Mekelle University

Ethiopian Institute of Technology-Mekelle

Faculty of Civil and Enviro mental Engineering

MSc in Civil Engineering (Construction Technology and Management)

Assessment of concrete prefabrication adoption in Tigray Region: barriers, benefits, and strategic framework for implementation.

By

Brhane Kahsay Desta

Advisor: Zenagebriel G/Medhn (Ph.D.)

September 2025

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A Master's Thesis Submitted to the Faculty of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science (MSc) in Civil Engineering (Construction Technology and Management)

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Board of Examiners' Approval

We undersigned members of the Board of Examiners for the final open defense of Brhane Kahsay Desta, have read and evaluated the thesis entitled "*Assessment of concrete prefabrication adoption in Tigray region: barriers, benefits, and strategic framework for implementation*" and assessed the candidate's performance. We hereby certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, with specialization in Construction Technology and Management.

Approved by Board of Examiners

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Declaration

I attest that the thesis research work titled *"Assessment of concrete prefabrication adoption in Tigray region: barriers, benefits, and strategic framework for implementation"* is my original research work and has not been presented for a degree in any other university. The material sources used in this thesis research work are duly acknowledged

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As research Advisor, I hereby certify that I have read and evaluated this thesis research paper prepared under my guidance, by Dr. Zenagebriel G/medhn Entitled *"Assessment of concrete prefabrication adoption in Tigray Region: barriers, benefits, and strategic framework for implementation"* and recommend and would be accepted as a fulfilling requirement for the Master of Science in Civil Engineering (Construction Technology and Management).

Dr. Zenagebriel G/medhn		27-12-2025
Advisor	**Signature**	**Date**

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Abstract

The global construction industry is increasingly pivoting toward modular and off-site manufacturing to address growing demands for housing and infrastructure. In the Tigray region of Ethiopia, where post-conflict reconstruction requires urgent and scalable solutions, the adoption of efficient building methodologies has become a developmental priority. This research investigates the impact of concrete prefabrication encompassing off-site manufacturing, logistics, and on-site assembly on construction efficiency and economic viability.

The study employs a mixed-methods research design, integrating interviews with industry professionals and comparative case studies of conventional versus prefabricated projects. Key Performance Indicators (KPIs) such as labor costs, material utilization, project duration, and waste generation were evaluated. Data collection was supported by 95 distributed questionnaires, yielding 73 valid responses (a 76.8% response rate), providing a robust empirical basis for analysis.

The findings demonstrate that projects utilizing prefabricated components achieved a 30% to 60% reduction in construction duration, primarily due to the concurrent execution of factory production and site preparation. Furthermore, the study identified cost savings ranging from 5% to 20%, driven by enhanced material efficiency and reduced on-site labor requirements. The controlled factory environment also contributed to superior quality control and structural consistency compared to traditional methods.

Despite these advantages, significant barriers to adoption remain, including limited local manufacturing capacity, logistical constraints, and a shortage of specialized technical expertise. To mitigate these challenges, the study recommends targeted institutional support, investment in regional production facilities, and the implementation of specialized vocational training. Strengthening policy frameworks and fostering public-private partnerships will be essential to scaling these technologies. Ultimately, this research concludes that concrete prefabrication provides a rapid, cost-effective, and resilient pathway for the reconstruction and long-term development of the Tigray region.

Keywords: concrete prefabrication, construction cost, economic efficiency, Tigray Region strategic framework.

Abbreviations

BIM	Building Information Modelling
BoUDC	Bureau of Urban Development and Construction (Tigray regional body)
BTCS	Building Technology and Construction Sector
CBO	Community-Based Organization
ECWC	Ethiopian Construction Works Corporation
EBCS	Ethiopian Building Code Standard
HDB	Housing Development Board (Singapore)
IDP	Internally Displaced Persons
JIT	Just-In-Time
NGO	Non-Governmental Organization
PBPPE	Prefabricated Building Parts Production Enterprise
PCI	Precast/Pre-stressed Concrete Institute (US standards)
RII	Relative Importance Index
SME	Small and Medium Enterprise
TVET	Technical and Vocational Education and Training
WRAP	Waste & Resources Action Program (UK)

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Chapter one

1. Introduction

1.1 Background of the study

In a lot of places around the world, people have started using concrete prefabrication, where the building pieces are made somewhere else in a factory and then taken to the construction site for assembly. It has been getting popular mainly because it saves time and usually gives better quality since things are made in a more controlled environment. It also cuts down on waste.

Prefabrication was introduced to Ethiopia earlier, but its expansion to the regional states limited and practiced only in the capital Addis Ababa. Tigray as one of those regions is basically dependent on conventional construction methods. difficulty of transporting prefabricated elements from the capital, un-availability of prefabrication plants, lack of awareness by the stakeholders and other reasons made prefabrication almost unexplored method in the region.

Keeping those challenges in mind, it is important that to identify the reasons that kept from practicing such construction methods and mitigate them. understanding the benefits of prefabrication within the Tigray's situation may successfully keep solve the problem associated to damaged infrastructures and buildings in the region.

1.2 Problem statement

For decades, construction projects in Tigray are conventionally done mainly using conventional method. Practicing same method for long period of time led to higher cost, lower quality and frequent delays. In addition to this, the conflict also became more challenge by breakage of supply chains, because of shortage of materials and drove skilled manpower to migrate from the region.

Having these issues construction projects forced to stop, prices kept rising and quality of projects continue to deteriorate. In order to resolve these problems pre-fabrication is an alternative way, by which, prefabrication elements are manufactured in a controlled plant to higher quality inspection in shorter time and lower cost. But, since the practice of pre-fabrication is not well in the region, proper plan and strategy is needed to adopt and implement on the ground.

This research looks at the economic benefits of pre-fab, awareness of construction stockholders on the method, quality and time saving outcomes and the barriers that inhibit for the practice.

1.3 Research objectives

1.3.1 General objective

The study is intended to identify the benefits of pre-fabrication on economy, time and quality improvement on construction projects in Tigray region. In addition, it also studies if the practice of pre-fab exists, and what barriers kept it from using as a construction method and defining ways to adopt it for future use.

1.3.2 Specific objectives

1. To assess the level of awareness among construction stakeholders regarding prefabrication technologies.
2. To quantify the potential for cost reduction and time savings through the use of prefabrication
3. To analyze the impact of factory-controlled production on construction quality
4. To identify the primary socio-economic and technical barriers inhibiting adoption in the region.
5. To evaluate the influence of government policies and investment opportunities on the adoption of these systems.
6. To develop strategic recommendations for the successful integration of prefabrication in Tigray.

1.4 Research questions

1. What is the current level of awareness regarding prefabrication among stakeholders in Tigray?
2. How does prefabrication influence project costs and timelines compared to conventional methods?
3. What are the measurable quality outcomes of adopting prefabricated systems?
4. How do existing government policies and investment climates affect the adoption of these technologies?

5. What are the fundamental barriers preventing the widespread adoption of prefabrication in the region?
6. What strategies are most effective for ensuring the successful adoption of prefabricate

1.5 Scope of the study

This research focuses specifically on building projects within the Tigray region. The target population includes clients, consultants, and grade 1–3 contractors. The study is limited to concrete prefabrication systems, focusing on variables such as cost, time, quality, institutional factors, and stakeholder awareness.

1.6 Significance of the study

This research provides valuable insights for policymakers, investors, contractors, and development partners working in Tigray's reconstruction sector. By identifying the economic benefits and barriers to prefabrication, the study supports evidence-based decisions on how best to integrate the method into regional practice. The findings also help construction professionals understand how prefabrication could reduce costs, improve quality, and accelerate project delivery.

1.7 Research limitation

The study was constrained by several factors, including limited accessibility in post-conflict zones and a restricted budget for data collection. Due to the current absence of local prefabrication plants in Tigray, the analysis relies on professional insights, available secondary data, and case studies rather than direct local observation. Additionally, long-term lifecycle cost analysis was excluded due to a lack of documented historical records in the region.

1.8 Research beneficiary

Government Institutions provides data to support policies that encourage sustainable construction. Community Members facilitates faster delivery of essential infrastructure like schools and clinics.

Manufacturers and Suppliers insights market to align production capacity with regional demand.

1.9 Research organization

This thesis is structured into five chapters and represented in the following Figure;

Figure 1-1: Research organization

Chapter two

2. Literature Review

2.1 General

Prefabricated concrete construction is turning into a major technique in the current building field. It brings a lot of benefits that include speeding up construction, controlling quality, having more managed costs and doing better for the environment.

