ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Precast Construction in Ethiopia - An In-Depth Look At The PBPPE Precast Plant

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

(Construction Management and Technology)

by

KIBIRT BAYOU CHANE

GSR/1527/05

June 2017

Addis Ababa, Ethiopia

Advised by: Abebe Dinku, Prof. (Dr.-Ing)

Acknowledgements

First, I would like to thank the Lord for all that He has done for me in my life, and creating all the conditions needed for the fruition of this research. I would also like to express my sincere appreciation to all PBPPE staff who contributed to this project by responding to my requests for information and insight. I thank my advisor and instructors at AAIT for following up on my progress and providing me encouragement and support.

I am grateful for my dad for making me keep pushing myself in the academic path and inspiring me to excel. Thanks to the rest of my family members for their all rounded support. Last but not least, I would like to thank my husband for his overwhelming love and support which gave me the energy to fulfill the requirements for an MSC thesis.

TABLE OF CONTENTS

ACRONYMS

BC: Building Contractor
BoQ: Bill of Quantity
C-30-1W-2.9M: 30 x 30 cm 1 Span Column with length of 2.9 m
C-30-2W-5.8M: 30 x 30 cm 2 Span Column with length of 5.8 m
C-30-1W(L=7M): 30 x 30 cm 1 Span Column with length of 7 m
Col.: Column
CTQ: Critical to Quality
CVP: Cost-Volume-Profit
DMAIC: Define-Measure-Analyze-Improve-Control
EBCS: Ethiopian Building Code of Standards
F1: Footing with dimensions of 120 x 120 x 80 cm
F3: Footing with dimensions of 200 x 200 x 80 cm
FDRE: Federal Democratic Republic of Ethiopia
FRP: Fiber Reinforced Polymer
G-30-1: 30 x 30 cm Girder with 1 Span
G-30-2: 30 x 30 cm Girder with 2 Spans
G-30-4: 30 x 30 cm Girder with 4 Spans
GC: General Contractor
LBW: Load Bearing Wall
LEED: Leadership in Energy and Environmental Design
MMFX: Martensitic Micro-composite Formable Steel
MoFED: Ministry of Finance and Economic Development
NPCA: National Precast Concrete Association
NPV: Net Present Value
PBPPE: Precast Building Parts Production Enterprise
PCI: Precast/Prestressed Concrete Institute
PDCA: Plan-Do-Check-Act
P.O.S.T.: Prestressed Open Space Truss
PQS: Personnel Qualification Standard
QC: Quality Control
RC: Reinforced Concrete
RC: Road Contractor
Rebar: Reinforcement Bar
RII: Relative Importance Index
ROI: Return on Investment
S-30-CL: 4.20 x 1.20 m Cantilever Slab on Left Side
S-30-CM: 4.20 x 1.20 m Cantilever Slab in the Middle
S-30-CR: 4.20 x 1.20 m Cantilever Slab on Right Side
S-30-N: 4.20 x 4.20 m Slab
SCC: Self Consolidating Concrete
TBL: Triple Bottom Line
VOC: Volatile Organic Compounds
Vol.: Volume
VSI: Visual Stability Index
WC: Water-to-Cement Ratio
WHE: World Housing Encyclopedia

KEYWORDS

- COMPARISON BETWEEN CONSTRUCTION METHODS
- CONSTRUCTION COST
- CONSTRUCTION QUALITY
- CONSTRUCTION SPEED
- PRECAST CONSTRUCTION
- PRECAST PLANT QUALITY EVALUATION
- SIX SIGMA ANALYSIS

ABSTRACT

It can be easily noticed how there are numerous defects in almost all of the concrete buildings in Ethiopia. Anyone who works in the construction industry would have witnessed poor quality of work in several projects. If such a person has an engineering and construction management background, the quality problems and subsequent technical risks would stand out even more.

This MSc thesis is about precast construction, specifically, about the significance of this construction method being introduced in Ethiopia. Despite the array of structural, serviceability, and quality problems that are very common, it is exciting to think of the tremendous opportunities that such a fresh start as precast construction would bring. Where the equipment and production space is available, structural concrete elements could be cast and cured in a controlled manner on the ground level. This could be seen as a characteristic feature of the precast method of construction.

The reader will find brief descriptions of the in-situ construction method, where concrete is mixed and cast on site, with further details of how many construction activities are done manually in Ethiopia. These details will probably draw a very old-fashioned and inefficient picture where construction is a messy, and slow series of disorganized activities. There are exceptions to this scenario, where supervision is sufficiently carried out by capable professionals, and project managers ensure timely completion within the construction budget.

The research then goes on to study aspects of precast construction that are relevant to the Ethiopian construction sector. It does so starting from what the country already has to work with, then it looks at the standard level of the precast construction method internationally. It takes that as a guideline to analyze what aspects should be considered if the country is to make substantial shift from the in-situ method towards the precast method. It also makes systematic comparisons between the two construction methods, between the work quality level of the precast plant in Ethiopia and the standard level in the international scene.

The findings are mostly as would be expected. Mainly, the precast method was found to be better in quality, resources, and time, than the in-situ construction method. It was also found that there are certain types of buildings that are more suitable to be constructed using the precast method. Finally, it was no surprise to find that the 28-year-old PBPPE precast plant got a score lower than the passing score in the standard NPCA quality control manual used in the US to evaluate precast plants and award them accreditations.

This is a major reason that this topic was chosen for the thesis. It was arrived upon while searching for ways of modernizing the construction process in leaps and bounds. With the degree of outdatedness of the construction process in Ethiopia, a catapulting change is needed just to cop up with where the modern world has already reached.

CHAPTER I: INTRODUCTION

1.1. BACKGROUND ON PRECAST CONSTRUCTION AND ITS DEVELOPMENT

With the exception of underdeveloped regions, precast construction is used through out the world abundantly. The need for the systematic use of precast elements in construction arises from the need for fast-paced construction of standard quality. Rate of construction depends on the demand for usable spaces, which has a direct correlation with a country's economy. This might be the reason why precast construction has not taken deeper roots in Ethiopia or even in other parts of Africa. This section gives brief descriptions of where precast construction currently stands in the country.

1.1.1. The Current Status of the Ethiopian Construction Industry

Many modern buildings in Ethiopia are predominantly made of reinforced concrete. The common elements found in the majority of these buildings are briefly discussed here. Depending on soil conditions, most of them have isolated footings in their foundations, and others have mat or raft foundations. Pile foundations are also used in some buildings, especially in areas where the soil is too weak to carry typical building loads on isolated footings. Some real estates have employed pile foundations for housing units in Lege Tafo. Coming to the superstructure, reinforced concrete frames with shear walls are the popular choices for lateral load resistance. In such types, a concrete building has shear walls and skeletal structural elements that make up the frame of the building. These structural elements include columns, beams, slabs, and staircases.

It is common in Ethiopia to build all the structural elements mentioned above using in-situ methods of construction, where concrete is mixed on site and poured using manual labor. Through out this thesis, the terms 'in-situ construction', 'in-situ method', and 'in-situ method of construction' are used to refer to the handling of the activity series of bar bending, reinforcement bar and formwork placement and fastening, concrete mixing, placing, and consolidation, formwork removal, and concrete curing manually, with hand measurement, and no way of checking whether or not the work is being done properly. It should also be noted that the in-situ method is done by untrained laborers. An alternative that is being employed in a number of construction sites is employing ready mix trucks to mix and pour concrete. Another option is using precast construction from the precast plant. This has been utilized in government's building projects more than in private ones.

The in-situ construction activities being carried out in Ethiopia can be broadly categorized into two. In the first category, there are the construction projects, usually big scale ones, where theirs are professional project managers, site supervisors, and site engineers and that these persons fulfill their responsibilities with sufficient capability, honesty, and integrity. In the second category, we find projects that are essentially ridden with lack of supervision, poor quality management, and corrupt practices. This research abundantly focuses on the second category as it involves a lot of malpractices and problematic activities that result in buildings with numerous quality problems.

In-situ contractors have been known to use an excess of cement in their concrete mix in order to ensure that the final concrete product has a strength that is equal to or more than the design value. Other times, contractors attempt to save expenses by using as little cement as possible. The amount of water used to mix concrete is rarely measured, which means the strength of the finished concrete is not known. Hence, there is an abundance of irregularities in terms of quality of concrete structures in Ethiopia.

1.1.2. The Precast Building Parts Production Enterprise - Ethiopia's Precast Plant

The first and only precast production company in Ethiopia, the Prefabricated Building Parts Production Enterprise (PBPPE), was established in 1987 with the help of the then socialist country of Yugoslavia. Back then, the Ethiopian construction industry was at an infant stage, with only a number of modern buildings constructed in Addis Ababa, mainly with prefabricated elements. Within its 29 years of operation, PBPPE has not shown much progress as an organization. It still uses the same outdated batching plant, crane system, and even molds that had been installed during its establishment all those years ago. Additionally, it has fixed specifications for every single component of building construction. So if, for example, one designed a building with slabs spanning 6 meters as is the case in many building designs in Ethiopia, the building would have to be constructed in-situ (not prefabricated) because PBPPE doesn't have slabs spanning greater than 4.20 meters in either (x or y) direction. Neither does the plant have column sections greater than 0.30 m X 0.30 m, and shear wall height exceeding 2.62, among several other restrictions.

1.1.2.1. Organizational Components of the PBPPE

The Precast Building Parts Production Enterprise (PBPPE) has a Construction Department, a Production Department, and a Logistics Department. The tasks that each department performs and the roles that each play are briefly discussed below.

i. Construction Department

PBPPE plays the role of the contractor party when signing contracts with its clients. These clients could be private customers or government organizations. Since all of its precast structural elements are predesigned and detailed in the plant's original design manual, there is no design work to be carried out by a consulting firm, as is the usual case in in-situ construction projects. The client can have design analyses run by a design firm of their preference if they choose.

The construction department of PBPPE is responsible for certain activities. These activities include roles similar to overhead offices of construction companies like signing contracts with clients, overtaking projects from clients, and following up on ongoing projects. The construction department of PBPPE hence corresponds to the administration offices of in-situ construction companies.

ii. Production Department

This is the department responsible for carrying out the concrete works of the plant. It also carries out the erection works of the precast elements at the construction site. The works carried out by this department begin at the plant. It obtains drawings from the construction department. Reinforcement bars and other required materials are obtained directly from the logistics department. The production department uses the production manual to quantify and undertake precast production and provides project specific parameters and data such as water-cement ratio to the batching plant.

There is a “concrete works” team operating under the production department. The concrete team handles wedge and barrel production, and preparation of reinforcement bars and fresh concrete using drawings obtained from construction department. The production department is also responsible for concrete casting, curing, and erection works.

The role of this department corresponds to on-site works typically carried out by site engineers, foremen, and daily laborers.

iii. Logistics Department

Since nearly all concrete works are completed at the plant before being transported to the construction site for erection, all inputs are always ordered and delivered to the plant’s location. The logistics department handles the import, purchase, and inventory of all material inputs needed for precast production.

The department is responsible for cement, sand, coarse aggregate, and reinforcement bar purchases. In the beginning, it used to import the wedges, barrels, and plates from India and Belgium. Latter, it made purchases of these items from Gafat (METEC), but now these items are finally being produced in PBPPE. Nonetheless, PBPPE obtains prestressing wire through import and, as such, the logistics department is responsible for the import process. In addition, this department obtains necessary spare parts for maintenance of tower cranes, bridge cranes, the batching plant, or any other malfunctioning machinery.

In in-situ construction companies, procurement offices play the corresponding role of this department in the PBPPE precast plant.

1.2. STATEMENT OF THE PROBLEM

1.2.1. Description of Problems

One problem that this study addresses is that it is not quantitatively known with certainty how to choose between a precast and an in-situ method of construction for different types of buildings. Most of the precast buildings are government owned and they have been built with precast because the government didn’t use to have a capable agency of its own to build higher story buildings. Of course, it can be easily understood that the more repetitive elements there are in a building structure, the more economical choice that precast construction becomes. Nonetheless, repetitiveness is not the only determining factor that should be considered in this decision. The sizes of most structural elements, their shapes, and whether or not electrical and mechanical systems would be embedded in them, are a few of the additional factors to be considered.

Another problem that is being addressed is that it is assumed that precast construction is less economical than in-situ construction due to its higher direct cost, at least that is the case with PBPPE in Ethiopia. Even though the higher direct cost is a correct observation, even a simple calculation of the income lost due to the difference in construction time between an in-situ constructed building and a precast building is more than enough to rule out in-situ construction as highly uneconomical.

With precast construction, the waiting time that many buildings spend after completion and before operation commences can be avoided. This is achieved by undertaking the production and erection process within three months or less of the start of the intended operation for the building. Factors like material wastage, lower quality, poor safety conditions, etc further weaken such claims against precast.

The last issue that has been looked into in the study is where PBPPE stands against a minimum standard of operation that developed countries use to evaluate their own precast plants. The problem here is that with the number of years that have passed since PBPPE has started operation, a lot has changed worldwide in construction technology. What was acceptable 28 years ago, may not be up to par currently. Moreover, almost all equipments, forms and design and production manuals that the plant utilizes are the same ones that were put in place during its start almost three decades ago, that all their pages have parched and turned brown. They are very delicately handled as they have not yet been converted and filed into a soft copy format. Evaluations of the most critical precasting and prestressing activities carried out by PBPPE were undertaken in order to check if PBPPE at least surpassed the minimum requirement for a standard precast plant.

Hence, the actual problems that have initiated this study are summarized as follows:

i. Lack of a practical method to choose between a precast method of construction and an in-situ method of construction, according to the shape, size, type, desired quality, and speed of a construction project.
ii. Assumption that precast construction is typically less economical than in-situ construction, disregarding the indirect effects that construction speed, quality, and evasion of untimely maintenance have on cost.
iii. Lack of conclusive information and data about the current working capacity of PBPPE, which is needed to know, if precast construction is to be realized in Ethiopia.

As complementary points under this section, some of the major problems in the Ethiopian construction industry have been discussed in subsequent sections.

1.2.2. General Problems in In-Situ Constructed Structures

The statement that construction is of low quality in Ethiopia, even though it might be an obvious observation, is just a claim. The reason that this statement can only be considered a claim is because quality is not being measured or quantified in any systematized way. Certainly, it seems that there are so many buildings in Ethiopia without obvious quality problems. According to my observation, these problems include bent, deformed, crooked, or wavy concrete members or edges or surfaces of concrete members; water or rust stains under floor slabs or any other concrete surfaces; visible (uncovered) reinforcement bar surfaces on the outside of reinforced concrete members; honey-combed, scaled, chipped, discolored, dusty concrete surfaces, overly clumped (no spacing) or overly dispersed (too much spacing) reinforcement bars in reinforced concrete members, misalignment of concrete members against each other or a set reference line, messy and unsafe construction sites without clear paths for material and equipment movement, to name a few.

These are some of the several obvious problems one can notice. If all the buildings that are standing in Ethiopia were checked against any international building code, it is doubtful that there would be many buildings without at least one considerable defect in their reinforced concrete elements. It actually seems to be easier to pick out and set aside the buildings without major defects than to do the same for buildings with major and obvious defects. This theory is substantiated by the fact that there have been two evidences of brand new buildings that have collapsed in the Summit area of Addis Ababa.

So why couldn't there be a national quality control system for reinforced concrete structures, so that at least the extent and severity of building problems can be indexed, and the same errors would not be made repeatedly? On the one hand, if there was such a system, it would be difficult to measure and assure a reinforced concrete structure is made up to a standard in projects where construction activities are done by untrained daily laborers with little to none professional guidance and only a traditional understanding of the construction process. Besides, these activities are carried out using hand held, unpowered tools.

The other problem is that most activities conducted by manual labor result in considerable material wastage that it is difficult to reasonably measure how much material a certain activity actually consumes. Measuring the time taken and the labor, machinery and equipment cost would be just as challenging.

As a result, there is a large amount of construction being carried out in Ethiopia, with no standard means of measurement for quality or extent of error. This is one of the basic problems, in my opinion, that is preventing a continuous improvement in quality of construction activities. What can not be measured can not be improved, if not by chance.

1.2.3. Detailed Problems with the In-Situ Method of Construction in Ethiopia

Some construction projects in Ethiopia employ qualified professionals to supervise works, progress, and material and equipment use. Nonetheless, there are numerous construction projects where activities are done in a very unrefined kind of way in Ethiopia. Untrained daily laborers are heavily involved from start to finish. Contractors choose to use the services of daily laborers for extremely lower cost as compared to utilizing a machine. Most daily laborers have previous work experience at construction sites. Therefore, most construction work is done using manual hand tools and with very limited use of construction machineries.

At the foundation level, excavators may be used for digging the earthwork if it is considered substantial (the size required for commercial or office buildings instead of private homes). But, any resizing or reshaping of the dug volume is usually done by daily laborers using non-powered equipments like pick axes and shovels. In order to increase the speed of construction, Ethiopian contractors would hire more daily laborers, so the number of daily laborers employed at a construction site typically goes up during concrete placing activities, especially if the member being filled is voluminous, such as floor slabs. This usually leads to overcrowding of the construction site.

Precision works such as setting out of the site, elevation measurements, checking column and beam alignments, precise angles of corners and general dimensions of structural members are all done by technicians using non-motorized hand tools. Tube-water levels (water in a long thin tube), spirit levels, polypropylene ropes, wood panels, unprocessed eucalyptus wood, wood planks, hammers, hand saws, pliers, plumb bobs, chisels, pick axes, shovels, screwdrivers and wrenches are not only dominantly used, but they are also the only tools made available to do most of the work at a construction site.

This whole process has been done time and again for over three decades now. Despite being practiced for so long, it still provides the relatively poor quality results that have been enlisted at the beginning of this topic. This goes to show that this method is inadequate and it should simply be deemed as unacceptable, even though it has reached its maximum level of "refinery".

1.2.4. Problems with PBPPE

Most of the construction problems aforementioned in this section don't pose a significant challenge in most developed countries. There are lots of studies highlighting that not only the western world, but also, most parts of asia, especially northern asia, have a history of using precast systems to further the progress of their construction industries.

Taking a closer look at PBPPE, it was noted that no marketing works have been done to attract potential clients to consider PBPPE as a viable alternative for planned construction projects. This has resulted in an abundant number of partakers of the construction industry never having heard of precast building methods, let alone that there is a precast plant in Ethiopia. This is a major problem with the PBPPE institute.

In addition to marketing schemes, the PBPPE plant could hire out its batching plant, and other equipment that it might own, such as dump trucks, in order to create an alternative source of income. It used to produce precast concrete beams (ribs in the ribbed slabs) to supply to the low-cost housing (condominium) projects. Now, it gives trainings to construction teams working under the micro-finance governmental program on precast beam productions, so that they may take their skills and supply the precast beams to the low-cost housing projects directly.

The government faces conflicts in its aim to make layperson jobs, such as daily labor, available for a mass of untrained youth. Thus, policy makers tend to advance strategy that includes work methods that would create wide job opportunities for laypersons. The proper administration and development of precast plants, in addition to the one available at the moment, is seen as being against such a policy.

It has been a long time since PBPPE was built. Although it was set up with the help of the then Yugoslavian government, which was at the forefront of precast construction along with other eastern Europe and Soviet Union countries at that time, there is no evidence that shows that the plant is still up to standard. It uses the same machinery that was installed back then, specific design parameters and values that had been incorporated during its founding, and it has fixed sizes of molds as per these designs.

1.2.5. Additional Problems of the Ethiopian Construction Industry

When we take a bird's-eye-view look at the construction industry, there is an abundance of additional problems. On-time delivery is very rare. There are significant discrepancies between estimated and actual project cost. Lack of work ethic results in damages ranging from surplus time and cost expenses to compromising safety during construction and operation. Corruption and theft in most works aggravate most of the aforementioned problems.

1.2.6. Summary of Statement of the Problem

The amount of time and resources required to complete each construction activity in Ethiopia is not measurable and the time and cost of construction is almost always extended. This would prevent any practical quality improvement actions from having the desired results. Therefore, quality remains compromised. The in-situ method through which construction is being carried out, therefore, would not lead to significantly improved construction projects, unless heavily supervised by professionals.

Moreover, PBPPE's precast plant has not been utilized to its full potential. Being the first and only precast plant in Ethiopia, it should have played a more prominent role in eradicating major problems within the construction industry.

1.3. SIGNIFICANCE OF THE STUDY

While deciding which method to follow, analyzing the differences between different methods of construction helps the reader to become aware of what factors, in addition to direct cost, affect overall project outcome. Moreover, it shows what effect factors such as the 'type', 'shape', and 'size' of a building have in the selection process from alternative construction methods.

Starting to utilize the precast sector as a major role player within the construction industry would lead to higher quality, more economical, and faster construction works. So any reasonable person within Ethiopia's construction industry might ask, "why hasn't this happened yet?".

There is a functioning precast plant with all the equipment for precast production under the government. PBPPE was instituted in 1988, thus it has been running for 28 years now. Even though it has been operational for more than two decades, the precast plant is not functioning at its required capacity.

This thesis would open up the reader's mind to the fact that there are different types of construction methods that are better than the usual type, before settling on the best alternative for the project that they might be involved in. This is far better than following the status quo with little awareness about the kinds of time and material loss or loss of better opportunities that it exhibits.

1.4. SCOPE AND LIMITATIONS OF THE STUDY

Since PBPPE is the only existing precast concrete plant in Ethiopia, this research is limited to studying just one plant. This might not be enough to generalize the construction quality level in the industry as a whole, albeit having only one precast plant in such a growing construction industry is in itself a proof.

Any deviations from this central topic are intended to give a fuller picture of the existing situations in Ethiopia's construction industry and should be regarded as complementary information and data. A number of additional descriptions are mainly included in order to meet the objective of the research that using precast systems would result in a fundamental improvement of construction project outcomes and an overall more economical construction process.

On the application end, the data sample is limited to Class I through Class V general and building contractors of Ethiopia. This class limitation is in order to decrease the number of uncontrolled variables that would affect the outcomes of the research, namely financial issues that construction companies of lower classes may have that could prevent them from installing basic equipment necessary for transportation, installation and maintenance of precast elements, that are not major challenges for higher class construction companies.

The main reason for the exclusion of road contractors (RC) is that the problems with road construction in the country are much wider and fundamentally different from those of building construction, that it was deemed too wide for the scope of this research thesis. They would also require a geographically wider study with a bigger research budget.

Another limitation imposed on this study is the temporary interruption of precast building projects by the PBPPE. The last project that the plant worked on was two years ago.

Therefore, the study has had to use rather dated data. Also, there were a lot of problems with missing or damaged design files, which has resulted in such a small number of precast buildings being analyzed for cost comparison.

Another limitation that this research has faced is that there are no precast prestressed concrete members currently in production. Hence, records of past data have had to be used. Since PBPPE uses limited design parameters that have been in use since its establishment, it has been assumed no considerable technical changes could arise since its last precast building project two years ago. Gaps and incoherences in the reports have been filled out through semi-structured interviews with longstanding technical members of the precast plant.

1.5. RESEARCH HYPOTHESIS

This research predicts that most of the modern buildings that have been built with the in-situ method would have been economically more gainful had they been built using the precast method. The amount of material that has been wasted, in addition with the less than satisfactory quality of buildings that were the end result, would cost the clients considerable amounts of unnecessary expenditure in maintenance. Regrettably, this maintenance is needed immediately after completion.

What's more, the time that the clients themselves or their leasing parties must have waited before they could start soundly operating within the building space, if converted as per the rental rate would be in millions on average. When all these are factored into the comparison, this study is expected to find quite a discrepancy between the overall cost of the in-situ construction method and that of the precast construction method.

One factor affecting the attempt to push precast plants forward in Ethiopia could be the fact that many existing construction companies would be in risk of redundancy. They have invested millions in equipment, employee salaries, and overhead activities, that it would not be attractive to any one of them to throw it all away and start anew with what precast construction might require.

Secondly, the lack or shortage of awareness of most of the large scale investors and contractors about exactly what a precast plant does, what it has to offer, and the benefit it has over in-situ construction methods is a reason that it has not played a very active role in the current construction boom.

The third factor is the assumption that PBPPE's equipment and works wouldn't still be up to standard. Could they even produce a better result than at least in-situ construction works using manual labor and backward methods of ensuring consistency and accuracy?

1.6. RESEARCH QUESTIONS

The primary research question that this study is going to answer is whether or not a precast plant can compete with the building contractors in the Ethiopian construction industry. That is meant to ask if a precast plant can give its services for a price competitive to the average price requested by the in-situ contractors in the country.

Among other data, this draws up the need to obtain a definitive value of quality, time and an estimate of the overall rate and cost per unit area of in-situ construction methods, so that a reasonable comparison can be carried out between these traditional methods and those using the precast system of construction. The same measures for quality, project duration, and speed and cost per unit area were required for precast construction methods.

The study would provide a response to the question: "By how much does PBPPE fulfill standard requirements?" The study shows how the enterprise would measure up in an international industry. This is done by revising PBPPE as per the international quality control manual used in the USA. The NPCA Quality Control Manual for Precast and Prestressed Concrete Plants has been selected for this study. The reason why this all inclusive, comprehensive and accessible publication was selected among other manuals is also discussed in the methodology section of this study.

Although the NPCA grading schedule was found to be more comprehensive and user-friendly, the Precast Plant Evaluation format of the Precast/Prestressed Concrete Institute (PCI) was also used to take further assessments of the precast works carried out by PBPPE.

This assessment was included because PCI is the precast concrete "structures" industry which includes prestressed precast concrete and other precast elements used in buildings, bridges, and parking structures. In contrast, the precast concrete "products" industry, which mostly encompasses non-prestressed precast products for utilities construction (water distribution, road furniture, etc) is represented by the NPCA.

This zoom-in into the Ethiopian precast plant highlights where its major drawbacks lie and how far off the plant is from precast plants in other parts of the world. Laboratory data from the PBPPE's own in-house concrete laboratory recordings have been used in the NPCA manual's grading schedules, which has been used to obtain PBPPE's final score. This score's standing has been complemented by interview results from key PBPPE staff members in order to give a fuller picture of the plant's current conditions and performances. Following this discovery, the research has made recommendations on what PBPPE can do to improve its standing and operate above a standard level.

1.7. RESEARCH OBJECTIVES

The objective of this thesis revolves around giving the reader awareness about precast construction development, general procedures of this method of construction, where Ethiopia's precast construction stands as compared to precast construction in the developed world, and to what extent have construction industries in developed countries reached and surpassed the current level where Ethiopia's construction industry has reached.

1.7.1. General Objective

The research's main objective is to show that the precast construction method could break into the Ethiopian construction market. There are numerous decisive reasons to switch from the in-situ construction method currently being used extensively in Ethiopia to the precast construction method that is being just as widely used in developed countries. One significant indication that the precast method can provide transformative building construction projects is the abundant use of the method by numerous European countries to rebuild their cities after World War II. One can imagine the extent of demolition that these countries have had to face by the end of an exceedingly disruptive war. Hence, if they selected it as their go-to method of construction for such a critical situation, it could transform a backwards country like Ethiopia as well.

In order to meet this objective, the business side of such a plant has been studied as thoroughly as possible. Most values have been converted to similar formats as values in the in-situ construction method in order to make clear comparisons between the two methods.

One of the ways that the main objective, i.e., 'showing that switching to precast construction is the right move to make in the Ethiopian construction industry', was met is by demonstrating that precast construction is lower in overall cost than in-situ construction. Another point to show is that precast construction incontrovertibly exceeds in-situ construction in the parameters of resources, time, and quality. The numerical tool selected to meet this part of the objective is the Six Sigma analysis tool.

After it is indisputably shown that precast construction exceeds the in-situ method in quality, cost, and time (construction speed), the next logical step was to check where Ethiopia stands when it comes to starting a journey of incorporating precast construction as a mainstream alternative for building construction. This requires an inventory to be done of the existing precast plant and to see if it can operate satisfactorily. The way that precast plants in developed countries get checked is by checking if they meet the minimum requirements set in standard quality manuals.

The National Precast Concrete Association and the Precast/Prestressed Concrete Institute are the organizations directly responsible to ensure precast plant production quality in the Unites States. Both of these organizations have quality control manuals that can be used to evaluate precast plants and assign scores. The precast plants that achieve a lower score than the lowest allowed score are deemed to do major renovation works or, depending on how low the score is, relinquish the precast business altogether.

Even though PBPPE would not face any repercussions no matter its score, it is still important to know where it would stand if it was operating in a developed country like the United

States. Therefore, it has been evaluated according to the two international quality control manuals in order to comprehensively meet the research objective.

An argument usually made against using the precast method for building construction is that it is wasteful to employ all that machinery to produce similar reinforced concrete members if they are few in number. Repetitive production is one of the beneficial features of precast construction. Traditionally, contractors would use more motor equipment and heavier machinery for the taller buildings. This is mainly due to accessibility. It is difficult to manage and very time consuming to use manual labor to haul up construction equipment and materials as the number of stories increases along with building elevation.

As such, there usually is a certain building size that construction companies deem is more economic to build using lifting machinery than manual labor. Thus, it is only reasonable to ponder on the types and sizes of buildings best suited to construct using precast. Just the same, there is a certain building size that could be built more economically if precast systems were used instead of in-situ construction methods. This study will show, quantitatively, what factors to consider in the decision to switch to the precast method. In connection to this objective, common building types that are best fit to be built using the precast construction method are enlisted and prioritized.

This is why in addition to meeting research objectives, the research will produce a systematically arranged priority list of the building types best fit to be built by the precast method.

1.7.2. Specific Objectives

The specific objectives of the research are as follows:

i. show that if a modern precast plant were to be built in Ethiopia, it would be more lucrative than the average in-situ building construction company
ii. prove that precast construction is lower in overall cost than in-situ construction

iii. prove that precast construction exceeds in-situ construction in the parameters of economy of resources, economy of time, and improvement of quality
iv. show where PBPPE stands as compared to international precast plant standards

As it can be seen, there is a reasonable sequence in between the specific objectives, and they also relate to the fulfillment of the general objective. Showing if a precast plant would be more lucrative than an in-situ construction company would support the shift towards the precast method by eliminating one major concern that many people in the construction industry have against it.

Many have argued that this is not a method suitable to a developing country, as it is a much more expensive way than the status quo. That is why this research took as its second specific objective to show that that is indeed not true. Unless one has the economical awareness that time and quality have undeniable influences on project cost, they might come to the conclusion that a lower initial investment, manual labor, and things like that boil down to lower cost. It will also put to use the highly efficient Six Sigma analysis tool in order to show by exactly how much the precast method exceeds the in-situ method, when it comes to saving resources, time saving, and erecting better quality buildings.

Finally, a quality control evaluation of PBPPE will be done using international standards as guidelines. This is done in order to show that the country doesn't have to start its precast development from scratch.

CHAPTER 2: LITERATURE REVIEW

2.1. ORIGINS OF PRECAST CONSTRUCTION

Ancient Romans used to pour concrete into molds to build aqueducts, culverts and tunnels beginning around 100 B.C. In modern times, precast was first utilized in Liverpool, England by then city engineer John Alexander Brodie in 1905. Later, the method was widely adopted in Eastern Europe and Scandinavia. In the US, the precast concrete "products" industry, which mostly encompasses non-prestressed precast products for utilities construction is represented by the NPCA. Meanwhile, the precast concrete "structures" industry which includes prestressed precast concrete and other precast elements used in buildings, bridges, and parking structures, is represented by the PCI [1].

2.2. BRIEF HISTORY OF PRECAST CONSTRUCTION

Precast construction started to be widely used in the U.S.S.R. in 1954. The products mainly consisted of separate precast elements that would all be assembled on site. Since 1958, precast cell systems started to be produced. "By this new concept, individual large sections of buildings are manufactured instead of separate precast concrete elements…". Parts of apartment buildings, as big as one complete living unit at once, started to be precast and assembled. "… entire cells of buildings, for installation as completed sections of a block of apartments, have been manufactured" [2]. Figure 2.1 shows such an assembly.

