and less experience.

4.1.5. Working Role of Respondents

The **Figure 4.8** below shows the ratios of the duties of the respondents in the companies they work in. Employees working as engineers were the most responding group with 29%. They were followed by Department Chiefs and Project Managers with 25 %.

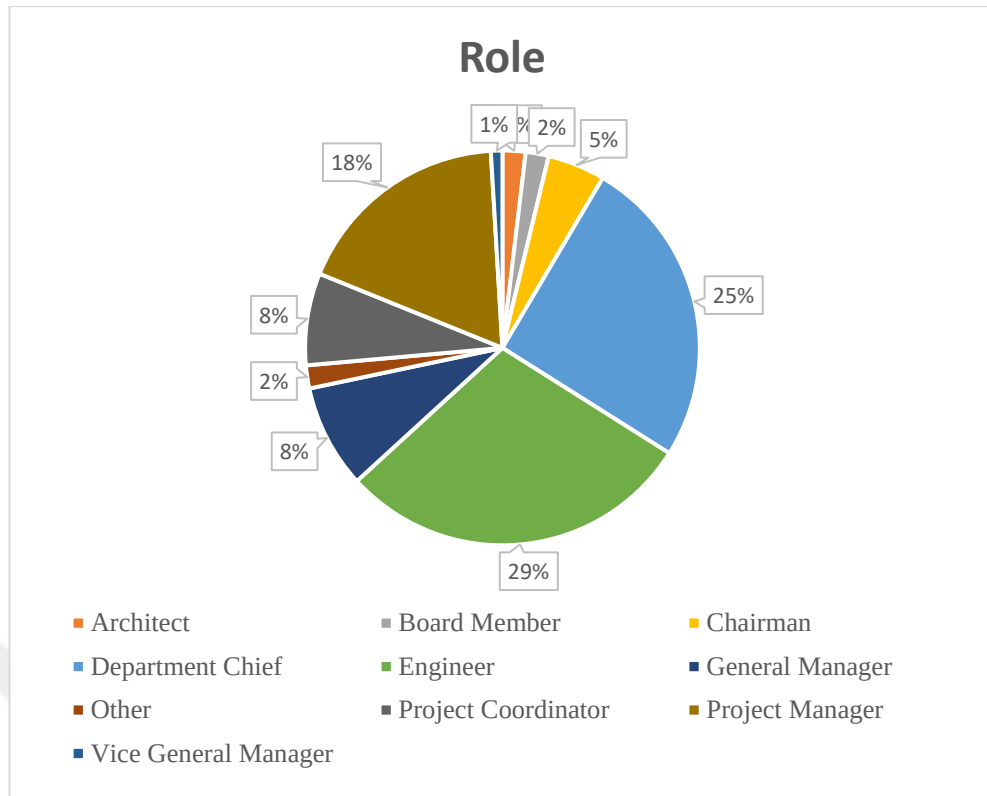


Figure 4.8: Working Role of Participants

4.1.6. Which Sector of Respondents

Figure 4.5 shows the ratios of the sectors in which the participants work. There were participants from a wide range of sectors.

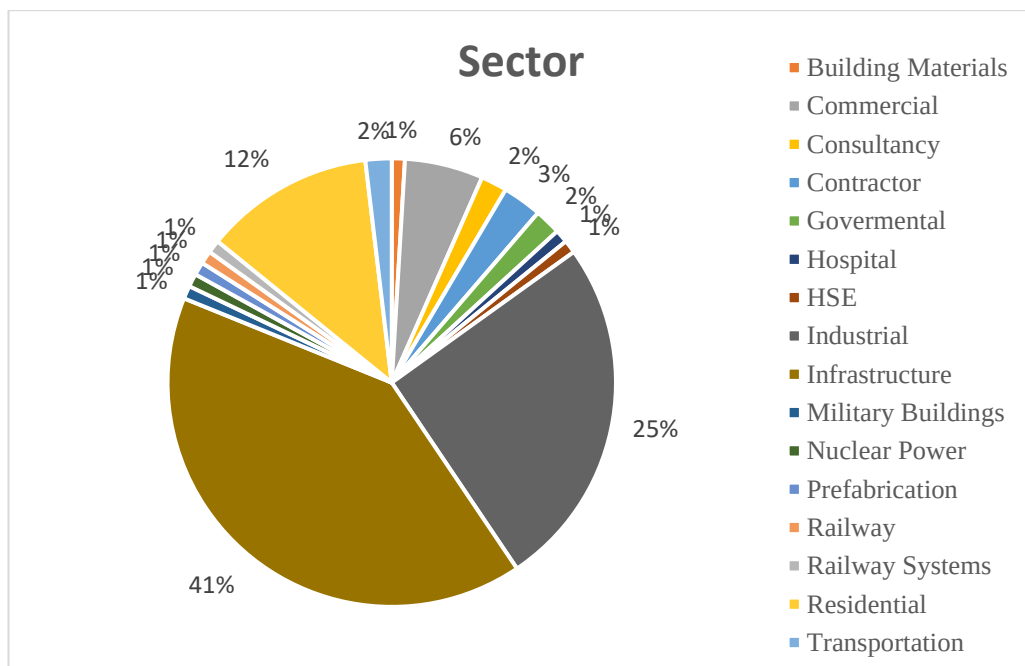


Figure 4.5: Working Sector of Participants.