Due to the rising of population across the world urban places become larger and larger and cities expanded to better accommodate occupants. The need for housing, civic amenities and infrastructure becomes the way or an answer of those demands. According to (Gorgolewski, 2008) prefer uses less labor, have superior quality and no delays due to weather, so using this modern way we can satisfy the demand for housing and other big projects in shorter period of time.

In Ethiopia prefabrication is not practiced well, even having those major benefits to serve urban livers (Gebeyaw T, 2017). In regions like Tigray after a devastating conflict pre fabrication could be more suitable to provide large scale housing in time and affordable way.

2.2 Theoretical frameworks

The Diffusion of Innovation (DOI) (Rogers, 2003) theory explained how new ideas, practices or technologies are adopted in the society over a time. It also identifies different categories of adopters based on the willingness to embrace change, ranging from innovators to early late prior to more hesitant ones.

The Technology Acceptance Model TAM (*Fred D,1989.*) is a theory that attempts to predict the like hood of an individual or organization successfully adopting a new system of technology. It helps to integrate and make practical the adoption of prefabs by construction stakeholders in the region.

In Ethiopia especially Tigray, the absence of constant supplies and policy support makes prefab to be unpractical and can be solved by introducing such frameworks which will manage the adoption of new technologies and techniques through structured and preplanned mechanisms.

2.2.1 Concept of concrete prefabrication

Off-site construction, commonly called prefabrication, involves the manufacturing of building components at a location other than the construction site. As stated by Blismas (Blismas N, 2009), prefabrication can consist of anything from partial components such as slabs or beams to complete modules. The system lessens site labor, improve quality consistency, and significantly speeds up project times compared with conventional cast in situ construction.

2.2.2 Historical evolution of prefabrication

The first use of prefabricated elements was in the 17th century when pre-cut timber houses were shipped from England to its colonies. The rise of prefabrication as cheaply produced construction to rebuild vast sections of Europe and Japan emerged after the war. Countries like South Africa and Kenya use prefabrication to counter housing shortages in Africa.
The habit began in the late 1980s in Ethiopia through the Prefabricated Building Parts Production Enterprise (PBPPE). The political instability, low manufacturing investment, and poor logistics limited its expansion (*Gebremicael T, 2020*). Evidence available at present indicates that in Ethiopia, prefabrication is largely applied to non-structural components such as lintels, poles, pipes, and cladding panels. Even in Addis Ababa, early enthusiasm now seems to be waning with regard to private initiatives such as Ybel industrial PLC (IJERT, 2020).

2.2.3 Types and Systems of Prefabricated Construction

The dimension of prefabrication systems depends on the project requirements. According (Lawson et al., 2014), prefabrication is categorized into large-panel systems, frame systems, slab-column systems with shear walls, modular or volumetric units, and hybrid configurations. Distinct structural and functional characteristics of each. The classification is useful to choose the right of its type of systems based on the design intention limitations at site and resources availability.

2.2.4 Benefits of concrete prefabrication

A. Time efficiency

Prefabrication allows for concurrent processing; while foundations are being laid on-site, structural components are manufactured off-site. This eliminates the sequential delays inherent in conventional cast-in-situ methods.

B. Cost reduction

Financial advantages stem from material efficiency and reduced on-site labor. Factory production minimizes waste through precision engineering and reduces the overhead costs associated with prolonged site management.

C. Quality improvement

Prefab elements are produced in controlled and clean purposes environment. This includes fine proportioning, mixing and casting of concrete units and curing of concrete units before transporting to construction site. The concrete units must pass certain structural tests to avoid low quality products. This explains why prefabrication using prefab improves quality.

D. Environmental sustainability

During the production of prefab elements wastage is minimized due to its controlled process. Additionally, in addition to this the assembly of the elements needs less labor and site activities, which minimizes consumption of fuel and carbon emissions.

2.2.3 Barriers to adoption of prefabrication

The benefits of using prefab are well known and practical but, its adoption is limited due to the shortage of prefab plants in poor countries, lack of awareness between con' stack holders and difficulty of transporting prefab elements through long distances.

A recent IDB research in Addis Ababa explains that shortage of funds, absence of skilled man power and cultural resistance are among the barriers of adopting prefab in Ethiopia (*IDB Invest,2023*.).

2.3 Conceptual frameworks

The conceptual framework illustrates how barriers, enablers (outcomes), and strategic interventions interact to influence both the rate and extent of prefabricated construction adoption.

The framework assumes that targeted strategic interventions can reduce existing barriers, thereby enhancing the perceived benefits of prefabrication and accelerating its uptake.

A. Barriers dimension

The adoption of prefabricated construction is constrained by several interrelated barriers. Technical barriers include inadequate local production capacity, a shortage of skilled labor, and insufficient quality control systems. Economic barriers arise from high initial setup costs, uncertainty in market demand, and expensive transportation and logistics. Institutional barriers are reflected in weak technical standards, limited regulatory support, and procurement systems that rarely prioritize or incentivize prefabricated solutions.

B. Benefits / outcome dimension

When these barriers are effectively addressed, prefabricated construction delivers significant benefits. From an economic perspective, project costs are reduced through more efficient resource utilization. In terms of time, project delivery is accelerated as factory production and on-site construction can proceed concurrently. Quality outcomes improve through greater consistency and durability of components produced in controlled environments. Furthermore, environmental benefits are realized through reduced material waste and a lower carbon footprint.

C. Strategic interventions

To overcome the identified barriers and unlock these benefits, the framework proposes a set of targeted strategic interventions. Policy actions involve establishing clear technical standards and providing tax incentives or preferential procurement policies to encourage prefabrication. Capacity-building initiatives focus on workforce training programs and the development of pilot manufacturing facilities to strengthen technical capability.

Financial instruments, such as blended financing mechanisms and long-term contract bundling, are recommended to reduce investment risk and ensure stable demand. Finally, awareness campaigns, including demonstration and pilot projects, aim to improve industry visibility, public acceptance, and stakeholder confidence in prefabricated construction.

2.4 Research gap

Majority of research regarding prefabrication are conducted in developed and Asian countries ignoring African experiences. Locally limited studies concentrate only on benefits neglecting on adoption.

Chapter three

3. Research Methodology

3.1 General

In this chapter the methodology used by the research are described. It outlines the study area, research design, sampling procedures, data sources, data collection instruments, inferential statistical analysis, reliability and validity test and ethical considerations.

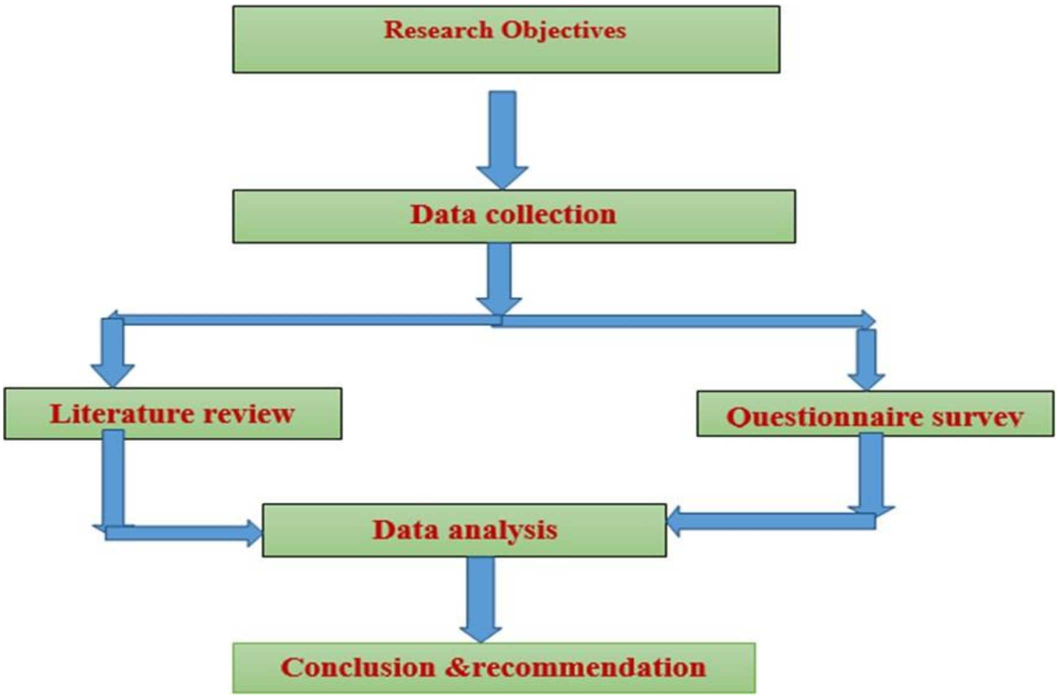

Figure 3-1: Research methodology layout

3.2 Study area

The research is conducted in the Tigray region, located in northern Ethiopia. Major urban centers such as Mekelle, Adigrat, Axum, Shire and Mekoni and selected rural places are included in the study.