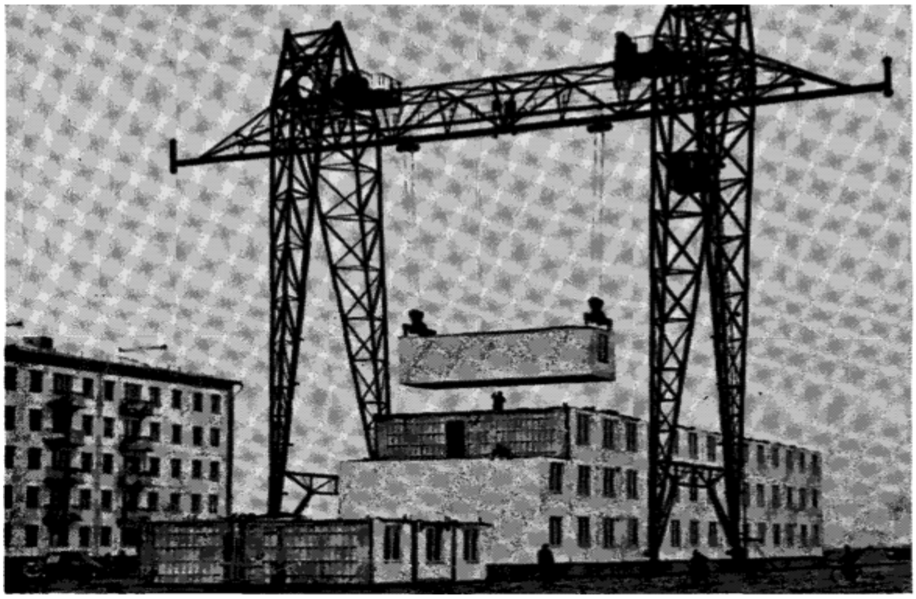


Figure 2.1: Apartment construction in the U.S.S.R. using prefabricated cells to make up the structure [2]

Marked use of machinery for concrete production, and the use of prestressed reinforcement became very prominent after this method of construction sprung up and gained popularity in the developed countries. In 1949, there was no precast prestressed concrete production in the US. In 1974, 1.4 billion dollars worth of precast was sold by north american precast plants. The first major prestressed structure built in the US is the Walnut Lane Bridge in 1949. It was designed by a European engineer, Gustave Magnel.

In a Canadian Conference on Prestressed Concrete in 1954, Magnel criticized the American production industry saying that they have highly specialized machinery which has resulted in a “save labor” philosophy that prevented Magnel’s team from producing 100,000 identical bridges. Special fittings like sandwich plates and rubber cores for the Walnut Lane Bridge were only needed in a few hundreds which no one in America was interested in “machine-tooling”, so they had to be manufactured in Europe.

Mikhailov states that in the beginning, there were five factors that mass production of prestressed concrete depended on.

"i. Availability of 7-wire cold drawn stress relieved steel strand, i.e. prestressing wire.

ii. Development of a workable strand vise, used to apply tension on the prestressing wire.

iii. Efficient production of high strength concrete.

iv. Implementation of the long straight line casting bed concept.

v. Development of standard cross sections"[2].

These are factors that affect PBPPE's production process. For example, the prestressing strand has to be imported from either Europe or India if production is being carried out. The wedge and barrel that are used to lock the prestressing wire could now be produced in-house, although they used to be imported for most of the plant's lifetime. "These five accomplishments made possible the rapid development of a mass production manufacturing industry in prestressed concrete" [3].

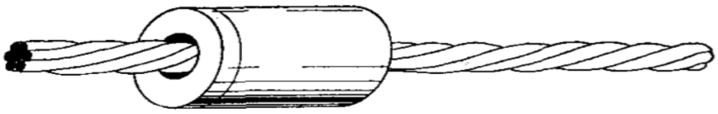


Figure 2.2: Seven-wire strand and strand vise [3]

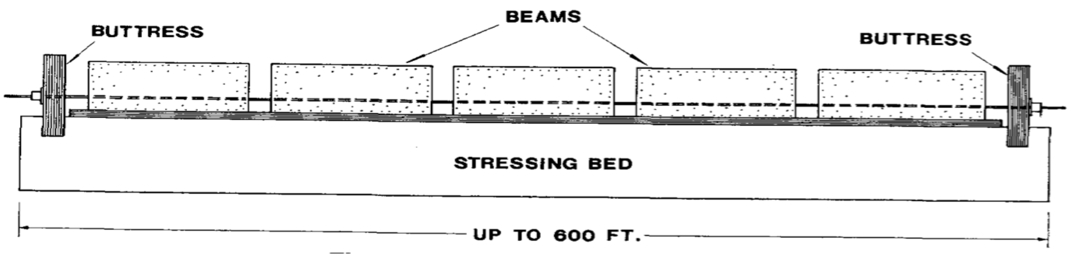


Figure 2.3: Long Line Casting Bed. [3]

A different method of prestressing had been tried prior to this classic method, which included winding wire "around rectangular beams to prestress them externally". Magnel mentioned additional concerns he had about prestressed precast production in the US stating that the high strength, zero slump concrete required for prestressing could not be achieved because the contractor preferred to save labor. They had to settle for 2 inch slumps which went down to 6 inch slumps towards the end of the project.

This led the American concrete production industry to use the vacuum process, “where relatively high-slump concrete was cast in special vacuum forms, and a low water-cement ratio was then obtained by removing the excess mix water by means of vacuum”. There are advanced methods that are being used now which can get much higher strength with zero slump but “in the early 50's the vacuum process gave the fledgling industry a way of obtaining high-strength concretes without decreasing the ease of placement” [3]. The Vacuum system was very large and expensive.

The long line casting method was another crucial development in precast production. Instead of casting individual elements in separate forms and on separate prestressing beds in rapid succession, it provides the more economic way of casting on a 150 meters long bed with prestressing wires of the same length jacked at the ends of the bed. As can be imagined, this method in itself presented enormous challenges relating to the shape of the structural element and the varying steel profile in each of the elements, which were required for the structural efficiency of the element.

Precast production seems to be most appropriate for producing precisely alike shapes and lengths of concrete members repetitively, but this is not frequently the case in most buildings. The long line process allows for the customization of concrete elements without losing the advantages of fast and highly controlled precast production. For bridges and other lineal road structures. the repetitive production serves great benefits of saving time and money.

2.3. MAJOR ADVANCES AND CURRENT STATUS OF THE PRECAST INDUSTRY

With the comprehensive technological advancements of concrete, precast concrete has also found applicable features. The Design Build Institute of America has published a paper discussing the widely applied inventions and citing other more specialized innovations on concrete.

The publication states that “[n]ew advancements in concrete and cement-based products are completely changing the design and construction worlds”. As in most North American publications on precast, equal importance is given to the architectural decorative aspect of concrete in the paper as it is to structural and workmanship aspects. However, since the focus of this thesis is on quality, cost, and construction or production time of structural concrete members, the applicable technologies have been included here.

Load-Bearing Wall (LBW) system is gaining recognition in high-rise buildings with repetitive cell layouts, such as hotels and apartments. "… The walls and slab are poured simultaneously when using the innovative tunnel form construction method".

The improvements in tilt-up systems have been quite remarkable that precast load-bearing walls can be lifted to large heights. This allows for different installations within the walls. "… The Tilt-Up industry is reaching new heights with the record lift nearing 100 feet. Production is streamlined with embedded facers cast integrally with wall panel to greatly reduce labor requirements with conventional brick and mortar veneer".

Aerated Autoclaved Concrete (AAC) is one of the most exciting inventions in concrete technology. "Lightweight Masonry takes the form of AAC block. With sufficient structural capacity to be used as low-rise bearing walls, AAC block greatly reduces masonry partition wall weights for elevated slab construction". Moreover, the porous nature of AAC allows for a thorough curing on a micro granular level of internal concrete structure.

The following probably offer more advanced solutions than the basic kind that the aforementioned innovations would provide, but the rapid competition within the international construction industry could pose such demands in the near future.

There are a number of new technologies that are changing the way we build and what we can build with concrete, among which using optical fibers to give concrete a translucent appearance is one of them. "This "see-through" development is changing the perception of concrete's opaque mass".

A pro-level knowledge on the common characteristics of concrete suggests that traits such as heavy weight, surface cracks and chipping are usually linked to the presence of coarse aggregates in concrete. Despite their side-effects, coarse aggregates are what provide the majority of compressive strength to the concrete. "Reactive powder concrete is extremely workable, durable and yields ultra-high strengths without using coarse aggregates. Reaching compressive strengths of 30,000 pounds per square inch (psi)…". Ideally, this is one solution that can be used nearly problem-free reinforced concrete members.

Self consolidating concrete is not really as recent as the other technologies mentioned above. It has even been put to use in some large construction projects in Ethiopia. It is an important innovation that allows for large size concrete bodies that would not be easy to consolidate using conventional means such as vibration. "Self Consolidating Concrete (SCC) eliminates the need for mechanical consolidation and yields a smooth surface finish without mix segregation. SCC and computerized precision color are revolutionizing the precast industry" [4].

A number of other inventions are gaining popularity in concrete construction ranging from fiber reinforcements as in Ultralite to long-span yet shallow truss systems such as Prestressed Open Space Truss (P.O.S.T.). Fiber reinforcements are briefly discussed as follows.

The earliest that the precast industry started to make use of fiber reinforced polymer (FRP) as an reinforcement alternative for concrete is in the early nineties in the United States. "The most common use of FRP in infrastructure is for repair and strengthening of existing structures. FRP is an attractive choice for these applications since it is often cost-effective, easy and quick to install, and does not significantly affect the mass or geometry of a structure…".

So far, the use FRP in concrete construction has not been wide spread, but it is forecasted to be more utilized in precast construction in the future. "…[R]ecent advances in the precast concrete industry have enabled more widespread use of FRP in new construction with a variety of new applications emerging".

Fiber reinforced polymers can be made in different forms like sheets, plates, bars, and grids. offering a wide range of applications for construction. “Construction of the panels consists of: (1) casting the bottom layer of concrete, (2) placing the insulated rigid foam with FRP grid, and (3) casting the top layer of concrete” [5].

Insulated Concrete Form walls (ICF) provide speed, sustainability, and endurance to concrete structures. “In addition to rapid construction, energy savings and increased durability, owners also gain a healthier and quieter environment. Most recently, blast-test experiments [on ICF walls] showed exceptional results for resistance to catastrophic loadings, including fire, wind, and tornados”.

PBPPE uses post-tensioning to prestress concrete members in precast construction projects. “Post-Tensioning has new construction and retrofit applications. An intumescent material creates fire-resistant PT strands for bridge deck and parking garages. The ‘Spider’ method retrofits buildings for earthquake protection, while External Post-Tensioning (EPT) helps solve strength and serviceability problems”.

Another finding that can be incorporated into precast construction systems is MMFX, a new highly corrosion resistant form of steel that can reduce the speed and precision of concrete mat construction. “…’Reinforcement Carpet’ gives a unique solution to reduce shipping and erection costs… Galvanized and stainless clad rebar offer less expensive, but corrosion-resistant alternatives to stainless steel rebar. The latest technology of MMFX micro-composite steel gives a high-strength, corrosion-resistant product with a cost-effective price” [4].

2.3.1. Precast Concrete and Sustainability

According to Sustainable Construction Techniques by Donna Sundblad, some of the techniques recognized in sustainable construction are low volatile organic compounds (VOC) paint, plywood processed without using formaldehyde, install big windows that provide plenty of fresh air and natural light, install energy and water efficient appliances, install low-emitting carpet, proper site selection and prevention of pollution on the construction site, build within walking distance to 10 basic services, provide space for storage and collection of recyclables, establish minimum level of indoor air quality performance, minimize environmental tobacco smoke, build near alternative transportation, and reuse or recycle construction materials when possible. Examples of sites not to select for construction include prime farmland, in a floodplain, on threatened animal habitat, and too close to wetlands.

“Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary room temperature. Their high vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate or sublimate from the liquid or solid form of the compound and enter the surrounding air, a trait known as volatility. For example, formaldehyde, which evaporates from paint, has a boiling point of only –19 °C (–2 °F)” [6].

On the contrary, sustainability measures such as installing energy and water efficient appliances, installing low-emitting carpet, prevention of pollution on the construction site, and providing space for storage and collection of recyclables are not common in Ethiopia. As such, the Ethiopian method of construction has so many aspects that are non-sustainable.

Sustainability is one of the major benefits of precast construction. Sustainability is often defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [7]. Basically, it means that the earth’s limited natural resource should not be depleted, overused, or damaged so that future generations would still have remaining resources on which to survive. It features some concepts that most professionals are not aware of. The subsequent sections briefly explain some of these concepts.

i. Triple Bottom Line

The triple bottom line (TBL) concept includes environment, society, and economy. It shows the relation between economic consequences and environmental and social consequences. The "bottom line" refers to either "profit" or "loss" usually recorded at the bottom of a statement of income and expenses. Coined by John Elkington in 1994, the Triple Bottom Line refers to two additional bottom lines for social and environmental concerns. this is based on the attempt to account for a company's full cost. For example, if a chemical processing factory dumps its waste into a nearby river, the government might have to spend tax payers' money to clean up the river, how is the true full cost-benefit analysis. Thus, the TBL adds two more lines for social concerns and environmental (ecological) concerns.

ii. Holistic/Integrated Design

Integrated design is mainly about taking into consideration factors like air conditioning, lighting, construction materials, operating energy and recycling options during the preliminary design stage. It is the most important principle of sustainability.

According to Vangeem, there are "eight elements of integrated design", which are:

a. Emphasize the integrated process;
b. Consider the building as a whole - often interactive,often multi-functional;
c. Focus on the life cycle;
d. Have disciplines work together as a team from the start;
e. Conduct relevant assessments to determine requirements and set goals;
f. Develop tailored solutions that yield multiple benefits while meeting requirements and goals;
g. Evaluate solutions; and
h. Ensure that requirements and goals are met [7].

Contracts and requests for proposals should clearly describe sustainability requirements and project documentation. Table 2.1 shows exactly how certain integration decisions that are made by the designer contribute to environmental sustainability.

Table 2.1: The Effects of Integration Schemes at the Design Stage [7]

Integration Strategy	**Attribute to Sustainability**
Use	Saves material; no need for additional framing and drywall.
Use hollow-core panels as ducts.	Saves material and energy; eliminates ductwork and charges thermal mass of panel.
Use thermal mass in combination with appropriate insulation levels in walls,	Thermal mass with insulation provides energy benefits that insulation alone in most climates.
Design for building function changes.	Saves material; extends service life of panels.
Use durable materials.	Materials with a long life cycle and low maintenance will require less replacement and maintenance during the life of the building.
Use trees for shading, and ventilation,	Reduces lighting and cooling energy use. Increases indoor air quality and employee productivity.
Use durable materials.	Materials with a long life cycle and low maintenance will require less replacement and maintenance during the life of the building.
Reduce	Reduces transportation and disposal costs of wastes. Less virgin materials are used if construction waste is recycled for another project.
Use building that building standards are met.	Energy savings and indoor air quality are most likely attained during the building life if inspections are made to ensure construction was as designed.

iii. Reduce, Reuse, Recycle

This is another concept defined by sustainability. "Reduce the amount of material used and the toxicity of waste materials; Reuse products and containers; repair what can be reused; Recycle as much as possible, which includes buying products with recycled content". Too much material usage is thus non-sustainable. Construction in Ethiopia is better in reducing and reusing, but recycling is not being put to practice yet.

iv. Green Building Rating Systems

When environmental protection becomes more serious in Ethiopia, there are ways to let the public know whether buildings are in line with such principles. "Labeling a green building with Leadership in Energy and Environmental Design (LEED), Green Globes, or Energy Star certification sends the message the building is green without having to perform a complex LCI [Life Cycle Inventory] or LCA [Life Cycle Assessment]".

While LEED could be used to label a "green" building itself, Energy Star is mainly for the equipment used day-to-day in offices, residencies and commercial buildings. "Buildings that meet certain criteria and achieve a rating of 75 or better are eligible to apply for the Energy Star" [7].

2.3.2. Precast Construction Applications

Precast construction can essentially be applied for any types and sizes of buildings and other structures, in some cases more so than in-situ construction. Nonetheless, it is neither economical, nor ideal to utilize this method for every type of building. The reason is that precast production requires molds, and if there are structural members with too much variety in their shapes, the required number of molds increases. On the other hand, if a structure has a repetitive number of structural elements, a few molds could be used repetitively and save mold cost substantially.

This rules out artistic architectural structures as poor fits to the precast method, whereas buildings such as the public schools, sub-city office buildings, and apartments as in the Tsehay Real Estate luxury real estate in Addis Ababa would have been good fits.

2.4. TYPES OF PRECAST SYSTEMS

According to the World Housing Encyclopedia (WHE), precast systems can be divided into the following categories, based on the load-bearing structure:

2.4.1. Large-Panel Systems

These include vertical walls and horizontal floors and roofs that can all resist gravity loads. The floors and roofs are either one-way or two-way slabs that transfer loads to the walls. The walls are usually one story high. Together with the horizontal members, they form a box like structure that serves as a spatial unit in a building.

2.4.2. Frame Systems

In frame systems, the beam-column frames can be cast as one spatial unit. This system would allow for the connecting faces between subassemblies to be placed away from critical frame regions around the corner points of the frame. On the contrary, it would be difficult to lift, place, and install such large-sized precast members on to building structures. Another option in the frame system is to cast beams and columns separately and assemble them on to a structure. This would generally place the connecting faces between adjacent members at the beam-column junctions. These junctions would be hinged, but sometimes rigid connections are used to allow for reinforcement bars to pass through to an adjacent story.

2.4.3. Slab-Column Systems with Shear Walls

In such systems, lateral load is resisted by shear walls and the slab-column framework mainly resists gravity loads.

There are two main systems in this category:

a. Lift-slab system with walls - The slabs are cast on ground level, one on top of the other, lifted to the top of the columns and descended to their final positions. The columns are usually two stories high. The slabs are temporarily supported until their ends have been fastened securely to the columns.

b. Prestressed slab-column system - Horizontal prestressing is used for continuity. The reinforced concrete slabs and columns are first assembled, and then prestressed by means of prestressing tendons. A hollow duct is passed during the casting of the beams and columns where the prestressing tendons would pass during prestressing. The ends of the tendons are fastened using wedge and barrel systems and the gaps and the fasteners are all filled and cast with in situ concrete to become part of the structure. The slab column system mainly resists gravity loads and precast or cast-in-place shear walls are placed at appropriate locations for lateral load resistance. The column heights range from one to three stories. This is the exact same type of system that is used by PBPPE.

2.4.4. Cell Systems

These are systems where all fittings (electrical and mechanical systems) and finishings are all installed during precasting. Whole units such as kitchens and bathrooms are done on ground level and installed at desired locations.

2.4.5. Mixed systems

A precast structure may include a combination of any of the above systems or even have some parts of cast-in-place members. This would bring no structural incompatibility, but stability and robustness should be checked for [8][19].

2.5. CLARIFICATION OF TERMS USED IN PRECAST CONSTRUCTION: PRESTRESSED, PRETENSIONED, POST-TENSIONED CONCRETE

"Prestressed concrete is concrete that has had internal stresses introduced to counteract, to the degree desired, the tensile stresses that will be imposed during operation". Prestressing tendons could be "individual hard-drawn wires, cables of hard-drawn wires, or bars of high strength alloy steel". They may be used for pretensioning or post-tensioning the precast concrete members.

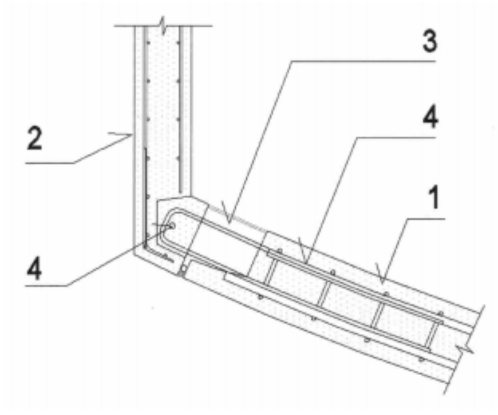
Pretensioning is a process that involves pulling prestressing tendon in a frame or between anchorages that would stay at the end surfaces of the member, and pouring fresh concrete around it. After the concrete has set, the tensioned steel is released slowly to transfer stress to the concrete that it has already bonded with. It takes a certain distance from the ends of the member for the force to transfer and this is called the transfer length.

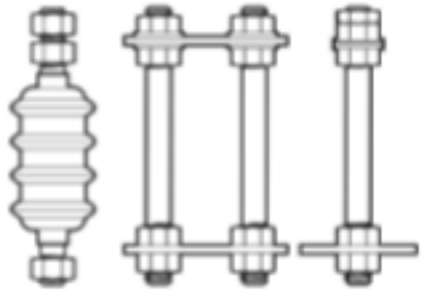
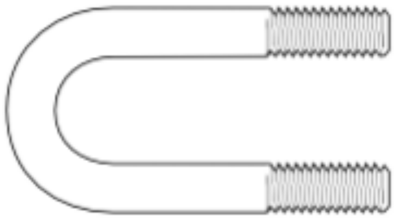
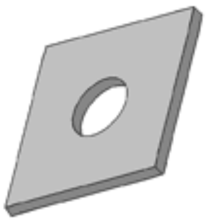
Post-tensioning is when the concrete is cast around ducts through which prestressing tendons would pass. After the concrete sets, the tendons are passed through the concrete member, "tensioned by means of portable jacks" and fastened to the ends of adjacent members. Anchorages are used for the fastening and they are left embedded in the concrete to maintain the longitudinal compressive stress that they had transferred to the precast members. The ducts are usually grouted to protect the tendons form rust. "Post-tensioning can be done on the job site without any need of heavy temporary anchorages. Anchorages are needed for each tendon, however, which is a significant cost item" [9].

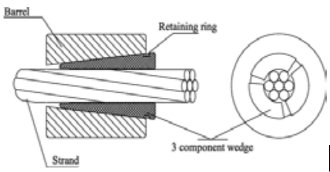
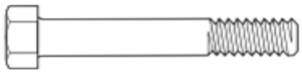
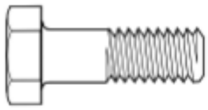
2.6. ELEMENTS OF PRECAST CONCRETE MEMBERS

There are different elements that are used in precast construction which are not requirements for in-situ construction. They are briefly described here to give the reader an idea of what they are used for and simplified picture of what they could look like.

Table 2.2: Precast Fixtures and Tools with Corresponding Illustrations

Precast Fixture or Tool	Illustration
Joints - in situ concrete joints and grouting joints commonly used; precast elements prepared with space at their ends for in situ concrete joints; section '3' shows an in situ concrete joint	

Precast Fixture or Tool	Illustration
Anchor Rods - have various types and sizes depending on what they are used to anchor	 [20]
Multi-strand Post-tensioning Anchor	 [26]
90° Anchor Bolts - commonly used to anchor steel to concrete	
Round U-Bolts - connect concrete surfaces to adjacent parallel surfaces	
Threaded Rebars - anchor different structures, being used in Ethiopia as a means of lengthening rebars without splicing	
Plates - used as a membrane between concrete and steel fixtures like wedges and barrels in post-tensioning	 [20]

Precast Fixture or Tool	**Illustration**
Wedge - thick conical steel element that is inserted in a barrel and grips the pre-stressing tendon also known as a Bullet or Carrot Barrel - grips the wedge and anchors it to the ends of the prestressing bed. It is also known as a collar, cone, or a chuck	 [27]
Hydraulic jack for tension cables - applies tension to prestressing tendons during the curing stage of concrete	 [18]
Barrier Pins - used in road construction	
Hex Bolts - commonly used as construction fasteners	
Structural Bolts - heavier than hex bolts, have structural purposes	 [20]

In addition to the fixtures illustrated in Table 2.2, the following parts should also be considered.

a. Corbel - a projection jutting out from a wall to support a structure above it. Precast slabs would rest on corbels that are an extension of the supporting beams.

b. Prestressing Tendons - Steel cables or bars that transfer pressure to reinforced concrete in order to resist tension that is subsequently imposed on the concrete member.

c. Longitudinal Transferring Rebars and Holes - The reinforcing bars jut out of the end of one precast member and are inserted into holes at the end of an adjacent member and grouted. The rebars and holes would have lengths of one-third of the member into which the transferring rebar is inserted. They ensure structural continuity between aligned members.

Furthermore, precast construction joints can be classified into wet joints and dry joints. The types of the precast element connections differ, according to the type of precast system to be used. Generally, connections can be categorized into wet joints and dry joints.

If wet joints are to be used, precast elements would have to have holes at the ends where extended rebars from adjacent elements would be inserted. The holes would be of slightly larger diameter than the rebar diameters to ease the insertion. Then, the remaining space in these holes is grouted and allowed to set. This process better resembles the cast in place concrete construction.

Dry joints are done by welding steel plates or fixtures at the ends of one precast element to those at the ends of an adjacent precast element. "Using one of these methods, each elements of a building structure are attached to their adjacent counterparts and assembled to form the whole building. One might find the process similar to building a LEGO house, in a way" [9].

2.7. THE PRECAST PREPARATION PROCESS

Precast construction includes the casting of reinforced concrete (RC) members on the ground level at a precast plant, or on a portion of the ongoing construction site. Briefly stated, the casting process first requires reinforcement bars (rebars) to be placed in the molds. Next, fresh concrete is poured into the molds and vibrated for consolidation. Then, these cast reinforced concrete members are placed in a curing pond, or a curing chamber so that the concrete can completely undergo hardening reactions.

There are a number of ways that each of the above processes can take place. First, the location of where to cast the RC members has to be decided. Availability, price, and, convenience of using heavy trucks for transportation or heavy duty precision cranes for onsite installments have to be compared. Whether or not to make the whole operation labor intensive or machinery intensive has to be thought about and compared. Availability of sufficient space for production and storage may also be a deciding factor.

The next decision would be based on whether the RC members are designed to be pre-stressed or not, pre-tensioned, or post-tensioned, what kind of bolts to use to fasten the elements together, the amount of tension to be applied to the rebars, and similar factors that have to do with rebar arrangement in precast.

Consolidation is one of the most important processes that must be applied to freshly cast concrete. It is primarily done by vibrating the freshly poured concrete mix. Vibration could be done using hand-held internal vibrators as is the usual case in almost all site-mixed concrete works in Ethiopia. Other alternatives that would provide a more even coverage include using external board vibrators that are installed at different intervals on the formwork's. Additional types of concrete vibrators are rebar shakers and external rotary vibrators. "…instead of the regular head that's inserted into the concrete, [a rebar shaker] uses a proprietary device that is slipped over the top of the rebar, and uses the rebar itself to transmit vibrations into the concrete". As for external rotary vibrators, They are "small, handheld vibrators…usually powered by cordless drills" [10].

When it comes to curing, the major comparison should be between immersing members in a curing pond, which is sure to provide a total coverage of all the concrete surface and thorough penetration into the concrete body in the days the concrete member is allowed to sit in the pond, or placing RC members in a curing chamber where water vapor is used instead of liquid water, in order to let the higher temperature increase the rate of curing. The latter option would require more energy to keep the water steaming, while the former might take longer number of days for complete curing.

The above descriptions are about the casting phase of precast construction. What follows would be the installation or erection phase, which deals with lifting the precast pieces to their final positions on the building and attaching them on to their adjacent counterparts. These activities can also be carried out using different kinds of methods.

The other set of options to choose from is whether the precast plant handles the material supply, element transportation, and non-precast site works or whether the client finds other means to obtain one or more of these services.

2.8. THE PRECAST ERECTION PROCESS

Four basic concerns face the people charged with responsibility for erection of precast concrete members: the weight and size of the members; the type of connections; the temporary bracing that will be required; and the individual site problems. The weight of the largest individual precast concrete member to be handled on a project will dictate the size of the crane and hauling equipment required.

Connections are the real key to fast erection techniques. Vertical standing members, such as walls and columns, are the most expensive to erect and the most difficult to keep in the correct position.

Connection details must be realistic and, the simpler the connection, the better. The erection sequence, the type of bracing required, provision for wind forces, pick-up techniques, and truck delivery are all problems facing the erector. All of these must be solved in proper relation to production at the plant and construction at the site if the erector is to do his job well and keep the final cost of the in-place precast concrete down.

2.8.1. Connections

Johnson (1969) states that precast concrete connections should serve the following purposes:

a. allow the erection of the member
b. be structurally adequate to provide for all design loading conditions
c. be architecturally acceptable in the completed structure

Structural and architectural considerations are usually taken because they are the main concern of the designers when drawings are being developed. The erection technique is usually not, however, considered during the design stage.

Activities through out the total precast project such as plant fabrication, site construction, and delivery and erection of products should be considered during design. “Special attention to connection design can appreciably lower the in-place cost of precast concrete… Through education, the precaster must show the structural engineer how to design a good, workable connection”.

According to Johnson, 1969, precast connections must meet some criteria:

a. They must be realistic, i.e. connections must recognize:

i. casting tolerances of the fabricator,
ii. final layout of foundations and other cast-in-place concrete,
iii. erection procedure to be used and economic limitations that exist.

b. They must be simple. Connections can be sophisticated in concept but they should remain simple in detail.

c. They must be tolerant. Connections could be adjusted in the field to meet job conditions. “One simply cannot pre-measure every item and every detail in advance to assure a perfect fit” [11].

2.8.2. Erection Sequence

Too often the sequence of erection is not considered during the design stage but this sequence becomes important at the start of construction, especially when Critical Path Method of scheduling is planned. The relationship of erection sequence to construction of elevator shafts, shear walls and stairways is necessary in multi-story erection. An erector simply must have some sort of "anchor" to tie to for lateral stability.

The question of which work should lead, cast-in-place or precast, often comes up in the design concept stage. The best answer is to do the cast-in-place work first because:

i. Development of fabrication shop drawings, tool-up time, and casting schedules are generally such that the general contractor can do his cast-in- place work ahead of time.

ii. Once the cast-in-place section forms an anchor for erecting the precast elements, the risk posed by earthquake or high winds is reduced.

iii. The overall construction time will be reduced.

2.8.3. Pick-Up Techniques

Horizontal members present no special handling problems once their weight and length have been considered. Weight, combined with the erection or lift off radius, will dictate the capacity of the crane required on the job.

According to Johnson, cranes should not lift at their full capacity because crane capacity is measured by what they will pick up with the shortest possible boom length and at the steepest angle that they will boom up. Hence a 100 ton crane will not pick up a 100 ton precast member if the boom is pulled out. Furthermore, tower cranes present design limitations of large radius, but small capacity. Johnson also points out that vertical members are most challenging to lift up as they are usually delivered laid down horizontally and they have to be rotated to the vertical position by the lifting crane on site.

2.8.4. Transportation

Truck delivery is the usual form of transportation and scheduling of truck deliveries is a never-ending problem. Due to the weight of precast concrete members, a large number of truck loads are involved. Usually the members are taken directly from the trucks and set in place. This requires predetermining the exact erection sequence. Each truck must be loaded with respect to mark number, position on trailer, and time of delivery.

2.9. STRUCTURAL PERFORMANCE OF PRECAST BUILDINGS

The performance of a structure is mainly linked to its strength, stiffness, and ductility, although functionality, aesthetics, speed of construction, and economy are also significant. Some functional requirements should be taken under consideration.

For instance, long spans with floor space uninterrupted by columns or structural walls give users maximum flexibility. A maximum floor-to-floor height allows adequate spaces and a reduced overall building height. Open-space apartments or offices (adaptable floors) can accommodate future tenant alterations with maximum speed and minimum disruption or cost. It is well known that the economic performance of a structural system greatly depends on the quantities of materials per square meter (for example, concrete, reinforcing bars, and strands), but the real construction cost can also depend on speed of construction, local market conditions, availability of labor and specialized equipment, and other factors.

In many cases, such as multistory buildings or structures in seismic areas, pure flat-slab structures have to be altered by the addition of vertical elements, such as shear walls or steel bracing systems, leading to dual systems. To improve the competitiveness of such a structure type and considering constructability as a powerful tool for reducing the cost and the time of construction, designers' interest has been focused on a standard precast concrete structure using fewer elements with standard dimensions that can be produced in large numbers on an industrial basis.