4.1.7. Company Age at Respondents

Figure 4.6 shows the age of the companies where the participants work. Here, it is seen that the majority of the participants are companies that have been serving in the sector for 20 years and more.

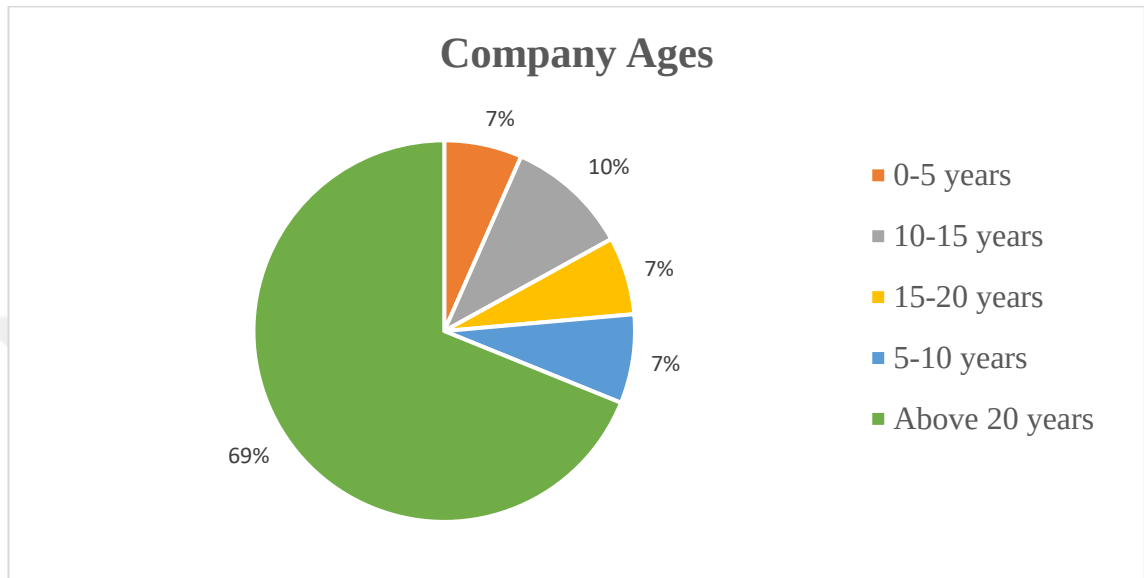


Figure 4.6: Company Ages of Participants

4.1.8. Total Annual Revenue of Company's at Respondents

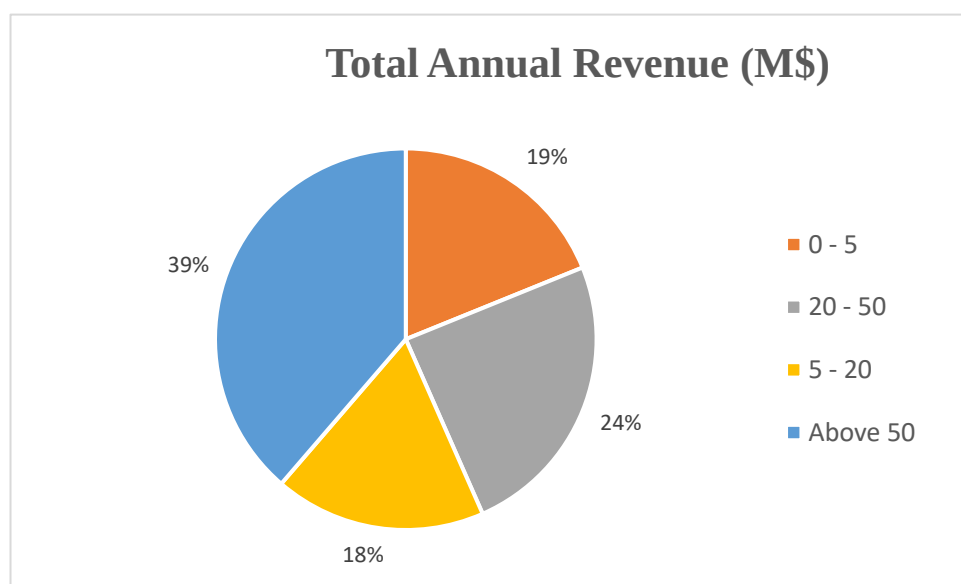


Figure 4.7: Total Revenue of Company's of Participants

4.1.9. Total Employee of Company's at Respondents

Table 4.2: Company's employee statistics.

Number of Company	106
Mean	1121
Median	500
Mode	1000
Minimum	2
Maximum	25000

4.2. Factor Analysis

Exploratory factor analysis was performed to investigate the critical success factors of precast concrete production. Exploratory Factor Analysis (EFA) is a multivariate statistical technique typically used to understand the structure of data and discover patterns in large datasets. The primary objective of EFA is to identify relationships and structures among variables in the dataset. This analytical method is generally not based on a pre-determined theoretical framework like Confirmatory Factor Analysis (CFA), but rather aims to uncover natural structures within the dataset.