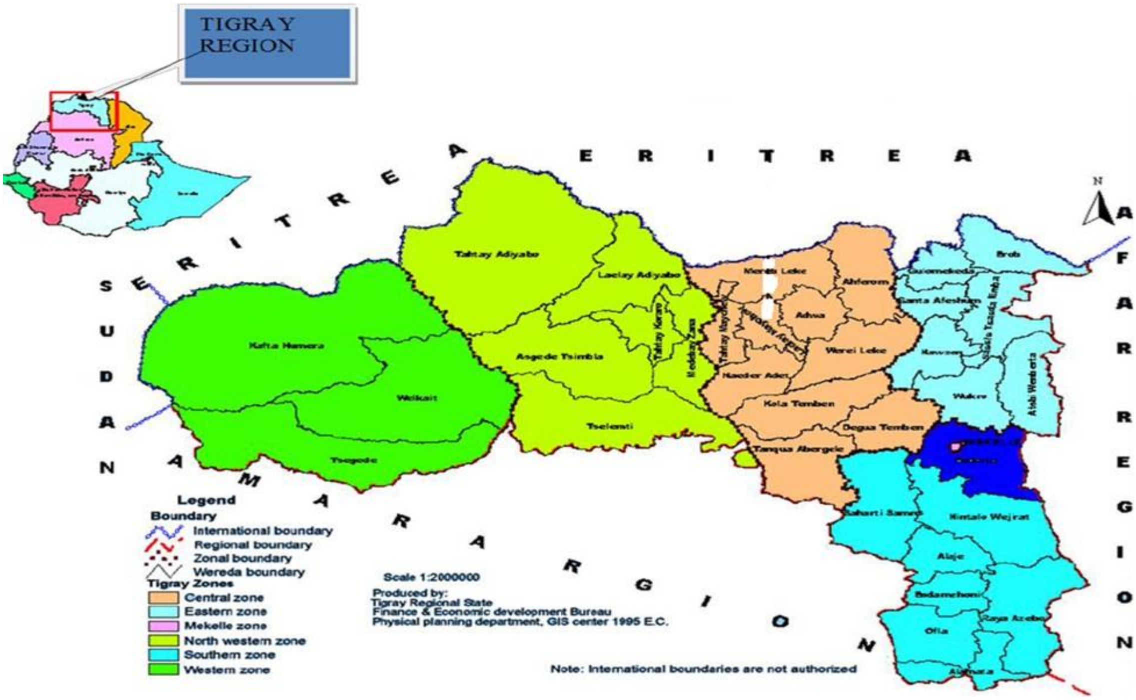

Figure 3-2: The map location of study area

3.3 Research design

The research uses both qualitative and quantitative methods to generate both numerical and contextual data.

Levels of awareness, barrier and benefits are measured using qualitative methods. Perceptions, institutional issues, policies and strategies are measured using quantitative methods. Using these two methods together allowed the study to capture not only to measurable trends but also the reasoning and experiences behind stakeholder decisions.

3.4 Sample design

3.4.1 Target population

The target population comprised of builders in Tigray, contractors, consultants, and clients in the first place. Contractors were the main target because they are the ones who actually control the whole process of construction methods, material selection, and execution. Consultants and clients were included in the sample to give their points on design and procurement decisions.

3.4.2 Sampling frame

The sampling frame was created based on the list of licensed contractors and consultants provided by the Tigray bureau of urban development, housing, and construction. To provide representation, contractors were classified by grade 1-3 and type general or building contractors.

3.4.3 Sample size determination

Sample size was calculated using the Yamane's formula (Yamane,1967) for finite populations:

$$N = n (1 + N * e^2)$$

Where:

n = necessary sample size

N = population size

e = precision level (margin of error)

The total population for this study was 270. The requisite sample size with a 10% margin of error was 73, thus 95 questionnaires were distributed to enhance representation, from which 73 valid responses were collected. This number slightly exceeded the required sample and reinforced the representativeness of the results.

3.5 Sampling technique

Different sampling techniques were employed for the qualitative and quantitative data of the study in order to achieve a balance between in-depth insights and representative data.

3.5.1 Sampling for qualitative data

The purposive sampling method was applied for interviews. Ten key informants consisting of competent contractors, engineers, and government representatives were picked not only for their familiarity with the construction practices but also their exposure to modern or industrialized building technologies.

3.5.2 Sampling for quantitative data

The study made use of the stratified proportional random sampling technique for the purpose of the questionnaire survey. The contractor grades were the strata, and a random selection of participants was made within each stratum to assure that small as well as large firms would be represented fairly.

3.6 Data Sources and collection methods

The study made use of both primary and secondary data. Questionnaires, interviews, and direct site observations were the sources of primary data. Questionnaires were used to collect structured data on awareness, perceptions, and practical challenges, while interviews provided qualitative depth. Observations at construction sites offered additional evidence to validate responses.

3.6.1 Primary data sources

Primary data is collected using:

Questionnaires: levels of awareness, perceptions, Inhibitory factor s and opinions about cost, time and quality. Interview: used to gather information from small use of participants regarding instructional, financial and policy issues. Field visits: to observe practical construction works of prefabricated elements.

3.6.2 Secondary sources

Different types of data are collected from a number of institutions which have written documents associated to prefabrication. Additionally, text books, internet and other researches are used to deepen and support the study.

3.7 Methods of data analysis

In this study both qualitative and quantitative data analysis were used.

3.7.1 Qualitative data analysis

Thematic analysis is used to analyze interviews and observation notes.

3.7.2 Quantitative data analysis

The quantitative data is analyzed using both descriptive and inferential statistics. Descriptive statistics is used to summarize respondent's characteristics and academic framework, percentage, means and standard deviations. The five point Likert scale is used and the relative importance index is applied to rank the characteristics. Inferential statistics is used to evaluate the relationships between the variables. Correlation and regression analysis methods are used to evaluate the independent and dependent variables reverently.

The relative importance index (RII) is computed as,

$$RII = \frac{5n5 + 4n4 + 3n3 + 2n2 + n1}{5(n5 + n4 + n3 + n2 + n1)}$$

Where: RII: relative important index (0≤RII≤1), n1, n2, n3, n4 & n5 number of responding items.

Table 3-1: Values assigned for the Likert scale in the questionnaire

Item	Not important	Low important	Moderately important	High important	Very high important
Scale	**1**	**2**	**3**	**4**	**5**

3.8. Inferential statistical analysis

A. Correlation analysis is used to determine the relationship between the dependent variable which is adoption of prefabrication

B. Regression a multiple linear regression model is used to evaluate the relationship between the dependent variable and the most influential factors such as: cost savings, time advantage, awareness levels and institutional support as independent variables.

3.9 Reliability and validity test

3.9.1 Reliability test

Reliability was measured by Cronbach's alpha, which is a common indicator of the internal consistency of the measurement scales used in the questionnaire. The level of 0.7 was considered as the minimum in this case. To enhance the quality of the research, the researchers chose to conduct pilot testing, get the experts' opinion on the research instruments, and finally, use the triangulation technique to gather information from different sources. The alignment of tools with research objectives was the ground on which internal validity was built, while the sample's representativeness was the support for external validity.

The rationale behind this is that every item in a test can be treated like a separate one-item test. Thus, the whole test consisting of n items is interpreted as one group of n parallel tests. The next step is to estimate the reliability according to the consistency of each individual’s performance from one item to another. The total test score variance =SD2X, Individual item score variance=SD2i, the number of items (n). This is called coefficient alpha or Cronbach's alpha. The α is interpreted as the level of measurement that all of the items are reflecting a common construct and internal consistency measurement as presented in Table 3- 3.

Table 3-2: Cronbach’s alpha for measuring reliability internal consistency

Cronbach’s alpha	**Internal consistency**
$0.9 \leq \alpha$	Excellent
$0.8 \leq \alpha < 0.9$	Good
$0.7 \leq \alpha < 0.8$	Acceptable
$0.6 \leq \alpha < 0.7$	Questionable
$0.5 \leq \alpha < 0.6$	Poor
$\alpha < 0.5$	un-acceptable

3.9.2 Validity

Content validity was established through expert review by the academic supervisors and practitioners in the field. Theoretical and empirical support helped to build the construct validity of the questionnaire. Face validity was enhanced through pilot testing and clarification of indecipherable items.

3.10 Ethical considerations

The whole research process was conducted while keeping ethical standards in mind. The subjects received information regarding the study's aim, and their consent was collected prior to gathering data. The participants were guaranteed confidentiality of their personal data and that the data would solely be used for scholarly purposes. Participation was not mandatory, and the persons had the option to exit at any point. The data that was gathered was kept secure and allowed to be analyzed and reported only in an anonymized form.