The earthquake resistance of prestressed structures has been studied in some detail by Blakeley, Park, and Shepherd. In their study 'Review of the Seismic Resistance of Prestressed Concrete', it was found that most prestressed structures built for earthquake resistance are precast. Nonetheless, at the World Conference on Prestressed Concrete, "Ban introduced his own proposals for extending the prestressing cable through to the column and hence placing the whole joint in compression. His scheme was the fore-runner of modern precast prestressed beam column connection details" [29]. This advocated the use of in-situ joints where precast, prestressed members are used for earthquake resistance.

Prestressed concrete has been widely used for earthquake resistance purposes. There are reinforced concrete structures that integrate prestressed shear wall elements for lateral load resistance. Subsequently, prestressed concrete is many times produced as a precast. Hence, it results in precast concrete being used in earthquake prone zones. This does not mean that precast connections are ideal for earthquake resistance. But structures with well grouted connections have been found without any major damages after earthquake attacks in Alaska [30].

Earthquake in Ethiopia has not caused as extreme a damage as it has in other parts of the world. Regions in the Far East have born repetitive and high intensity earthquakes and extensive damages to their buildings, roads, and infrastructures. The seemingly lower frequency and intensity in Ethiopia does not mean that it is in a low earthquake region, which is corroborated by the increase of earthquake load requirements in the revised version of EBCS. Nonetheless, personal experience indicates that tremors in Ethiopia are few and very far between, and the intensity has been known to be low and has not caused any serious damages to building structures. This makes precast construction, including its connection details, a satisfactory alternative for the region.

2.10. CONSTRUCTION IN ETHIOPIA

The Ethiopian construction industry is one of the country's predominant industries with substantial amounts of expansion and advancement. It takes a considerable portion from the federal budget and has a number of noticeable results in the country's infrastructure.

"The development of the construction industry can be measured using its Gross Value of Production (GVPC). The GVPC, at constant market price increased from Birr 7.6 billion in 1996/97 to Birr 18.9 billion in 2006/07 depicting an average annual growth of 9.6 percent over the period…".

The Ministry of Finance and Economic Development (MoFED) specifies the types of manufactured articles that are included in the construction industry as follows, relocating input production towards the manufacturing industry.

"…In the case of Ethiopia, …the activities actually covered under the [construction] industry are the construction and maintenance activities of: (1) Residential buildings in urban and rural areas, (2) Nonresidential buildings, i.e. factory buildings, ware houses, office buildings, garages, hotels, schools, hospitals, clinics, etc., (3) Other construction works, like roads, dams, dikes, athletic fields, electricity transmission lines, telephone & telegraph lines, etc. [MoFED, 2005]" [12].

The first step in concrete works is obtaining the required materials. These materials are then mixed as per the mix ratio specified in the design. Water-to-cement ratios should be provided and complied with while mixing. The whole of the mix ratio calculations would be redundant and the concrete would be weak if too much water is used during mixing. Next to the mixing of the fresh concrete, pouring is followed by consolidation works. Hand held vibrators of varying sizes are most widely used for this purpose.

Curing plays an equivalently important role in the quality of the final product as the previously explained steps of mixing. How well a finished concrete is cured is a decisive factor for the strength and quality of the finished product. In typical construction sites in Ethiopia, curing is usually done manually with a watering hose or by sprinkling water out of a bucket using a jug.

Through all the steps of preparing, pouring, and curing concrete, there should be as little impurity as practically possible in the concrete mix. For this reason, there should be a mixing area which is clean, flat, smooth, and lined with a material that the concrete wouldn't bond with. Examples would be "bricks or lean concrete or iron sheets, of a size as per requirement of the volume of concrete to be mixed. Commonly a platform made of iron sheet having $3m^2$ in size with strips or curbs are used".

If concrete is to be manually mixed, the required quantity of sand should first be spread evenly on the mixing platform. Next, cement in the required amount should be dumped on to the sand and spread out evenly. The sand and cement should be mixed using shovels and "turning the mixture over and over again until it is uniform in colour" [13]. Following this, coarse aggregate is spread out uniformly over the sand and cement mix. Care should be taken not to dump the coarse aggregate on one spot on the sand cement mix. Mix it from the center to the side, side to center, and center to side again.

The next step is to add water into the dry mix. First, a depression should be made in the center and one half to three quarters of the required amount of water should be added. The material should then be turned towards the middle with a shovel and the remaining quantity of water should be poured slowly during this time. The mixture should be turned over and over repeatedly until it has uniform color and consistency throughout. It is best to add the water with a gardener's can fitted with a rose-head. Water added all at once will wash away the cement from the mix.

In construction sites where all of the mixing, pouring, consolidation and curing is carried out by daily laborers, the presence of a site supervisor with a clear understanding of the basics of concrete technology is absolutely important. As nearly all daily laborers are illiterate, the supervisor should have a consistent follow up routine of all concrete work either directly or through a foreman. This continuity in follow up would decrease any risk of compromise in the quality of the finished product.

Untrained manual labor is one of the culprits preventing the systematic measurement of aspects of time and cost expenditure in regular Ethiopian construction. "During an interview with one of the project managers, it was learnt that productivity standards are used during the preparation of their main schedule but I believe that, it is meaningless if the information used during planning is not transferred to the crew by planning. From the above finding we can understand that the project management objectives are not appropriately transferred down to their crews showing that coordination that could have been obtained by this is lost" [14].

The first step to improving an existing system is to measure its performance. Regular Ethiopian construction practices are nearly impossible to measure even during the construction phase. To use such advanced tools, such as embedded microchips to measure their long-term structural performance is highly unlikely with such messy on site working conditions. The precast system of construction would fundamentally alleviate this problem. "…This production standardization produces high quality precast that can be delivered to a site just-in-time. There's no waiting around for concrete to cure on-site and no need to stockpile… In particularly sensitive applications, these same microchips can send a signal to indicate excessive movement or impact. This is particularly useful for bridges, tall buildings and structures in earthquake zones”.

Developing countries are the ones most affected by environmental pollution and its consequences. Probably the third most dominant source of pollution in the capital city of Addis Ababa is the carelessly disposed waste and dust from construction sites (the first and second being sewage waste and vehicular fumes). “The production of precast concrete in an off-site manufacturing plant means that construction sites are cleaner, quieter and safer… much less construction site debris and potential pollution to streams and natural areas…”. Precast concrete systems greatly reduce unnecessary or surplus building materials from ever reaching a project site.

Production and finishing materials and the waste they produce never even reach the project site… In addition, construction of a precast concrete structure generates very little dust – decreasing the likelihood of problems with dirt and poor air quality, the most common causes for complaints from residents near construction sites… Sustainable plant upgrades using emission control equipment recycle concrete dust and concrete washout water used in precast product manufacturing.

A hush-hush approach is habitually implemented when workers’ safety measures are compromised and accidents befall as consequences, which leads one to wonder, how many of these types of accidents have happened so far and have been kept guarded from the public eye. Insurance policies are not made available to site workers, unless for international projects, which reflects poorly on most contractors’ professional character.

Other nuances such as discontinuity in between, or in the middle of project activities, noise pollution, workers’ fatigue, unsightly construction sites and over expenditure of energy can serve as indications to some inefficiencies that most Ethiopian contractors exhibit while implementing in-situ construction methods. “Vibration, sawing and other noise-pollution activities that are part of concrete pours on the job site are eliminated because the precast is produced offsite. This results in substantially quieter construction sites. The easy installation of precast products makes for less noise pollution from the construction site, a significant benefit to those inhabiting or working in adjoining properties" [15].

2.11. PRECAST CONSTRUCTION IN ETHIOPIA

There are a number of studies on precast construction that can be found in the AAIT library. Amongst them, there are a number of studies that focus on the plant and the management of overall precast works. These sound more relative to the objectives of this study than the papers on the design parameters and available versus required mold sizes, etc. Some also provide the institutional history of the PBPPE. What has been challenging is that the analyses and results of these researches are more empirical than deductive. They give accounts of what has been attempted by the precast plant, but have not pin-pointed the cause of its shortcomings. The result reports also tend to be raw and could use more thorough analyses.

As a whole, most of the research papers focus on the existing organizational structure and history of PBPPE, which is a redundant study as it would solve more problems to discuss what can be done now, than when the enterprise was formed and random events that have happened since its establishment.

It is understandable that a researcher may stray from facing the multitude of problems head-on and come up with practical and constructive suggestions to tackle each and everyone of them, but more effort could be put in to carry out a systematic analysis of the problems so that future researchers could have a clearer picture of where to begin and what direction to take. Due to the difficulty of reviewing the AAIT studies because of the aforementioned reasons, this literature review focuses more on papers that have been published in the USA, European and Asian countries.

Professional members of the Ethiopian construction industry can learn a lot from the history of precast construction developments of more advanced countries. Scandinavian countries are among those that rebuilt most of their building structures using precast systems after the second world war. Thus, different literary works describing that initial venture into a highly modernized method of construction can be found online.

2.12. CONSTRUCTION COST ESTIMATION

Cost estimation is the prediction of construction cost based on available data. Total cost of construction is an aggregate of capital cost and operating cost. The initial capital cost for a construction project includes the expenses related to the initial establishment of the structure.

The major expenses that the client encounters are enlisted in Table 2.3 below.

Table 2.3: Major Construction Expenses encountered by clients

Major Expenses	Remark
Land acquisition	
Planning, feasibility studies, architectural and engineering design fees	
Construction fees paid to contractor or subcontractor, may include:	material, equipment and labor fees
	equipment and labor fees only
	material and labor fees only
	labor fees only
Relocation fees for remote project sites	camp construction
	daily allowance of overhead employees
	moving fees for equipment and tools
Contractor's profit	
Construction supervision on client's behalf	
General office and storage overhead of client	
Laboratory and in-situ testing, if available and/or requested	

Land acquisition and construction costs are the two most significant expenses from all of the above. Maintenance and operation costs of building structures, which are added to capital cost to obtain total cost of construction, are usually minor as compared to the capital cost itself. Construction cost usually surpasses any of the other expenses except probably land acquisition cost, as this comparison depends on the size of the structure to be built.

Some of the factors that affect the amount of construction-related costs are the "nature, size and location of the project" in addition to the "management organization" of the client. In the end, the client's ultimate objective is "achieving the lowest possible overall project cost that is consistent with their investment objectives".

Unexpected costs, which are very common in construction projects, are accounted for by contingency allowances. This amount is either paid as a separate expense according to the payment plan, or it is embedded in each cost category, expressed as a percentage of that cost. Still, if there is any unused amount from the contingency cost, it should be returned to the client at project completion. The contingency amount is determined from the practical expectation that the contractor obtains through experience about what kind of difficulties could possibly happen during the project's lifecycle.

There are four approaches used in cost estimating:

a. Production Function - This is the relation between the output of a process and the required inputs. In construction, this could be the volume of the building and the amount of material, or the total area of the building and labor hours.

b. Empirical cost inference - This method uses statistical data to obtain a cost function and uses it to estimate the best parameter values.

c. Unit costs for bill of quantities - This laborious but simple method is widely used in Ethiopia. It includes breaking down the construction project into measurable tasks and activities and assigning unit costs to them. These are tasks that would have to be completed for the completion of the project as a whole. Then, these tasks are quantified and each of their quantities are multiplied with their corresponding unit costs. The sum of their products gives us the total cost.

d. Allocation of joint costs - Here, the cost categories such as labor, material, equipment and overhead are allocated to different subdivisions of the project. "In many instances, however, a causal relationship between the allocation factor and the cost item cannot be identified or may not exist".

Using one or more of the above approaches, we can make the following types of cost estimates:

a. Design estimates - estimates that are made on the client's side depending the required level of details and available design information. There are four types of design estimates:

b. Screening estimates or order of magnitude estimates - made before the design, estimated from cost data of similar facilities built in the past.

c. Preliminary estimate or conceptual estimate - from the conceptual design after the methods of construction are determined.

d. Detailed estimate or definitive estimate - after the detailed design is in progress so that the essential aspects of the construction project are known.

e. Engineer's estimate - based on completed drawings and specifications when the client calls for bidders.

Bid estimates are estimates contractors make to compete in the bid. It includes direct construction cost, contractor's overhead cost, and profit. Direct construction cost is obtained from subcontractor quotations, quantity takeoffs, and construction procedures.

Control estimates are derived from available information prior to contracting, after contracting but prior to construction, and during construction, in order to monitor the project.

Construction cost is not always linearly dependent on the size of the building or structure, but the linear relationship could be used to determine cost within certain limits. For example, if X represents size of a building and Y represents construction cost, Y = aX + b, where 'a' and 'b' are positive constants to be determined from previous data. This function could be applicable for a range of building sizes between say 'X = c' and 'X = d' only, if it is known that building size and cost have a linear relationship for buildings between sizes 'c' and 'd'.

If a nonlinear cost relationship is assumed, it can be represented in the form of: Y = aX ^ b. Taking the logarithm of both sides gives, ln Y = ln a + b ln X. Nevertheless, this equation is also applicable for a certain range of 'X'.For production facilities, the exponential rule can be used to obtain cost estimates from costs of similar previous production facilities with a different production capacity.

The unit cost method can be applied to both design estimates and bid estimates. Depending on the level of detail, the elements included in the estimate would vary. There are three different formula that can be used for unit cost calculations: Simple Unit Cost Formula, Factored Estimate Formula, and Formula Based on Labor, Material and Equipment. Of these, the most applicable one for the construction industry of Ethiopia is the formula based on labor, material, and equipment:

$$y = \sum_{i=1}^{n} y_i = \sum_{i=1}^{n} Q_i (M_i + E_i + W_i L_i)$$

……………………………………………Equation 2.1

where:

Q_i = work

M_i = unit material cost

E_i = unit equipment rate

L_i = units of labor per unit of Q_i

W_i = wage rate per L_i for task 'i' [16]

Example 2.1: Cost estimate using labor, material and equipment rates.

For the given quantities of work Qi for the concrete foundation of a building and the labor, material and equipment rates in Table 2.4 below, the cost estimate is computed on the basis of the above equation. The result is tabulated in the last column of Table 2.4.

Table 2.4: Illustrative Cost Estimate using Labor, Material and Equipment Rates

Item	**Quantity**	**Material Cost**	**Equipment Cost**	**Wage Rate**	**Labor Input**	**Labor Cost**	**Direct Cost, Birr**
Formwork	12,000 m	0.4 Birr/m	0.8 Birr/m	15 Birr/hr	0.2 hr/m	3.0 Birr/m	50,400
Rebars	4,000 kg	0.2/kg	0.3/kg	15/hr	0.04 hr/kg	0.6/kg	4,440
Concrete	500 m	5.0/m	50/m	15/hr	0.8 hr/m	12.0/m	33,500
						Total	**88,300**

If historical cost data is available, it might be used in cost estimation if it is in the same format as current cost estimates. Even so, such data should be regarded with caution as there is room for error in data collection. Additionally, the change of relative cost might make it difficult to predict some cost values. This is to say that certain materials such as cement might grow in cost at a different rate than say steel.

Historical cost data could be available on a number of sources such as registers of suppliers' data, periodicals, commercial cost reference manuals, and summaries of actual project costs. In Ethiopia, the Central Statistics Agency has a fairly usable collection of construction material cost.

In order to properly utilize historical cost data, changes in price levels over several years are usually kept. From substantial compilations of such data, cost indices for different construction values of labor, material, equipment, etc can be calculated. “A price index is a weighted aggregate measure of constant quantities of goods and services selected for the package”.

Indices are used to obtain a relatively accurate current price value by using them to adjust historical cost data. “Some of these adjustments may be done using compiled indices, whereas others may require field investigation and considerable professional judgment to reflect differences between a given project and standard projects performed in the past”.

The last type of cost estimate is that based on the engineer’s list of quantities. The client estimates the construction cost from the quantities on this list, and bidders would only fill out unit prices and total cost. The prices filled in by the winning bidder can be used for budget control as the project progresses.

Another aspect of construction cost to consider is the allocation of cost over the time span of the project. This is especially important for large projects that could take years to complete. The owner or financier of the project would be interested to know the pattern of cash flow that can be expected. The calculation of cash flow can also help determine the percentage of completion of the project by comparing the expense incurred so far with the total budget of the project. Of course this may be an inaccurate estimation as the amount of money spent might not always imply the value of the finished part or because it might have been spent inefficiently. "A more reliable method is based on the concept of value of work completed which is defined as the product of the budgeted labor hours per unit of production and the actual number of production units completed, and is expressed in budgeted labor hours for the work completed" [16]. Figure 2.4 below shows project progress calculated using cash flow, where the rate of cost expenditure increases in the mobilization period, becomes constant during the construction phase, and goes down towards completion.

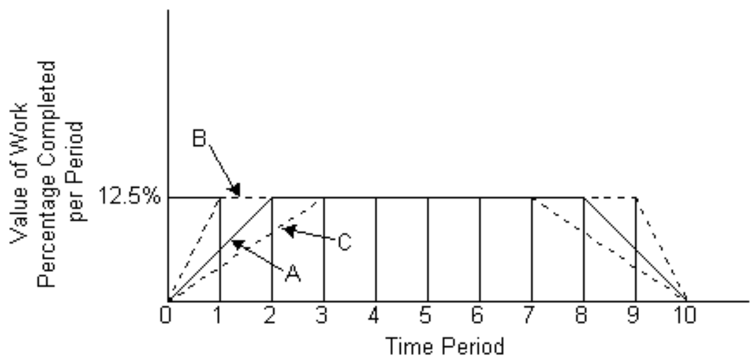


Figure 2.4: Rate of Work Progress over Project Time [16]

The dotted lines B and C represent fast and slow mobilization activities respectively. The curve shown in Figure 2.5 represents the cumulative project progress. Note that with all rates of mobilization, the curves have an "S" shape.

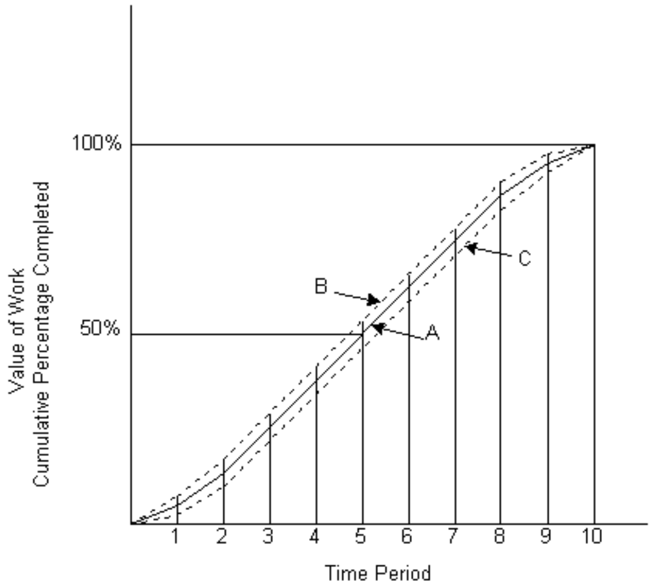


Figure 2.5: Value of Work Completed over Project Time [16]

There are several cost estimation softwares used to carry out computer aided estimates. They are usually seen as additional cost due to their cost of purchase, maintenance, training and computer hardware, but their efficiency is undeniable. They make cost estimation easy, fast, and produce different tabulated data about the project as a result.

2.13. INTRODUCTION TO SIX SIGMA

Six Sigma is a set of techniques and tools that are used for process improvement. Bill Smith, an engineer working at Motorola came up with this method in 1986. It became widely popular when John Francis Welch, chairman and CEO of General Electric between 1981 and 2001, made it central to his business strategy in 1995. The way Six Sigma is designed to improve the quality of the output of a process is by identifying the causes of defects, by removing these causes, and by minimizing variabilities in the processes.

Six Sigma first develops a special organizational structure of people within an organization who are experts in its methods of using empirical and statistical methods of quality management. Then, a Six Sigma project is carried out within an organization that follows a defined sequence of steps and has specific value targets, such as reducing process cycle time, environmental pollution, and production costs, and increasing customers' satisfaction and profits.

There are several other methods that can be applied to improve and maintain production quality like Control Charts, Plan-Do-Check-Act (PDCA), Juran's Trilogy, Value Analysis Teams, Quality Circles, Total Quality Management, and Lean, also known as "Toyotism". The kind of quality management style chosen depends on application.

One of the major features of Six Sigma is the DMAIC process. DMAIC stands for Define - Measure - Analyze - Improve - Control. Looking closely, each of these steps include a number of tasks under them. The five stages of applying Six Sigma and the activities included in each of these stages are enumerated in Table 2.5.

Table 2.5: Stages and Activities in Six Sigma

Stages	**Activities**
The Define Stage	define the customer, their requirements, their expectations
	select and propose projects
	define the project boundaries and the timeline
	define Critical to Quality (CTQ) issues
	build a team
	define core business process involved
	define the process to be improved by mapping process flow
	create a sense of urgency
The Measure Stage	select the key indicator of project success
	develop a data collection plan for the process
	collect and display the necessary data
	calculate sigma (a measure of process variations)
	analyze customer survey results
	identify potential shortcomings

Stages	**Activities**
The Analyze Stage	analyze the data collected
	analyze the process map
	identify many possible causes
	make statistical calculations
	determine one or more actual root causes
	identify gaps between current and goal performance
	determine the opportunities for improvement
	prioritize opportunities to improve
	identify sources of variation
	quantify expected results and savings and the process map
The Improve Stage	design creative solutions
	create innovative solutions using technology and discipline
	identify a plan of action
	test result of this plan
	refine results
	develop and deploy implementation plan
	implement with effective solutions
	improve the target process
The Control Stage	develop systems for the implementation of solutions
	deploy systems in order to make sure that the implemented solutions remain effective
	keep the process on the new course
	prevent reverting back to previous states of work
	develop, document, and implement an ongoing monitoring plan
	institutionalize improvements through modification of systems and structures such as staffing, training, and incentives

2.14. LEAN MANUFACTURING TO IMPROVE PRODUCTIVITY IN THE PRECAST CONCRETE INDUSTRY

Lean manufacturing and Six Sigma are closely related management tools. The main difference between the two is that Six Sigma aims to eliminate or reduce defects in a process, while Lean aims to eliminate or reduce what it defines as waste. In Six Sigma, defects are defined to be any quality of the finished product which vary from the customer's expectation.

The preparation of precast is more of a manufacturing process than a construction or assembly process. Therefore, the application of any of the above Six Sigma methods would be effective. Nonetheless, the erection phase of precast construction has some similarities to construction. Thus, it is beneficial to discuss its application in construction.

Despite its wide use in other industries, lean manufacturing has only recently been applied to the precast concrete industry. Lean manufacturing finds waste and reduces costs. Its end purpose is to transform a company into an efficient, smoothly running, competitive, and profitable organization that continues to learn and improve.

2.14.1. Reduction of Waste

Lean manufacturing starts by defining "value added." Value added is defined as any activity that transforms the product toward what the customer wants. Everything else is defined as "waste." Waste is any processing step that consumes resources without adding value. There are eight types of waste that occur in the precast concrete industry. These parameters are discussed in Table 2.6.

Table 2.6: Waste Parameters and Corresponding Descriptions

Waste Parameters	**Description**
Motion	Any movement of people or machines that is not value added
Waiting	Idle time created while waiting for items that are not immediately available
Defects	Product does not meet customer specifications
Transport	Moving work over short or long distances without adding value
Overproduction	Making more product earlier or faster than is required by the next process step
Inventory	Inventory in excess of the minimum needs of the next transforming step
Process	Work processes or materials that add value to the product from the customer’s viewpoint
People	The waste of not using employees’ mental, creative, or physical abilities

2.14.2. Value Stream Mapping

The basic, analytical starting point in the lean manufacturing process is to break down the work process into detailed steps. The process steps are then classified as either value added or waste. An example of “value added” and “waste” steps of a bar bending activity is summarized in Table 2.7.

Table 2.7: Bar Bending Steps Identified as "Value Added" and "Waste"

Activity	**Value Added**	**Time, min**	**Waste**	**Time, min**
Unload rebar from delivery truck			Transport	12
Shake down bar from storage racks			Motion	5
Transport bar to shear			Transport	5
Set stops for cutting bar			Process	1
Cut bar on shear	Value added	3		
Stack bar in piles			Motion	3
Transport to bender			Transport	7
Set stops on bender			Process	1
Bend bar	Value added	3		
Stack bent bar in piles			Motion	7
Wait for crane to be available			Waiting	3
Transport to cage building area			Transport	10
Total of all activities	**10%**	**6**	**90%**	**54**

2.14.3. Lean Manufacturing Methods and Tools

The lean method uses several analysis and management tools. These tools can be any one of the following; rapid improvement events (also called "Kaizen"), standardized tasks, balanced flow, workplace organization (sometimes called "5-S"), visual controls, plant layout, mistake proofing, inventory reduction, correction at the source, bed setup reduction, total preventative maintenance (TPM), and team problem solving (TPS).

Lean manufacturing can truly transform an organization. Indeed, by its very definition, the lean manufacturing process will not be successful unless a company changes the way it does business. There are seven trends that companies should follow in order to succeed in Lean. These trends are management commitment, learning and change, dedicated staffing, organization structure, management style, no cuts policy and consultants.

2.15. APPLICATION OF SIX SIGMA IN CONSTRUCTION PROJECT ASSESSMENTS

The norm of the price-based comparison has influenced contractors to lower their standards and discouraged high performance, for the sake of retaining the profit margin. The least price approach is commonly used in the contract offers of the Ethiopian construction industry, which has usually led for some contractors with quality compromising approaches to be awarded projects, so long as they can get the job done for the minimum cost.

The best value approach compares factors in addition to price to select the most advantageous offer. "In a best value environment, it is in the interest of the contractor as well as the client to raise performance".

Attempting to solve problems in construction while approaching it as a project has been proving challenging. The project approach should be used when the problem in performance is caused by differences between similar projects. Since each construction project is unique in the way that each brings forth a different set of challenges than the last, it has been impossible to compare any project performance measures between different construction projects. "Without related and relative performance data, the industry must depend on the expertise of experts, consultants, and knowledgeable construction and project managers. It makes it difficult for clients to know what they are getting, and for contractors to continuously improve".

A better way to follow is the process approach. "The contractors are currently submitting their best craftspeople in the performance-based environment". According to Kashiwagi,
"[t]he process based solution is to treat construction as a process which can be continually improved… The process approach will ignore the project specific data and identify the root causes of nonperformance" [17].

By definition of the performance-based environment, the client does not control the contractor. Therefore, the way for the client to control the environment is to ensure that the contractors are keeping their owner performance information and controlling their performance. The client then controls by forcing the contractors to control themselves, using the performance-based environment to minimize the risk of a nonperforming contractor getting a project. The risk to the process is then defined by nonperforming contractors destabilizing the environment with political pressure and considers the process as unfair and exclusionary.

2.16. PRECAST PLANT QUALITY

The product of construction projects has certain requirements assigned to it. These requirements may be imposed by national standards, industrial standards, or it could be agreed upon and stated on contract documents. Quality simply means that the project meets these requirements set for it. “The precise meaning of quality for manufactured products and in construction is that the product satisfies requirements set for it”[19]. The role that quality manuals play in the precast industry is that they help improve production of quality products and give recognition to precast plants who do this.

Quality control is a set of actions taken in order to insure that products meet the requirements set by purchasers or specifiers. Halvorsen states that “QC involves inspection and testing, record- keeping, and being ready to deal with nonconformance.” In concrete production, quality is usually measured by the concrete strength and durability.

Standards help the precast producers to have a minimum level of quality that their products must meet. “As a purchaser of materials, the precaster is a ‘user’ of standards. As a manufacturer, the precaster is a ‘producer’ of products to the requirements of standards or project specifications”. Quality control professionals could use standards as a measure against which they check whether or not products conform to them. In the case of non conformance, they can change an input or improve an activity and prevent the below standard product from delivery to clients. “Testing and inspection don’t add quality to a product. They evaluate a product against established standards and provide the opportunity to correct non-conforming work, and to adjust materials or production before nonconforming products are fabricated” [19].

For precast plants, the main factors to check in order to control quality are, completeness of work orders and product drawings, quality of raw materials, quality of forms, placement of reinforcement, tensioning and transfer of prestressing stress, concrete quality, placement and consolidation of concrete, product dimensions, positioning of embedded items, plant conditions, curing of concrete, handling, storage, and transportation of products, record keeping, and nonconformance.

2.17. GAPS IDENTIFIED DURING LITERATURE REVIEW

The literature review covers topics in a deductive manner, starting from the origins of precast construction, moving on to major developments, explaining types of precast systems, and defining technical terms, moving into details such as components of precast concrete buildings, production and erection processes. Following this, it moves into scientific literatures that discuss the current status of construction in Ethiopia, specifically construction using the precast method.

In addition to giving a comprehensive view of the progress of precast construction, the literature review includes assessments of texts written on construction cost, economic analyses of the cost-volume-profit (CVP) relationship. Finally, it goes on to cover writings that entail precast plant quality, the Six Sigma method of improving processes and how it can be applied to the precast process.

Among all these, the economic aspect of the Ethiopian construction industry seems to have less amount of scientific literature coverage. Furthermore, there was nothing written on the economic effects that would ensue if precast construction companies were available as alternatives to the existing building construction companies.

This shows how this research topic was decided upon and why all the subsequent data gathering and analysis works were executed. Among the numerous gaps that were found among the existing literature on the Ethiopian construction industry in general and the precast industry in particular, the specific topic that this research covers falls under construction economics. It is very important to analyze the economic aspects of a construction business.

This is because it should be verified that the existing ways that activities are being carried out and the construction methods that are being used are the most efficient and most economical ways to get desired results.

This research was not done with the intent of finding ways to increase profits for the wealthy construction companies. Rather, it has the objective of tackling the housing and work space problems of the majority of the population. There is no doubt buildings that can be built four or five times as fast for an equal or lower cost as the ones currently being built would play a decisive role in alleviating the scarcity of living and working spaces in Addis Ababa. The exceeding quality of precast construction is also a considerable advantage. For purposes of the reader's understanding, the research has covered many topics that are considered relevant in getting a better understanding of the precast process.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. RESEARCH DESIGN

Based on the research goal, this research can be categorized under applied research. This is because the results of the research analyses are meant to be applied instead of solely enriching the knowledge base; Based on research objectives, it is both a descriptive and exploratory research. The reason it could be under these two categories is because the research has both aspects. It has abundant descriptions of its topics of consideration, wherever it is deemed necessary, while it also critically explores topics that need to be analyzed, explained, and put in perspective.

Based on research approach, it is again both a qualitative research and quantitative research; It has a qualitative approach when it deals with the quantitative data, and it takes on a qualitative nature for numerous non-number data. Based on research design, it is a non-experimental type, as it does not involve any experimental works in its data collection and analysis; Accordingly based on data type, it is secondary research (desk study), as no experimental works were needed.

3.2. RESEARCH AREA

The location where research is carried out in Addis Ababa, as it is where the research subjects are located. Addis Ababa is the capital city of Ethiopia. It is also the nominated capital of the African Union (AU) and the United Nations Economic Commission for Africa (ECA). The city is located at the center of the country and spans from 2200 to 3000 m above mean sea level in altitude. Its topography ranges from rolling to hilly areas with relative steep gradients. The municipality expands over 540 square kilometers, 10 sub-cities, and 116 “Woredas". It has 220 square kilometers allocated for green area and a vegetation cover of $80km^2$. Even though the dominant species are Eucalyptus trees, it is rich in a variety of rare but diverse flora and fauna.

Addis Ababa is also known for being an up-and-coming construction center in Eastern Africa. The whole city seems to be under construction for buildings, roads, and other similar utilities. This makes the research highly relevant.

3.3. RESEARCH METHODS

One of the specific objectives of the research is proving that a modern precast plant could compete, or be lucrative, in the Ethiopian construction industry. The way that this is done is by calculating the starting capital costs for a hypothetical precast plant to be built in Ethiopia, and computing its return period if it made its services available for a price equal to the current average price of the precast and in-situ construction method.