Descriptive statistics of 106 responses to the questionnaire are given in the table below. According to the first findings here, the most important factor is 'Schedule Planning' and the least important factor is 'Virtual Reality'.

Table 4.3: Criterias of factors researching.

Labor Force	FR1
Automation	FR2
Just-in Time	FR3
QA/QC Manegement	FR4
Robotics & AI	FR5
Visual Management	FR6
Virtual Reality	FR7
Transportion	FR8
Market Conditions	FR9
Inventory Management	FR10
Resource (Material) Management	FR11
Schedule Planning	FR12
Lean Construction	FR13
Assembly&Testing	FR14
Climate Changing	FR15
Durability&Sustainability	FR16
Re-cycling	FR17
BIM	FR18
HSE Training	FR19

Table 4.4: Descriptive statistics factors.

	Mean	Std. Deviation	Variance
FR12	4,21	0,97	0,95
FR4	4,18	1,01	1,02
FR3	4,08	0,95	0,91
FR8	4,07	1,00	1,00
FR11	3,99	0,98	0,96
FR14	3,95	1,05	1,09
FR10	3,91	1,02	1,04
FR19	3,87	1,16	1,33
FR9	3,78	1,06	1,12
FR16	3,76	1,11	1,23
FR2	3,66	1,16	1,35
FR13	3,56	0,96	0,92
FR1	3,55	1,06	1,13
FR18	3,50	1,20	1,43
FR6	3,32	1,13	1,29
FR17	3,27	1,17	1,36
FR15	3,10	1,12	1,26
FR5	3,02	1,23	1,50
FR7	2,85	1,22	1,48

The Kaiser-Meyer-Olkin (KMO) measure, with a value of 0.910, is at an acceptable level, indicating that the dataset is suitable for factor analysis. The Bartlett's Test of Sphericity yielded a significant Chi-Square value of 1518.273 (< 0.001), demonstrating sufficient correlations among the variables.

Table 4.5: KMO and Bartlett's test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0,910
Bartlett's Test of Sphericity	Approx. Chi-Square	1518,273
	df	171
	Sig.	0,000

Communalities indicate the proportion of variance in each variable explained by the factors extracted through factor analysis. Initially set at 1.000 for each variable, communalities after extraction range from 0.459 to 0.829. For instance, a communalities value of 0.829 for FR5 suggests that this variable explains 82.9% of the total variance. These values highlight the contribution of each variable to the model after factor analysis.

Table 4.6: Communalities.

	Initial	Extraction
FR5	1,000	0,829
FR12	1,000	0,760
FR16	1,000	0,756
FR6	1,000	0,749
FR8	1,000	0,735
FR7	1,000	0,733
FR4	1,000	0,722
FR2	1,000	0,719
FR10	1,000	0,707
FR11	1,000	0,706
FR3	1,000	0,702
FR14	1,000	0,700
FR17	1,000	0,698
FR9	1,000	0,653
FR15	1,000	0,637
FR19	1,000	0,583
FR13	1,000	0,562
FR18	1,000	0,526
FR1	1,000	0,459

The Total Variance Explained table shows that the first three components account for 68.090% of the total variance. Specifically, Component 1 explains 52.198%, Component 2 explains 9.703%, and Component 3 explains 6.188% of the variance. This cumulative explanation indicates that the model captures a substantial portion of the variability in the dataset.

Table 4.7: Total variance explained.

Compon ent	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9,92	52,20	52,20	9,92	52,20	52,20	6,31	33,21	33,21
2	1,84	9,70	61,90	1,84	9,70	61,90	3,34	17,56	50,76
3	1,18	6,19	68,09	1,18	6,19	68,09	3,29	17,33	68,09
4	0,88	4,64	72,73						
5	0,84	4,44	77,17						
6	0,68	3,56	80,73						
7	0,50	2,64	83,37						
8	0,45	2,39	85,76						
9	0,43	2,25	88,01						
10	0,37	1,94	89,95						
11	0,33	1,72	91,67						
12	0,28	1,46	93,13						
13	0,26	1,39	94,51						
14	0,25	1,34	95,85						
15	0,24	1,25	97,10						
16	0,18	0,95	98,05						
17	0,15	0,77	98,82						
18	0,13	0,66	99,48						
19	0,10	0,52	100,00						

The Component Matrix illustrates the relationships between variables and the components derived from factor analysis. For example, FR1 has a loading of 0.654 on Component 1, indicating a strong association with this component. This matrix clarifies how each variable contributes to each component.