Chapter four

4. Results and Discussions

4.1 General overview

This chapter comprises the analysis of questionnaires, interviews, and observations made in the course of the study. A cross-section of building contractors, architectural and engineering consultants and clients or developers who are key stakeholders in the construction industry within Mekelle city were engaged in the data collection process as respondents.

As far as this chapter was concerned, ninety-five questionnaires were administered and out of the total number, seventy-three were received representing 86.67% of total were returned questionnaires. Histograms, tables, pie charts and percentages below were used to present the data collected. The data was subjected to rigorous statistical analysis after respondents reacted to all the items contained in the questionnaire alongside interviews, observations exercise concerning the research topic.

4.2 Demographic data

4.2.1 Type or category of respondents

The study involved a total of 73 respondents, representing various stakeholder categories within the construction sector. Among them, 12 participants were clients, accounting for 16.45% of the total sample. Contractors constituted the largest group, with 32 respondents, representing 43.83% of the participants. Consultants comprised 29 individuals, making up 39.72% of the total respondents. Together, these categories accounted for the entire sample, providing a comprehensive perspective from key actors involved in the adoption and implementation of concrete prefabrication in the region, as shown in Table 4 – 1.

Table 4-1: Number of respondents with their respective percentages

Category	Frequency	Percentage (%)
Clients	12	16.45
Contractors	32	43.83
Consultants	29	39.72
Total	**73**	**100**

Table 4 - 1 shows the number of respondents with their percentages from the following category: contractors, architectural/engineering consultants and clients. From those 32 out of 73 representing 43.83% of the respondents were contractors, 29 out of 73 respondents were architectural/engineering representing 39.72%, and 12 respondents were clients or government agency representing 16.45% as shown in Figure 4 - 1.

Figure 4-1: Respondents category

4.2.2 Level of education

The educational qualifications of the 73 respondents were of a different kind, which means that the construction sector was not uniformly trained at a particular level. Among the respondents, four represented the least educated group, making up 5.48% of the total while having no formal education at all. Nine participants, which is 12.32%, had a diploma, the next level of education, and most of the participants, 42 individuals (57.53%), had the first degree. Eighteen respondents, which is 24.67%, were the ones who had the second degree, and none of the participants were the ones who had already earned a doctorate. Overall, the sample consisted of a highly educated group of stakeholders from the tertiary education sector, which gave the decision-makers in this region a knowledgeable base for evaluating the adoption of concrete prefabrication, as illustrated. in Table 4 - 2

Table 4-2: Respondent's level of education

Variable	Category	Number of respondents	Percentage
Level of education	None	4	5.48
	Diploma	9	12.32
	1st Degree	42	57.53
	2nd Degree	18	24..67
	PhD	0	0
Total		73	100%

Table 4 - 2 depicts the level of education of respondents, 5.48% of the respondents are not graduated, 12.32% of the respondents are college graduates, 57.53% of the respondents have first degree and 24.67% of them have second degree. Majority of the respondents were educated and had a good understanding of the questionnaire that they were required to respond.

4.2.3 Years of working experience

The respondents' work experience varied across different ranges, reflecting a mix of junior and senior professionals in the construction sector. Eleven respondents, representing 15.06% of the sample, had between 0 to 5 years of work experience. The majority, 38 individuals or 52.05%, had 6 to 10 years of experience, indicating a substantial level of practical exposure. Additionally, 24 respondents, accounting for 32.89% of the total, had more than 10 years of experience, bringing extensive expertise to the study. Collectively, the sample encompassed a balanced combination of emerging and seasoned professionals, providing comprehensive insights into the adoption of concrete prefabrication in the region, as shown in Table 4 - 3.

Table 4-3: Respondents work experience

Variable	Work experience in years	Frequency	Percentage
Work experience	0-5	11	15.06
	6-10	38	52.05

	>10	24	32.89
Total		**73**	**100**

Table 4 - 3 shows the years of working experience of respondents in the construction industry specifically in building construction, 11 respondents representing 15.06% have working experience between zero to five years. 38 respondents out of 73 respondents have 6-10 years working experience representing 52.05%. In addition, 24 of the respondents have greater than 10 years working experience representing 32.89%, This implies that majority of the respondents were quite experienced in the construction industry as far as responding to this questionnaire is concerned as shown in Figure 4 - 2.

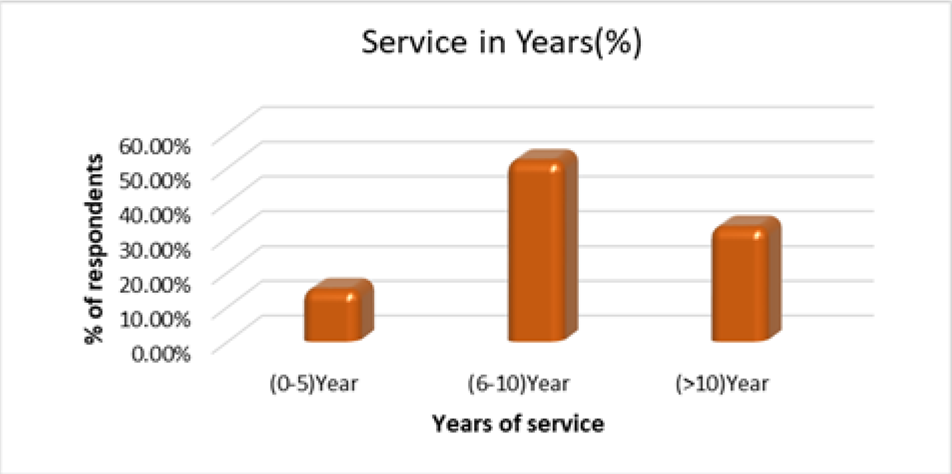

Figure 4.2 Respondents experience

4.3 Awareness of construction stakeholders about prefabrication

The respondents' level of awareness regarding concrete prefabrication varied, reflecting different degrees of familiarity with the concept. A majority of 41 participants, representing 56.16% of the sample, were highly aware of prefabrication practices. Twenty-six respondents, accounting for 35.60%, had a moderate or less awareness of the subject.

Table 4-4: Respondents level of awareness of concrete prefabrication

Variable	Frequency	Percentage (%)
Highly-Award	41	56.16

Less-Award	26	35.60
Not-Award	6	8.24
Total	**73**	**100**

The study shows that the level of awareness across the stock holders is moderate but unevenly distributed which aligns with DOI theory (Rogers, 2003a).

4.4 Forms of concrete casting

The next table shows the forms of concrete casting used by construction workers in Tigray region.

Table 4-5: Respondents current method of construction

Method	Frequency	Percentage (%)
Cast in-situ	73	100
Pre-Cast	0	0
Combined	0	0
Total	**73**	**100**

The study shows that currently concrete is casted using conventional way and other methods are not utilized.

4.4.1 Reason of respondents to select the method of construction

The respondents provided several reasons for selecting the cast in-situ construction method over prefabrication. The most cited reason, reported by 31 participants representing 42.46%, was that cast in-situ is the only practical method currently available in the region. Another significant factor, mentioned by 28 respondents representing 38.38%, was that the precast construction method has not been well introduced and is not considered practical at this time. Nine respondents representing 12.32% highlighted the absence of prefabrication plants in the region, which would result in higher transportation costs if precast methods were used. A smaller number, 3 participants representing 4.10% believed that cast in-situ provides better results in terms of time, cost, and quality, while

2 respondents representing 2.74% noted a lack of acceptance of precast methods among construction stakeholders. These findings indicate that practical limitations, infrastructure gaps, and limited familiarity with precast technology are the primary reasons for the continued reliance on cast in-situ construction in the region, as shown in Table 4 - 1

Table 4-6: Reasons of respondents for selecting cast in-situ construction method

Reason	Frequency	Percentage (%)
Cast in-situ is the only method practical in the region	31	42.46
Cast in-situ have better result than precast constructing method in terms of time, cost and quality.	3	4.10
Prefabricating plants are not available at the region leading to higher costs of transportation	9	12.32
Luck of acceptance for precast construction method by construction stakeholders	2	2.74
Precast construction method is not introduced well and not practical at the moment in the region	28	38.38
Total	**73**	**100**

The result shows that the total reliance on conventional method is due to limitations to other methods but not on preference.