The types of data that needed to be analyzed in order to meet this objective are: current price data of required equipments to establish a new precast construction company; current price data of required equipments to establish a new in-situ construction company; latest sales prices of in-situ construction companies selected for this research each for ten of their latest building construction projects along with project sizes (in terms of total floor area); and PBPPE's sales prices for up to ten of its latest precast construction projects along with project sizes (in terms of total floor area).

The methods through which these data are collected are varied. To obtain the current price data of required equipments to establish a new precast construction company, a list of all required components for a basic size precast plant was obtained from various websites. Following that, current prices were obtained for each component from alibaba.com. The reason why this particular website was selected is because it is believed to have numerous options of such equipments for reasonable prices. Additionally, the massive number of suppliers that post their product information on the website can be deemed proof that alibaba.com has no affiliation to any particular supplier, sales agent, or manufacturer.

In order to attain a representative price value, the first twenty results on alibaba.com that fit the required specifications were taken, and the mean price value was calculated for each required precast plant component.

To collect current price data of equipments required to establish a new in-situ construction company, the equipment requirements for Building Contractors of Grades I through X (BC 1 up to BC 10) were first obtained directly from Ministry of Works and Urban Development.

Subsequently, current price data of each equipment was collected from ten machinery suppliers in Addis Ababa, and the corresponding mean values were calculated to acquire a representative price.
Requests for the latest sales prices of building construction projects were included in interviews given to the corresponding professional employees in sampled in-situ companies. Also included in the interviews were requests for the corresponding project sizes.

Finally, PBPPE's sales prices data were obtained directly from the Construction Department of the company. Unfortunately, not many project documentations were available from the plant's past projects. The current staff members attribute this problem to the high rate of employee overturn and poor document transfer during such transitions.

Another objective set for the research is to show that precast construction is lower in overall cost than in-situ construction. This is accomplished by obtaining an overall cost for in-situ construction, an overall cost for precast construction and by comparing these two values. The first group of data analyzed to obtain these values includes direct cost, overhead cost, profit margin, and corresponding project sizes each for ten of the in-situ contractors' latest building projects. The second group of data includes direct project cost, overhead cost, and profit margin for up to ten of PBPPE's latest projects along with project sizes.

In order to meet the objective, all cost components that result from the in-situ construction method of the sampled construction companies and all cost components from up to ten of PBPPE's latest projects were calculated. A representative cost value was achieved by calculating the mean of the last ten completed building projects of each in-situ construction company, and then calculating another mean for the sampled in-situ construction companies. The same was done for the precast method, albeit for only one precast construction company. After that, the two values were put in unit cost format for each project. The way that this was done is by dividing the total project cost by the total area of corresponding building space for that project. This gives us a representative cost value in a 'Birr/m^2' unit for each construction method, which were simply compared to each other for the final result.

The next part of the research shows that precast construction exceeds in-situ construction in the parameters of resources, time, and quality. This is done by running a Six Sigma analysis using the ‘cost’, ‘time’, and ‘quality’ parameters to compare the two construction methods. The steps used in the Six Sigma comparison are categorized under the ‘Analyze’ phase of the DMAIC process. The unit cost values obtained for the overall cost comparison were used in obtaining the scores for the cost parameter. Construction speed was also calculated in order to obtain the time parameter scores.

When it comes to the quality parameter, the in-situ contractors and PBPPE staff were asked for records of all quality control measures taken during ten of their latest completed building projects through the interviews. Unfortunately, the records that were available for quality control measures carried out were few and far between, for either type of construction company. Hence, the availability of such data was seen as a plus all in itself, when calculating scores for the quality parameter in the Six Sigma analysis. The corresponding values have been displayed in a sequence of tables in Chapter 4 and the details of the calculations executed to get the Six Sigma comparison results have been explained under each step of the analysis.

The last part of the objective to grade PBPPE was done according to the NPCA and PCI quality control manuals. The manuals are guidelines that can be referred to in order to evaluate a precast plant as per the grading schedules included in the manual. This is the basic reason that the researcher felt that PBPPE could be graded even without taking the formal ‘evaluator’s training' that NPCA and PCI require.

3.4. RESEARCH POPULATION

The study population for this research includes various members of the construction industry. For the set of data collected about the in-situ construction method, the main population is a set of ten general construction companies and building construction companies with Grades 1 through 5. The reason for narrowing this to the five contractor grade levels is because they have the facilities, equipment, and manpower to undertake construction activities at a level of speed, quality, and cost that could be competent to the precast method of construction.

For the set of data collected about the precast construction method, the PBPPE precast plant was the only member of the study population. This is owing to the fact that there is only one precast plant within the country. In the preliminary phase of the research, a questionnaire was distributed to randomly selected contractors that probes into their know-how on the precast method. The analytical results of the consequently collected data strongly supported the decision to go forward with the research.

As can be inferred, the evaluation of PBPPE according to international quality control manuals was done based on information collected through formal and informal interviews of key PBPPE staff members.

3.5. SAMPLING TECHNIQUE AND SAMPLE SIZE DETERMINATION

The method used to select a sample population is stratified sampling technique, followed by random sampling for the substrata. The reason behind the selection of stratified sampling is that the members of the study population are already classified under the 'contractor grading' system by the government. Within the contractor classes, random sampling was used to select samples so that each member of the subpopulation would get an equal chance of being selected. Respondents consist of a total number of 15 professionals: 10 from contractors and 5 from PBPPE.

In addition to interviews, data for desk study was collected from available design documents and financial documents of sampled in-situ construction companies and of the PBPPE plant. The required sample size for the research for each parties involved in the survey was determined statistically using the following expression.

$$n_0 = [p \times (1-p)] / v^2 \quad \text{Equation 3.1}$$

$$n = n_0 / [1 + (n_0 / N)] \quad \text{Equation 3.2}$$

where:

n_0: First estimate of sample size
p: The proportion of the characteristic being measured in the target population
v: maximum standard error allowed
N: population size
n: sample size [21]

3.6. RESEARCH VARIABLES

Simply put, independent variables are values in a research that the researcher manipulates in order to see the effect that the manipulation has on the results that will be reported. The results that change due to such manipulation are the dependent variables. Correspondingly, the independent variables of this research are: the sales price of modern precast plant's building space products; the construction speed of modern precast plant; precast construction basic cost components; precast construction cost influencing factors; in-situ construction basic cost components; influencing factors of in-situ construction cost; and 'cost', 'time', and 'quality' measures and records from PBPPE.

The dependent variables are: the return period of starting capital cost of modern precast plant; the return period of starting capital cost of in-situ construction company; precast construction total direct cost; precast construction overall indirect cost; in-situ construction total direct cost; in-situ construction overall indirect cost; six sigma results; and NPCA and PCI quality grade

3.7. DATA COLLECTION PROCEDURES

First, a checklist was prepared as a guideline for data collection purposes. Then, identification of major challenges was done through literature review, desk study and site observation on past building projects.

Guide lines contain basic reminders such as: calculate current starting capital costs for a new precast plant and in-situ construction company to be built and compute their return periods; calculate all cost components that result from the precast and the in-situ construction methods and compare them; collect 'cost', 'time', and 'quality' data for the precast and the in-situ construction methods and use the available data in a Six Sigma analysis; and use 'cost', 'time', and 'quality' data to grade PBPPE as per international standards.

From findings, interviews were developed and given to respondents. Then, data was collected from the relevant population (contractors & PBPPE staff members) to evaluate perception of different stakeholders on issues of precast construction and ranking of variables. Next, checking and organization of data was done with thorough investigation to draw a conclusion. After the conclusion, recommendations were forwarded based on findings. Desk study was undertaken to obtain actual data from source documents such as design drawings, financial documents, progress report and site diaries and to acquire the appropriate data about the in-situ contractors' building projects.

Professionals' opinions and relevant data were obtained to identify major benefits that precast construction has over in-situ construction, shortcomings and their effects on cost, time and quality. Structured written interviews were given to the top managers, overhead workers and site workers in the sampled in-situ construction companies and the PBPPE technical and managerial staff members.

In the written interviews, participants were requested to allocate marks from 0 to 5 (a 5-point Likert's scale), employed the five point type Likert ordinal scale to measure level of relevance for responding firms from "Least beneficial" to "Most beneficial" that is, 1= Least beneficial, 2= Less beneficial, 3= Medium beneficial, 4= Very beneficial , 5= Most beneficial. Each number has its own weight. Informal interviews were conducted to further clarify information.

The data for this portion of the study was collected using written interviews distributed to sampled general and building contractors selected by stratified sampling. This provided an estimation of the cost per unit area of in-situ construction that is currently applicable. It was a structured written interview that consisted of concise and brief number of questions. The interview questions are attached in the appendix while the analysis results can be found in the data presentation and analysis section.

The other data that was used was obtained using the cost breakdown template that PBPPE uses, along with the design values they used for one of their last precast projects. Then these data were analyzed to obtain a cost per unit area of precast construction.

Another goal of this study is to check how PBPPE measures up to the NPCA quality control manual for precast and prestressed concrete plants, and the PCI quality standard manual for precast plants, and highlight which of its sections need improvement. For this purpose, the two manuals have been reviewed and precast working data from PBPPE has been assessed as per the provided grading schedules. A copy of these schedules has been attached as an appendix. This process has resulted in a precast plant quality grade out of 100%. The critical works of the plant that have been evaluated as per data availability, are listed in Table 3.2.

Table 3.1: PBPPE Works Evaluated according to NPCA and PCI Quality Control Manuals

Manual Used	**Evaluated Works**
NPCA Quality Control Manual of Precast and Prestressed Concrete Production	Fabrication of Reinforcement and Block-outs
	Positioning of Reinforcement
	Slump, Slump Flow, and VSI
	Temperature
	Density (Unit Weight)
	Air Content
	Compressive Strength
PCI manual, MNL-116	Quality System
	Production Practices
	Raw Materials and Accessories
	Concrete
	Reinforcement and Prestressing
	Product Tolerances

Since PBPPE has not built any precast prestressed buildings since 2013, the recorded laboratory data from past projects have had to be studied to fill out the grading schedules. Additional information has been obtained from PBPPE staff members who have long years of experience on the precast projects.

The method used to obtain technical information and data from PBPPE staff is through semi-structured interviews. The interviews were designed in a way that it was possible, in the end, to summarize and obtain usable results. The analysis from the interviews and the data from the lab records was what made it possible to grade PBPPE as per an international standard. The results of the analysis have been discussed in the data analysis section.

3.8. DATA PROCESSING AND ANALYSIS

According to Courville & Thompson, 2001, [24] multiple regression analysis has two kinds of purposes; prediction and explanation. When used for prediction purposes, the regression derives an equation from research sample data, then uses this equation to predict unknown data in a similar sample. Despite its predictive nature, Johnson & LeBreton, 2004, state that "[this] type of index is often desired when the explanatory aspects of regression analysis are of interest" [25].

For explanation purposes, the regression analysis is used to explain theories that claim facts such as 'one variable is more important than the other'. It is used to show the extent to which each variable contributes to the prediction. This is obviously the approach that this research takes while employing multiple regression analysis.

Historically, measurement methods of the relative importance of predictors dates back to the 1930s to research done by Englehart. In 1960, preceding the first debate to be held on the issue, Hoffman used the index to describe cognitive processes that clinicians used to make judgements about their patients. Many statisticians and researchers have contributed key improvements to the process since. Ward, Gibson, and Darlington in the 1960s, Green & Tull & Heeler, Okechuku, & Reid in the 70s, Lindeman, Merenda & Gold, Jaccard, Brinberg, & Ackerman and Kruskal & Majors in the 80s, and McLauchlan, Budescu, Grisaffe, Myers, Thomas, Hughes & Zumbo, Dunn, Mount, Barrick & Ones in the 1990s are some authors who drew interest to relative importance index research and analysis.

The several indices of measuring relative or variable importance in multiple regression can be broadly categorized into three: single-analysis methods, multiple-analysis methods, and variable transformation methods. The process of inputing Likert's scale values into relative importance index (RII) calculations and ranking them implemented in this research is categorized under single-analysis methods.

Categorized data was coded and analyzed using Microsoft Excel. Relative Importance Index (RII) was then calculated using the formula:

$$RII = \frac{\sum W}{A \times N} \quad \text{.........................} \quad \text{Equation 3.3}$$

where:
W = weight given to each factor by respondents; ranges from 1 to 5
$W = w_i * x_i$; Where: i = response category index
w_i = weight assigned to i^{th} response = 1, 2, 3, 4, 5
x_i = i^{th} frequency of total response for each factor
A = highest weight = 5
N = total number of respondents [25]

Five point Likert scales with values of 0, 1, 2, 3, and 4 were used to calculate RII for each benefit of precast construction and then used to determine their relative ranking. The resulting ranks were then used in Six Sigma calculations to obtain the final scores.

The next step is to check for correlation. The purpose of a correlation test is to see if there is difference in ranking between two groups of respondents and to avoid being deceived by chance occurrences and impacts as ranked by a single part. Correlation tests also help to evaluate whether agreement of opinions exists among respondents.
Spearman's rank correlation coefficient for measuring agreement or difference in ranking between two groups of respondents scoring each factor is applied because of its advantages of not requiring assumption of normality and/or homogeneity of variances. The coefficient is used to show degree of agreement between different parties involved in the survey. The ranking correlation coefficient ranges from -1 to +1. A correlation coefficient of +1 indicates perfect linear correlation i.e. good or strong correlations, while a value of -1 indicates negative correlation implying high ranking in one group associated with low ranking in the other. A correlation coefficient value near zero indicates little or no correlation.

Spearman's rank correlation coefficient (r_s), for agreement in ranking between two parties is given by the following formula. Correlation coefficients are used to measure and compare the association between rankings of two parties, while ignoring ranking of a third one. The rank correlation coefficient is used for measuring differences or agreement in ranking between two groups of respondents scoring various factors (in-situ contractors versus PBPPE staff).

$$r_s = 1 - \frac{6\sum d^2}{N(N^2 - 1)} \quad \text{…………………………. Equation 3.4}$$

where;
r_s = Spearman's rank correlation coefficient
d = difference in ranking in between interview subjects
N = number of variables [25]

3.9. DATA QUALITY ASSURANCE

To assure quality of data, interviews were administered to the relevant respondents in an effort to achieve necessary information. Data collection was focused on important aspects of the interview and how to handle respondents and the data carefully. During data analysis to obtain quality of data, attention was given to important points. As such, raw data used in MS Excel was checked repeatedly to ensure values were exactly the same as the given value by respondents to avoid any wrong results. In addition, before data was collected, the availability of all the source population had to be checked and respondents' daily work schedules had to be respected. All questions had to be put in a simple and clear way, and all systems for quality control or assurance of data collection had to be worked out effectively.

The averages for the cost and price values are needed. However, since average is a general term, and there are three types of averages, the appropriate type is selected based on the type of data. The types of averages and their appropriate use is summarized in Table 3.2. The data type are also listed below, along with brief descriptions and examples.

Table 3.2: Types of Averages to Take According to Data Type

Data Type	**Type of Average to Implement**		
Nominal	Mode	—	—
Ordinal	Mode	Median	—
Quantitative (Interval/Ratio)	Mode	Median	Mean

Nominal - shows no inherent order in categories. E.g. Eye color, ethnicity, diagnosis

Ordinal - has categories that have inherent order. E.g. Job grade, age groups

Binary - has 2 categories. It is a special case of Ordinal. E.g. Gender

Quantitative (Interval/Ratio) - can be of two types.

Discrete - usually contains whole numbers. E.g. Size of household (ratio)

Continuous - can, in theory, take any value in a range, although necessarily recorded to a predetermined degree of precision. E.g. Temperature °C/°F (no absolute zero) (interval), Height, age (ratio)

The cost and price data collected for this research apparently falls in the interval/ratio category. This is why all three types of average calculation have been implemented.

The ‘structural tests and problems’ data have been used in the Six Sigma analysis as per the procedural and computational steps that the Six Sigma method requires. This has been explained and tabulated in sufficient detail in Chapter 4: Presentation and Analysis of Data. The ‘quality control data’ have been used in the evaluation process of PBPPE as per the NPCA and PCI quality control manuals according to their availability.

CHAPTER 4: PRESENTATION AND ANALYSIS OF DATA

4.1. COST BREAKDOWN OF PRECAST AND IN-SITU CONSTRUCTION PROJECTS

4.1.1. Precast Building Project Cost (Islamic Affairs Building)

This part of the research required a cost comparison between the project cost of the precast construction method and that of the in-situ construction method in units it can use to compare them.

In order to make such a comparison, a precast building's design was analyzed and its material, labor, and equipment costs calculated using PBPPE's design and cost breakdown templates. This supplied the actual direct cost that the building incurred as it was calculated by PBPPE. The building design analyzed for this purpose is attached as an appendix.

The first two tables showing the cost breakdown details for this particular building design are displayed in Table 4.3 and Table 4.4. The remaining tables are attached in the Appendix section for further perusal.

Table 4.3: Erection Cost Breakdown for Normal Slab without Ceiling, S-30-N

	PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE								
	COST BREAKDOWN FOR PRODUCTION & ERECTION								
	PRE-FABRICATED BUILDING ELEMENTS								
Project:	**Islamic Affairs Building**								
Work Item:	**Normal Slab without Ceiling, S-30-N**								
Labor Hrly Output:	**2.0**	**pc/hr**						**Total**	
Total Work Item Qty:	**120.0**	**pcs**							
Material Cost	No.	1	2						
	Type of Material	Pre-stressing Wire	Concrete Grout, C40						
	Unit	kg	m						
	Quantity	148.0	0.1						
	Rate	27.3	3079.9					Total Material Cost =	
	Unit Cost	4040.4	369.6					4410.0	**4410.0**
Labor Cost	Labor By Trade	Foreman	Senior Surveyor	Surveyor II	Erector	Daily Labor			
	Quantity	1.0	1.0	1.0	4.0	4.0			
	Unit Factor	1.0	1.0	1.0	1.0	1.0		Total Labor Cost =	
	Indexed Hrly Rate	21.8	16.6	14.2	13.1	7.3		Hrly cost/Hrly Output =	
	Hourly Cost	21.8	16.6	14.2	52.5	29.2		134.3	**67.1**
Equipment Cost	Equipment Type	Crane (Kato 45T)	Support	Pre-stressing machine	Generator				
	Quantity	1.0	4.0	1.0	1.0				
	Unit Factor	0.5	1.0	1.0	0.5			Total Equipment Cost =	
	Hrly Rate	700.0	10.0	20.0	500.0			Hrly cost/Hrly Output=	
	Hrly Cost	350.0	40.0	20.0	250.0			660.0	**330.0**
Transportation :	7pcs/trip=	4.38X100 =	**438.4**	birr/pc					
			TOTAL ERECTION COST =			**I-13 + I-18 + I-23 =**			**5245.6**

Table 4.4: Production Cost Breakdown for Normal Slab without Ceiling, S-30-N

	Prefabricated Building Parts Production Enterprise										
	Cost Breakdown for Production and Erection										
	Pre-Fabricated Building Elements										
Project:	**Islamic Affairs Building**										
Work Item:	**Normal Slab without Ceiling, S-30-N**										
Labor Hrly Output:	**1.0**	**pc/hr**			**Eqpt Hrly Output:**	**1.0**	**pc/hr**			**Total**	
Total Work Item Qty:	**120.0**	**pcs**									
	No.	1.0	2.0								
	Type of Material	Cement	Sand	Coarse Aggregate	Re-bar	Black Iron Wire	Form work	R.D	Lubricating Oil		
Material Cost	Unit	Qt	m	m	kg	kg	m	pcs	Lts		
	Quantity	9.1	0.8	1.6	147.4	2.4	30.8	4.0	2.0		
	Rate	320.0	430.0	400.0	27.0	31.0	18.0	48.0	18.0	Total Material Cost =	
	Unit Cost	2918.4	361.2	624.0	3979.8	74.4	553.5	192.0	36.0	8739.3	8739.3
Labor Cost	Labor By Trade	Foreman	Batching plant Operator	Scraper Operator	Distributor Operator	Bridge crane Operator	Skilled Labor	Daily Labor			
	Quantity	1	2	1	1	1	6	4			
	Unit Factor	0.25	1.0	1.0	1.0	1.0	1.0	1.0		Total Labor Cost =	
	Indexed Hrly Rate	21.75	11.25	8.25	4.25	5.28	11.25	7.3		Hrly cost/Hrly Output =	
	Hourly Cost	5.4	22.5	8.3	4.3	5.3	67.5	29.2		142.4	142.4
Equipment Cost	Eqpm't Type	Batching Plant	Vibrator	Bridge Crane	Scraper						
	Quantity	1	1	1	1						
	Unit Factor	0.4	1	1	1					Total Equipment Cost =	
	Hrly Rate	200.0	20.0	20.0	10.0					Hrly cost/Hrly Output=	
	Hrly Cost	80.0	20.0	20.0	10.0					130.0	**130.0**

[Cont.] *Table 4.4: Production Cost Breakdown for Normal Slab without Ceiling, S-30-N*

Total Production and Erection Cost							
Total Production Cost =		L13+L18+L23 =		9,358.52			
Total Production:	9,358.52		Labor Charge for re-bar preparation:				
			Labor By Trade	No.	Unit Factor	Indexed Hrly Rate	
Total Erection :	5,245.56		Re-bar cutter	1.00	2.00	8.90	17.80
Total Production and Erection :		14,604.08	Re-bar bender	2.00	7.00	8.90	124.60
Add 20% Overhead :	1.2	17,524.90	Helper	4.00	7.00	7.30	204.40
Add 15% Profit	1.15	20,153.63	Total				346.80
Grand Total		20,153.63					

Table 4.5 shows a summary of the cost breakdowns that are shown above. It can be noted that since overhead cost and profit were added in each cost breakdown table, the amounts summarized here are the final PBPPE prices.

Table 4.5: Summary of Costs of Precast Construction

PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE						
Islamic Affairs Building						
Construction of Skeleton in Pre-Fab Elements						
Summary of Costs						
		Islamic Affairs Building Quantity				
No.	**Description**	**Ground Floor**	**1St - 5Th Floors**	**Qty**	**Unit Price**	**Total**
1	Normal Slab Type S-30-N		120	120	20,153.63	2,418,435.79
2	Cantilever Slab S-30-CL		110	110	8,507.22	935,794.44
3	Cantilever Slab S-30-CM			0	8,209.54	0.00
4	Cantilever Slab S-30-CR			0	8,519.52	0.00
5	Edge Girder G-30-1		30	30	3,500.99	105,029.74
6	Edge Girder G-30-2	6		6	3,608.34	21,650.04
7	Edge Girder G-30-4			0	4,051.93	0.00
8	Initial Column C-30-1W(L=7M)	39		39	7,091.65	276,574.41
9	Column C-30-2W-5.8M			0	11,516.04	0.00
10	Column C-30-1W-2.9M		195	195	7,124.83	1,389,342.67
11	Shear Wall 378X262X15	5	25	30	10,403.88	312,116.41
12	Staircase Flight	2	10	12	6,901.97	82,823.59
13	Staircase Landing	1	5	6	14,978.97	89,873.82
14	Footing Pad F1(120X120X80CM)	28		28	5,685.59	159,196.45
16	Footing Pad F3(200X200X80CM)	11		11	9,688.77	106,576.44
TOTAL		**92**	**495**	**587**	**129,942.87**	**6,040,690.87**

The total precast construction price in Table 4.5 is inclusive of PBPPE’s profit margin of 15%. This means the actual construction cost is:

ETB 6,040,690.87 / 1.15 = ETB 5,252,774.67

Table 4.6: Unit Cost and Unit Price of the Precast Method

Item	**As-Built Area**	**Construction Cost, Br**	**Construction Unit Cost, Br/m**	**Construction Unit Price, Br/m**
Islamic Affairs Building	3,421.44	5,252,774.67	1,535.25	1,765.54

Table 4.6 shows that the actual cost of precast construction, including overhead, is ETB 1535.25. The precast construction unit price is found to be ETB 1765.54.

4.1.2. In-Situ Contractors' Cost Data

The in-situ construction cost values shown in Table 4.7 are for the concrete work of the structure of buildings. In other words, it does not include the cost of masonry partitions, finishing works, earthwork, or roofing. The price values obtained through the interviews from the sampled construction companies are the latest prices that the companies have demanded. The same goes for the overhead and profit margins, which the interviewees provided. For the interview subjects that could not provide the unit cost for the concrete work of their projects, the cost of concrete works was obtained from project 'Bills of Quantity' (BoQs), and overhead and profit amounts were deducted where it was found necessary.

Table 4.7: Cost Breakdown of In-Situ Construction

Contractor	License Class	Cost of Concrete Work, Br/m	Overhead Margin, %	Overhead Unit Cost, Br/m	Total Unit Cost, Br/m	Profit Margin, %	Profit, Br/m	Unit Price, Br/m
Elmi Olindo Contractors PLC	I	2,900.00	15	435.00	3,335.00	10	333.50	3,668.50
Wonder Construction PLC	I	3,500.00	15	525.00	4,025.00	10	402.50	4,427.50
Eyob Construction P.L.C	IV	2,900.00	15	435.00	3,335.00	10	333.50	3,668.50
Andualem Kebere Construction PLC	IV	2,500.00	15	375.00	2,875.00	10	287.50	3,162.50
Samuel Wosene Eshete Construction PLC	IV	2,400.00	15	360.00	2,760.00	10	276.00	3,036.00
Triangle General Construction PLC	IV	2,500.00	15	375.00	2,875.00	10	287.50	3,162.50
Elham Engineering PLC	IV	2,200.00	10	220.00	2,420.00	10	242.00	2,662.00
Shewangzaw Construction &Trading PLC	V	2,900.00	10	290.00	3,190.00	10	319.00	3,509.00
Fetish Construction PLC	V	2,700.00	10	270.00	2,970.00	10	297.00	3,267.00
G.B.C. Construction P.L.C.	V	2,700.00	10	270.00	2,970.00	10	297.00	3,267.00
Mean		**2,720.00**	**13**	**353.60**	**3,073.60**	**10**	**307.36**	**3,380.96**

Seeing as the only information needed from Table 4.7 are the 'Total Unit Cost' and 'Unit Price' columns, these particular values have been summarized in Table 4.8.

Table 4.8: Summary of Costs of In-Situ Construction

Contractor	Contractor Class	Total Unit Cost, Br/m	Unit Price, Br/m
Elmi Olindo Contractors (EoC)	I	3,335	3,668.50
Wonder Construction (WC)	I	4,025	4,427.50
Eyob Construction (EC)	IV	3,335	3,668.50
Andualem Kebere Construction (AKC)	IV	2,875	3,162.50
Samuel Wosene Eshete Construction (SWE)	IV	2,760	3,036.00
Triangle General Construction (TGC)	IV	2,875	3,162.50
Elham Engineering (EGC)	IV	2,420	2,662.00
Shewangzaw Construction &Trading (SCON)	V	3,190	3,509.00
Fetish Construction (FC)	V	2,970	3,267.00
G.B.C. Construction	V	2,970	3,267.00
Mean		**3,073.6**	**3,380.96**

4.2. CONSTRUCTION TIME OF THE IN-SITU CONSTRUCTION METHOD AND THE PRECAST CONSTRUCTION METHOD

In this section, the construction time and total as-built area of the precast Islamic Affairs Building was used to compute the speed of construction of PBPPE. This value is presented in Table 4.9. Following that, the construction rates of ten of the latest in-situ building projects carried out by the ten sampled contractors were used to compute their speeds of construction. Finally, the average of the ten contractors' speeds of construction were compared to the speed of construction of the Islamic Affairs Building.

Table 4.9: Construction Speed of the Precast Method

Item	As-Built Area	Construction Time (yrs)	Construction Speed (m
Islamic Affairs Building	3,421.44	1	3,421.44

It should be noted that of the 12 months it took for this precast construction project to be completed, only 4 months were spent on the production and erection of its precast components. This fact presents the need to adjust the computed value for construction speed. The adjusted value then becomes:

(3421.44 / 4) X 12 = 10,264.32 m^2/yr.

Table 4.10: Construction Speed of the In-Situ Construction Method

Contractor	Contractor Class	Unit Cost Estimate of Concrete Work, Birr/m	Rate Of Construction of 10 Building Projects, m^2	Construction Speed of 10 Projects, m
Elmi Olindo Contractors (EoC)	I	3,335	300	3,600
Wonder Construction (WC)	I	4,025	320	3,840
Eyob Construction (EC)	IV	3,335	305	3,660
Andualem Kebere Construction (AKC)	IV	2,875	275	3,300
Samuel Wosene Eshete Construction (SWE)	IV	2,760	255	3,060
Triangle General Construction (TGC)	IV	2,875	250	3,000
Elham Engineering (EGC)	IV	2,420	240	2,880
Shewangzaw Construction &Trading (SCON)	V	3,190	240	2,880
Fetish Construction (FC)	V	2,970	120	1,440
G.B.C. Construction.	V	2,970	60	720
Average		**3,073.6**	**236.5**	**2,838**

4.3. CONSTRUCTION QUALITY OF THE IN-SITU CONSTRUCTION METHOD AND THE PRECAST CONSTRUCTION METHOD

It can be challenging to compare quality of the final outcomes of construction projects. Yet, when it comes to the results obtained based off of the most basic questions presented to the subjects of this research, it can be seen that almost no quality checks are being carried out.

4.3.1. Quality Assessment Measures Taken by In-Situ Construction Companies

There is almost no evidence of systematic quality assessment procedures taken by the contractors under study. The quality measurement or assessment data that was available has been presented in Table 4.12 and Table 4.13. Table 4.11 actually shows the degree of availability and scarcity of quality measurement or assessment in the sampled in-situ construction companies.

Table 4.11: Frequency of Tests and Structural Problems in In-Situ Construction Projects

	EOC	**WC**	**EC**	**AKC**	**SWE**	**TGC**	**EGC**	**SCON**	**FC**	**GBC**	**PBPPE**
Conc. Comp. Strength Test Frequency**	0.17	0*	0*	N/A	0*	0*	0*	N/A	N/A	N/A	0*
Re-Bar Tensile Strength Test Frequency**	0*	0*	0*	N/A	0*	0*	0*	N/A	N/A	N/A	0*
No. of Mandatory Maintenance Works in One Year	0	0	0	1	0	0	0	0	0	0	0
No. of Serviceability Problems in One Year	0	0	0	0	0	0	1	0	0	0	0

** Test made available upon client's request, and denied*
*** Number of tests per 1000 square meters of concrete work*

Table 4.12: Concrete Compressive 28-day Strength Test Results

Company	**Test Type**	**Sample Dimension**	**Sample No.**	**Concrete Class**	**Test Result (MPa)**
Elmi Elindo Contractors	Concrete Comp. Strength	Cube Edge = 15 cm	EETstCPe77/ 2005	C30	27.7
			e78/2005	C30	27.1
			e82/2005	C30	25
				Average	**26.6**

Table 4.13: Structural Failure Results

Company	Item	Failure Type	Cause of Failure	Maintenance Method	Measures on	
					Contractor	Client
Analem Kent (AKC)	Bent Cantilever Beams	Flexural	Non-comp. with design details	Hollow Steel Props on Added Footings	Maintenance and Overhead Expenses	Time Delay

4.4. IN-SITU CONSTRUCTION COST ESTIMATE OF THE ISLAMIC AFFAIRS BUILDING

For further understanding, the cost if the Islamic Affairs building were built in-situ is estimated. The typical floor dimensions of the Islamic Affairs Building are shown below. In total, the building has 24 spans of 4.2 by 4.2 meters each plus 22 spans of 1.2 by 4.2 meters cantilevers. This brings the L-shaped building's external dimensions to 40.2, 23.4, 10.8, 12.6, 29.4, and 10.8.