Table 4.8: Component matrix

	Component		
	1	2	3
FR1	0,590		
FR2	0,640		0,542
FR3	0,711		0,341
FR4	0,804		
FR5	0,608	0,572	0,362
FR6	0,748	0,429	
FR7	0,592	0,614	
FR8	0,780	-0,354	
FR9	0,704	-0,393	
FR10	0,805		
FR11	0,818		
FR12	0,855		
FR13	0,746		
FR14	0,802		
FR15	0,591		-0,479
FR16	0,775		-0,387
FR17	0,650	0,396	-0,345
FR18	0,648	0,323	
FR19	0,763		

The Rotated Component Matrix that where blow, provides a clearer picture of the relationships between variables and the components identified through Principal Component Analysis, following Varimax rotation. The rotation process helps to achieve simpler and more interpretable component structures by maximizing the variance of squared loadings of a factor (component) across variables, making high loadings higher and low loadings lower for each component.

Component 1:

- FR1 (0.654): FR1 has a strong loading on Component 1, indicating it is primarily associated with this factor.
- FR3 (0.779): FR3 is very strongly associated with Component 1.
- FR4 (0.763): FR4 also shows a strong relationship with Component 1.
- FR8 (0.814): FR8 is highly correlated with Component 1.
- FR9 (0.763): FR9 demonstrates a strong loading on Component 1.

- FR10 (0.680): FR10 has a moderate to strong association with Component 1.
- FR11 (0.688): FR11 is strongly loaded on Component 1.
- FR12 (0.742): FR12 is significantly associated with Component 1.
- FR14 (0.726): FR14 has a strong loading on Component 1.
- FR19 (0.595): FR19 shows a moderate association with Component 1.

Component 2:

- FR2 (0.673): FR2 has a strong loading on Component 2.
- FR5 (0.878): FR5 shows a very high loading on Component 2, indicating it is primarily associated with this factor.
- FR6 (0.686): FR6 is significantly associated with Component 2.
- FR7 (0.747): FR7 has a strong loading on Component 2.
- FR13 (0.346): FR13 has a moderate loading on Component 2.
- FR18 (0.503): FR18 shows a moderate association with Component 2.
- FR19 (0.321): FR19 has a weak to moderate loading on Component 2.

Component 3:

- FR6 (0.433): FR6 has a moderate loading on Component 3.
- FR7 (0.414): FR7 shows a moderate association with Component 3.
- FR10 (0.469): FR10 has a moderate loading on Component 3.
- FR11 (0.437): FR11 demonstrates a moderate association with Component 3.
- FR12 (0.375): FR12 has a weaker but still notable loading on Component 3.
- FR13 (0.418): FR13 shows a moderate relationship with Component 3.
- FR14 (0.381): FR14 has a moderate loading on Component 3.
- FR15 (0.753): FR15 shows a very strong association with Component 3.

- FR16 (0.673): FR16 is strongly loaded on Component 3.
- FR17 (0.719): FR17 has a strong association with Component 3.
- FR18 (0.448): FR18 shows a moderate loading on Component 3.

The Varimax rotation has distributed the loadings in such a way that each component now has distinct and clear associations with specific variables. This makes it easier to interpret which variables are most relevant to each component and to understand the underlying structure of the data. The rotation converged in 8 iterations, indicating the process efficiently achieved a stable solution. The clear separation of loadings across components after rotation indicates well-defined factors, which can be interpreted to understand the data structure better.

Table 4.9: Rotated component matrix

	Component		
	1	2	3
FR1	0,654		
FR2	0,508	0,673	
FR3	0,779	0,307	
FR4	0,763	0,334	
FR5		0,878	
FR6	0,301	0,686	0,433
FR7		0,747	0,414
FR8	0,814		
FR9	0,763		
FR10	0,680		0,469
FR11	0,688		0,437
FR12	0,742		0,375
FR13	0,517	0,346	0,418
FR14	0,726		0,381
FR15			0,753
FR16	0,541		0,673
FR17		0,393	0,719
FR18		0,503	0,448
FR19	0,595	0,321	0,355

The Component Transformation Matrix shows how the original components are transformed into rotated components through the Varimax rotation process. The values

in this matrix indicate the correlation between the original and rotated components, thereby facilitating the interpretation of the rotated solution.

Component 1:

- The first original component has strong positive correlations with the first rotated component (0.746), indicating that most of the variance in the first original component is captured by the first rotated component.
- There are also moderate correlations with the second (0.457) and third (0.485) rotated components, suggesting that the original first component influences these rotated components to a lesser extent.

Component 2:

- The second original component has a negative correlation with the first rotated component (-0.634), indicating an inverse relationship.
- It has a strong positive correlation with the second rotated component (0.710), showing that this rotated component captures the majority of the variance from the second original component.
- There is also a moderate positive correlation with the third rotated component (0.306).

Component 3:

- The third original component shows a weak positive correlation with the first rotated component (0.204).
- A moderate positive correlation is observed with the second rotated component (0.536).
- A strong negative correlation is observed between the third rotated component and the third original component (-0.819), indicating that the third rotated component captures the majority of the variance from the third original component in an inverse direction.