4.4.2 Practices of prefabrication in Tigray region

The respondents' experience with precast or combined concrete construction methods in the Tigray region. Out of the 73 participants, only 6 respondents representing 8.22% reported having experience with precast construction alone, while 18 respondents representing 24.66% indicated experience with a combined approach that integrates both precast and cast in-situ methods. The majority, 49 participants representing 67.12%, reported no experience with precast or combined construction throughout their professional practice. These results suggest that the use of precast or hybrid methods is still limited in the region, highlighting a significant reliance on conventional cast in-situ construction practices as shown in Table 4 - 7.

Table 4-7: Respondents experience of using precast or combined concrete construction

Form of Construction	Frequency	Percentage %
Pre-Cast	6	8.22
Combined	18	24.66
None	49	67.12
Total	**73**	**100**

The table shows that construction workers in Tigray region have minimum experience of using prefabrication throughout their work time.

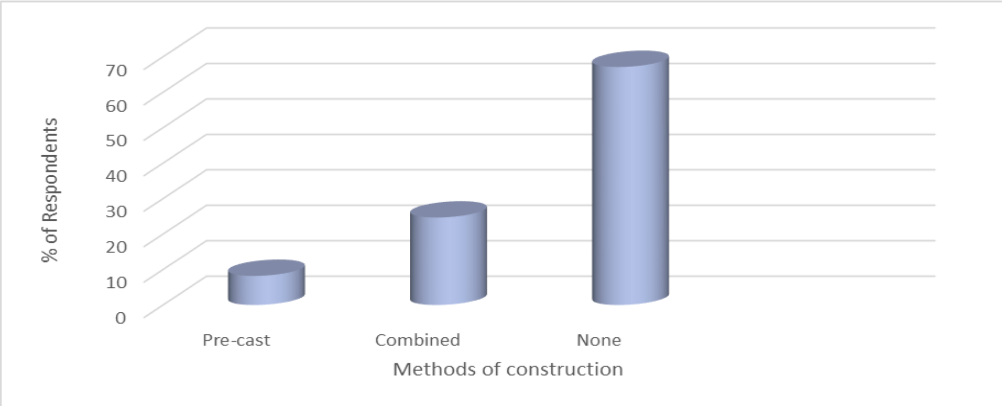

Figure 4-3: Respondents experience of using precast or combined concrete construction

From a diffusion perspective (Rogers, 2003b), emphasizes that pilot and demonstration projects play a vital role in enhancing observability and promoting innovation diffusion. In the Tigray region, one notable example is the initiative by the Tigray education bureau, which constructed more than 35 schools using precast components in remote areas particularly in Wolkayte, Tsegede, and Adyete districts. These single-story schools, known locally as precast element buildings, consist of standardized precast columns, beams, wall sections, and tie beams designed for rapid assembly.

The schools were designed for faster construction in remote and rural areas having harsh conditions in order to meet the millennium goals set by the region in 2000 in Ethiopian colander. All the schools have same structural and architectural design having a capacity to withstand seismic loads and environmental impacts such as high temperature and moisture.

To produce the precast elements mobile molds have been used, and the molds are transported to construction site. production of precast elements starts at earlier stages.

Raw materials like, sand, cement, aggregate, reinforcement bar and water are transported to the construction place.

Production begins with preparation of reinforcement bar and concrete and placing on the provided steel molds. After 24 hours de-molding (removal of molds) is done and similar cycle continues to produce enough precast elements. Curing is also done for three days.

Construction starts after stone foundation is prepared; precast grade beam is placed on the masonry foundation by providing cement mortar to get enough bond. Similarly, columns, top tie beams and section walls are assembled following each other. Small mobile crane is used for moving, handling and assembly of precast elements. as shown in Figure 4 - 4.

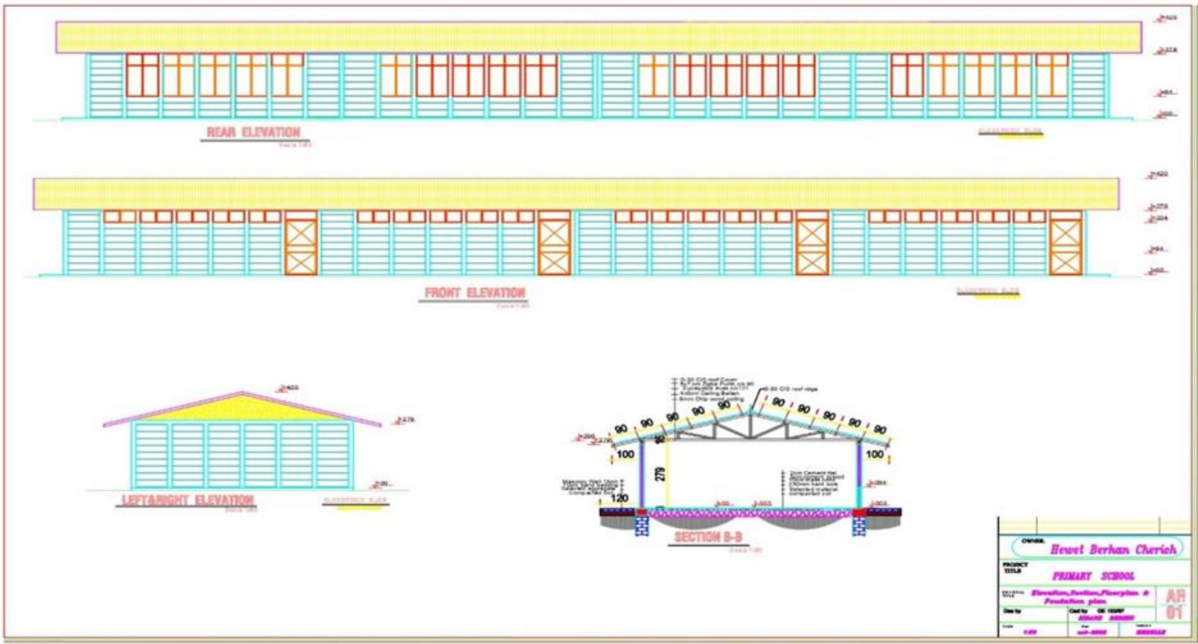

Figure 4-4: Typical elevation plan of element precast school constructed by Tigray education bureau

4.4.3 Assessment of inhibiting factors for the adoption of concrete prefabrication in Tigray

The adoption of precast concrete construction in the Tigray region is hindered by a range of interrelated challenges shaped by both technical and socio-economic realities. Many of these obstacle's stem from the region's pre- and post-war conditions, which have disrupted economic stability, governance, and infrastructure. In addition to common constraints such as shortages of materials, limited technical expertise, and financial barriers Tigray faces a series of region-specific challenges.

Using the Likert scale, the relative importance index (RII) method was applied to quantify each factor's level of influence.

Table 4-8: Factors inhibiting the adoption of concrete prefabrication

No	Reason	RII	Rank
1	Political instability and conflict	0.964	1
2	Absence of prefabrication plants	0.953	2
3	Transportation challenges	0.937	3
4	Bad regional government policy	0.926	4
5	Lack of regional and international investors	0.912	5
6	Financial constraints	0.899	6
7	High initial investment	0.882	7
8	Raw material scarcity	0.858	8
9	Inadequate power supply	0.816	9
10	Limited technical expertise	0.775	10
11	Absence of local standards/cods	0.745	11
12	Inflexibility in design changes	0.707	12
13	Low market acceptance	0.649	13

The data from seventy-three respondents unveiled that there are certain barriers having a very strong impact on the slow acceptance of prefabrication in the area. Impediments with an RII rating higher than 0.85 were placed in the group of primary limitations, indicating their decisive influence in stopping the spread of advanced technology. Below, these results are discussed and explained in more detail.

4.4.4 Discussion of critical factors from the result

The analysis that is represented in Figure 4-5 led the researchers to the conclusion and the ranking of the barriers to prefabrication adoption in Tigray based on the relative importance index. The barriers have been recognized as the main factors that hinder the use of prefabricated construction technologies in the region and these were the ones that got the highest scores of above 0.85.

The ranking has placed the issue of political instability and conflict at the top of the list of barriers (RII = 0.964). The long-lasting instability has been the reason for the destruction of existing infrastructure, the weakening of the government and judicial institutions, and the discouragement of investment both from the public and private sectors. Security issues and the diversion of resources to recovery have been the main reasons for construction projects being delayed or even stopped completely. The situation has been such that the introduction of new technologies like prefabrication has not been considered.

The fact that there are no prefabrication plants is rated second (RII = 0.953). It is not possible to have precast elements produced locally if there are no factories, and importing parts from far-off regions makes the price of the whole thing very high. Limited skilled human resources and potential investors shying away from backing such factories' establishment are part of the problem too.

Third on the list is transportation problems (RII = 0.937), which mirror bad road conditions, costly fuel, and hard times in transporting large materials or parts.