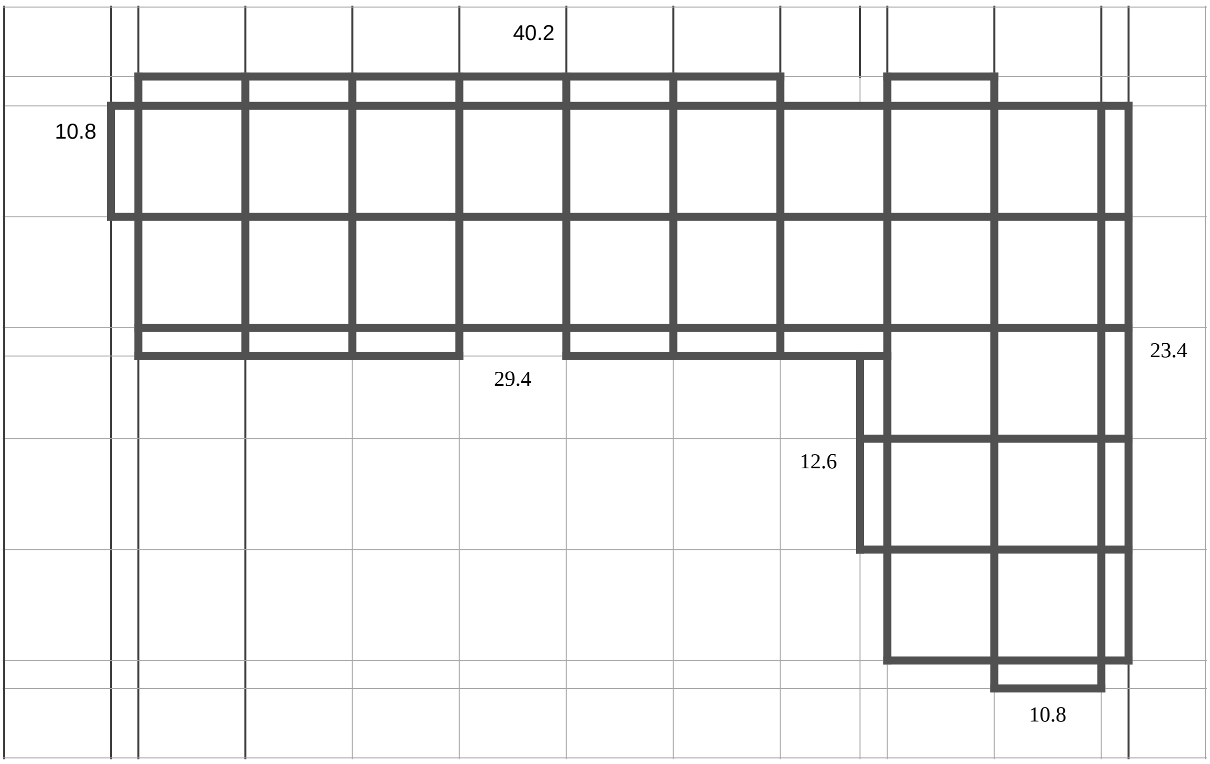


Figure 4.1: Typical Floor Plan of Islamic Affairs Building

With precast construction, the unit price is 1765.54 Birr/m^2, while the average unit price of in-situ contractors is 3380.96 Birr/m^2. This gives us the total cost of structural concrete works for the Islamic Affairs Building as follows:

Full Span Slabs:

[(24 X 4.2 X 4.2) sq.m./story] X [6 stories] X [ETB 1279.38/sq.m.] = ETB 3,249,829.90.

Cantilever Slabs:

[(22 X 4.2 X 1.2) sq.m./story] X [6 stories] X [ETB 1279.38/sq.m.] = ETB 851,145.93.

Full Span Slabs:

[(24 X 4.2 X 4.2) sq.m./story] X [6 stories] X [ETB 3073.60/sq.m.] = ETB 7,807,435.78.

Cantilever Slabs:

[(22 X 4.2 X 1.2) sq.m./story] X [6 stories] X [ETB 3073.60/sq.m.] = ETB 2,044,804.61.

This means that the building was constructed for ETB 4,100,975.83 (direct construction cost) using precast but it would have been built for ETB 8,636,544.00 if it were constructed in-situ. This clearly shows the large difference in precast cost and cost of in-situ construction.

Using a cost breakdown document produced by the Ethiopian Building Design Enterprise (BDE) in 2008, a second analysis was done to estimate how much it would have cost if the Islamic Affairs building was built with the in-situ method. The results obtained using these BDE rates are much lower than can be realistically expected. Thus the rates cannot be taken as eligible values and were not used for the purposes of this research.

Table 4.14: In-Situ Construction Cost of the Islamic Affairs Building Using BDE Prices

ITEM	FOOTING PAD F3, 200X200X 80 CM	FOOTING F1 (120X120 X80CMS)	COL. C-30-1W, 7M (INITIAL)	NOR MAL S/W SWN (378 x262 x15)	NORMA L SLAB WITHO UT CEILIN G, S-30- N	CANTI LEVER SLAB S-30- CL(CR)	ED GE GIR DE R G-3 0-1	ED GE GIR DE R G-3 0-2	COL UM N C-30 -1W, 2.9M	STAIR CASE FLIG HT	STAIR CASE LAND ING
QUANTITY	11.00	28.00	39.00	30.00	120.00	110.00	30.00	12.00	195.00	12.00	12.00
VOLUME, M	3.20	1.15	0.63	1.49	2.65	0.76	0.38	0.21	0.26	1.13	0.68
INSITU UNIT COST, BIRR/M	4,644.90	4,644.90	4,644.90	4,644.	4,644.90	4,644.90	4,644	4,644	4,644.	4,644.9	4,644.90
INSITU TOTAL COST, 1000 BIRR	**163.50**	**149.83**	**114.13**	**207.01**	**1,474.85**	**386.27**	**52.67**	**11.71**	**236.40**	**62.98**	**37.91**
WEIGHT, KG	97.00	70.36	85.00	235.20	367.40	144.00	50.80	65.00	85.00	84.00	286.00
REBAR LABOR COST	82.60	82.60	92.86	79.73	346.80	205.80	147.4	147.4	88.11	147.40	147.40
INSITU UNIT COST, BIRR/KG	98.00	98.00	98.00	92.00	92.00	92.00	92.00	92.00	92.00	92.00	92.00
INSITU TOTAL COST, 1000 BIRR	**9.59**	**6.98**	**8.42**	**21.72**	**34.15**	**13.45**	**4.82**	**6.13**	**7.91**	**7.88**	**26.46**
AREA, M2	6.40	3.84	8.40	19.81	17.64	5.04	3.78	3.78	3.48	7.14	4.17
RATE, BIRR/M2	87.42	87.42	93.19	88.18	88.18	88.18	89.26	89.26	93.19	93.19	93.19
TOTAL FORMWORK COST, 1000 BIRR	**0.56**	**0.34**	**0.78**	**1.75**	**1.56**	**0.44**	**0.34**	**0.34**	**0.32**	**0.67**	**0.39**
TOTAL, 1000 BIRR	**173.65**	**157.14**	**123.33**	**230.47**	**1,510.55**	**400.17**	**57.83**	**18.17**	**244.63**	**71.53**	**64.76**
SUM, ETB =	**3,052,229.96**										

4.5. INDIRECT ERECTION COSTS OF PRECAST CONSTRUCTION

To explore what kind of indirect costs may be incurred during the erection phase of precast construction, let us briefly discuss the erection costs for precast buildings. Cranes are used for this purpose. High monthly lease costs for tower cranes significantly impact project costs and scheduling. The cost of erection cranes is directly related to the amount of time that they will be utilized. In addition to the direct rental cost, it should be checked whether the usage of cranes will have any effect on lengthening the erection time. Hence, such an analysis is briefly discussed below.

The differences in precast erection speed due to building types has been stated as follows; “For commercial buildings (offices, shopping centers, schools etc.) about 100 m^2 of a building can be erected each day, including the erection of all components and all necessary connections. The corresponding figure for the erection of apartment buildings is about 80 m^2 per day. The difference is generally due to smaller pieces and stricter tolerances” [22]. A study on “Analysis of Operation Efficiency of Cranes” by Lee, Son, and Kim shows the following durations for the lifting time of cranes in the Multiple Housing projects in Korea. These data is taken for cranes serving the top floors of twenty-story buildings [28].

Table 4.15: Average Durations for the Lifting Time of Cranes in 20 Story Building Projects [28]

Dec. 08, 2010		**Work**		
Start, h:m:s	**Finish, h:m:s**	**Limiting Time, m:s**	**Activity**	**Up/Down**
8:51:46	8:53:13	01:27	Prepare	
8:53:13	8:55:00	01:47	Load	Down
8:55:00	8:57:20	02:20	Prepare	Up
8:57:20	8:59:21	02:01	Load	Down
8:59:21	9:02:49	03:28	Prepare	
9:02:49	9:04:11	01:22	Load	Down
9:04:11	9:08:30	04:19	Prepare	Up
9:08:30	9:25:02	16:32	Load	Waiting
9:25:02	9:28:13	03:11	Rearrange	

As can be seen from Table 4.14, it takes a maximum of 37 minutes for two trips for the cranes in this study.

Another study on “Overhead Bridge Crane Operating Speeds” carried out by Dearborn Crane gives Standard Speeds for the motions to Hoist, Trolley, and Bridge items using cranes of capacities ranging from 2 to 20.

According to this study, for an average-sized bridge crane (capacity of 10 tons), it would take 35 minutes to hoist, trolley and bridge an object up to 18 meters of height. This is taken as the approximate height of the building in question. Assuming a linear relationship, there is a 5.83 minute increase for every story.

Table 4.16: Average Crane Lifting Time in the Islamic Affairs Building Project

Story	Crane Time Per Item (Minutes)	Avg. No. of Precast Items	Total Crane Time (Minutes)
1	5.83	138	804.54
2	11.66	138	1,609.08
3	17.49	138	2,413.62
4	23.32	138	3,218.16
5	29.15	138	4,022.7
6	34.98	138	4,827.24
		TOTAL	**16,895.34**

There are on average 138 items that have been lifted for every story of the Islamic Affairs building during its construction. As it can be seen in Table 4.15, it took a total of 16,985.34 minutes to lift and place the total number of precast items. The computations are presented in Table 4.15. This is less than 5 hours in total, which means the erection time is greatly insignificant compared to the precast production time. Being the slowest activity in the process, the production speed is the maximum speed that can be taken for precast construction by PBPPE.

In addition to the erection time, the hourly rental rate for equipment including cranes used in the erection of the Islamic Affairs building can be seen to be ETB 600, which would not have made the equipment rental cost a decisive factor.

Table 4.17: Precast Production Time in the Islamic Affairs Building Project

A	Avg. Area per Story (m	570.24
B	PBPPE Production Speed (m	400.00
C	No. of Beams and Columns per Story	92.00
D = (‘C’ X Column Dimension)	Vol. of Beams and Col’s per Story	34.78
E = (‘D’ / Slab Depth)	Slab Area Equivalent of B&C	231.84
F = (‘A’ + ‘E’)	Total Area per Story (m	802.08
G = (‘F’ / ‘B’)	Time Taken per Story (Months)	2.01
H = (No. of Stories X ‘G’)	Total Time Taken (Months)	12.03

The result in Table 4.16 shows that the 12 months it took for the construction of the Islamic Affairs Building was mainly due to the limited number of molds that PBPPE owns.

4.6. OBSERVED FEATURES IN THE IN-SITU CONSTRUCTION METHOD AND THE PRECAST CONSTRUCTION METHOD

The categories used to compare the different activities of the two methods of construction are differences in production process, differences in installation process, equipments used in each method, and comparisons in non-quantitative quality (such as finished look). The differences between the two construction methods have been categorized in Table 4.17.

Table 4.18: Non-Quantitative Comparison of Precast Construction and In-Situ Construction

Processes	**Precast Construction**	**In-Situ Construction**
Production	batched and mixed by a plant	batched and mixed by daily laborers
	less water added to ease work for mixer	more water added to ease work for daily laborers
	measured amount of input materials	roughly estimated amount of input materials
	concrete always poured and vibrated on ground level	concrete manually poured and vibrated on final levels
	cured in an enclosed curing pond	cured on location by water hoses
Installation	members lifted by cranes onto heavy duty trucks and transported considerable distances	fresh concrete mixed on site
	members lifted from trucks by cranes and erected with few trained technicians	fresh concrete carried by a team of daily laborers or winches and placed and vibrated by another team of daily laborers
	very small amount of wet work on site for grouting	all wet work done on site, mostly on unprepared surfaces
	requires considerable prestressing tendons	requires a large amount of eucalyptus trunks
	requires costly installation equipment	requires a lot of manpower
Equipments	batching plant	shovels, “barella”, handcart, buckets
	reusable steel forms	short lifetime wooden plank forms
	pouring cranes, erection cranes, prestressing tendons, jacking equipment, tension gauge, wedge, barrel	eucalyptus trunks, nails
	curing ponds or steam chambers	water hose or barrels and buckets
Manpower	batching plant operator	daily laborers
	mixer truck operator	foreman
	casting crane operator	storekeeper
	lifting crane operator	
	trained erection crew	
	grouting technician	
Finished Look	completely uniform and smooth	usually varies in different areas
	doesn’t need chiseling and coating with mortar	almost always chiseled and coated to get smooth and level surfaces
Drawbacks	costly equipment	poor safety conditions
	Trained workmen	considerable amount of materials wasted
	Erection crane is a prerequisite	untrained laborers need close follow up

4.7. THE SIX SIGMA COMPARISON BETWEEN THE PRECAST CONSTRUCTION METHOD AND THE IN-SITU CONSTRUCTION METHOD

Six Sigma is so reliable that it is said to have a 3.4 in a million chance of failed results. It can be used to grade an output and decide whether or not to device a new one, or to compare between different outputs and rank them as per priorities input into it in the ‘criteria evaluation matrix’ stage.

Criteria evaluation matrix is the first step of Six Sigma. The significant criteria by which construction methods are measured are taken to be Quality, Cost, Time and Safety of construction for the purposes of this study. Hundreds of other criteria could be added to analyze using this method, if they are found equally important.

Table 4.19: Criteria Evaluation Matrix

	Quality	**Cost**	**Time**	**Safety**	**Total**
Quality	—	0	0	1	1
Cost	1	—	1	1	3
Time	1	0	—	1	2
Safety	0	0	0	—	0
Total	**16.67%**	**50.00%**	**33.33%**	**0.00%**	**6**

As shown in Table 4.18, values of 0’s and 1’s are given in the criteria comparison. A value of ‘0’ represents “The criteria in that column is *less* important than the criteria in that row”, while a value of ‘1’ represents “The criteria in that column is *more* important than the criteria in that row”. The hyphens are for the equal value that a criteria obviously has to itself. The percentage values in the “Total” row show the ratios of the sum points that each criteria obtained to the total points of all the criteria. Hence, ‘Cost’ got a total of 3 points, which ,when divided by the total point of 6 and multiplied by 100%, gives 50% (column 3, row 6).

The next step is forming a concept matrix and filling out a score of 1 up to 5 for each criteria in both methods. This step is demonstrated in Table 4.19.

Table 4.20: Concept Matrix

Score	**1**	**2**	**3**	**4**	**5**
Quality	Very Poor	Poor	Satisfactory	Good	Excellent
Cost	Steep	Considerable	Reasonable	Affordable to Middle Class	Affordable to Lower Class
Time	more than 3 times the estimate	2 to 3 times estimate	1.5 to 2 times estimate	1 to 1.5 times estimate	less than or equal to estimate
Safety	Very Risky	Moderately Risky	Satisfactory	Safe	Extremely Safe

The rank is calculated based on the criterion's importance as obtained from the criteria evaluation matrix. Quality has a 1/6 importance value, cost a 3/6 = 1/2 value, and time a 2/6 = 1/3 value. Apparently, safety is shown to be of '0' value. These values are then multiplied by the score given for each parameter in the concept matrix.

The scoring index used for the criteria is as shown in Table 4.20:

Table 4.21: Scoring Index

Construction Method	**Quality**		**Cost**		**Time**		**Safety**		**Final Score**
	Score	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	
In-Situ Construction	1.00	0.17	0.50	0.25	1.00	0.33	2.00	0.00	0.75
Precast Construction	5.00	0.83	1.73	0.87	4.00	1.33	4.00	0.00	3.03

As the Final Score in the concept matrix (Table 4.19) shows, In-Situ Construction got a final score of 0.75 out of 5 and Precast Construction got 3.03. This shows that overall precast construction is about four folds the better choice than in-situ construction.

4.8. OPTIMAL BUILDING SIZES FOR PRECAST CONSTRUCTION

Some assumptions have been taken for the analysis of a hypothetical building. The slab is assumed to be uniquely shaped, and thus needs custom made molds for precast construction. It has 500 square meters of typical floor area. There is a 1 km distance between the precast plant and the construction site. The slab design requires rebars of dia. 14mm c/c 10 cm (in both directions, top and bottom). Finally, the slab depth is 15 cm. A preliminary sketch of the typical floor plan is shown in Fig. 4.2.

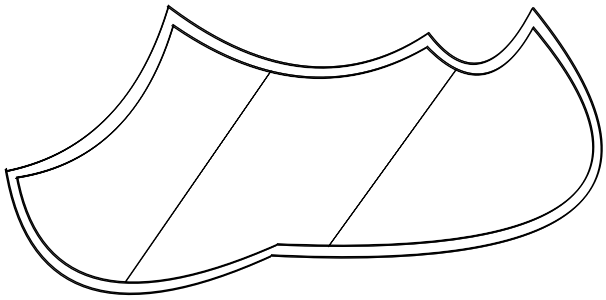


Figure 4.2: Hypothetical Building Floor Plan

There are many construction inputs that would be used in the same amount in either construction method:

i. material (cement, coarse aggregate, fine aggregate, reinforcement bar) cost
   a. C25 RC cost = ETB 2169.01/m3 (ETB 162,675.75 for 500m^2 X .15m)
   b. rebar cost = ETB 27/kg [(1m^2/ 0.1) + 1] X 4 = 44m/m^2; 44X500 = 22000m; 22000m X 1.209kg/m = 26598 kg; ETB 27/kg X 26598 kg = ETB 718,146 for 500m2 (Rebar unit price obtained from merkato.com);

   total material cost= ETB 880,821.75
ii. raw material transportation cost
   a. from source to batching plant = ETB 700/14m^3 (For 500m^2 X .15m), ETB 16,650
iii. bar bender labor cost = ETB 67.50/hour

Cost items to be considered for precast construction:

i. custom made imported concrete forms cost = USD 92.50/m^2 (average of custom precast concrete form costs per unit square meters on alibaba.com) = ETB 2220/ m^2; 3 months
ii. batching plant cost (energy) = ETB 80/hour; 1 hour
iii. batching plant operator cost = ETB 22.50 /hour; 1 hour
iv. casting/bridge crane cost (energy) = ETB 20/hour
v. casting/bridge crane operator cost = ETB 5.28/hour
vi. precast element lifting crane cost (bridge crane)
   a. from casting plant on to trucks - Negligible

   b. from trucks on to curing pond - Negligible
   c. from curing pond on to trucks - Negligible
   d. from trucks on to place in building = ETB 350/hour

vii. Prestressing cost

   a. prestressing wire cost = ETB 27.3/kg
   b. prestressing machine cost = ETB 20/hour
   c. wedge and barrel cost = ETB 345.6/piece

viii. concrete transportation cost

   a. fresh concrete from batching plant to casting - Negligible
   b. precast element from casting to curing pond - Negligible
   c. precast element from precast plant to site = ETB 800/km

ix. erection labor cost = ETB 41/hour

x. costs due to time delay

   a. opportunity cost = ETB 400/m^2/month
   b. “time value of money” cost - Negligible

The results of the foregoing cost calculations are enlisted and summed in Table 4.21.

Table 4.22: Cost of Precast Construction for Hypothetical Building

Cost Items	**Unit Rate**	**Amount**	**Total**
custom made imported concrete forms	ETB 2220/m	500 m	1,110,000.00
batching plant cost	ETB 80/hour	1 hour	80.00
batching plant operator cost	ETB 22.50/hour	1 hour	22.50
precast element transportation cost from precast plant to site	ETB 800/km/ element	5 elements; 1 km	4,000.00
casting/bridge crane cost	ETB 20/hour	1 hour	20.00
casting/bridge crane operator cost	ETB 5.28/hour	1 hour	5.28
precast element placement cost (bridge crane) from trucks on to location in building	ETB 350/hour	1 hour	350.00
prestressing wire cost	ETB 27.3/kg	4195.01 kg	114,523.77
prestressing machine cost	ETB 20/hour	1 hour	20.00
wedge and barrel cost	ETB 345.6/piece	10 pieces	3,456.00
erection labor cost	ETB 41/hour	1 hour	41.00
opportunity cost	ETB 400/m month	No delay	0.00
		TOTAL	**1,232,518.55**

Cost items to be considered for in-situ construction:

i. mixer = ETB 60/hour

ii. vibrator = ETB 30/hour

iii. hand tools (shovel, barella, concrete iron) - ETB 5/hour

iv. wasted raw material cost = 10% of RC Cost = ETB 16267.50

v. form work cost = ETB 197.25/m^2

   a. For 500 m^2, ETB 98,625

vi. skilled labor cost (Foreman) = ETB 267/day

   a. For 63.3 days, ETB 16901.1

vii. unskilled labor cost = ETB 80/day/laborer

   a. For 2.11 months (63.3 days), 10 laborers, ETB 50640

viii. time cost

   a. opportunity cost = 400/m^2/month

1) For 500 m^2, at a rate of 2838 m^2/month, 2.11 months' opportunity cost = (2.11-1.75) months X ETB 400/m^2/month X 500 m^2 = ETB 72,832.98

b. "time value of money" cost - Negligible

Table 4.22 below shows that the in-situ construction method would be less costly than the precast construction method (shown inTable 4.21) for this hypothetical building.

Table 4.23: Cost of In-Situ Construction for Hypothetical Building

Cost items	**Unit Rate**	**Amount**	**Total**
Mixer	ETB 60/hour	506.4 hours	30,384
Vibrator	ETB 30/hour	506.4 hours	15,192
Hand Tools (Shovel, Barella, Concrete Iron)	ETB 5/hour	506.4 hours	2,532
Wasted Raw Material Cost (10% Of RC Cost)	ETB 2169.01/m	area 500m	16,268
Form Work	ETB 197.25/m	500 m	98,625
Skilled Labor	ETB 267/day	63.3 days	16,901
Unskilled labor	ETB 80/day/	63.3 days, 10 laborers	50,640
Opportunity Cost	ETB 400/m	0.36 months (d/c in time b/n the 2 methods); area 500 m	72,832
		Total	**303,374**

The next step is to check for what number of floors of this building would the precast construction method be a more economic choice. Through iteration, it was found that for seven stories or more, the precast method costs less than the in-situ method.

Table 4.24: Iteration of Cost for Precast and In-Situ Construction Methods

Number of Stories	Cost of Precast Method (ETB)	Cost of In-Situ Method (ETB)	Remarks
1 Story	1,232,518.55	303,373.67	
2 Stories	1,355,037.10	606,747.34	
3 Stories	1,477,555.65	910,121.01	
4 Stories	1,600,074.20	1,213,494.68	
5 Stories	1,722,592.75	1,516,868.35	
6 Stories	1,845,111.30	1,820,242.02	
7 Stories	1,967,629.85	2,123,615.69	
8 Stories	2,090,148.40	2,426,989.36	
9 Stories	2,212,666.95	2,730,363.03	
10 Stories	2,335,185.50	3,033,736.70	

The values of all cost items in the precast, except the custom made formwork, would increase in direct proportion with the number of stories of the hypothetical building. As it is shown in Table 4.23, the cost of precast construction remains higher than the cost of in-situ construction up to 6 stories of this hypothetical building. However, after the seventh story, that pattern changes and in-situ construction becomes more expensive. This is a somewhat assumptive computation, as it only considers direct cost and a specific floor area of a hypothetical building. Nonetheless, it clearly indicates that the incremental nature of the inputs in the in-situ method of construction in Ethiopia would always have a volume at which it ceases to be an economic choice when compared to a systematic precast method where initial investments are made for the affordability, speed, quality and ease of subsequent construction.

4.9. OPTIMAL BUILDING TYPES FOR PRECAST CONSTRUCTION

Since a brief general comparison between precast construction and in-situ construction that has been carried out in the introduction section has rendered the result that precast construction is four folds better in cost, time and quality than in-situ construction, now which buildings are most suited for precast construction is going to be systematically shown. This systematic assessment is going to make use of the Six Sigma comparison operations one more time.

Initially in the relative importance index calculation, the Likert scale results were measured for frequency. For every question on the questionnaire, the number of respondents that selected each of the options from 1 up to 5 were counted and the count was listed under the corresponding number. Secondly, the frequency counts were multiplied by their corresponding numbers and these products were summed up for each question. The sum was then divided by a product of the highest value on the Likert scale, i,e, 5, and the number of respondents in that category. Equation 3.3, previously discussed in Chapter 3 is used for this calculation.

$$RII = \frac{\sum W}{A \times N} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.3}$$

For this analysis, A represents the maximum weight of 5 on the Likert Scale; and N is total number of 15 respondents, 5 of which are from PBPPE, and 10 are from in-situ contractors. The overall RII values are obtained by averaging the RII values under the PBPPE category and the Contractor category. The issues enumerated in the questionnaire are arranged in a decremental order of these average values. This arrangement is the final ranking of the issues. Table 4.24 shows the RII values and the final ranks.

Table 4.25: Relative Importance Index Values and Corresponding Ranks

Benefits of Precast Construction	PBPPE Technical Employees					RII	RANK	Construction Company Engineers					RII	RANK	Over all RII	RANK
	1	2	3	4	5			1	2	3	4	5				
Controlled Consolidation	1	4	1	4	3	1.72	3	3	3	3	4	4	1.08	1	1.40	1
No Material Wasted	1	2	2	4	3	1.68	4	0	0	3	3	2	0.62	8	1.15	2
Modularity (Repetitive Production)	3	3	2	2	4	1.72	2	0	3	0	3	2	0.56	10	1.14	3
Controlled Curing	1	4	1	2	3	1.40	8	2	3	4	2	3	0.86	2	1.13	4
Shorter Time	1	1	3	2	4	1.60	5	1	2	0	3	3	0.64	7	1.12	5
Finished Surface at Form Removal	3	2	3	2	4	1.76	1	0	2	0	0	4	0.48	11	1.12	6
Little Supervision Needed	0	1	3	3	3	1.52	6	0	2	3	2	3	0.72	5	1.12	7
In-House Lab Testing	1	4	4	2	1	1.36	9	1	1	3	1	4	0.72	4	1.04	8
No Falsework Needed	4	3	2	0	3	1.24	11	3	0	0	4	4	0.78	3	1.01	9
Repetitive Formwork Reuse	3	3	4	4	0	1.48	7	1	3	0	0	2	0.34	14	0.91	10
Safety	2	3	1	3	2	1.32	10	0	4	1	1	1	0.40	13	0.86	11
Fixed Rebar Positions	1	2	1	1	2	0.88	12	2	3	3	2	1	0.60	9	0.74	12
Little Maintenance Needed	1	2	1	0	1	0.52	13	0	2	2	2	1	0.46	12	0.49	13
Less Number Of Laborers (Easy Human Resources Management)	1	0	1	0	0	0.16	15	0	4	3	4	0	0.66	6	0.41	14
Controlled Casting	2	2	1	1	0	0.52	14	2	1	3	0	0	0.26	15	0.39	15

This ranking was used in the criteria evaluation matrix of the Six Sigma calculations. The criteria were compared against each other for prioritization. This comparison can be seen in Table 4.26. Roman numbers were assigned for ease of presenting the criteria evaluation in a table. Table 4.25 shows these roman number assignations.

Table 4.26: Assigned Symbols for Benefits of Precast Construction

I	Finished Surface at Form Removal	**IX**	Controlled Consolidation
II	No Material Wasted	**X**	Repetitive Formwork Reuse
III	Fixed Rebar Positions	**XI**	Shorter Time
IV	Controlled Casting	**XII**	Safety
V	Controlled Curing	**XIII**	Little Maintenance Needed
VI	No Falsework Needed	**XIV**	Little Supervision Needed
VII	In-House Lab Testing	**XV**	Less Number Of Laborers (Easy Human Resources Management)
VIII	Modularity (Potential for Repetitive Production)		

Table 4.27: Criteria Evaluation Matrix

Type	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**XIII**	**XIV**	**XV**	**Sum**	**%**
I	-	1	0	0	1	1	0	1	0	0	1	0	0	0	0	5	0.048
II	0	-	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0.010
III	1	1	-	0	1	1	1	1	1	1	1	1	0	1	0	11	0.105
IV	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	14	0.133
V	0	1	0	0	-	1	0	1	0	0	0	0	0	0	0	3	0.029
VI	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0.000
VII	1	1	0	0	1	1	-	1	0	0	1	0	0	1	0	7	0.067
VIII	0	1	0	0	0	1	0	-	0	0	0	0	0	0	0	2	0.019
IX	1	1	0	0	1	1	1	1	-	0	1	0	0	1	0	8	0.076
X	1	1	0	0	1	1	1	1	1	-	1	0	0	1	0	9	0.086
XI	0	1	0	0	1	1	0	1	0	0	-	0	0	0	0	4	0.038
XII	1	1	0	0	1	1	1	1	1	1	1	-	0	1	0	10	0.095
XIII	1	1	1	0	1	1	1	1	1	1	1	1	-	1	0	12	0.114
XIV	1	1	0	0	1	1	0	1	0	0	1	0	0	-	0	6	0.057
XV	1	1	1	0	1	1	1	1	1	1	1	1	1	1	-	13	0.124
															Total =	**105**	**1.000**

Secondly, the precast construction features are rearranged in order of their importance and priority as obtained from Table 4.26 above. The new order of the criteria is shown in Table 4.27.

Table 4.28: Criteria Priorities

1	IV	**6**	X	**11**	XI
2	XV	**7**	IX	**12**	V
3	XIII	**8**	VII	**13**	VIII
4	III	**9**	XIV	**14**	II
5	XII	**10**	I	**15**	VI

A second RII computation was done from results of the Likert style interview given to PBPPE staff members alone. Here, five selected technical experts were asked to score each precast construction benefit based on its importance to particular building types. The results of the second RII analysis are shown as a list of scores of 1 up to 5 for the criteria as per building type in Table 4.28.

Table 4.29: Criteria Scores

	Features of Precast Construction															
B.T.	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**XIII**	**XIV**	**XV**	**Total**
A	0.19	0.04	0.31	0.40	0.11	0.00	0.13	0.10	0.30	0.34	0.15	0.29	0.46	0.23	0.50	**3.55**
B	0.14	0.03	0.31	0.53	0.11	0.00	0.20	0.04	0.23	0.34	0.15	0.29	0.34	0.11	0.37	**3.21**
C	0.14	0.04	0.42	0.53	0.11	0.00	0.27	0.08	0.30	0.34	0.15	0.48	0.46	0.17	0.50	**3.99**
D	0.10	0.04	0.31	0.40	0.09	0.00	0.13	0.08	0.23	0.26	0.11	0.29	0.46	0.23	0.37	**3.09**
E	0.11	0.27	0.31	0.29	0.34	0.37	0.13	0.06	0.00	0.09	0.27	0.31	0.27	0.11	0.11	**3.04**
F	0.23	0.27	0.42	0.29	0.46	0.37	0.20	0.11	0.00	0.11	0.27	0.39	0.27	0.11	0.11	**3.61**
G	0.11	0.20	0.21	0.29	0.46	0.50	0.13	0.03	0.00	0.03	0.20	0.31	0.27	0.08	0.25	**3.07**
H	0.17	0.27	0.42	0.38	0.46	0.50	0.20	0.09	0.00	0.11	0.20	0.31	0.27	0.11	0.11	**3.60**
I	0.23	0.20	0.42	0.38	0.46	0.50	0.20	0.03	0.00	0.06	0.20	0.31	0.20	0.11	0.11	**3.40**
J	0.11	0.05	0.11	0.11	0.11	0.11	0.05	0.05	0.05	0.10	0.20	0.31	0.20	0.11	0.11	**1.78**

The scores in Table 4.28 are then multiplied by the priorities in Table 4.26. Table 4.29 shows these products along with their sums under each building type.