Table 4.10: Component transformation matrix

Component	1	2	3
1	0,746	0,457	0,485
2	-0,634	0,710	0,306
3	0,204	0,536	-0,819

Each coefficient in the matrix represents the importance of the corresponding variable in the calculation of component scores. Positive coefficients show a direct relationship in which an increase in the variable increases the component score. Negative coefficients show an inverse relationship in which the increase in the variable reduces the component score. These scores become important for understanding the underlying structure of the data and for further analysis, such as regression or clustering based on component scores. The matrix provides a clear direction for measuring the contributions of each variable to the overall component scores and thus facilitates a more detailed interpretation of the data.

The Component Score Coefficient Matrix shows the coefficients used to calculate the scores for each component based on the observed variables. These coefficients represent the weight that each variable contributes to the corresponding component score.

Component 1:

- Variables like FR1 (0.172), FR2 (0.099), FR3 (0.210), FR4 (0.161), FR8 (0.187), FR9 (0.178), FR10 (0.094), FR11 (0.097), FR12 (0.120), FR13 (0.032), FR14 (0.125), and FR19 (0.072) contribute positively to Component 1.
- Negative contributions are noted from variables such as FR5 (-0.088), FR6 (-0.078), FR7 (-0.154), FR15 (-0.121), FR16 (0.014), FR17 (-0.147), and FR18 (-0.070).

Component 2:

- Significant positive contributions to Component 2 are observed from variables FR2 (0.325), FR5 (0.413), FR6 (0.233), FR7 (0.298), FR13 (0.029), FR17 (0.025), and FR18 (0.135).

- Negative contributions include FR1 (0.003), FR3 (0.079), FR4 (0.051), FR8 (-0.083), FR9 (-0.145), FR10 (-0.105), FR11 (-0.073), FR12 (-0.033), FR14 (-0.085), FR15 (-0.099), FR16 (-0.166), and FR19 (0.021).

Component 3:

- Positive contributions to Component 3 come from variables FR6 (0.056), FR7 (0.079), FR10 (0.123), FR11 (0.089), FR12 (0.024), FR13 (0.080), FR14 (0.054), FR15 (0.403), FR16 (0.297), FR17 (0.338), FR18 (0.115), and FR19 (0.028).
- Negative contributions are made by variables FR1 (-0.145), FR2 (-0.325), FR3 (-0.250), FR4 (-0.129), FR5 (-0.127), FR8 (-0.048), and FR9 (0.008).

Table 4.11 : Component score coefficient matrix

	Component		
	1	2	3
FR1	0,172	0,003	-0,145
FR2	0,099	0,325	-0,325
FR3	0,210	0,079	-0,250
FR4	0,161	0,051	-0,129
FR5	-0,088	0,413	-0,127
FR6	-0,078	0,233	0,056
FR7	-0,154	0,298	0,079
FR8	0,187	-0,083	-0,048
FR9	0,178	-0,145	0,008
FR10	0,094	-0,105	0,123
FR11	0,097	-0,073	0,089
FR12	0,120	-0,033	0,024
FR13	0,032	0,029	0,080
FR14	0,125	-0,085	0,054
FR15	-0,121	-0,099	0,403
FR16	0,014	-0,166	0,297
FR17	-0,147	0,025	0,338
FR18	-0,070	0,135	0,115
FR19	0,072	0,021	0,028

The Component Score Covariance Matrix illustrates the covariance between the scores of different components. The diagonal elements represent the variances of component scores, while the non-diagonal elements represent the covariances between component scores.

1. Diagonal Elements:

- The variances of the component scores for Components 1, 2, and 3 are all 1.000. This indicates that each component has been standardized to have a variance of one.

2. Off-Diagonal Elements:

- The covariances between the different components are all equal to zero. This indicates that the components are orthogonal to one another, which implies that they are uncorrelated. Each component is capable of capturing unique variance in the data, without overlapping with the other components.

This matrix shows that the components are independent of each other. Each component describes a different aspect of the data structure. In this aspect, it is a result of the Varimax rotation, which aims to maximize the variance explained by each component while maintaining the independence of the components. Component scores can be compared and interpreted using standardized variances. The components are different and make a unique contribution to the overall variance in the dataset.

Table 4.12: Component score covariance matrix

Component	1	2	3
1	1,000	0,000	0,000
2	0,000	1,000	0,000
3	0,000	0,000	1,000

5. DISCUSSION

The survey results obtained from 106 participants through online channels were analyzed in this study. The analysis, performed using the SPSS program, aimed to identify relationships among the survey data variables and group these variables under fewer factors. The findings will be discussed in this section.

5.1. Demographic Data Analysis

The demographic structure of the participants was examined, and it was found that the average age of the participants is 40.9 years. The oldest participant is 70 years old, while the youngest is 24 years old. This age distribution indicates that the sector has an experienced and mature workforce, reflecting the importance of long-term expertise in the industry.

Eighty-four percent of the participants are male, and 16% are female. In consideration of the low number of female employees in the sector, it was observed that the ratio of women in managerial and expert positions is relatively high. This highlights the gender imbalance in the sector and the gender disparity in managerial positions, suggesting that while overall female representation is low, women tend to occupy significant roles when they are present.