To tackle the problems an integrated approach is needed that will lead to a stable political environment, improved infrastructure, both local and foreign investments being encouraged and supportive government policies being formulated. Moreover, the setting up of pilot projects and the granting of financial incentives could serve to show the practicality and long-term benefits of prefabrication, thus gaining trust among contractors and policymakers.

In summary, it can be said that while prefabrication is a possible and even a good choice to speed up the process of post-war reconstruction and the development of Tigray in a sustainable way; its use will still be limited if these systemic barriers are not addressed one by one in a coordinated manner through regional planning and institutional commitment.

4.4.5 Assessment of the potential consequences of inhibited adoption on Tigray construction industry

Below is a comprehensive analysis of potential consequences of inhibited precast concrete adoption on Tigray's construction industry. Based on questioner survey responses from 73 respondents. The impacts are ranked by relative importance index (RII) to reflect their perceived severity in Tigray's context as shown in Table 4 - 9.

Table 4-9: The potential consequences caused by the inhibited adoption of prefabrication

No	Consequence	RII	Rank
1	Prolonged project timelines	0.964	1
2	Escalated construction costs	0.945	2
3	Inconsistent construction quality	0.926	3
4	Reduced housing/infrastructure delivery	0.899	4
5	Wasted materials	0.863	5
6	Heightened safety risks	0.816	6
7	Suppressed technical innovation	0.767	7
8	Environmental strain	0.726	8

4.4.6 Discussion on the potential consequences

The limited use of prefabricated construction methods in Tigray has produced a range of serious consequences, both before the conflict and more sharply in the post-war setting.

1. Prolonged timelines (RII 0.964)

Pre-war: Before the conflict construction in Tigray were slow in progress and facing delays due to shortage of material, shortage of skilled manpower, weather conditions and infrastructure problems.

Post-war: After the conflict the problem became severe because buildings and infrastructure damaged, skilled manpower migrates and materials become scarce.

2. Escalated construction costs (RII 0.945)

Pre-war: Conventional construction methods already carried high costs. Material wastage, long project durations, the cost of transporting bulk materials over poor roads, and frequent inefficiencies all contributed to budget overruns. Internal assessments by the Ethiopian construction design and supervision works corporation (ECDSWC, 2020) consistently reported cost fluctuations and overruns in major public projects.

Post-war: Due to the conflict construction material cost increases because local material manufacturers and sources have damaged heavily.

3. Inconsistent construction quality (RII 0.926)

Pre-war: Quality problem in construction in Tigray is a common problem. Contractor skills, shortage of quality material, supervision and corruption are the main causes.

Post-war: After the conflict quality issues increases dramatically.

4. Reduced housing/infrastructure delivery (RII 0.899)

Pre-war: In Tigray the growth in population and speed of project delivery are not matched. Delays and lack of capacity of contractors funding mass construction projects are the main causes of the problem.

Post-war: After the conflict a large scale of Infrastructure and buildings are damaged which increased the demand for housing. Migration of skilled manpower, shortage of funds and instability of political instability within the region reduced the speed to deliver projects.

4.4.7 Assessment of potential intuitions and stakeholders for the successful adoption of concrete prefabrication

The next table shows the institutions and stakeholders which have the potential to influence the adoption of prefabrication in Tigray. The rank is according to their impact and role.

Table 4-10: Potential intuitions and stakeholders for adoption of concrete prefabrication

No	Intuitions & Stakeholders	RII	Rank	Role
1	Regional government Institutions	0.92	1	Directly controls permits, land allocation, local standards, and reconstruction budgets. Critical for implementation.
2	International funding agencies	0.89	2	Financing & conditionality: Provide grants/loans mandating prefabricated use. Essential for capital-intensive factories.

3	International NGOs	0.85	3	Piloting & capacity: Deploy rapid prefabricated shelters, train local labor, and demonstrate viability in IDP camps.
4	Regional academic sectors	0.81	4	Training: Adapt designs to local materials train technicians, and certify quality.
5	Federal responsible body	0.76	5	*Policy & standards: Set national building codes, tax waivers for prefabricated materials, and coordinate cross-regional logistics.
6	Foreign investors	0.73	6	Tech transfer & factories: Establish prefabricated plants in Major Tigray Cities. (Limited by security and ROI concerns).
7	Regional stakeholders	0.68	7	Local supply chains: Mobilize SMEs for material supply, transport, and subcontracting. (Limited capital post-war).
8	Public	0.65	8	Demand & acceptance: End-user buy-in determines adoption. Participate in assembly and maintenance.
9	Regional investors	0.61	9	Small-scale pilots: Invest in modular schools/clinics. Constrained by destroyed assets and liquidity.

1. Regional government institutions (RII: 0.92)

Regional government bodies hold the most influential position in creating an enabling environment for prefabrication. Their role is central because they control land allocation, industrial regulation and the policy frameworks that determine how quickly new technologies are adopted. Several practical measures can help accelerate prefabrication uptake. One approach is establishing fast-tracked industrial zones by allocating tax-free land near major urban centers and shortening permit approval timelines from the usual year-long process to around three months (Tigray investment bureau, 2023). Securing reliable cement access is another essential step for example, reserving 40% of Messebo cement factory’s output for certified prefabrication projects once the plant becomes operational. Introducing a regional local-content policy that requires at least 50% of inputs, particularly volcanic ash and recycled rubble, to be sourced locally would also support sustainable and large-scale prefabrication development.

1. International funding agencies (RII: 0.89)

Adopting technologies like prefabrication needs large capital for building prefabrication plants, creating awareness in the society and providing equipment for site assembly. In case of Ethiopia especially Tigray region budget is minimum and uses only for basic purposes. So, the international funding agencies dominant by must provide funds and enable adopting such construction method.

2. International NGOs (RII: 0.85)

On post-conflicts NGOs hugely participate in helping the people affected by it. In case of Tigray where large scale of infrastructure is damaged, peoples internally migrated and public institutions like schools, health centers are demolished, the NGOs are key bodies for overcoming the problem. By using prefabrication system, they can reconstruct damaged buildings and infrastructure in short period of time.

3. Regional academic sectors (RII: 0.81)

Regional academic sectors like the Mekelle, Raya, Adigrat and Axum Universities can serve as innovation and technology hubs by applying researches and studies. prefabrication can be studied deeply and identified its advantage for use in the region.

4.5 Inferential statistical results and discussion

Adoption of prefabrication was treated as the dependent variable, while cost benefits, time efficiency, quality performance, awareness level, and policy support served as independent variables.

To determine if there were any relationships, Pearson correlation coefficients (r) were derived. The findings are shown below.

N= 73

Significance levels:

* p < 0.05

** p < 0.01

Table 4.11: Pearson correlation matrix

Variable	Cost benefit	Time Efficiency	Quality Improvement	Awareness Level	Policy support	Adoption
Cost benefit	1	0.622	0.511	0.438	0.571	0.684

Time Efficiency	0.622	1	0.594	0.461	0.603	0.724
Quality improvement	0.511	0.594	1	0.382	0.557	0.614
Awareness Level	0.438	0.461	0.382	1	0.496	0.568
Policy Support	0.571	0.603	0,557	0.496	1	0.752
Adoption	0.684	0.724	0.614	0.568	0.752	1

A, Interpretation

The correlation of policy support with prefabrication adoption was the highest among all the factors considered ($r = .752$, $p < .001$), thus confirming that the institutional and regulatory frameworks are the primary determinants.

Time efficiency was the second highest factor with a strong correlation ($r = .724$, $p < .001$), signaling that quick completion of projects is a strong reason for the stakeholders.

Cost benefit showed to have a somewhat strong but significant relationship with adoption ($r = .684$, $p < .001$) in line with global research stating that lower cost is the main factor that drives the development.

Awareness level was associated with a moderate but statistically significant relationship ($r = .568$, $p < .001$) which indicates that training and exposure have a positive effect on the willingness to adopt.

Quality improvement also presents a significant correlation ($r = .614$, $p < .001$), which supports the argument of the need for controlled factory production.

All these factors together suggest that the adoption decisions are made based on the combination of several factors that are interconnected, rather than relying on one factor only.

B. Regression analysis results

A multiple linear regression model was used to determine which independent variables significantly predict adoption of concrete prefabrication.

Regression model summary

Table 4.12 Regression analysis values

Statistic	Value
R	0.842
R^2	0.708
Adjusted R^2	0.691
F-statistic	42.87

P-value< 0.001

Table 4.13 Regression analysis results

Predictor	Unstandardized β	Standardized β	t-value	Sig. (p-value))
Constant	0.421		1.82	0.073
Cost Benefit	0.278	0.286	3.44	0.001
Time Efficiency	0.312	0.303	3.69	<0.001
Quality Improvement	0.194	0.188	2.41	0.018
Awareness Level	0.167	0.174	2.18	0.033
Policy Support	0.389	0.402	4.92	<0.001

A multiple linear regression technique was applied to find out which independent variables can predict the usage of concrete prefabrication in a statistically significant way.