Table 4.30: Final Six Sigma Scores

		Apartment Buildings - C	Modular Real Estate Houses - A	Office Buildings - F	Dual Home & Work Compounds - H	Mixed Use Buildings - B	Schools - D	Hospitals - E	Religious & Worship Buildings - I	Residencies - G	National Landmarks - J
1	Shorter Time	3	4	4	3	3	2	2	4	2	2
2	Finished Surface at Form Removal	4	4	4	4	3	4	4	3	3	1
3	Little Maintenance Needed	4	3	4	4	3	3	3	4	2	2
4	No Material Wasted	4	3	3	4	4	3	3	4	3	2
5	Safety	4	4	4	4	4	3	3	4	4	2
6	Controlled Curing	4	4	3	4	4	3	3	4	4	2
7	Modularity (Ability for Repetitive Production)	4	2	3	3	3	2	2	3	2	1
8	Repetitive Formwork Reuse	4	5	4	3	2	4	3	1	1	1
9	Fixed Rebar Positions	4	4	4	4	3	3	3	1	1	1
10	No Falsework Needed	4	4	4	4	4	3	3	2	1	2

		apartment buildings - C	modular real estate houses - A	office buildings - F	dual home & work compounds - H	mixed use buildings - B	schools - D	hospitals - E	religious & worship buildings - I	residencies - G	national landmarks - J
11	controlled casting	4	4	4	3	4	3	4	3	3	1
12	decreased number of laborers (easier HR management)	5	3	4	3	3	3	3	3	3	1
13	in house lab testing	4	4	4	4	3	4	4	3	4	1
14	controlled consolidation	3	4	3	3	2	4	3	3	2	1
15	little supervision needed	4	4	3	3	3	3	3	3	2	1

Index:

B.T. — Building Types

Building Types:

- A — modular real estate houses
- B — mixed use buildings (malls, city centers)
- C — apartment buildings
- D — schools
- E — hospitals
- F — office buildings
- G — residencies (individual designs)
- H — dual home-work compounds (embassies, international organizations, universities)
- I — religious/worship buildings (churches, mosques)
- J — national landmarks (palaces, museums)

4.10. GRADING PBPPE ACCORDING TO INTERNATIONAL STANDARDS

The study takes an in-depth look at the PBPPE precast plant. It takes a systematic approach in analyzing where the enterprise stands as a standard precast concrete production plant, and reviews it as per an international quality control manual.

It is important to analyze PBPPE in this way, as there initially needs to be an explanation for the rather slow pace at which it has been functioning. At first, this study was going to be a comparison between our own PBPPE and a systematically selected functioning precast plant in a more developed country, with the aim of highlighting any gaps that PBPPE might exhibit. Then again, most developed countries have a standard system that serves as a benchmark against which such plants could be measured. That's why a reasonably selected international quality control manual was used as a standard for this research. The NPCA manual is the most widely used quality control manual in the United States.

Before finding quick fixes for the recurrent problems in the construction industry, it is much more logical and worthwhile to get to the root cause of the problems and eliminate them for good. This is the reason that PBPPE should be studied in depth and analyzed critically before suggesting that more resources and time should be expended on precast systems.

This particular study has resulted in a precast and prestressed plant score for PBPPE. As could be assumed, this score is far below the passing grade that NPCA recommends, which would have been grounds for serious legal measures had it been in the United States. This shows that PBPPE requires immediate and abundant support from the government if it is to be a functional, income-generating, and solution-providing enterprise. The details of the scoring process have been discussed in the data analysis section of the research.

The data that have been compiled for the fulfillment of this objective can be grouped into two. In the first group, there are laboratory data that have been skimmed from a number of report files from past precast building projects that have been completed by the plant. These lab data have been obtained from PBPPE's lab records of previous building projects. The second group of data that has been collected as supportive information is through interviewing key members of PBPPE's staff.

These data have then been analyzed using NPCA quality control manual's grading schedules, to obtain PBPPE's plant score. They have been reviewed as per the manual and used as checkpoints of availability and level of quality of works carried out by the plant. Then, the grading schedules available in the manual have been filled out as per the guides that have been discussed in detail within the manual. For the sections marked 'critical' in the grading schedules, the manual has provided with deduction templates to follow and a brief note on its grading philosophy, which reads as follows:

4.10.1. Grading PBPPE According to NPCA

According to NPCA's "General Grading Philosophy", if the plant is meeting all the requirements at the proper frequencies, the lowest possible score for each section is zero. A sample of the deduction templates has been included here for better understanding. For a complete list of the deductions from critical sections of the schedule, refer to the attachments in the appendix. The standard deductions listed in Table 4.30 should be subtracted from a grade of 100%, assuming that no other deficiencies are noted.

Table 4.31: NPCA Standard Deductions [23]

Detailed reinforcing steel plan documents are not available for precast products produced	100%
Some detailed reinforcing steel plan documents do exist but not for all precast products produced	Estimate %
Detailed reinforcing steel plan documents do not specify applicable tolerance information	10%
Detailed reinforcing steel plan documents do not specify complete reinforcing detail	10%

Firstly, a part of the grading schedule is going to be presented, and the grading deduction of a critical section is discussed. This will show how the rest of the table was filled out, how the score of each section was calculated, and how these grades have been adjusted as per applicability to PBPPE.

Table 4.32: Chapter 1 of the NPCA Grading Schedule for PBPPE

	CHAPTER 1 GENERAL	**Points (A)**	**Grade % (B)**	**(A x B) / 100**	**(A x B) Adjusted**
1.1	Plant Quality Control Procedures and Management Policies				
	1.1.3 PQS & ACI Training Elements	6	0	0	
	1.1.1 Plant Mgmt. & Personnel 1.1.2 Plant-Specific QC Manual 1.1.4 Plant Requirements	3	66.67	2.00	
1.2	Plant Safety				
	1.2.1 Safety Program	1	0	0	
1.3	Drawings & Mock-Ups				
	1.3.1 Drawings 1.3.2 Mock-Ups	3	50	1.5	
	Total Chapter 1	**13**		**3.50**	**2.87**

Table 4.32 shows the first section within the grading schedule for a precast and prestressed concrete manufacturing plant. Since PBPPE currently doesn't use any Production Quality Systems or training elements, a grade of 0% has been given. The values under the 'Points (A)' column are predetermined by the NPCA and pre filled in the table. Out of the following three units, i.e., Plant Mgmt. & Personnel, Plant-Specific QC Manual, and Plant Requirements, the first two are available and utilized by PBPPE. Hence, a score of (2/3) * 100 = 66.67 has been given to that portion. The rest of the section and the whole table was first filled out this way with reflective scores.

The next step is to multiply the plant scores put in percentage by the points assigned for the particular requirement, and filling it in the column '(A*B)/100'. This provides a weighted score point for each particular requirement.

A challenge arises when a section of the table is particularly not applicable to PBPPE. An example of such a section is shown in Table 4.33.

Table 4.33: Part of Chapter 4 of the NPCA Grading Schedule for PBPPE

	Chapter 4 Production Practices	**Points (A)**	**Grade % (B)**	**(A x B) / 100**	**(A x B) Adjusted**
4.1	General				
	4.1.1 Plant Layout	10.00	60.00	6.00	
	4.1.2 Housekeeping				
	4.1.3 Forms and Forming Equipment				
	4.1.4 Handling Equipment				
	4.1.5 Machine-Made and/or Dry-Cast Products				
	4.1.6 Architectural Precast Concrete	10.00	N/A		
	4.1.6.1 Surface Finishes				
4.2	Fabrication of Reinforcement and Blockouts				
	4.2.1 Fabrication of Reinforcement CRITICAL SECTION	4.00	N/A		
	4.2.2 Welding of Reinforcing Steel	8.00	80.00	6.40	
	4.2.3 Welding of Steel Assemblies				
	4.2.4 Fabrication and Positioning of Blockouts				

Let’s consider section 4.1.6 of the section shown in Table 4.32. PBPPE does not produce architectural concrete pieces and does not provide any surface finishing services included in casting works. This makes grading this section an impossible feat, and so this section is filled out with a ‘Not Available’ value.

The final score calculation in the table is carried out by summing up all the (A X B)/100 scores of each section and dividing this value by the total sum of possible points pre filled in the table, which is 218 for this particular table. Therefore, summing up all the (A X B)/100 would add the N/A scores as ‘0’, but still divide the final sum by the whole sum of possible points. This would obviously result in an erroneous score. The solution that the table provides for this “conundrum” is a calculated score adjustment.

“The grade adjustment consists of multiplying the sum of A x (B/100) for each chapter by 100 and dividing by the total possible points that are applicable and/or observable. For example, using the Precast and Prestressed Plant Certification Program Grading Schedule, if all of the items in Section”… 4.1.6 (which is assigned 10 points) “…are marked NA, the sum of A x (B/100) for each chapter is multiplied by…“ 100/(218-3) or 100/215. “…The final plant score represents the percentage of total points earned by the plant versus the total applicable and/or observable points” [23].

In actuality, there are 96 assigned points in the whole table that don’t apply to PBPPE. Thus, the adjustment factor that was used is 100/(218-96) = 0.82. The completed grading schedule is presented in Table 4.34 below:

PLEASE REFER TO PAGE 1 OF INSERT 01 - PBPPE'S NPCA GRADE

PLEASE REFER TO PAGE 2 OF INSERT 01 - PBPPE'S NPCA GRADE

PLEASE REFER TO PAGE 3 OF INSERT 01 - PBPPE'S NPCA GRADE

PLEASE REFER TO PAGE 4 OF INSERT 01 - PBPPE'S NPCA GRADE

PLEASE REFER TO PAGE 5 OF INSERT 01 - PBPPE'S NPCA GRADE

PLEASE REFER TO PAGE 6 OF INSERT 01 - PBPPE'S NPCA GRADE

PLEASE REFER TO PAGE 7 OF INSERT 01 - PBPPE'S NPCA GRADE

PLEASE REFER TO PAGE 8 OF INSERT 01 - PBPPE’S NPCA GRADE

PLEASE REFER TO PAGE 9 OF INSERT 01 - PBPPE'S NPCA GRADE

This concludes the NPCA grading process. However, NPCA is a company that was established to focus on Precast Construction of utility structures such as bridges, roads, water supply lines, etc. The US company founded solely to support and overlook the precast construction of buildings is actually the Precast/Prestressed Concrete Institute (PCI).

4.10.2. Grading PBPPE According to Precast/Prestressed Concrete Institute (PCI)

It was more challenging to obtain detailed information on PCI assessment procedure for their precast plant certification programs, but an evaluation has been made based on information obtained through email correspondence with Ken Kwilinski (Quality Management Systems Coordinator) of the PCI organization and the 4th edition of “Manual for QUALITY CONTROL for Plants and Production of STRUCTURAL PRECAST CONCRETE PRODUCTS” (MNL-116-99), published by the PCI in 1999.

The results of the PCI evaluation are presented in Table 4.35.

Table 4.34: The PCI Evaluation Schedule for PBPPE

DIVISION 1 – QUALITY SYSTEM	**Scores out of 10**	**Section Average**
1.1 Objective		
1.2 Plant Quality Assurance Program		
1.2.1 General	**0.00**	
1.2.2 Documented Procedures	**7.00**	
1.2.3 Management Responsibilities	**5.83**	
1.3 Personnel		
1.3.1 General	**5.00**	
1.3.2 Engineering	**1.25**	
1.3.3 Drafting	**10.00**	
1.3.4 Production	**10.00**	
1.3.5 QualityControl	**1.67**	
1.4 Design Responsibilities		
1.4.1 General	**10.00**	
1.4.2 Shop Drawings	**10.00**	
1.5 Project Samples		
1.5.1 General	**10.00**	
1.5.2 Size and Shape	**10.00**	
1.5.3 Identification	**10.00**	
1.5.4 Visual Mock-ups and Initial Production Approval of Finishes	**10.00**	
	100.75	**7.20**
DIVISION 2 – PRODUCTION PRACTICES		
2.1 General Objectives and Safety		
2.1.1 General	**10.00**	
2.1.2 Plant Safety	**0.00**	

DIVISION 2 – PRODUCTION PRACTICES	**Scores out of 10**	**Section Average**
2.2 Production and Curing Facilities		
2.2.1 Area Requirements	**6.67**	
2.2.2 Form Fabrication	**5.00**	
2.2.3 Storage of Release Agents and Other Chemicals	**10.00**	
2.2.4 Hardware Fabrication and Storage	**2.22**	
2.2.5 Concrete Handling and Consolidation Equipment	**4.44**	
2.2.6 Curing and Finishing Areas	**5.71**	
2.2.7 Handling Equipment	**10.00**	
2.2.8 Storage Area for Finished Product	**8.33**	
2.3 Welding		
2.3.1 Welding of Structural Steel	**6.36**	
2.3.2 Welding of Reinforcement	**5.56**	
2.3.3 Stud Welding	**5.00**	
2.4 Forms		
2.4.1 Materials and Construction	**8.89**	
2.4.2 Verification and Maintenance	**10.00**	
2.5 Hardware Installation	**8.46**	
2.6 Product Identification	**10.00**	
2.7 Product Handling		
2.7.1 General	**10.00**	
2.7.2 Stripping	**5.00**	
2.7.3 Yard Storage	**8.00**	
2.7.4 Loading	**10.00**	
2.8 Surface Finishes		
2.8.1 General	**10.00**	
2.8.2 As-Cast Formed Surface Finishes	**10.00**	
2.8.3 Exposed or Visible Unformed Surface Finishes	**8.33**	
2.8.4 Applied Coatings	**10.00**	
2.9 Repairs	**10.00**	
2.10 Acceptability of Appearance	**10.00**	
2.11 Sealers and Clear Surface Coatings	**10.00**	
	217.98	**7.79**

DIVISION 3 – RAW MATERIALS AND ACCESSORIES	**Scores out of 10**	**Section Average**
3.1 Concrete Materials		
3.1.1 General	**0.00**	
3.1.2 Cement	**0.00**	
3.1.3 Fine Aggregate	**0.00**	
3.1.4 Coarse Aggregate	**0.00**	
3.1.5 Aggregates for Lightweight Concrete	**—**	
3.1.6 Mixing Water	**10.00**	
3.1.7 Admixtures	**—**	
3.2 Reinforcement and Hardware		
3.2.1 Reinforcing Steel	**9.17**	
3.2.2 Prestressing Materials	**10.00**	
3.2.3 Hardware and Miscellaneous Materials	**1.11**	
3.2.4 Handling and Lifting Devices	**6.67**	
3.2.5 Strand Restraining Devices	**10.00**	
3.3 Insulation	**0.00**	
3.4 Welding Electrodes	**0.83**	
	47.78	**3.98**
DIVISION 4 – CONCRETE		
4.1 Mix Proportioning	**3.33**	
4.1.1 Qualification of New Concrete Mixes	**0.00**	
4.1.2 Specified Concrete Strength	**0.00**	
4.1.3 Statistical Concrete Strength Considerations	**0.00**	
4.1.4 Proportioning to Ensure Durability of Concrete	**0.00**	
4.2 Special Considerations for Air Entrainment	**—**	
4.3 Mix Proportioning for Concrete Made with Structural Lightweight Aggregate	**—**	
4.3.1 Lightweight Aggregates-Absorption and Moisture Content	**—**	
4.3.2 Lightweight Aggregates-Gradation	**—**	
4.3.3 Water-Cementitious Material Ratio for Lightweight Aggregate Concrete	**—**	
4.3.4 Air Entrainment for Lightweight Aggregate Concrete	**—**	
4.4 Proportioning for Concrete Workability	**3.33**	

DIVISION 4 – CONCRETE	**Scores out of 10**	**Section Average**
4.5 Water-Cementitious Material Ratio		
4.5.1 General	**0.00**	
4.5.2 Relationship of Water-Cementitious Material Ratio to Strength, Durability and Shrinkage	**0.00**	
4.5.3 Relationship of Water-Cementitious Material Ratio to Workability	**0.00**	
4.6 Effects of Admixtures	**—**	
4.7 Storage and Handling of Concrete Materials		
4.7.1 General	**0.00**	
4.7.2 Storage and Handling of Aggregates	**0.00**	
4.7.3 Storage and Handling of Cement	**6.67**	
4.7.4 Storage and Handling of Admixtures	**—**	
4.8 Batching Equipment Tolerances	**1.00**	
4.9 Scale Requirements	**1.43**	
4.10 Requirements for Water Measuring Equipment	**0.00**	
4.11 Requirements for Batchers and Mixing Plants		
4.11.1 General	**8.00**	
4.11.2 Requirements for Concrete Mixers	**0.00**	
4.11.3 Mixer Placard Requirements	**5.00**	
4.11.4 Maintenance Requirements for Concrete Mixers	**0.00**	
4.12 Concrete Transportation Equipment		
4.12.1 General	**0.00**	
4.12.2 Requirements for Concrete Agitating Delivery Equipment	**0.00**	
4.13 Placing and Handling Equipment	**10.00**	
4.14 Batching and Mixing Operations		
4.14.1 General	**3.33**	
4.14.2 Batching of Aggregates	**5.00**	
4.14.3 Batching of Cement	**3.33**	
4.14.4 Batching of Water	**10.00**	
4.14.5 Batching of Admixtures	**—**	

DIVISION 4 – CONCRETE	**Scores out of 10**	**Section Average**
4.15 Mixing of Concrete		
4.15.1 General	**5.00**	
4.15.2 Methods of Concrete Mixing	**6.67**	
4.15.3 Mixing Time and Concrete Uniformity	**0.00**	
4.15.4 Mixing Time – Stationary Mixers	**10.00**	
4.15.5 Mixing Time – Shrink Mixing	**—**	
4.15.6 Mixing Time – Truck Mixing	**—**	
4.15.7 Special Batching and Mixing Requirements for Lightweight Aggregates	**—**	
4.15.8 Cold Weather Mixing	**2.50**	
4.15.9 Hot Weather Mixing	**5.00**	
4.16 Requirements for Transporting and Placing of Concrete		
4.16.1 General	**0.00**	
4.16.2 Transporting and Placing Concrete	**10.00**	
4.16.3 Preventing Aggregate Segregation	**0.00**	
4.16.4 Preparation of the Forms	**10.00**	
4.16.5 Placing Concrete Under Severe Weather Conditions	**—**	
4.16.6 Placing Concrete in Wet and Rainy Conditions	**10.00**	
4.16.7 Placing Concrete in Hot or Windy Conditions	**5.00**	
4.16.8 Placing Concrete in Cold Weather Conditions	**—**	
4.16.9 Placing Concrete	**10.00**	
4.17 Consolidation of Concrete		
4.17.1 General	**5.00**	
4.17.2 Consolidation of Lightweight Concrete	**—**	
4.17.3 Consolidation of Complex Precast Concrete Products	**—**	
4.17.4 Use of Internal Vibrators	**0.00**	
4.17.5 Use of External Form Vibrators	**—**	
4.17.6 Use of Surface Vibrators	**—**	
4.17.7 Use of Vibrating Tables	**—**	

DIVISION 4 – CONCRETE	**Scores out of 10**	**Section Average**
4.18 Requirements for Curing Concrete		
4.18.1 General	**10.00**	
4.18.2 Curing Temperature Requirements	**6.67**	
4.18.3 Curing to Attain Specified Stripping or Transfer Strength	**0.00**	
4.18.4 Monitoring of Concrete Curing Temperatures	**0.00**	
4.19 Accelerated Curing of Concrete		
4.19.1 General	—	
4.19.2 Curing with Live Steam	—	
4.19.3 Curing with Radiant Heat and Moisture	—	
4.20 Curing by Moisture Retention Without Supplemental Heat		
4.20.1 General	—	
4.20.2 Moisture Retention Enclosures	—	
4.20.3 Curing with Membrane Curing Compound	—	
4.21 Post-Tensioning Tendon Grout		
4.21.1 Scope and Purpose	**10.00**	
4.21.2 Materials for Post-Tensioning Tendon Grout	**5.00**	
4.21.3 Proportioning of Grout	**0.00**	
4.21.4 Grout Mixing and Pumping Equipment	**0.00**	
4.21.5 Mixing of the Grout	**0.00**	
4.21.6 Grout Temperature	**10.00**	
	181.26	**3.49**
DIVISION 5 – REINFORCEMENT AND PRESTRESSING		
5.1 Reinforcing Steel		
5.1.1 General	**0.00**	
5.1.2 Storage of Reinforcing Steel	**0.00**	
5.1.3 Fabrication of Reinforcing Steel	—	
5.1.4 Installation of Reinforcing Steel	**7.27**	

5.2 Tensioning	**Scores out of 10**	**Section Average**
5.2.1 General Tensioning Requirements	**0.00**	
5.2.2 Tensioning of Tendons	**2.00**	
5.2.3 Methods of Force Measurement	**10.00**	
5.2.4 Gauging Systems	**6.67**	
5.2.5 Control of Jacking Force	**10.00**	
5.2.6 Wire Failure in Strand or Tendons	**5.00**	
5.2.7 Calibration Records for Jacking Equipment	**0.00**	
5.3 Pretensioning		
5.3.1 Storage of Prestressing Steel	—	
5.3.2 General	—	
5.3.3 Strand Surfaces	—	
5.3.4 Stringing of Strands	—	
5.3.5 Strand Chucks and Splice Chucks	—	
5.3.6 Strand Splices	—	
5.3.7 Strand Position	—	
5.3.8 Spacing of Strands	—	
5.3.9 Initial Tensioning	—	
5.3.10 Measurement of Elongation	—	
5.3.11 Elongation Calculation and Corrections	—	
5.3.12 Force Corrections	—	
5.3.13 Final Tensioning of Straight Strands	—	
5.3.14 Final Tensioning of Harped Strands	—	
5.3.15 Equal Distribution of Force in Harped Strand	—	
5.3.16 Strand Debonding	—	
5.3.17 Detensioning	—	
5.3.18 Detensioning of Harped Strand	—	
5.3.19 Detensioning of Dry Mix, Machine Cast Products	—	
5.3.20 Protection of Strand Ends and Anchorages	—	

5.4 Post-Tensioning of Plant-Produced Products	**Scores out of 10**	**Section Average**
5.4.1 General	**8.00**	
5.4.2 Details and Positions for Ducts	**8.00**	
5.4.3 Friction in Ducts	**10.00**	
5.4.4 Tensioning	**6.67**	
5.4.5 Anchorages	**6.67**	
5.4.6 Grouting	**0.00**	
5.4.7 Sealing of Anchorages	**10.00**	
	90.27	**5.02**
DIVISION 6 – QUALITY CONTROL		
6.1 Inspection		
6.1.1 Necessity for Inspection	**0.00**	
6.1.2 Scope of Inspection	**0.00**	
6.2 Testing		
6.2.1 General	**0.00**	
6.2.2 Acceptance Testing of Materials	**1.00**	
6.2.3 Production Testing	**1.47**	
6.2.4 Special Testing	**10.00**	
6.3 Records		
6.3.1 Recordkeeping	**3.33**	
6.3.2 Suppliers' Test Reports	**0.00**	
6.3.3 Tensioning Records	**0.00**	
6.3.4 Concrete Records	**1.90**	
6.3.5 Calibration Records for Equipment	**0.00**	
6.4 Laboratory Facilities		
6.4.1 General	**10.00**	
6.4.2 Quality Control Testing Equipment	**10.00**	
6.4.3 Test Equipment Operating Instructions	**3.33**	
	41.04	**2.93**

DIVISION 7 – PRODUCT TOLERANCES	**Scores out of 10**	**Section Average**
7.1 Requirements for Finished Product	**0.00**	
7.2 Measurement	**0.00**	
	0.00	
	0.00	**0.00**

It can be seen that all of the topics that are not applicable to the PBPPE precast plant have not been scored. Neither have they been included in the 'Section Average' calculations. Any of the topics concerned with 'Accelerated Curing', 'Admixtures', 'Air Entrainment', 'Cold Weather Conditions and Severe Weather Conditions', 'Complex Precast Concrete Products', 'External Form Vibrators, Surface Vibrators, and Vibrating Tables', 'Fabrication of Reinforcing Steel', 'Lightweight Aggregate', 'Lightweight Concrete', 'Moisture Retention', 'Pretensioning', and 'Truck Mixing and Shrink Mixing' have been skipped during scoring.

CHAPTER 5: RESULTS AND DISCUSSIONS

5.1. OVERALL COST COMPARISON BETWEEN THE PRECAST CONSTRUCTION METHOD AND THE IN-SITU CONSTRUCTION METHOD

The direct cost values for the two methods have been expressed in terms of unit cost and unit price and summarized in Table 5.2. The unit profit has also been calculated and enlisted along with the construction speeds of the two methods for ease of comparison. These figures have been used to analyze the precast plant competency in Subtopic 5.1.

Table 5.1: Unit Cost, Unit Price, and Construction Speed of In-Situ and Precast Construction Methods

Contractor Method	Average Unit Cost, Br/m	Average Unit Price, Br/m	Unit Profit, Br/m	Construction Speed, m
In-Situ	3,073.60	3,380.96	307.36	2,838.00
Precast	1,535.25	1,765.54	230.29	3,421.44

These results clearly show that precast construction costs significantly less than the in-situ construction method. The figures in Table 5.2 are not inclusive of the indirect cost components that would ensue due to the abundant difference in the speed of construction between the two construction methods. As has been previously indicated, one of the simplest ways to estimate the additional indirect cost would be to calculate the income that an in-situ building space would generate if it had been rented out as early as the delivery time of its precast equivalent.

Other than that, some components of direct construction cost increases in proportion to the completion time of a construction project. Equipment rental cost and hourly labor cost are a few examples. Finally, material waste is an additional yet unnecessary cost incurred by using the in-situ method.

Unforeseen expenses such as untimely maintenance and, in some cases, partial or total building collapses are other means that the in-situ construction method could incur unnecessary cost.

5.2. SIX SIGMA COMPARISON BETWEEN THE PRECAST AND THE IN-SITU CONSTRUCTION METHODS USING 'COST', 'TIME', AND 'QUALITY' PARAMETERS

It can be recalled that the Six Sigma system makes use of five steps, namely: Define, Measure, Analyze, Improve, and Control. The Six Sigma analysis that this research has run is categorized under the 'Measure' stage of the five steps of Six Sigma. This stage includes tools to analyze existing production schemes and compare productivity measurement results to corresponding values of other suggested alternatives. Since this is a highly appropriate measurement and comparison that could improve the status quo of the Ethiopian construction industry, it was accordingly selected.

In the Six Sigma measurement, In-Situ Construction got a final score of 0.75 out of 5 and Precast Construction got 3.03. This shows that overall precast construction is about four folds the better choice than in-situ construction.

5.3. PBPPE'S GRADES ACCORDING TO THE NPCA QUALITY CONTROL MANUAL

The NPCA evaluation of PBPPE has produced the following results.

Table 5.2: Summary of PBPPE's NPCA Grading Results

Chapter	**Description**	**Score**
4	Production Practices	29.51
3	Concrete	9.48
5	Quality Control Operations	7.87
2	Materials	5.25
1	General	2.87
6	Special Requirements for Specific Products	0.00
Total Possible Points		**218.00**
Total Applicable and/or Observed Points		**122.00**
Sum Of AxB for Each Chapter		**54.99**
Plant Score		**45.07**

As it can be observed from the NPCA grading results, PBPPE obtained a score of 45%, which is 30% lower than the minimum accepted score by the NPCA. “Plants scoring less than 75% in one or more Critical Requirement Section shall receive probationary certification, must document and take corrective action within 30 days to improve plant operations, and may be required to complete an additional inspection within 90 days (at the plant’s expense) and must receive a score equal to or greater than 75%” [23]. This goes to show that the plant has fallen direly below standard and would be considered incapable of producing quality building parts by this international organization. This could be one of the reasons that most clients inherently find this option unappealing.

This being said, the three most substandard sections where PBPPE got its lowest scores are for 'special requirements for specific products’, ‘general’, and ‘materials’. A closer look into these three sections shows the particular features of the plant that have been evaluated.

Under Chapter 6 for Special requirements for specific products, it can be seen that most of the evaluation points are not applicable to PBPPE. The non-applicable evaluation topics are ‘Storm-water Concrete Pipe Requirements’, ‘Round Manhole Component Requirements’, ‘Box Culvert Requirements’, and ‘Septic Tank Requirements’. None of these are items that the PBPPE plant produces. The only evaluation topic that is applicable is ‘Products

Manufactured According to ASTM International and Other Industry Standards'. Since neither actions in the subtopics, i.e., 'Product Manufacture' and 'Proof of Conformance' are done according to 'ASTM International and Other Industry Standards' as the topic states, the scores given to them are Zero. It also explains why the plant got a score of Zero for the chapter.

Table 5.3: Chapter 6 'Special Requirements For Specific Products' of the NPCA Grading Schedule

	Chapter 6 Special Requirements For Specific Products	**Points (A)**	**Grade % (B)**	**(A x B) / 100**	**(A x B) Adjusted**
6.1	Products Manufactured According to ASTM International and Other Industry Standards				
	6.1.1 Product Manufacture				
	6.1.2 Proof of Conformance	3	0	0	
6.2	Storm-water Concrete Pipe Requirements				
	6.2.1 Reinforcing Steel Inspection	10	N/A		
	6.2.2 Three-Edge Bearing Testing	10	N/A		
	6.2.3 Absorption Testing	1	N/A		
	6.2.4 Dimensional Checks				
	6.2.5 Joint Design and Testing				
	6.2.6 Gasket Quality Control	6	N/A		
6.3	Round Manhole Component Requirements				
	6.3.1 Reinforcing Steel Inspection	10	N/A		
	6.3.2 Flat Slab Tops				
	6.3.3 Base, Riser and Cone Sections				
	6.3.4 Joint Design				
	6.3.5 Gasket Quality Control	6	N/A		
6.4	Box Culvert Requirements				
	6.4.1 Absorption Testing				
	6.4.2 Joint Design	6	N/A		
	6.4.3 Pre-Pour Inspections	10	N/A		
	6.4.4 Dimensional Checks	10	N/A		

	Chapter 6 Special Requirements For Specific Products	**Points (A)**	**Grade % (B)**	**(A x B) / 100**	**(A x B) Adjusted**
6.5	Septic Tank Requirements				
	6.5.1 Structural Proof-of-Design	3	N/A		
	6.5.2 Watertightness Testing	10	N/A		
	Total Chapter 6	**85**		**0**	**0**

The second lowest scored chapter of the NPCA grading schedule is the Chapter 1: 'General' evaluation topic. It includes the subtopics; 'Plant Quality Control Procedures and Management Policies', 'Plant Safety', and 'Drawings & Mock-Ups'. The plant was given scores of zero for its lack of 'PQS & ACI Training Elements', or any training elements for that matter, and its lack of 'Safety Program' of any kind. These two points have markedly brought its score down to 2.87 out of the maximum adjusted score of 10.66 for this chapter.

Table 5.4: Chapter 1 'General' of the NPCA Grading Schedule

	Chapter 1 General	**Points (A)**	**Grade % (B)**	**(A x B) / 100**	**(A x B) Adjusted**
1.1	Plant Quality Control Procedures and Management Policies				
	1.1.3 PQS & ACI Training Elements	6	0	0	
	1.1.1 Plant Mgmt. & Personnel				
	1.1.2 Plant-Specific QC Manual				
	1.1.4 Plant Requirements	3	66.67	2.00	
1.2	Plant Safety				
	1.2.1 Safety Program	1	0	0	
1.3	Drawings & Mock-Ups				
	1.3.1 Drawings				
	1.3.2 Mock-Ups	3	50	1.5	
	Total Chapter 1	**13**		**3.50**	**2.87**

The third chapter to be taken under considerations Chapter 2, which deals with Materials. The last subtopic, which contributed the lowest score of '1.33', has only been given score for the 'Embedded Steel Shapes and Plates', 'Headed Studs and Deformed Anchor Studs', 'Fiber Reinforcement' and 'Joint Sealants and Connectors' points. Since 'Lifting Devices and Lifting Apparatus' and 'Manufacturing Accessories' have not been refurbished since the plant was founded, they have been given scores of Zero. It should be noted that even though the subtopic of 'Miscellaneous Materials' has lost points for two of its evaluation points, it still got a low score of '1.33' because it was given a score weight of only 2 in the manual. The plant did not do well in the remaining two subtopics of 'Reinforcement' and 'Concrete' either which is the reason for its third lowest score in the 'Materials' chapter.