In terms of educational attainment, 74% of participants hold a bachelor's degree, 21% hold a master's degree, and 5% hold a doctorate. This indicates that the majority of sector employees have a high level of education, which is essential for comprehending and executing the intricate processes involved in prefabricated concrete production.

Upon analysing the years of experience, it was found that 56% of participants have accrued 16 years or more of experience. This indicates that a considerable proportion of the participants have been engaged in the sector for a considerable length of time, amassing considerable experience. Such extensive experience is likely to be a pivotal factor in the successful execution of projects and innovation within the sector.

When the job distribution of the participants was examined, it was seen that engineers were the most responsive group with 29%, followed by department heads and project managers with 25%. This distribution shows that engineers have an important position

in the sector. The presence of a large number of engineers emphasizes the technical nature of the work, while the significant representation of managers emphasizes the importance of strategic supervision and project coordination.

When the sectors in which the participants work are examined, it turns out that they represent various industries. This diversity increases the ability of the study to reflect the situation in various sectors, suggesting that the findings may be applicable in different contexts in the construction sector.

In terms of the age of the companies, it is seen that the majority of the participants have been working in companies that have been operating in the industry for 20 years or more. This indicates that the participants work in well-established and experienced companies, probably have well-developed processes and a deep understanding of the industry's best practices.

The analysis of the annual revenues of the companies where the participants worked reveals a wide distribution. This suggests that companies of different scales are represented, from small firms to large companies, and there is a wide applicability of the findings.

A more detailed examination of the number of employees in companies revealed that the average number of employees is 1121, the minimum number of employees is 2 and the maximum number of employees is 25,000. These data show that the survey covers both small and large-scale companies and provides insights that are important for organizations of various sizes

5.2. Factor Analysis

An exploratory factor analysis was conducted with the objective of investigating the critical success factors of prefabricated concrete production. Exploratory factor analysis (EFA) is a multivariate statistical technique employed to elucidate the structure of data and identify patterns within large data sets. The initial findings indicate that the most significant factor is 'Scheduling Planning', while 'Virtual Reality' is the least significant.

The Kaiser-Meyer-Olkin (KMO) measurement value was found to be 0.910, indicating that the data set is suitable for factor analysis. The Bartlett's Sphericity Test yielded a

significant Chi-square value (1518.273, $p < 0.001$), indicating a sufficient correlation between the variables. December. The results confirm that the sample size and data quality are sufficient to conduct a reliable factor analysis.

The factor analysis yielded the proportions of each variable in the total variance explained. The values range from 0.459 to 0.829, thereby emphasising the contribution of each variable to the total variance described by the model.

The Total Variance Description table indicates that the first three components collectively account for 68.090% of the total variance. This finding indicates that the model captures a significant proportion of the variability in the dataset, making the three identified components important for further analysis and interpretation.

The Component Matrix illustrates the interrelationships between the variables and the components derived from factor analysis. The rotated component matrix provides a more accurate representation of the relationships between variables and components. This facilitates the generation of more straightforward and comprehensible structures from the components derived from factor analysis.

The identified components can be categorized and named based on the criteria as follows:

5.2.1. Component 1: Operational Efficiency

This component includes factors such as:

- Labor Force (FR1)
- Just-in-Time (FR3)
- QA/QC Management (FR4)
- Transportation (FR8)
- Market Conditions (FR9)
- Inventory Management (FR10)
- Resource (Material) Management (FR11)
- Schedule Planning (FR12)
- Lean Construction (FR13)

- Assembly & Testing (FR14)

Operational Efficiency covers the processes and resources involved in the efficient functioning of production activities. Timely and Quality Control emphasizes the importance of reliable operations, Effective resource management and the overall optimization of production programs.

5.2.2 Component 2: Technological Integration

This component includes factors such as:

- Automation (FR2)
- Robotics & AI (FR5)
- Visual Management (FR6)
- Virtual Reality (FR7)
- BIM (FR18)

Technological integration encompasses the incorporation of advanced technologies into production processes. This encompasses automation, robotics, artificial intelligence, and digital tools such as BIM and virtual reality. The aforementioned technologies play a pivotal role in enhancing productivity, precision, and innovation within the sector.

5.2.3. Component 3: Sustainability and Adaptability

This component includes factors such as:

- Climate Change (FR15)
- Durability & Sustainability (FR16)
- Recycling (FR17)
- HSE Training (FR19)

Sustainability and Compliance focuses on the environmental and adaptive aspects of production. This includes measures to combat climate change, ensure the durability and sustainability of materials, promote recycling, and implement health, safety and

environmental education. These factors have become important for creating durable and environmentally responsible manufacturing practices.

As a result, the resulting factors were well defined and helped to better understand the data structure. These factors provide an important basis for understanding the underlying structure of the data and conducting more detailed analyses. The separation of data into components highlighted the unique contribution of each component to the overall variance of the data. This study can be considered as an important step in determining the critical success factors in the production of prefabricated concrete and can provide valuable insights for both academic research and practical applications in industry.

5.3. Literature Comparing

The findings of this study are compared with similar studies in the literature to evaluate the consistency and significance of the identified factors in prefabricated concrete production. This comparison provides a broader context and validates the results within the existing body of knowledge.