The model accounts for 70.8% of the variance in adoption, thus it is a powerful predictor in the social-science domain.

The F-statistic is significant ($p < 0.001$), indicating that the overall model is valid

Among all factors, policy support ($\beta = .402$, $p < .001$) was the most convincing predictor of adoption.

The next best predictor was time efficiency ($\beta = .303$, $p < .001$).

Cost benefit ($\beta = .286$, $p = .001$) also had a very strong significance.

Awareness ($\beta = .174$, $p = .033$) and quality ($\beta = .188$, $p = .018$) were found to be less strong but still significant predictors.

This confirms the assumption that prefabrication in Tigray is increasingly conditioned by the policies, economic advantages, and time efficiency of the adoption.

C. Hypothesis testing results

Based on the regression and correlation results:

Table 4.14 Hypothesis testing results

Hypothesis	Decision	Evidence
H1: Awareness significantly affects adoption.	Accepted	r = .568, p < .001; β = .174, p = .033
H2: Cost benefits significantly increase adoption likelihood.	Accepted	r = .684, p < .001; β = .286, p = .001
H3: Policy supports, significantly influences adoption.	Accepted	r = .752, p < .001; β = .402, p < .001
H4: Time advantage significantly affects adoption	Accepted	r = .724, p < .001; β = .303, p < .001
H5: Quality improvement positively affects adoption.	Accepted	r = .614, p < .001; β = .188, p = .018

D. Integration with qualitative findings

The statistical results are in very close agreement with the interview data:

Experts repeatedly mentioned that poor regional policy, no factories and little investment are the principal hindrances. Contractors pointed out transport problems, big starting costs, and lack of knowledge, which correspond to the moderate–strong correlations. Consultants pointed out time savings, which is the strong quantitative association (r = .724). Hence, the inferential results have made the qualitative findings more credible and at the same time technological, economic and institutional factors are confirmed to be together determining adoption decisions.

4.6 The cost, time and quality benefits of adopting concrete prefabrication

4.6.1 The cost benefits of adopting concrete prefabrication in Tigray

Introducing concrete prefabrication (precast) in Tigray presents major opportunities for reducing construction costs an especially important advantage given the region's post conflict rebuilding demands and the increasing need for affordable housing and infrastructure. Although the approach requires an initial capital outlay, the long-term savings and structural efficiencies demonstrated globally make it a financially viable option. The following sections outline the key cost-related advantages, supported by real-world evidence.

A. Core cost advantages of concrete prefabrication

1. Reduced on-site labor costs and time

Producing components in a factory shifts most skilled activities such as formwork, reinforcement placement, casting, and curing away from the construction site and into a controlled environment. As a result, on-site work becomes largely an assembly process. A World Bank study on housing in India reported that prefabrication lowered on-site labor requirements by 30–50% compared to traditional construction methods.

2. Faster construction speed and reduced overheads

The production of prefabricated element takes place in factories. Because of this site preparation can be done parallelly. Prefabricated elements are tested before, during and after production which minimizes supervision costs. The assembly is also faster.

3. Optimized material usage and reduced waste

Production of prefabricated elements is done using automated system centralized to computers which helps to optimize material usage and reduce wastage.

B. C o r e quality advantages of concrete prefabrication

1. Superior consistency and dimensional accuracy:

Prefabricated elements are casted and molded in specialized mound in the factory which eliminates dimensional errors. The process of batching, curing and casting is done using automated machine which avoids inconsistence in quality.

2. Enhanced strength and durability

The production line ensures the accuracy of concrete mix, casting and curing. This helps the prefab elements to pass certain structural tests and get their strength and durability demands.

3. Reduced defects and improved finishes:

Molds used to cast the concrete prefab elements is specialized and designed to provide good finishes. The production process which is automated also helps to minimize defect.

4. Improved structural integrity and seismic resilience (When designed properly)

The precast/prestressed concrete institute (PCI) has compiled comprehensive evidence confirming that precast systems designed according to seismic demands retain their reliability. In Chile, a country with high seismicity, precast concrete has become the material of choice in the construction of multi-story buildings.

Because of the seismic performance it offers, which is corroborated by the assessments done after the 2010 Maule earthquake.

For Tigray, where the issue of seismic resilience is paramount, the use of precast technology will be subjected to Ethiopian building regulations and will require strict supervision especially in the elaboration and execution of connections to guarantee safety and durability of the structure through good performance.

5. Better thermal and acoustic performance

Factories for precast sandwich panels manufacture insulated panels that can have tremendous thermal and acoustic barriers. But because these components are made with such high accuracy, there is very little air leakage and thermal bridging. A study conducted by the European precast concrete organization (BIBM) showed that the insulated precast panels achieved consistently better u-values than the wall systems built on-site. Hospitals, schools, and housing developed with precast systems in Scandinavia and Germany constantly meet the high standards of comfort and energy efficiency.

In Tigray, where indoor comfort and power expenses are of greater concern, these quality-of-life factors lead to cooler living spaces in hot climates, and eventually lower energy costs, and even better indoor environmental quality mainly in educational and medical facilities.

C. Core time-saving mechanisms

1. Concurrent activities and factory parallelism

Both production of prefab elements and site preparation can be done parallelly because the production process is done away of the site in pre fab plants.

1. Rapid on-site assembly

Assembling of prefabricated elements is done using special equipment's which is faster. False works like scaffoldings forms works are eliminated.

2. Elimination of on-site curing time

Concrete needs time to cure to reach its design strength. Traditional site-cast concrete can take days or weeks before the next phase can start. Precast elements, however, arrive fully cured and ready to carry structural loads immediately. Controlled factory curing often accelerated with heat or steam ensures elements reach strength in hours or days instead of 7–28 days. This alone can save 1–3 weeks per floor in multi-story buildings.

3. Reduced weather dependency

Factory production is largely immune to weather conditions such as rain, extreme heat, or dust storms. Only the brief assembly stage is exposed to the elements, which is much less sensitive than traditional wet concrete work. Projects in extreme climates, from the Middle East to Nordic countries, rely on precast methods to keep schedules on track. In Tigray, avoiding rain-related delays during key construction stages could be a major benefit.

4. Simplified finishes and reduced rework

Precast elements often come with smooth, high-quality finishes, reducing or eliminating time-consuming plastering and correction work on-site.

4.7 Strategic framework for prefab adoption in Tigray

4.7.1 Balancing Scalability, Local Context, and Resilience

Phase 1: Foundation and piloting (0–18 months)

At the starting phase in order to create awareness and prove its worth for the society it must start at lower scale using semi-mechanized smaller plants for example setting up these plants in major towns such as Mekelle, Axum, Adigrat, Shire and starting production at lower scale in order to minimize risks.

Phase 2: Scaling and integration (18–36 Months)

At this phase scaling up production and distribution is going to start because better acceptance and awareness is created by the phase 1.

Phase 3: Mass production and innovation (36+ months)

On this phase mass production and innovation took place to satisfy demands of consumers. It is achieved that on phase 1 and 2 construction stakeholders are become familiar to the concept of prefabrication and its practice. So, bigger plants are needed to be setup.

4.8 Environmental and sustainability implications

The study's outcomes confirm that the use of prefabrication greatly cuts down on material waste and improves the efficiency of resources. In addition to the direct savings on costs, prefabrication fits into the larger picture of Ethiopia's sustainability and climate-resilience goals. Past studies indicate that the adoption of prefabricated construction can lead to a 15-25% reduction in the embodied carbon of buildings, mainly owing to better resource utilization and lower energy consumption on-site (Aghasizadeh et al., 2022). Production in a factory environment with strict controls also minimizes rework, and it is possible to recycle the construction by-products, which is a significant advantage in Tigray, a region where material shortages are often encountered. The emphasis on these environmental advantages would make the government support more plausible, as the approach aligns with national development priorities and the global climate goals.

Chapter five

Conclusions and Recommendations

The outcomes of the research signify that concrete prefabrication is the most efficient, fastest, and highest quality way of performing building projects in Tigray. To this effect, the technology, though known, is still not these days used very widely as a result of the combined technical, financial, and institutional handicaps.

5.1 Conclusions

There is a theoretical comprehension of prefabrication among most contractors and consultants, but only very few have gained practical experience with it. This leads to indecision, thus casting a shadow of doubt over the acceptance of new methods.