Table 5.5: Chapter 2 'Materials' of the NPCA Grading Schedule

	Chapter 2 Materials	**Points (A)**	**Grade % (B)**	**(A x B) / 100**	**(A x B) Adjusted**
2.1	Concrete				
	2.1.1 Cement				
	2.1.2 Aggregates				
	2.1.3 Lightweight Aggregate				
	2.1.4 Mixing Water				
	2.1.5 Chemical Admixtures				
	2.1.6 Supplementary Cementitious Materials	3.00	94.33	2.83	
2.2	Reinforcement				
	2.2.1 Reinforcing Bars				
	2.2.2 Reinforcing Wire, Prestressed Reinforcing and Post Tension Strands				
	2.2.3 Bar Mats and Welded-Wire Reinforcement				
	2.2.4 Zinc or Epoxy-Coated Reinforcement	3.00	75.00	2.25	
2.3	Miscellaneous Materials				
	2.3.1 Lifting Devices and Lifting Apparatus				
	2.3.2 Embedded Steel Shapes and Plates				
	2.3.3 Headed Studs and Deformed Anchor Studs				
	2.3.4 Manufacturing Accessories				
	2.3.5 Fiber Reinforcement				
	2.3.6 Joint Sealants and Connectors	2.00	66.50	1.33	
	Total Chapter 2	**8.00**		**6.41**	**5.25**

5.4. PBPPE'S GRADES ACCORDING TO THE PCI QUALITY CONTROL MANUAL

The PCI evaluation of PBPPE has produced the following results.

Table 5.6: Summary of PBPPE's PCI Grading Results

Division	Description	Score
7	Product Tolerances	0.00
6	Quality Control	2.93
4	Concrete	3.49
3	Raw Materials and Accessories	3.98
5	Reinforcement and Prestressing	5.02
1	Quality System	7.20
2	Production Practices	7.79

The PCI evaluation was done based on the interview results obtained for the purpose of the NPCA grading schedule. As it has been formerly discussed, an effort was made to understand the PCI grading policy through an email request to Ken Kwilinski, the Quality Management Systems Coordinator at PCI. Unfortunately, it was not permitted to give out the information for non staff members, and Mr Kwilinski suggested that the researcher make use of the PCI manual the best they could.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

This chapter presents an overview of the technical merit and scientific value gained from the study and concludes with the lessons learned. The conclusions include analysis results, followed by recommendations for future research and practice.

In general, the overriding purpose of this study was to determine the level of acceptance that the Ethiopian construction industry would have for the precast construction system. In order to accomplish that goal, it was necessary to reach some prerequisite goals. The research has shown Determining what precast construction is and how this system affects the country's construction industry assumed a high degree of importance during the literature review conducted for this dissertation. Related to that effort, it became necessary to reach an understanding about the nature of Ethiopia's construction method. To provide for the possibility that precast construction could be perceived and measured as a viable method of the booming construction business, it was important to systematically compare the method of construction that is currently being used with the precast method. Once these fundamental steps were achieved, this research was able to go forward. This chapter reports the conclusions and recommendations that resulted from this study.

For this study, a systematic comparison between in-situ construction and precast construction was done using the Six Sigma analysis, it was initially found that the precast method of construction is the better option when compared with the in-situ method. In addition, the works of the PBPPE precast plant were studied by analyzing a collection of cost data that has been gathered from the plant's records. From this information, the more economic option was found to be the precast system.

The next step analyzed which building types would be more optimal to build using precast. Scores of 1 up to 5 were crunched to input into the Six Sigma analysis. This final analysis quantitatively showed the priority in which different building types are fit to be built by precast. More importantly, it prioritized the criteria with which to choose precast construction method over the in-situ method.

For the next part, PBPPE was graded using two international quality control manuals for precast plants; the NPCA manual and the PCI manual. It was shown that in its current state, the plant would fail these evaluations of quality standard, which are the minimum requirements for their much coveted certification.

When we come to the particulars of showing that research objectives have been met, it is good to keep in mind that all specific objectives have been set in order to fully meet the main aim of the research stated in ‘general objective’. Therefore, in this chapter, it will be shown that the specific objectives have been met and it will be explained how they all tie into the general objective.

In analyzing data for the first part of the objective, the return period for a medium sized precast plant and in-situ construction company is taken as a point of comparing the precast plant’s and in-situ contractors. It can be seen that it was found to take the precast plant a period of 2.39 years to return its staring capital cost versus a 5.39 year period for an in-situ construction company. This clearly shows that a precast plant would be a more competent business than an in-situ construction company.

Most of the research subjects have expressed concern that precast construction is an expensive method that is not ideal for an underdeveloped country like Ethiopia. Surprisingly, this concern has been raised in the United States as well, and the only reason that was found for the hiked up prices of precast contractors is the higher profit margin that they impose on their lower production and erection costs. Their justification could be that they provide higher quality and faster construction services than their in-situ counterparts, but no study has been found to confirm this assumption.

While the profit margin that precast contractors fix can not be controlled by others, their overall cost value can be measured and compared to the in-situ contractors’ cost values. This is also the only reasonable value to compare as it is typically dependent only on the starting and operating expenses that the plants face. The unit cost actually plays a more important role in being a decisive factor as it is not a value over which either type of construction company has complete control. The direct unit cost of 3380.96 Br/m^2 for in-situ construction is shown to be decisively higher than that of 1765.54 Br/m^2 for precast construction.

This cost is not taking into account all the time, material, and untimely maintenance waste evident in the in-situ construction method. In addition to the direct cost component, some foreseeable indirect cost components have been discussed. Along with the apparent major difference in direct cost, the precast construction method is shown to be lower in overall cost than its in-situ counterpart.

The next part uses the Six Sigma analysis tool to numerically prove that precast construction is the better option in time, cost and quality measures than in-situ construction. The Six Sigma scores given under the cost parameter are based on the analysis carried out on the cost of the two alternative methods in the previous section on overall cost comparison. Cost data was sufficiently available, and it was utilized accordingly to show that, again, the precast method has better standing in this parameter than in-situ construction.

When it comes to the time parameter, it was the most direct measure of comparison between the two construction methods. The precast method has been shown to have the obvious lead in this aspect. It should be taken under notice that, although the measurement and comparison using the time parameter is direct, the implications of the outcome are more complex. This is because decrease of project delivery time affects all the other parameters indirectly. For starters, overall cost is lowered due to lower overhead cost, lower machinery operating hours, and lower overhead salary.

The quality parameter scores given for the two alternative construction methods under the quality parameter are based on the available quality data that was obtained from the in-situ and precast construction companies sampled for this study. As it can be understood, this data was not available from most of the companies under question. The reason is thought to be that the culture of executing or documenting quality control schemes is poor in most construction companies.

Quality has more chance of being compromised the longer it takes for construction activities to be completed or the longer it takes for a sequential activity to begin. There are more ways that time can affect quality in a construction project. An example is that employee morale decreases when a project takes considerably more time than it should.

Just like quality, safety is a value that encounters more risk of being compromised with any unnecessary increase of project delivery time. Hence time should always be given higher priority for a project’s wellbeing.

Lastly, the PBPPE precast plant was evaluated according to the NPCA and PCI quality control manuals to obtain a score for the quality of its performance. The low score that PBPPE got during its international standard evaluation should in no way reflect on the potential level of quality that the precast construction method could operate. What it boils down to is the fact that PBPPE has been in operation for way too long without any relevant renovations. The score that it got was within the range that was expected during the numerous observations made during this research. Nonetheless, it can still be of use if it got thorough maintenance in the areas where it got its lowest scores. Moreover, a more applicable and user-friendly precast production and erection manual could be drawn and put to use so as not to start from scratch.

6.2. RECOMMENDATIONS

Based on the research results and findings, it is recommended to act immediately to establish a standard precast construction company in Ethiopia. Even after this research started, a number of building collapses have happened in Addis Ababa. Partial collapses have been witnessed long before the research through out the country, but hopefully this unacceptable pattern will not be allowed to continue into the future. It is important that the government have a strong conviction to explore all its options and decide on a course of action to solve the critical problem of poor construction quality in Ethiopia.

In such a course of action, the deep running problems with the in-situ construction method are sure to surface. That is when this research would come in handy. It is recommended that the results of this research be seen as a starting point to carry out renovation of the existing PBPPE precast plant. The points of weakness that the plant exhibits have been singled out, but more problem areas may be discovered with a deeper investigation into the enterprise. Hence, a systematic renovation should start with improving the plant in those areas.

It is highly recommended that other precast plants not be formed before renovating PBPPE and recommencing its operation. This would be a good chance to experiment and improve the precast process without all the financial and time expenses of establishing a new precast plant from scratch.

If the government could incorporate PBPPE into a long term plan to alleviate major problems in construction, thereby creating the space needed for further investment activities, opportunities would be created in the job market that would serve the youth. In such an execution, more precast plants would be needed to meet construction demands and PBPPE could serve as a model unit to build and operate these additional plants.

The government has to pioneer in this area as it has in other areas in the past. The five year growth and transformation plan set in motion by the FDRE is having the result of a country under construction. The amount of ongoing construction in the country is currently at its all-time maximum. This demands faster and more reliable construction solutions to be delivered immediately. As per the results of this research, precast construction is a viable and fitting method for the construction industry, which brings about the conclusion that many more precast plants in different regions of Ethiopia should be set up and commence operations.

Accordingly, the study recommends that the government pay due attention to developing precast construction as a viable solution to improve the quality, speed, and economy of upcoming construction activities. It is also recommended that many more studies should be done to further show any other ways in which the current precast plant can be enhanced in order to provide the required information for the expansion of the precast industry in Ethiopia.

All the results in the above sections, conclusively show that precast construction is considerably more economic, and extremely faster than the in-situ method and further studies should be carried out in order to find more practical ways to incorporate this system into the Ethiopian construction industry.

REFERENCES

[1] Ancient Rome, wikipedia.org/wiki/Ancient_Rome#Technology, 2017

[2] Mikhailov, V. V.; Susnikov, A. A.; Development of Factory Production of Precast Prestressed Concrete in the U.S.S.R.; PCI Journal, 1995

[3] Bennett Jr, W. B.; Manufacture and Production of Prestressed Concrete; PCI Journal, 1976

[4] High Performance Construction Materials - 'What are the Opportunities for Design-Builders?'; Design-Build Institute of America, 2005

[5] Lunn, D.; Lucier, G.; Rizkalla, S.; Cleland, N.; Gleich, H.; New Generation of Precast Concrete Double Tees Reinforced with Carbon-Fiber-Reinforced Polymer Grid; PCI Journal, 2015

[6] Prestressed Concrete, en.wikipedia.org/wiki/Prestressed_concrete, 2017

[7] VanGeem, M.; Achieving Sustainability with Precast Concrete; PCI Journal, January 2006

[8] Precast Considerations, Building and Construction Authority, Singapore Government, bca.gov.sg/publications/BuildabilitySeries/others/pcpr_s2, 2015

[9] Construction Resources, concreteconstruction.net, 2017

[10] Concrete Consolidation, ICF Magazine, icfmag.com/articles/how-to/concrete_consolidation.html

[11] Johnson, C. D.; Erection of Precast Concrete, Precast/Prestressed Concrete Institute (PCI), 1969

[12] Report On The Ethiopian Economy, Volume VI, The Current State of the Construction Industry; Ethiopian Economic Association (EEA), 2006/07

[13] Suryakanta; How to Mix Concrete Manually, civilblog.org/2016/02/13/how-to-mix-concrete-manually-on-site/, 2016

[14] Alemu, T.; Measurement of Labour Productivity in Construction Projects; AAU Press, 2006

[15] The Little Green Book of Concrete, Precast Concrete for Sustainable Construction; National Precast Concrete Association; British Precast Concrete Federation Ltd., 2008

[16] Hendrickson, C.; Tung Au; Cost Estimation, pmbook.ce.cmu.edu/05_Cost_Estimation.html, 1998

[17] Kashiwagi, D.; The Changing Construction Environment, 2004; ascpro0.ascweb.org/archives/cd/2004/2004pro/2003/Kashiwagi04d.htm

[18] Post Tensioning Cables - Hydraulic Jack for tensioning Cables, Wikimedia Commons, 2008

[19] Halvorsen, G.T.; Quality Control for Precast Plants; The Aberdeen Group, 1993

[20] Precast Concrete - Portland Bolt, Portland Bolt, portlandbolt.com/about/industries/precast-concrete/

[21] Arain, F. M.; Pheng, L. S.; The Potential Effects of Variation Orders on Institutional Building Project Facilities, 2005

[22] Sustainable Construction, sustainableprecast.ca, 2016

[23] NPCA Quality Control Manual for Precast and Prestressed Concrete Plants, National Precast Concrete Association (NPCA), 9th Edition, 2012

[24] Courville, T.; Thompson, B.; Use of Structure Coefficients in Published Multiple Regression Articles: β is not Enough, Sage Publications, 2001

[25] Johnson, J.; LeBreton, J.; History and Use of Relative Importance Indices in Organizational Research, Sage Publications, 2004

[26] Prestressed Concrete, wikipedia.org, 2004

[27] Ruggeri, P, Ph.D.; Segato, D, Ph.D.; Scarpelli, G; Sheet Pile Quay Wall Safety: Investigation of Post-tensioned Anchor Failures, Journal of Geotechnical and Geo-environmental Engineering, Vol. 139, Issue 9, 2013

[28] Lee, D.; Son, K; Kim, S; "Analysis of Operation Efficiency of Cranes", National Research Foundation of Korea (NRF), 2011

[29] Blakeley, R. W. G.; Park, R.; Shepherd, R.; "A Review of the Seismic Resistance of Prestressed Concrete", University of Canterbury, 1964

[30] Sutherland, W. M.; "Prestressed Concrete Earthquake Resistant Structures - Development, Performance, and Current Research", New Zealand Prestressed Concrete Institute, 1969

[31] Senior Design Handbook

Additional References

- Precast Concrete Foundations, http://precast.org/precast-product/foundations
- cement.org/think-harder-concrete-/buildings-structures/design-aids/emerging-trends
- portlandbolt.com/about/industries/precast-concrete/

- safequarry.com/hotTopics/2014-11-12PrestressingDocumentEndorsedbyHSE.pdf
- brighthubpm.com
- missourienterprise.org/ManufacturingServices/ContinuousImprovement/SixSigma/tabid/142/Default.aspx
- dtic.mil/dtic/tr/fulltext/u2/a285732.pdf
- elematic.com
- astm.org
- learntech.uwe.ac.uk/da/issuesofanalysis2.aspx
- Ray, B; Ripley, P; Neal, D; Lean Manufacturing - A Systematic Approach to Improving Productivity in the Precast Concrete Industry; PCI Journal, January 2006
- ASC Proceedings of the 40th Annual Conference; Brigham Young University, April, 2004

APPENDIX A

WRITTEN INTERVIEW FOR CONSTRUCTION COMPANIES

INTERVIEW SET 1

Name of Construction Company: ________________________________ *(optional)*

Contractor Grade: BC ____________

GC ____________

Full Name of Interviewee: ________________________________ *(optional)*

Position of Interviewee in the Company: ______________________________ *(optional)*

1. What have been the contract amounts of the last ten building construction projects of the company? What were the sizes of these buildings in total floor area?

a._______ b._______ c._______ d._______ e._______

f._______ g._______ h._______ i._______ j._______

2. Please provide records or notes of any quality control measures that have been taken by the company in the last ten building projects.

3. In your opinion, what are major benefits that precast construction has that in-situ construction does not? Choose from the list below.

A. controlled consolidation
B. no material wasted
C. modularity (repetitive production)
D. controlled curing
E. shorter time
F. finished surface at form removal
G. little supervision needed
H. in-house lab testing
I. no falsework needed
J. repetitive formwork reuse
K. safety
L. fixed rebar positions
M. little maintenance needed
N. less no. of laborers (easy HR management)
O. controlled casting

4. What have been the costs of the 'concrete work' in the last ten building construction projects of the company? Please provide supporting documents, if available.

No.	Project Name	Cost of Concrete Work
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

5. What are the overhead margin and profit margin that the company sets for building projects? Do the margins vary from project to project? (If yes, please provide a range.)

Overhead Margin = ___________ % Profit Margin = __________ %

Range = _________ % up to _________ %

6. Does your company have an overall estimate of unit cost for concrete works? (Cost per unit area and/or unit volume)
   6.1. Yes
   6.2. No

   [If you answered question no. 1 "No", please provide the researcher with priced BoQs of your past projects (Up to 20 is acceptable).]

If you answered question no. 1 "Yes",

7. Please state at how much your company estimates the unit cost for the direct cost of construction? ____________________________________
8. How did you come up with your estimate? Circle one of the following.

8.1. You made experienced guesses.

8.2. You used data from data collection websites like constructionproxy.com (please specify) ______________________________________

8.3. You used recorded data from more than one of your past projects.

8.4. You used recorded data from an ongoing project or the last project you completed.

8.5. You got it from your peers or from another company who obtained it using one of the methods listed above.

8.6. Other

____

____

____

____

____

____

9. Does your company have an estimate on any of the items in a standard Bill of Quantity for building works?

9.1. Yes

9.2. No

[If yes, please write down the estimates that you have.]

10. Please list, in order of importance, the most critical challenges your company has faced during construction works.

I. ____

II. ____

III. ____

IV. ____

V. ____

INTERVIEW SET 2

Written Interview to Contractors

1. How many projects has your company completed that are buildings of less than or equal to 6 stories that have at least one structural shear wall component?
   1.1. One up to 3
   1.2. 4 up to 6
   1.3. More than 6

2. How many of them were completed within the original estimate of time?
   2.1. None of the projects (0%)
   2.2. More than 0% and less than 25%
   2.3. More than 25% and less than 50%
   2.4. More than 50% and less than 75%
   2.5. More than 75% and less than 100%
   2.6. 100% of the projects.

3. What were the reasons for any differences in time?
   3.1. Client's financial constraints
   3.2. Inefficiencies of overhead staff, skilled laborers, and/or unskilled laborers
   3.3. Contractor's financial constraints
   3.4. Interruption or quantity limitations of construction material supply in the market
   3.5. Unavailability of effective, efficient, and/or ethical overhead or site workers
   3.6. Other (Please specify.)

4. What portion of your company's projects were completed within the original estimate of cost?
   4.1. None of the projects (0%)
   4.2. More than 0% and less than 25%
   4.3. More than 25% and less than 50%
   4.4. More than 50% and less than 75%
   4.5. More than 75% and less than 100%
   4.6. 100% of the projects.

5. What were the reasons for any differences in cost?
   - 5.1. Market price fluctuation of material, labor, and/or equipment
   - 5.2. Design revisions due to design errors
   - 5.3. Design revisions due to client's change in preference
   - 5.4. Revision in construction due to errors
   - 5.5. Incorrect initial estimation of construction time

6. What class of concrete have you used most for the structural elements of your company's building construction projects?
   - 6.1. C-20
   - 6.2. C-25
   - 6.3. C-30
   - 6.4. C-35
   - 6.5. C-40
   - 6.6. Other (Please specify.)

7. What is the justification behind using the concrete class in your answer to question no. 5 the most?

____

____

____

____

8. To your knowledge, what portion of your company's building projects had cracking problems within a year of completion?
   - 8.1. None of the projects (0%)
   - 8.2. More than 0% and less than 25%
   - 8.3. More than 25% and less than 50%
   - 8.4. More than 50% and less than 75%
   - 8.5. More than 75% and less than 100%
   - 8.6. 100% of the projects.

9. To your knowledge, what portion of your company's building projects had bending problems within a year of completion?
    9.1. None of the projects (0%)
    9.2. More than 0% and less than 25%
    9.3. More than 25% and less than 50%
    9.4. More than 50% and less than 75%
    9.5. More than 75% and less than 100%
    9.6. 100% of the projects.

10. To your knowledge, what portion of your company's building projects had settlement problems within a year of completion?
    10.1. None of the projects (0%)
    10.2. More than 0% and less than 25%
    10.3. More than 25% and less than 50%
    10.4. More than 50% and less than 75%
    10.5. More than 75% and less than 100%
    10.6. 100% of the projects.

11. What measures do you take in order to lower direct cost of construction? (*)
    11.1. No attempt is made to decrease construction cost.
    11.2. Renting equipment instead of purchasing them
    11.3. Lowering number of site workers, when not needed
    11.4. Obtaining materials with lower cost
    11.5. Hiring laborers full time in order to decrease hourly rate
    11.6. Hiring staff based on required technical skill rather than qualification
    11.7. Compensating for expenses by hiring out equipment on the side
    11.8. Other (Please specify.)

(* Choose all options that apply.)

12. What is the minimum profit margin you had taken in a project?
    - 12.1. More than 0% and less than 5% of total project cost
    - 12.2. More than 5% and less than 10%
    - 12.3. More than 10% and less than 15%
    - 12.4. More than 15% and less than 35%
    - 12.5. More than 35% and less than 55%
    - 12.6. More than 55% of total project cost

13. What is the maximum profit margin you had taken in a project?
    - 13.1. More than 0% and less than 5% of total project cost
    - 13.2. More than 5% and less than 10%
    - 13.3. More than 10% and less than 15%
    - 13.4. More than 15% and less than 35%
    - 13.5. More than 35% and less than 55%
    - 13.6. More than 55% of total project cost

14. What is the estimated average of your profit margins?
    - 14.1. More than 0% and less than 5% (of total project cost)
    - 14.2. More than 5% and less than 10%
    - 14.3. More than 10% and less than 15%
    - 14.4. More than 15% and less than 35%
    - 14.5. More than 35% and less than 55%
    - 14.6. More than 55% of total project cost

INTERVIEW SET 3

Interview Questions to PBPPE Staff Members

1. How long have you worked in PBPPE?
   1.1. More than 0 years and less than 5 years
   1.2. More than 5 years and less than 10 years
   1.3. More than 10 years and less than 15 years
   1.4. More than 15 years

2. In your opinion, is PBPPE functioning up to its capacity?
   2.1. Yes
   2.2. No, but it can
   2.3. No and it cannot

3. In your opinion, does PBPPE need any major renovations?
   3.1. Yes
   3.2. I cannot say
   3.3. No it is working well enough

4. If you answered “Yes” to question number 3, please discuss which elements you would suggest for renovations.

____

____

____

____

5. Do you think PBPPE offers a fair price for construction?
   5.1. Yes
   5.2. I cannot say
   5.3. No, but it should
   5.4. No, and it should not

6. What is your justification for your answer to question number 5?

____

____

____

____

7. What do you say is the biggest obstacle against the development of the plant?

____

____

____

____

8. Do you think that PBPPE has become obsolete?

____

____

____

____

9. Do you think a precast plant is a requirement in Ethiopia?

____

____

____

____

10. In your opinion, is there anything that should be noted about the history, works, development, or challenges of PBPPE?

11. What score, from 1 up to 5, 1 being very bad and 5 being very good, would you give PBPPE on issues of the NPCA Grading Schedule topics with no data to back them up? Please refer to the NPCA Grading Schedule distributed.

12. Please provide records or notes of any quality control measures that have been taken by the plant in the last ten precast building projects.

13. In your opinion, what are major benefits that precast construction has that in-situ construction does not? Choose from the list below.

A. controlled consolidation
B. no material wasted
C. modularity (repetitive production)
D. controlled curing
E. shorter time
F. finished surface at form removal
G. little supervision needed
H. in-house lab testing
I. no falsework needed
J. repetitive formwork reuse
K. safety
L. fixed rebar positions
M. little maintenance needed
N. less no. of laborers (easy HR management)
O. controlled casting

14. From the benefits of precast construction you chose in question number 13, please give a score of 1, least beneficial, up to 5, most beneficial.

A. ____________
B. ____________
C. ____________
D. ____________
E. ____________
F. ____________
G. ____________
H. ____________
I. ____________
J. ____________
K. ____________
L. ____________
M. ____________
N. ____________
O. ____________

15. Please choose which precast construction benefit in 'Column B' is important to the building type listed in 'Column A'. Several choices can be selected for each building type.

COLUMN A	**COLUMN B**
A — modular real estate houses	i. controlled consolidation
B — mixed use buildings (malls, city centers)	ii. no material wasted
C — apartment buildings	iii. modularity (repetitive production)
D — schools	iv. controlled curing
E — hospitals	v. shorter time
F — office buildings	vi. finished surface at form removal
G — residencies (individual designs)	vii. little supervision needed
H — dual home-work compounds (embassies, international organizations, universities)	viii. in-house lab testing
	ix. no falsework needed
I — religious/worship buildings (churches, mosques)	x. repetitive formwork reuse
J — national landmarks (palaces, museums)	xi. safety
	xii. fixed rebar positions
	xiii. little maintenance needed
	xiv. less no. of laborers (easy HR management)
	xv. controlled casting

	PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE							
	COST BREAKDOWN FOR PRODUCTION & ERECTION							
	PRE-FABRICATED BUILDING ELEMENTS							
Project:	**Islamic Affairs Building**							
Work Item:	**Cantilever Slab S-30-CL(CR)**							
Labor Hrly Output:	**1.0**	**pc/hr**	**Equipment Hrly Output:**			**1**	**pc/hr**	
Total Work Item Qty:	**110.0**	**pcs**					**Total**	
Material Cost	No.	1						
	Type of Material	Wedge & Barrel						
	Unit	Pcs.						
	Quantity	2.0						
	Rate	345.6					Total Material Cost =	
	Unit Cost	691.2					691.2	**691.2**
Labor Cost	Labor By Trade	Foreman	Senior Surveyor	Surveyor II	Erector	Daily Laborer		
	No.	1.0	1.0	1.0	2.0	2.0		
	Unit Factor	1.0	1.0	1.0	1.0	1.0	Total Labor Cost =	
	Indexed Hrly Rate	21.8	16.6	14.2	13.1	7.3	Hrly cost/Hrly Output =	
	Hourly Cost	21.8	16.6	14.2	26.3	14.6	93.4	**93.4**
Equipment Cost	Equipment Type	Crane (Kato 45T)	Support	Pre-stressing machine	Generator			
	No.	1.0	4.0	1.0	1.0			
	Unit Factor	1.0	1.0	1.0	1.0		Total Equipment Cost =	
	Hrly Rate	700.0	10.0	20.0	500.0		Hrly cost/Hrly Output=	
	Hrly Cost	700.0	40.0	20.0	500.0		1260.0	**1260.0**
Transportation :	7pcs/trip=	3.41X100 =	**341.0**	birr/pc				
			TOTAL ERECTION COST =			**I-13 + I-18 + I-23 =**		**2385.6**

	Prefabricated Building Parts Production Enterprise									
	Cost Breakdown for Production and Erection									
	Pre-Fabricated Building Elements									
Project:	**Islamic Affairs Building**									
Work Item:	**Cantilever Slab S-30-CL(CR)**									
Labor Hrly Output:	**2.0**	**pc/hr**		**Equipment Hrly Output:**			**1.0**	**pc/hr**	**Total**	
Total Work Item Qty:	**110.0**	**pcs**								
Material Cost	No.	1	2	3	4	5	6	7		
	Type of Material	Cement	Sand	Coarse Aggregate	Re-bar	Black Iron Wire	Form work	Lubricating Oil		
	Unit	m	m	m	kg	kg	m	Lts		
	Quantity	2.1	0.2	0.4	84.0	1.8	11.0	1.0		
	Rate	320.0	430.0	400.0	27.0	31.0	18.0	18.0	Total Material Cost =	
	Unit Cost	675.2	81.7	144.0	2268.0	54.3	198.0	18.0	3439.2	**3439.2**
Labor Cost	Labor By Trade	Foreman	Batching plant Operator	Scraper Operator	Bridge crane Operator	Skilled Labor	Daily Labor			
	Quantity	1	2	1	1	6	4			
	Unit Factor	0.3	1.0	1.0	1.0	1.0	1.0		Total Labor Cost =	
	Indexed Hrly Rate	21.8	11.3	8.3	5.3	11.3	7.3		Hrly cost/Hrly Output =	
	Hourly Cost	5.4	22.5	8.3	5.3	67.5	29.2		138.2	**69.1**
Equipment Cost	Eqpm't Type	Batching Plant	Vibrator	Bridge Crane	Scraper					
	Quantity	1	1	1	1					
	Unit Factor	0.4	1.0	1.0	1.0				Total Equipment Cost =	
	Hrly Rate	200.0	20.0	20.0	10.0				Hrly cost/Hrly Output=	
	Hrly Cost	80.0	20.0	20.0	10.0				130.0	**65.0**

Project:	**Islamic Affairs Building**							
Work Item:	**Cantilever Slab S-30-CL(CR)**							
Total Production Cost =	L13+L18+L23 =		3779.03					
Total Production:	3779.03		Labor Charge for re-bar preparation:					
Total Erection:	2385.62		Labor By Trade	No.	Unit Factor	Indexed Hrly		
Total Production and Erection:		6164.65	Re-bar	1.00	2.00	8.90	17.80	
Add 20% Overhead:	1.20	7397.58	Re-bar	2.00	4.00	8.90	71.20	
Add 15% Profit	1.15	8507.22	Helper	4.00	4.00	7.30	116.80	
Grand Total		**8507.22**	Total				205.80	

	PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE							
	COST BREAKDOWN FOR PRODUCTION & ERECTION							
	PRE-FABRICATED BUILDING ELEMENTS							
Project:	**Islamic Affairs Building**							
Work Item:	**Edge Girder G-30-1**							
Labor Hrly Output:	**2.0**	**pc/hr**		**Equipment Hrly Output:**		**2.0**	**pc/hr**	
Total Work Item Qty:	**30.0**	**pcs**					**Total**	
Material Cost	No.	1						
	Type of Material	Concrete Grout, C40						
	Unit	m^3						
	Quantity	0.08						
	Rate	3079.94					Total Material Cost =	
	Unit Cost	246.40					246.4	**246.4**
Labor Cost	Labor By Trade	Foreman	Senior Surveyor	Surveyor II	Erector	Daily Laborer		
	No.	1.00	1.00	1.00	2.00	2.00		
	Unit Factor	1.00	1.00	1.00	1.00	1.00	Total Labor Cost =	
	Indexed Hrly Rate	21.75	16.61	14.20	13.13	7.30	Hrly cost/Hrly Output =	
	Hourly Cost	21.75	16.61	14.20	26.26	14.60	93.4	**46.7**
Equipment Cost	Equipment Type	Crane (Kato 45T)	Support	Pre-stressing machine	Generator			
	No.	1.00	4.00	1.00	1.00			
	Unit Factor	1.00	1.00	1.00	1.00		Total Equipment Cost =	
	Hrly Rate	700.00	10.00	20.00	500.00		Hrly cost/Hrly Output=	
	Hrly Cost	700.00	40.00	20.00	500.00		1260.0	**630.0**
Transportation :	7pcs/trip=	2.19X100 =	**219.00**	birr/pc				
			TOTAL ERECTION COST =			**I-13 + I-18 + I-23 =**	**1142.1**	

	Prefabricated Building Parts Production Enterprise										
	Cost Breakdown for Production and Erection										
	Pre-Fabricated Building Elements										
Project:	**Islamic Affairs Building**										
Work Item:	**Edge Girder G-30-1**										
Labor Hrly Output:	**6.0**	**pc/hr**			**Eqpt Hrly Output:**	**6.0**	**pc/hr**			**Total**	
Total Work Item Qty:	**30.0**	**pcs**									
Material Cost	No.	1	2	3	4	5	6	7			
	Type of Material	Cement	Sand	Coarse Aggregate	Re-bar	Black Iron Wire	Form work	R.D			
	Unit	Qt	m	m	kg	kg	m	pcs			
	Quantity	0.61	0.06	0.1	30.8	0.65	2.5	1			
	Rate	320.00	430.00	400.00	27.00	31.00	18.00	50.00		Total Material Cost =	
	Unit Cost	195.20	25.80	40.00	831.60	20.15	45.00	50.00		1207.8	**1207.8**
Labor Cost	Labor By Trade	Foreman	Batching plant Operator	Scraper Operator	Bridge crane Operator	Skilled Labor	Daily Labor				
	Quantity	1	2	1	1	6	4				
	Unit Factor	0.25	1.00	1.00	1.00	1.00	1.00			Total Labor Cost =	
	Indexed Hrly Rate	21.75	11.25	8.25	5.28	11.25	7.30			Hrly cost/Hrly Output =	
	Hourly Cost	5.44	22.50	8.25	5.28	67.50	29.20			138.2	**23.0**
Equipment Cost	Eqpm't Type	Batching Plant	Vibrator	Bridge Crane	Scraper						
	Quantity	1	1	1	1						
	Unit Factor	0.25	1.00	1.00	1.00					Total Equipment Cost =	
	Hrly Rate	200.00	20.00	20.00	10.00					Hrly cost/Hrly Output=	
	Hrly Cost	50.00	20.00	20.00	10.00					100.0	**16.7**