5.3.1. Operational Efficiency

The first component, Operational Efficiency, is consistent with previous studies that emphasise the importance of efficient resource management, quality control, and streamlined production processes in the construction industry. For instance, studies by Ofori (2015) and Marhani et al. (2013) highlight the critical role of just-in-time production, quality assurance/quality control (QA/QC), and effective scheduling in improving operational performance. These studies indicate that the optimisation of labour force management, transportation logistics, and inventory control is essential for the minimisation of delays and costs, thus enhancing overall productivity.

Similar to the findings of this study, the literature consistently demonstrates that operational efficiency is a key determinant of success in construction projects. It has been demonstrated that effective resource and schedule management directly contributes to the timely completion of projects and the reduction of waste, which is critical for maintaining competitiveness in the market (Chan et al., 2004).

5.3.2. Technological Integration

The second component, Technological Integration, is supported by numerous studies that discuss the impact of advanced technologies on the construction industry. Research by Bock and Linner (2015) and Eastman et al. (2011) indicates that the adoption of automation, robotics, artificial intelligence (AI), and Building Information Modeling (BIM) significantly enhances precision, reduces labour costs, and improves overall project management.

The findings of this study align with those of previous research, which highlights the profound impact of digital tools and technologies on the construction industry. For instance, the utilisation of BIM has been demonstrated to enhance visualisation, coordination, and communication among project stakeholders, resulting in enhanced project efficiency (Azhar, 2011). Similarly, the utilisation of robotics and AI in construction has been identified as a means of enhancing accuracy and safety, while reducing the reliance on manual labor (Sawhney et al., 2020).

5.3.3. Sustainability and Adaptability

The third component, Sustainability and Adaptability, is in alignment with the growing body of research focused on environmental sustainability and adaptive practices in construction. The studies by Kibert (2016) and Tam et al. (2007) emphasise the importance of incorporating sustainable materials, recycling practices, and climate resilience into construction projects. These studies advocate for the adoption of green building practices and the implementation of health, safety, and environmental (HSE) training to ensure sustainable development.

The findings of this study are consistent with the existing literature, which emphasises the necessity of addressing the impacts of climate change and promoting sustainable practices within the construction industry. The integration of durability and sustainability measures is of paramount importance for extending the lifecycle of buildings and reducing the environmental footprint of construction activities (Ding, 2008). Furthermore, the prioritisation of HSE training is consistent with the literature's recommendation of enhancing worker safety and environmental awareness to mitigate risks and optimise overall project outcomes (Zhou et al., 2015).

6. CONCLUSION

This study aims to make important contributions to understanding the critical success factors in the production of prefabricated concrete. Using exploratory factor analysis, three main components have been identified: Operational Efficiency, Technological Integration, and Sustainability and Adaptability. These findings have been compared with the existing literature. It has also been supported from the literature and its consistency has been shown. It provides a comprehensive framework for valued industry stakeholders.

The first component, Operational Efficiency, includes factors such as workforce management, transportation logistics, inventory control, resource management and planning. These elements have been emphasized in the literature as important for ensuring timely and cost-effective production processes. Effective labor management has been associated with increased productivity and reduced labor costs. Similarly, efficient transport logistics is becoming very important to minimize delays and ensure timely project delivery. Inventory and resource management, together with meticulous planning, reduce waste and optimize resource utilization, thereby increasing overall operational efficiency.

The second component, Technological Integration, covers automation, robotics and artificial intelligence (AI), visual management, virtual reality and assembly and testing technologies. The integration of advanced technologies into production processes has been shown to significantly increase precision, reduce errors and improve overall productivity. For example, automation and robotics are increasingly being adopted to perform repetitive and complex tasks with high accuracy. Visual management tools and virtual reality are being used for better project visualization and planning, facilitating the early detection of possible problems and improving decision-making processes. The literature supports these findings and highlights the role of technological advances in transforming the construction sector and increasing productivity.

The third component, Sustainability and Adaptability, includes assessments for climate change, resilience and sustainability practices, and recycling efforts. This component reflects the increasing awareness and emphasis on environmental

responsibility in the industry. Sustainable practices such as the use of durable materials and recycling not only contribute to the protection of the environment, but also increase the long-term viability of construction projects. The obligation to respond to the effects of climate change emphasizes the importance of adaptability. The literature confirms these findings by highlighting a global trend towards more sustainable and durable construction practices.

6.1. Limitations

Despite the insights it provides, this study is not without limitations. Firstly, although the sample size is adequate for factor analysis, it may not fully represent the entire prefabricated concrete industry. The data were collected from a specific geographical region, which limits the generalisability of the findings to regions with different market conditions and regulatory environments. Furthermore, the rapid evolution of technology means that the relevance of the identified technological factors may change over time. Future research should employ longitudinal approaches to capture these dynamic changes over time.

Furthermore, the use of self-reported data from survey participants introduces the possibility of response biases. It is possible that participants may overstate or understate certain factors based on their personal experiences or perceptions. To address this, future research should incorporate multiple data sources, including direct observations and case studies, in order to validate and triangulate findings.