The study produced strong consensus that prefabrication could cut construction time considerably, enhance quality, and decrease waste generated on-site to the very minimum. In the context of post-conflict situations, these benefits are tremendous as the quick provision of shelter and public facilities is the top priority.

Initially, the barriers that hinder the adoption of the technology are quite large. The key challenges recognized are: unavailability of qualified manpower, absence of production units and tools, heavy initial capital outlay, road and transport problems due to long distance and poor condition of roads, very little support from institutions and ambiguous government regulations and some resistance from contractors trained in traditional in-situ methods who do not want to change. These barriers emphasize that the problem is not only technological but also organizational and related to policies.

The lack of effective communication among the relevant government agencies, scarce standardization and no guidelines for the specific region prefabricated construction further shake the technology's credibility. Without favorable regulations, building contractors will not be willing to commit themselves for a long time and thus will not invest in the technologies.

It has been revealed by the analysis that the use of prefabrication technology could offer a significant advantage to Tigray's reconstruction plans through cutting down on project delays, bettering the utilization of resources, and providing more uniform quality. Nevertheless, the success is reliant upon the proper institutional setting being established, the training of competent workers, and overcoming the logistical problems.

5.2 Recommendations

5.2.1 For regional government and policymakers

1. The regional framework for prefabricated construction should be developed, technical standards, guidelines and approval processes should be clearly defined to assist contractors and to attract investors.

2. Support public–private partnerships (PPP), The government can cooperate with the private sector to set up small- to medium-scale prefabrication industries, especially close to cities like Mekelle, Shire, and Adigrat.

3. Upgrade infrastructure and logistics, better roads and transport systems will make it less expensive and risky to move prefabricated parts.

4. Introduce incentives for technology adoption, a tax cut, loan subsidies, and public project priority could push companies to embrace the building method.

5.2.2 For contractors and consultants

1. Create a technical foundation, companies must provide training in the design, production, and installation of prefabricated components to their employees.

2. Take hybrid ways, mixing prefabricated with cast-in-place methods can slowly move contractors down the path and lower the concerns about the risks involved.

3. Collaborative planning, involvement of designers, fabricators and site teams at the beginning is necessary for minimizing errors and making compatibility between components.

5.2.3 For educational and training institutions

1. Incorporate prefabrication into engineering and construction curricula, universities and technical colleges should provide courses and hands-on training on prefabrication and industrialized construction.

2. Offer short-term certification programs, the existing skills gap will be filled through targeted training for site supervisors, technicians and machine operators.

5.2.4 For donors and development organizations

1. Support capacity-building initiatives, the international partners can fund research, training programs and demonstration projects to help build the capacity in the local

populations.

2. Help in setting up pilot projects, the pilot prefabricated schools, clinics, or housing units can be the proof for the wider adoption of the technology and can also help build trust in it.

5.2 Future Research

The study has provided a good overview of the economic benefits of concrete prefabrication in the building projects in the Tigray region; however, it has also revealed that there are still several areas that need to be explored further:

Future research might concentrate on:

1. Cost–benefit analyses of specific prefabricated components in Tigray
2. Supply-chain planning for regional manufacturing plants
3. Comparative studies between hybrid and fully prefabricated systems
4. Environmental and lifecycle performance assessments
5. Social acceptance and user satisfaction with prefabricated buildings

These areas will not only broaden the understanding but also strengthen the decisions made based on evidence for the expansion of prefabrication in the region

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Appendixes

Study Title: "*Assessment of concrete prefabrication adoption in Tigray region: barriers, benefits, and strategic framework for implementation,*"

Dear respondent;

I am a Civil Engineering (Construction Technology and Management) postgraduate student at the Ethiopian Institute of technology, Mekelle University, currently conducting a research study as part of my thesis entitled: " *Assessment of concrete prefabrication adoption in Tigray region: barriers, benefits, and strategic framework for implementation.*"

The purpose of this study is to assess the cost-effectiveness and economic impact of using concrete prefabrication in building construction, with a particular focus on projects in the Tigray region. As part of this research, I am collecting data from professionals like you who are directly involved in the construction sector.

You are kindly invited to participate by completing the attached questionnaire. Your responses will provide valuable input for understanding the real-world application, benefits, and challenges of prefabricated concrete systems in Ethiopia.

Please be assured that your participation is voluntary, and all information provided will be kept strictly confidential and used solely for academic purposes. You are free to decline or withdraw from the study at any stage without any consequences. No personal or organizational identifiers will be published in the final report.

I kindly request your cooperation in completing the attached questionnaire/interview. Your insights will contribute greatly to the understanding of prefabrication technologies in the Ethiopian context.

Should you have any questions or need further clarification, please do not hesitate to contact me at brhane.kahsay@gmail.com or +25194096940.

Thank you in advance for your valuable time and support.

General Instruction

- Writing your name is not mandatory
- Please kindly respond the following questions by simply ticking (√) in the appropriate box or write your answer in the space provided respectively to each question.

Appendix I - Questionnaire Survey

1. Profession________________________

2. Educational Status

 No College first-degree Masters PHD

3. Experience

 Below five years Five up to ten years Greater than ten years

4. Contribution

 Contractor Consultant Owner

5. What form of construction are you using currently on your project?

 In-situ Precast Composite (combination of both)

6. What is your Reason for selecting the Method of Construction?

No	Reason	Remark
1	Cast in situ is the only method practical in the region	
2	Cast-in-situ has better results than the precast construction method in terms of Time, Cost, and quality.	
3	Prefabricated plants are not available in the region, leading to higher costs of transportation	
4	Lack of acceptance for the precast construction method by construction stakeholders	
5	The precast construction method is not well-introduced and is not practical at the moment in the region	

7. What form of construction other than in-situ have been used in your entire experience?

 Precast Composite (combination of both) none

8. What is your awareness about precast/prefabrication concrete in building construction?

 No aware less aware highly aware

9. Do you think the adoption of concrete prefabrication is inhibited?

 Yes No

10. If your answer to question number nine is yes please specify your level of agreement on what factors could possibly inhibited the adoption of concrete prefabricated system in Tigray depending on the listed reasons?

Where 1=Strongly disagree 2= Disagree 3= Neutral 4= Agree 5=Strongly agree

No	**Reason**	**Strongly dis agree**	**Dis agree**	**Neutral**	**Agree**	**Strongly Agree**
1	Political instability and conflict					
2	Absence of prefabrication plants					
3	Transportation challenges					
4	Bad regional government policy					
5	Lack of regional and international investors					
6	Financial constraints					
7	High initial investment					
8	Raw material scarcity					
9	Inadequate power supply					
10	Limited technical expertise					
11	Absence of local Standards/cods					
12	Inflexibility in design changes					
13	Low market acceptance					

11. What do you think the potential consequences of inhibited adoption in Tigray's construction industry?

Where 1=Strongly disagree 2= Disagree 3= Neutral 4= Agree 5=Strongly agree

No	Consequence	Strongly dis-agree	Disagree	Neutral	Agree	Strongly agree
1	Prolonged project timelines					
2	Escalated construction Costs					
3	Inconsistent construction quality					
4	Reduced housing/infrastructure Delivery					
5	Wasted materials					
6	Heightened safety risks					
7	Suppressed technical Innovation					
8	Environmental strain					

12. Who do you think play the main role for the successful adoption of concrete prefabrication from the listed intuitions and stakeholders?

Where 1=Strongly disagree 2= Disagree 3= Neutral 4= Agree 5=Strongly agree

No	Intuitions & Stakeholders	Strongly dis-agree	Disagree	Neutral	Agree	Strongly agree
1	Regional government institutions					
2	International funding agencies					
3	International NGOs					
4	Regional academic sectors					
5	Federal responsible body					
6	Foreign investors					
7	Regional stakeholders					
8	Public					
9	Regional investors					

Appendix II - Interview question

1. Have you had experience with concrete prefabrication methods in building projects? If yes, in what capacity?
2. From your experience, how do the total costs of prefabricated concrete construction compare to traditional cast-in-place methods?
3. What specific areas (e.g., labor, materials, and time) contribute most to the cost savings in prefabricated construction?
4. Are there any cost disadvantages or unforeseen expenses associated with prefabrication?
5. How does prefabrication affect the speed of project completion compared to conventional construction?
6. What are the primary economic or infrastructural challenges to implementing prefabrication in local projects?
7. In your opinion, what steps can be taken to promote the wider adoption of prefabrication in Ethiopia?
8. What types of projects do you believe are most suitable for prefabricated concrete methods in the Tigray Region?
9. Do you see prefabrication as a sustainable long-term solution for cost-effective construction in post-conflict or rapidly growing regions?
10. Is there anything else you would like to add regarding the economic aspects or practical experiences of prefabricated concrete construction?