Project:	**Islamic Affairs Building**						
Work Item:	**Edge Girder G-30-1**						
Total Production Cost =	L13+L18+L23 =	1394.84					
Total Production:	1394.84		Labor Charge for re-bar preparation:				
Total Erection:	1142.11		Labor By Trade	No.	Unit Factor	Indexed Hrly	
Total Production and Erection:		2536.95	Re-bar	1.00	2.00	8.90	17.80
Add 20% Overhead:	1.20	3044.34	Re-bar	2.00	4.00	8.90	71.20
Add 15% Profit	1.15	3500.99	Helper	2.00	4.00	7.30	58.40
Grand Total		**3500.99**	Total				147.40

	PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE							
	COST BREAKDOWN FOR PRODUCTION & ERECTION							
	PRE-FABRICATED BUILDING ELEMENTS							
Project:	**Islamic Affairs Building**							
Work Item:	**Edge Girder G-30-2**							
Labor Hrly Output:	**2.0**	**pc/hr**		**Equipment Hrly Output:**		**2.0**	**pc/hr**	
Total Work Item Qty:	**6.0**	**pcs**					**Total**	
Material Cost	No.	1						
	Type of Material	Concrete Grout, C40						
	Unit	m³						
	Quantity	0.08						
	Rate	3079.94					Total Material Cost =	
	Unit Cost	246.40					246.4	**246.4**
Labor Cost	Labor By Trade	Foreman	Senior Surveyor	Surveyor II	Erector	Daily Laborer		
	No.	1.00	1.00	1.00	2.00	2.00		
	Unit Factor	1.00	1.00	1.00	1.00	1.00	Total Labor Cost =	
	Indexed Hrly Rate	21.75	16.61	14.20	13.13	7.30	Hrly cost/Hrly Output =	
	Hourly Cost	21.75	16.61	14.20	26.26	14.60	93.4	**46.7**
Equipment Cost	Equipment Type	Crane (Kato 45T)	Support	Pre-stressing machine	Generator			
	No.	1.00	4.00	1.00	1.00			
	Unit Factor	1.00	1.00	1.00	1.00		Total Equipment Cost =	
	Hrly Rate	700.00	10.00	20.00	500.00		Hrly cost/Hrly Output=	
	Hrly Cost	700.00	40.00	20.00	500.00		1260.0	**630.0**
Transportation :	7pcs/trip=	2.19X100 =	**219.00**	birr/pc				
			TOTAL ERECTION COST =			**I-13 + I-18 + I-23 =**		**1142.1**

	Prefabricated Building Parts Production Enterprise										
	Cost Breakdown for Production and Erection										
	Pre-Fabricated Building Elements										
Project:	**Islamic Affairs Building**										
Work Item:	**Edge Girder G-30-2**										
Labor Hrly Output:	**5.0**	**pc/hr**			**Eqpt Hrly Output:**	**5.0**	**pc/hr**			**Total**	
Total Work Item Qty:	**6.0**	**pcs**									
Material Cost	No.	1	2	3	4	5	6	7			
	Type of Material	Cement	Sand	Coarse Aggregate	Re-bar	Black Iron Wire	Form work	R.D			
	Unit	Qt	m	m	kg	kg	m	pcs			
	Quantity	1.1	0.1	0.19	25	0.6	3.5	1			
	Rate	320.00	430.00	400.00	27.00	31.00	18.00	50.00		Total Material Cost =	
	Unit Cost	352.00	43.00	76.00	675.00	18.60	63.00	50.00		1277.6	**1277.6**
Labor Cost	Labor By Trade	Foreman	Batching plant Operator	Scraper Operator	Bridge crane Operator	Skilled Labor	Daily Labor				
	Quantity	1	2	1	1	6	4				
	Unit Factor	0.25	1.00	1.00	1.00	1.00	1.00			Total Labor Cost =	
	Indexed Hrly Rate	21.75	11.25	8.25	5.28	11.25	7.30			Hrly cost/Hrly Output =	
	Hourly Cost	5.44	22.50	8.25	5.28	67.50	29.20			138.2	**27.6**
Equipment Cost	Eqpm't Type	Batching Plant	Vibrator	Bridge Crane	Scraper						
	Quantity	1	1	1	1						
	Unit Factor	0.25	1.00	1.00	1.00					Total Equipment Cost =	
	Hrly Rate	200.00	20.00	20.00	10.00					Hrly cost/Hrly Output=	
	Hrly Cost	50.00	20.00	20.00	10.00					100.0	**20.0**

Project:	**Islamic Affairs Building**							
Work Item:	**Edge Girder G-30-2**							
Total Production Cost =	L13+L18+L23 =		1472.63					
Total Production:	1472.63		Labor Charge for re-bar preparation:					
Total Erection:	1142.11		Labor By Trade	No.	Unit Factor	Indexed Hrly		
Total Production and Erection:		2614.74	Re-bar	1.00	2.00	8.90	17.80	
Add 20% Overhead:	1.20	3137.69	Re-bar	2.00	4.00	8.90	71.20	
Add 15% Profit	1.15	3608.34	Helper	2.00	4.00	7.30	58.40	
Grand Total		**3608.34**	Total				**147.40**	

	PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE								
	COST BREAKDOWN FOR PRODUCTION & ERECTION								
	PRE-FABRICATED BUILDING ELEMENTS								
Project:	**Islamic Affairs Building**								
Work Item:	**Column C-30-1W, 2.9m**								
Labor Hrly	**2.0**	**pc/hr**		**Equipment Hrly Output:**			**2.0**	**pc/hr**	
Total Work Item	**195.0**	**pcs**						**Total**	
Material Cost	No.	1	2	3					
	Type of Material	Wedge & Barrel	Wooden Wedge	Concrete Grout, C40					
	Unit	pcs	pcs	m					
	Quantity	3.00	4.00	0.05					
	Rate	345.60	15.00	3079.94				Total Material Cost =	
	Unit Cost	1036.80	60.00	138.60				1235.4	**1235.4**
Labor Cost	Labor By Trade	Foreman	Senior Surveyor	Surveyor II	Erector	Daily Laborer			
	No.	1.00	1.00	1.00	2.00	4.00			
	Unit	1.00	1.00	1.00	1.00	1.00		Total Labor Cost =	
	Indexed Hrly Rate	21.75	16.61	14.20	13.13	7.30		Hrly cost/Hrly Output =	
	Hourly Cost	21.75	16.61	14.20	26.26	29.20		108.0	**54.0**
Equipment Cost	Equipment Type	Crane (Kato 45T)	High-bed Truck	Support	Bracing	Pre-stressing	Generator		
	No.	1.00	1.00	4.00	4.00	1.00	1.00		
	Unit	1.00	0.14	1.00	1.00	1.00	1.00	Total Equipment Cost =	
	Hrly Rate	700.00	500.00	10.00	10.00	20.00	500.00	Hrly cost/Hrly Output=	
	Hrly Cost	700.00	71.50	40.00	40.00	20.00	500.00	1371.5	**685.8**
Transportation :	7pcs/trip=	3.84X100 =	**384.00**	birr/pc					
				TOTAL ERECTION COST =			**I-13 + I-18 + I-23 =**		**2359.2**

	Prefabricated Building Parts Production Enterprise									
	Cost Breakdown for Production and Erection									
	Pre-Fabricated Building Elements									
Project:	**Islamic Affairs Building**									
Work Item:	**Column C-30-1W, 2.9m**									
Labor Hrly Output:	**3.0**	**pc/hr**			**Eqpt Hrly Output:**	**3.0**	**pc/hr**		**Total**	
Total Work Item Qty:	**195.0**	**pcs**								
Material Cost	No.	1	2	3	4	5	6	7		
	Type of Material	Cement	Sand	Coarse Aggregate	Re-bar	Black Iron Wire	Formwork	R.D		
	Unit	Qt	m	m	kg	kg	m	pcs		
	Quantity	1.58	0.15	0.27	65	1.25	3.5	2		
	Rate	320.00	430.00	400.00	27.00	31.00	18.00	50.00	Total Material Cost =	
	Unit Cost	505.60	64.50	108.00	1755.00	38.75	63.00	100.00	2634.9	**2634.9**
Labor Cost	Labor By Trade	Foreman	Batching plant Operator	Scraper Operator	Bridge crane Operator	Skilled Labor	Distributor Operator	Daily Labor		
	Quantity	1	2	1	1	6	1	4		
	Unit Factor	0.25	1.00	1.00	1.00	1.00	1.0	1.00	Total Labor Cost =	
	Indexed Hrly Rate	21.75	11.25	8.25	5.28	11.25	4.25	7.30	Hrly cost/Hrly Output =	
	Hourly Cost	5.44	22.50	8.25	5.28	67.50	4.3	29.20	142.4	**47.5**
Equipment Cost	Eqpm’t Type	Batching Plant	Vibrator	Bridge Crane	Scraper					
	Quantity	1	1	1	1					
	Unit Factor	0.25	1.00	1.00	1.00				Total Equipment Cost =	
	Hrly Rate	200.00	20.00	20.00	10.00				Hrly cost/Hrly Output=	
	Hrly Cost	50.00	20.00	20.00	10.00				100.0	**33.3**

Project:	**Islamic Affairs Building**							
Work	**Column C-30-1W, 2.9m**							
Total Production Cost =	L13+L18+L23 =		2803.76					
Total Production:	2803.76		Labor Charge for re-bar preparation:					
Total Erection:	2359.16		Labor By Trade	No.	Unit Factor	Indexed Hrly		
Total Production and		5162.92	Re-bar	1.00	2.00	8.90	17.80	
Add 20% Overhead:	1.20	6195.51	Re-bar	2.00	2.17	8.90	38.63	
Add 15% Profit	1.15	7124.83	Helper	2.00	2.17	7.30	31.68	
Grand Total		**7124.83**	Total				**88.11**	

	PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE								
	COST BREAKDOWN FOR PRODUCTION & ERECTION								
	PRE-FABRICATED BUILDING ELEMENTS								
Project:	**Islamic Affairs Building**								
Work Item:	**Normal S/W SWN(378X362X15)**								
Labor Hrly Output:	**1.0**	**pc/hr**		**Equipment Hrly Output:**			**1.0**	**pc/hr**	
Total Work Item	**30.0**	**pcs**		**TRANSPORTATION :**		2	pcs/hr	**Total**	
Material Cost	No.	1							
	Type of Material	Concrete Grout, C40							
	Unit	m							
	Quantity	0.11							
	Rate	3079.94						Total Material Cost =	
	Unit Cost	338.79						338.8	**338.8**
Labor Cost	Labor By Trade	Foreman	Senior Surveyor	Surveyor II	Erector	Daily Laborer			
	No.	1.00	1.00	1.00	2.00	5.00			
	Unit	1.00	1.00	1.00	1.00	1.00		Total Labor Cost =	
	Indexed Hrly Rate	15.63	15.63	9.38	5.48	3.25		Hrly cost/Hrly Output =	
	Hourly Cost	15.63	15.63	9.38	10.96	16.25		67.9	**67.9**
Equipment Cost	Equipment Type	Crane (Kato 45T)	High-bed Truck						
	No.	1.00	1.00						
	Unit	0.50	0.25					Total Equipment Cost =	
	Hrly Rate	700.00	500.00					Hrly cost/Hrly Output=	
	Hrly Cost	350.00	125.00					475.0	**475.0**
Transportation :	7pcs/trip=	3.84X100 =	**384.00**	birr/pc					
				TOTAL ERECTION COST =			**I-13 + I-18 + I-23 =**		**881.6**

	Prefabricated Building Parts Production Enterprise									
	Cost Breakdown for Production and Erection									
	Pre-Fabricated Building Elements									
Project:	**Islamic Affairs Building**									
Work Item:	**Normal S/W SWN(378X362X15)**									
Labor Hrly Output:	**1.0**	**pc/hr**		**Equipment Hrly Output:**			**1.0**	**pc/hr**	**Total**	
Total Work Item Qty:	**30.0**	**pcs**								
Material Cost	No.	1	2	3	4	5	6			
	Type of Material	Cement	Sand	Coarse Aggregate	Re-bar	Form work	R.D			
	Unit	m	m	m	kg	m	pcs			
	Quantity	6.53	0.60	1.12	115.20	17.50	2.00			
	Rate	450.00	350.00	280.00	27.00	18.00	40.00		Total Material Cost =	
	Unit Cost	2938.50	210.00	313.60	3110.40	315.00	80.00		6967.5	**6967.5**
Labor Cost	Labor By Trade	Foreman	Batching plant Operator	Scraper Operator	Bridge crane Operator	Skilled Labor	Daily Labor	Bar Bender		
	Quantity	1.00	2.00	1.00	1.00	6.00	4.00	1.00		
	Unit Factor	0.25	1.00	1.00	1.00	1.00	1.00	1.00	Total Labor Cost =	
	Indexed Hrly Rate	15.63	7.50	5.07	5.07	5.07	3.25	172.80	Hrly cost/Hrly Output =	
	Hourly Cost	3.91	15.00	5.07	5.07	30.42	13.00	172.80	245.3	**245.3**
Equipment Cost	Eqpm’t Type	Batching Plant	Vibrator	Bridge Crane	Scraper					
	Quantity	1	1	1	1					
	Unit Factor	0.4	1.0	1.0	1.0				Total Equipment Cost =	
	Hrly Rate	200.0	20.0	20.0	10.0				Hrly cost/Hrly Output=	
	Hrly Cost	80.0	20.0	20.0	10.0				130.0	**130.0**

Project:	**Islamic Affairs Building**							
Work Item:	**Normal S/W SWN(378X362X15)**							
Total Production Cost =	L13+L18+L23 =		7342.77					
Total Production:	7342.77							
Total Erection:	881.64							
Total Production and		8224.41						
Add 15% Overhead:	1.15	9458.07						
Add 10% Profit	1.10	10403.88						
Grand Total		**10403.88**						

	PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE								
	COST BREAKDOWN FOR PRODUCTION & ERECTION								
	PRE-FABRICATED BUILDING ELEMENTS								
Project:	**Islamic Affairs Building**								
Work Item:	**Staircase Flight**								
Labor Hrly Output:	**1.0**	**pc/hr**				**Equipment Hrly Output:**	**1.0**	**pc/hr**	
Total Work Item	**12.0**	**pcs**			**TRANSPORTATION :**	**2**	**pcs/hr**	**Total**	
Material Cost	No.	1							
	Type of Material	Concrete Grout, C40							
	Unit	m							
	Quantity	0.08							
	Rate	3079.94						Total Material Cost =	
	Unit Cost	246.40						246.4	**246.4**
Labor Cost	Labor By Trade	Foreman	Senior Surveyor	Surveyor II	Erector	Daily Laborer			
	No.	1.00	1.00	1.00	2.00	4.00			
	Unit	1.00	1.00	1.00	1.00	1.00		Total Labor Cost =	
	Indexed Hrly Rate	21.75	16.61	14.20	13.13	7.30		Hrly cost/Hrly Output =	
	Hourly Cost	21.75	16.61	14.20	26.26	29.20		108.0	**108.0**
Equipment Cost	Equipment Type	Crane (Kato 45T)	Generator						
	No.	1.00	1.00						
	Unit	0.50	0.50					Total Equipment Cost =	
	Hrly Rate	700.00	500.00					Hrly cost/Hrly Output=	
	Hrly Cost	350.00	250.00					600.0	**600.0**
Transportation :	7pcs/trip=	2.60X100 =	**260.00**	birr/pc					
						TOTAL ERECTION COST =	**I-13 + I-18 + I-23 =**		**1214.4**

	Prefabricated Building Parts Production Enterprise									
	Cost Breakdown for Production and Erection									
	Pre-Fabricated Building Elements									
Project:	**Islamic Affairs Building**									
Work Item:	**Staircase Flight**									
Labor Hrly Output:	**2.0**	**pc/hr**			**Eqpt Hrly Output:**	**2.0**	**pc/hr**		**Total**	
Total Work Item Qty:	**12.0**	**pcs**								
Material Cost	No.	1	2	3	4	5	6	7		
	Type of Material	Cement	Sand	Coarse Aggregate	Re-bar	Black Iron Wire	Form work	R.D		
	Unit	Qt	m	m	kg	kg	m	pcs		
	Quantity	3.36	0.31	0.57	64.00	1.90	10.00	2.00		
	Rate	320.00	430.00	400.00	27.00	31.00	18.00	50.00	Total Material Cost =	
	Unit Cost	1075.20	133.30	228.00	1728.00	58.90	180.00	100.00	3503.4	**3503.4**
Labor Cost	Labor By Trade	Foreman	Batching plant Operator	Scraper Operator	Bridge crane Operator	Skilled Labor	Distributor Operator	Daily Labor		
	Quantity	1	2	1	1	6	1	4		
	Unit Factor	0.25	1.0	1.0	1.0	1.0	1.0	1.0	Total Labor Cost =	
	Indexed Hrly Rate	21.75	11.25	8.25	5.28	11.25	4.25	7.3	Hrly cost/Hrly Output =	
	Hourly Cost	5.4	22.5	8.3	5.3	67.5	4.3	29.2	142.4	**71.2**
Equipment Cost	Eqpm't Type	Batching Plant	Vibrator	Bridge Crane	Scraper					
	Quantity	1	1	1	1					
	Unit Factor	0.4	1	1	1				Total Equipment Cost =	
	Hrly Rate	200.0	20.0	20.0	10.0				Hrly cost/Hrly Output=	
	Hrly Cost	80.0	20.0	20.0	10.0				130.0	**65.0**

Project:	**Islamic Affairs Building**							
Work Item:	**Staircase Flight**							
Total Production Cost =	L13+L18+L23 =		3787.01					
Total Production:	3787.01		Labor Charge for re-bar preparation:					
Total Erection:	1214.42		Labor By Trade	No.	Unit Factor	Indexed Hrly		
Total Production and Erection:		5001.42	Re-bar	1.00	2.00	8.90	17.80	
Add 20% Overhead:	1.20	6001.71	Re-bar	2.00	4.00	8.90	71.20	
Add 15% Profit	1.15	6901.97	Helper	2.00	4.00	7.30	58.40	
Grand Total		**6901.97**	Total				**147.40**	

	PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE								
	COST BREAKDOWN FOR PRODUCTION & ERECTION								
	PRE-FABRICATED BUILDING ELEMENTS								
Project:	**Islamic Affairs Building**								
Work Item:	**Staircase Landing**								
Labor Hrly Output:	**1.0**	**pc/hr**	**Equipment Hrly Output:**				**1.0**	**pc/hr**	
Total Work Item	**6.0**	**pcs**						**Total**	
Material Cost	No.	1							
	Type of Material	Concrete Grout, C40							
	Unit	m							
	Quantity	0.08							
	Rate	3079.94						Total Material Cost =	
	Unit Cost	246.40						246.4	**246.4**
Labor Cost	Labor By Trade	Foreman	Senior Surveyor	Surveyor II	Erector	Daily Laborer			
	No.	1.00	1.00	1.00	2.00	5.00			
	Unit	1.00	1.00	1.00	1.00	1.00		Total Labor Cost =	
	Indexed Hrly Rate	21.75	16.61	14.20	13.13	7.30		Hrly cost/Hrly Output =	
	Hourly Cost	21.75	16.61	14.20	26.26	36.50		115.3	**115.3**
Equipment Cost	Equipment Type	Crane (Kato 45T)	Generator						
	No.	1.00	1.00						
	Unit	0.50	0.50					Total Equipment Cost =	
	Hrly Rate	700.00	500.00					Hrly cost/Hrly Output=	
	Hrly Cost	350.00	250.00					600.0	**600.0**
Transportation :	7pcs/trip=	2.60X100 =	**260.00**	birr/pc					
				TOTAL ERECTION COST =			**I-13 + I-18 + I-23 =**		**1221.7**

	Prefabricated Building Parts Production Enterprise									
	Cost Breakdown for Production and Erection									
	Pre-Fabricated Building Elements									
Project:	**Islamic Affairs Building**									
Work Item:	**Staircase Landing**									
Labor Hrly Output:	**2.0**	**pc/hr**			**Eqpt Hrly Output:**	**2.0**	**pc/hr**		**Total**	
Total Work Item Qty:	**6.0**	**pcs**								
Material Cost	No.	1	2	3	4	5	6	7		
	Type of Material	Cement	Sand	Coarse Aggregate	Re-bar	Black Iron Wire	Form work	R.D		
	Unit	Qt	m	m	kg	kg	m	pcs		
	Quantity	3.94	0.36	0.67	266.00	5.40	12.00	2.00		
	Rate	320.00	430.00	400.00	27.00	31.00	18.00	50.00	Total Material Cost =	
	Unit Cost	1260.80	154.80	268.00	7182.00	167.40	216.00	100.00	9349.0	**9349.0**
Labor Cost	Labor By Trade	Foreman	Batching plant Operator	Scraper Operator	Bridge crane Operator	Skilled Labor	Distributor Operator	Daily Labor		
	Quantity	1	2	1	1	6	1	4		
	Unit Factor	0.25	1.0	1.0	1.0	1.0	1.0	1.0	Total Labor Cost =	
	Indexed Hrly Rate	21.75	11.25	8.25	5.28	11.25	4.25	7.3	Hrly cost/Hrly Output =	
	Hourly Cost	5.4	22.5	8.3	5.3	67.5	4.3	29.2	142.4	**71.2**
Equipment Cost	Eqpm't Type	Batching Plant	Vibrator	Bridge Crane	Scraper					
	Quantity	1	1	1	1					
	Unit Factor	0.4	1	1	1				Total Equipment Cost =	
	Hrly Rate	200.0	20.0	20.0	10.0				Hrly cost/Hrly Output=	
	Hrly Cost	80.0	20.0	20.0	10.0				130.0	**65.0**

Project:	**Islamic Affairs Building**						
Work Item:	**Staircase Landing**						
Total Production Cost =	L13+L18+L23 =		9632.61				
Total Production:	9632.61		Labor Charge for re-bar preparation:				
Total Erection:	1221.72		Labor By Trade	No.	Unit Factor	Indexed Hrly Rate	
Total Production and Erection:		10854.32	Re-bar Cutter	1.00	2.00	8.90	17.80
Add 20% Overhead:	1.20	13025.19	Re-bar Bender	2.00	4.00	8.90	71.20
Add 15% Profit	1.15	14978.97	Helper	2.00	4.00	7.30	58.40
Grand Total		**14978.97**	Total				**147.40**

	PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE								
	COST BREAKDOWN FOR PRODUCTION & ERECTION								
	PRE-FABRICATED BUILDING ELEMENTS								
Project:	**Islamic Affairs Building**								
Work Item:	**Footing F1 (120X120X80cm)**								
Labor Hrly Output:	**1.0**	**pc/hr**	**Equipment Hrly Output:**				**1.0**	**pc/hr**	
Total Work Item	**28.0**	**pcs**						**Total**	
Material Cost	No.	1							
	Type of Material	Concrete Grout, C40							
	Unit	m							
	Quantity	0.05							
	Rate	3079.94						Total Material Cost =	
	Unit Cost	154.00						154.0	**154.0**
Labor Cost	Labor By Trade	Foreman	Senior Surveyor	Surveyor II	Erector	Daily Laborer			
	No.	1.00	1.00	1.00	2.00	5.00			
	Unit	1.00	1.00	1.00	1.00	1.00		Total Labor Cost =	
	Indexed Hrly Rate	21.75	16.61	14.20	13.13	7.30		Hrly cost/Hrly Output =	
	Hourly Cost	21.75	16.61	14.20	26.26	36.50		115.3	**115.3**
Equipment Cost	Equipment Type	Crane (Kato 45T)	Generator						
	No.	1.00	1.00						
	Unit	0.50	0.50					Total Equipment Cost =	
	Hrly Rate	700.00	500.00					Hrly cost/Hrly Output=	
	Hrly Cost	350.00	250.00					600.0	**600.0**
Transportation :	7pcs/trip=	3.84X100 =	**384.00**	birr/pc					
				TOTAL ERECTION COST =			**I-13 + I-18 + I-23 =**		**1253.3**

	Prefabricated Building Parts Production Enterprise										
	Cost Breakdown for Production and Erection										
	Pre-Fabricated Building Elements										
Project:	**Islamic Affairs Building**										
Work	**Footing F1 (120X120X80cm)**										
Labor Hrly Output:	**2.0**	**pc/hr**			**Eqpt Hrly Output:**	**2.0**	**pc/hr**			**Total**	
Total Work Item Qty:	**28.0**	**pcs**									
Material Cost	No.	1	2	3	4	5	6	7			
	Type of Material	Cement	Sand	Coarse Aggregate	Re-bar	Black Iron Wire	Formwork	Lubricating oil			
	Unit	Qt	m	m	kg	kg	m	Lts			
	Quantity	2.83	0.26	0.48	50.36	1.47	5.00	1.00			
	Rate	320.00	430.00	400.00	27.00	31.00	18.00	18.00		Total Material Cost =	
	Unit Cost	905.60	111.80	192.00	1359.72	45.57	90.00	18.00	0.00	2722.7	**2722.7**
Labor Cost	Labor By Trade	Foreman	Batching plant Operator	Scraper Operator	Bridge crane Operator	Skilled Labor	Distributor Operator	Daily Labor	Bar Bender		
	Quantity	1	2	1	1	6	2	4	1		
	Unit Factor	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	Total Labor Cost =	
	Indexed Hrly Rate	21.75	11.25	8.25	5.28	11.25	4.25	7.30	41.30	Hrly cost/Hrly Output =	
	Hourly Cost	5.44	22.50	8.25	5.28	67.50	8.50	29.20	41.30	188.0	**94.0**
Equipment Cost	Eqpm't Type	Batching Plant	Vibrator	Bridge Crane	Scraper						
	Quantity	1	1	1	1						
	Unit Factor	0.25	1	1	1					Total Equipment	
	Hrly Rate	200.0	20.0	20.0	10.0					Hrly cost/Hrly Output=	
	Hrly Cost	50.0	20.0	20.0	10.0					100.0	**50.0**

Project:	**Islamic Affairs Building**						
Work Item:	**Footing F1 (120X120X80cm)**						
Total Production Cost =	L13+L18+L23 =		2866.67				
Total Production:	2866.67		Labor Charge for re-bar preparation:				
Total Erection:	1253.32		Labor By Trade	No.	Unit Factor	Indexed Hrly Rate	
Total Production and Erection:		4119.99	Re-bar Cutter	1.00	2.00	8.90	17.80
Add 20% Overhead:	1.20	4943.99	Re-bar Bender	2.00	4.00	8.90	71.20
Add 15% Profit	1.15	5685.59	Helper	2.00	4.00	7.30	58.40
Grand Total		**5685.59**	Total				**147.40**

	PREFABRICATED BUILDING PARTS PRODUCTION ENTERPRISE								
	COST BREAKDOWN FOR PRODUCTION & ERECTION								
	PRE-FABRICATED BUILDING ELEMENTS								
Project:	**Islamic Affairs Building**								
Work Item:	**Footing F3 (200X200X80cm)**								
Labor Hrly Output:	**1.0**	**pc/hr**	**Equipment Hrly Output:**				**1.0**	**pc/hr**	
Total Work Item	**11.0**	**pcs**						**Total**	
Material Cost	No.	1							
	Type of Material	Concrete Grout, C40							
	Unit	m							
	Quantity	0.05							
	Rate	3079.94						Total Material Cost =	
	Unit Cost	154.00						154.0	**154.0**
Labor Cost	Labor By Trade	Foreman	Senior Surveyor	Surveyor II	Erector	Daily Laborer			
	No.	1.00	1.00	1.00	2.00	5.00			
	Unit	1.00	1.00	1.00	1.00	1.00		Total Labor Cost =	
	Indexed Hrly Rate	21.75	16.61	14.20	13.13	7.30		Hrly cost/Hrly Output =	
	Hourly Cost	21.75	16.61	14.20	26.26	36.50		115.3	**115.3**
Equipment Cost	Equipment Type	Crane (Kato 45T)	Generator						
	No.	1.00	1.00						
	Unit	0.50	0.50					Total Equipment Cost =	
	Hrly Rate	700.00	500.00					Hrly cost/Hrly Output=	
	Hrly Cost	350.00	250.00					600.0	**600.0**
Transportation :	7pcs/trip=	5.12X100 =	**512.00**	birr/pc					
						TOTAL ERECTION COST =	**I-13 + I-18 + I-23 =**		**1381.3**

	Prefabricated Building Parts Production Enterprise										
	Cost Breakdown for Production and Erection										
	Pre-Fabricated Building Elements										
Project:	**Islamic Affairs Building**										
Work	**Footing F3 (200X200X80cm)**										
Labor Hrly Output:	**1.5**	**pc/hr**			**Eqpt Hrly Output:**	**1.5**	**pc/hr**			**Total**	
Total Work Item Qty:	**11.0**	**pcs**									
Material Cost	No.	1	2	3	4	5	6	7			
	Type of Material	Cement	Sand	Coarse Aggregate	Re-bar	Black Iron Wire	Form work	Lubricating oil			
	Unit	Qt	m	m	kg	kg	m	Lts			
	Quantity	5.66	0.52	0.97	97.00	2.95	10.50	1.00			
	Rate	320.00	430.00	400.00	27.00	31.00	18.00	18.00		Total Material Cost =	
	Unit Cost	1811.20	223.60	388.00	2619.00	91.45	189.00	18.00	0.00	5340.3	**5340.3**
Labor Cost	Labor By Trade	Foreman	Batching plant Operator	Scraper Operator	Bridge crane Operator	Skilled Labor	Distributor Operator	Daily Labor	Bar Bender		
	Quantity	1	2	1	1	6	1	4	1		
	Unit Factor	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	Total Labor Cost =	
	Indexed Hrly Rate	21.75	11.25	8.25	5.28	11.25	4.25	7.30	82.60	Hrly cost/Hrly Output =	
	Hourly Cost	5.44	22.50	8.25	5.28	67.50	4.25	29.20	82.60	225.0	**150.0**
Equipment Cost	Eqpm't Type	Batching Plant	Vibrator	Bridge Crane	Scraper						
	Quantity	1	1	1	1						
	Unit Factor	0.25	1	1	1					Total Equipment	
	Hrly Rate	200.0	20.0	20.0	10.0					Hrly cost/Hrly Output=	
	Hrly Cost	50.0	20.0	20.0	10.0					100.0	**66.7**

Project:	**Islamic Affairs Building**						
Work Item:	**Footing F3 (200X200X80cm)**						
Total Production Cost =	L13+L18+L23 =		5639.53				
Total Production:	5639.53		Labor Charge for re-bar preparation:				
Total Erection:	1381.32		Labor By Trade	No.	Unit Factor	Indexed Hrly Rate	
Total Production and Erection:		7020.85	Re-bar Cutter	1.00	2.00	8.90	17.80
Add 20% Overhead:	1.20	8425.01	Re-bar Bender	2.00	2.00	8.90	35.60
Add 15% Profit	1.15	9688.77	Helper	2.00	2.00	7.30	29.20
Grand Total		**9688.77**	Total				**82.60**

APPENDIX C

NPCA DEDUCTION TEMPLATE

APPENDIX D

NPCA GRADING SCHEDULE

APPENDIX E

NPV AND ROI CALCULATIONS