Finally, while exploratory factor analysis is a robust method for identifying underlying constructs, it is subjective in terms of factor labelling and interpretation. It is possible that different researchers may derive slightly different factors from the same dataset. Future research could benefit from the use of confirmatory factor analysis to validate the factor structure identified in this study.

6.2. Final Remarks

In conclusion, this study definitively identifies key components contributing to the success of prefabricated concrete production. It offers a structured framework for industry practitioners to enhance operational efficiency, integrate advanced technologies, and adopt sustainable practices. Despite its limitations, the findings

provide valuable insights and a basis for further research. Addressing these limitations and building upon the current study, future research can continue to advance the understanding and implementation of critical success factors in the prefabricated concrete industry.



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BIOGRAPHY

Ersin METİN, Graduating from Tuzla High School in Tuzla, Istanbul, I entered the Civil Engineering program of Kocaeli University in 2000. After graduating in 2004, I started my business life. I entered my 20th year of professional life in industrial facilities, warehouses, shopping malls and metro constructions. I joined GTU in 2022 to do my MSc. degree. I hope to graduate with this thesis and start my doctoral journey.



PUBLICATIONS AND PRESENTATIONS FROM THE THESIS

Metin, E. (2024, May). “Critical success factors of precast concrete production.”, 8th Graduate Research Symposium, Graduate Institute, Kocaeli, Türkiye



APPENDICES

APPENDIX-A: SURVEY

CRITICAL SUCCESS FACTORS OF PRECAST CONCRETE PRODUCTION

1. Please indicate your age.

2. Please indicate your gender.

☐ Female

☐ Male

3. Please indicate your level of education.

☐ PhD

☐ MSc

☐ BSc

4. How long have you been working in the construction industry?

☐ 0-5 years

☐ 6-10 years

☐ 11-15 years

☐ 16-20 years

☐ Above 20 years

5. What's current role in the construction industry?

- ☐ Chairman
- ☐ Board Member
- ☐ General Manager
- ☐ Vice General Manager
- ☐ Project Coordinator
- ☐ Project Manager
- ☐ Department Chief
- ☐ Architect
- ☐ Engineer
- ☐ Other.....

6. What's the main business area of your company?

- ☐ Infrastructure
 - ☐ Residential
 - ☐ Commercial
 - ☐ Industrial
 - ☐ Water Structures
 - ☐ Other:
-

7. How long has your company been operating in the construction industry?

- ☐ 0-5 years
- ☐ 5-10 years
- ☐ 10-15 years
- ☐ 15-20 years
- ☐ Above 20 years

8. What's the total number of employees in your company?

9. What 's annual turnover of your company? (Million USD)

- ☐ 0 - 5
- ☐ 5 - 20
- ☐ 20 - 50
- ☐ Above 50



10. Please indicate the importance level of below listed factors in the precast concrete production.

	Very Low	Low	Medium	High	Very High
Labor Force	☐	☐	☐	☐	☐
Automation	☐	☐	☐	☐	☐
Just-in Time	☐	☐	☐	☐	☐
QA/QC Manegement	☐	☐	☐	☐	☐
Robotics & AI	☐	☐	☐	☐	☐
Visual Management	☐	☐	☐	☐	☐
Virtual Reality	☐	☐	☐	☐	☐
Transportation	☐	☐	☐	☐	☐
Market Conditions	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
Resource (Material) Management	☐	☐	☐	☐	☐
Schdule Planning	☐	☐	☐	☐	☐
Lean Construction	☐	☐	☐	☐	☐
Assembly&Testing	☐	☐	☐	☐	☐
Climate Changing	☐	☐	☐	☐	☐
Durability&Sustainability	☐	☐	☐	☐	☐
Re-Cycling	☐	☐	☐	☐	☐
BIM	☐	☐	☐	☐	☐
HSE Training	☐	☐	☐	☐	☐

11. Please indicate the succes level of below listed factors in the precast concrete production.

	Poor	Fair	Average	Good	Very Good
Labor Force	☐	☐	☐	☐	☐
Automation	☐	☐	☐	☐	☐
Just-in Time	☐	☐	☐	☐	☐
QA/QC Manegement	☐	☐	☐	☐	☐
Robotics & AI	☐	☐	☐	☐	☐
Visual Management	☐	☐	☐	☐	☐
Virtual Reality	☐	☐	☐	☐	☐
Transportation (Nakliye)	☐	☐	☐	☐	☐
Market Conditions	☐	☐	☐	☐	☐
Inventory Management	☐	☐	☐	☐	☐
Resource (Material) Management	☐	☐	☐	☐	☐
Schdule Planning	☐	☐	☐	☐	☐
Lean Construction	☐	☐	☐	☐	☐
Assembly&Testing	☐	☐	☐	☐	☐
Climate Changing	☐	☐	☐	☐	☐
Durability&Sustainability	☐	☐	☐	☐	☐
Re-cycling	☐	☐	☐	☐	☐
BIM	☐	☐	☐	☐	☐
HSE Training	☐	☐	☐	☐	☐