ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

"STUDY ON CURRENT FORMWORK PRACTICES AND TRENDS IN ETHIOPIAN BUILDING CONSTRUCTION INDUSTRIES: CASE OF SELECTED CONTRACTORS IN ADDIS ABABA"

By

Getaw Tessema

A thesis submitted to school of graduate studies in partial fulfillment of the requirements for the degree of Master of Science in civil engineering, (Construction Technology and Management major)

June 2019

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Approved by Board of Examiners

Dr. Abraham Assefa	Abrahamassefa	08/01/19
Advisor	Signature	Date
Dr. Girmay Kahsay		30/07/19
Internal Examiner	Signature	Date
Eng. Yibeltal Zewdu		30/07/2019
External Examiner	Signature	Date
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DECLARATION

This thesis is my original work, and has not been presented for a degree in any other university and all sources of materials used for the thesis have been given proper acknowledgment.

Candidate

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ABBREVIATIONS

EBCS	Ethiopian Building Codes and Standards
ACI	American Concrete Institute
BATCODA	Building and Transport Construction Design Authority
IRJAES	International Research Journal of Advanced Engineering and Science

ABSTRACT

Formwork has been used since the introduction of Portland cement and construction of concrete structures. It has remained a labor intensive activity where most of the carpenters start off as daily laborers and finish up as formwork carpenters without any formal training especially in the Ethiopian construction industry. But nowadays due to globalization across the world, the construction industry has started focusing on new innovative ways of formwork construction and approaches to increase overall efficiency of the project.

Formwork not only holds the concrete during its wet stage but has many other important functions in the activity of concreting. It becomes integral part in construction and the foremost important trade in the reinforced concrete construction works which leads and determines the smooth flow of all subsequent construction activities. Formwork types and the way they are erected and handled affect the quality of the concrete finish and also the economy. Good quality of formwork can contribute to good quality of concrete. On the other hand, bad formwork has often produced failures of minor as well as major magnitude leading to additional treatments. Questionnaires results from 36 respondents and observations in 3 projects sites for this research conducted in Addis Ababa, indicated that bad form joints, offsets, verticality problems and poor facing material are some of the evident that bad forms can potentially have on the surface of concrete and leads to additional treatments. Financial capacity of contractors is found the main factor that affect formwork selection which contributes to bad concrete surface finishing; and improper selection of form release agents together with poor workmanships have highly affected the reusability of plywood in the building construction sites in Addis Ababa. One of the root causes for poor formwork practices by some of the local contractors in Addis Ababa is, striving to compensate the low bid amount by low cost materials, for example, used oil which highly affects the formwork. Based on results, this research contributes on improving future formwork constructions in Ethiopia by creating awareness from current practices in Addis Ababa.

Keywords: Formwork, Current practice, reuse of formwork, form release agent, life-cycle

1. INTRODUCTION

1.1. Background

Ethiopia is one of the developing countries with fast urbanization. Many high-rise buildings are being constructed in urban areas, especially in the capital Addis Ababa, due to increased population and businesses. The majority of high-rise buildings are concrete works which are one of the most important elements in such huge infrastructures. Fast and efficient construction of the concrete is therefore, essential to maintain phased (gradually staged) progress on other parts of the building.

Formwork is one of the most important factors in determining the success of a construction project in terms of speed, quality cost and safety of work as it accounts a big share of the total project cost of the concrete structure, which in some countries such as United States will take half or more of the cost of concrete work. The cost of formwork in the United States can be as much as 60% of the total cost of the completed concrete structure in place and sometimes greater, (ACI 347 R-04, 2004).

Formwork sometimes termed as form is temporary structure erected together with supporting members called false works. Formwork holds the plastic concrete in place until it gains enough strength to hold up its weight and has been used since the introduction of Portland cement. It is of the most important element in concrete construction next to the concrete itself and reinforcement bars. It is self-supporting structure that is also sufficient to hold the dead load of the reinforcement, fresh concrete and the live load of equipment, workers, and miscellaneous materials (Baxi, 2011).

Baxi also addressed the importance of formwork that it is a concrete quality tool which is very important in concrete construction; that it moulds the concrete to the required size and shape while controlling its position and alignment. Formwork and the way it is erected and handled affect the quality of the concrete finish. Inferior quality of formworks has often caused failures of minor as well as major magnitude. Some of the imperfections that forms can potentially have on the surface of concrete such as poor form joints, offsets or poor facing material could be taken as results of poor quality of formwork.

Therefore, forms` functional as well as financial share in the entire concreting activity can't be ignored and need same care as the permanent structure from the planning stage through last touch of forms.

The forms must also be strong enough to support the pressure and the weight of the fresh concrete and any construction loads such as finishing equipment and workers. In addition, the forms should be able to withstand the effects of vibration caused by vibrators that are used for consolidation. It is important to inspect the condition of the forms and how they are put together. If the erecting of forms and false works is not complete correctly, the finished surfaces of the structure will be unsatisfactory. Forms` joints must also be tight enough to prevent concrete mortar from leaking through the joints during placement (Rubaratuka, 2013).

Assembling of formwork components can be in variety of systems for casting concrete with different structural shapes. It is generally classified according to the direction of placement as Vertical Systems for wall and column and Horizontal Systems for slab and beam.

The selection of a formwork system and materials for the construction of concrete structure would seriously influence the quality as well as cost and time of project delivery. The materials serving as the contact face of forms such as plywood, laminated board or steel sheets should be treated well with good releasing agents and used in both the vertical and horizontal systems.

Generally, formwork should be designed & built appropriately so that the desired size, shape position, right location, quality and finish of acceptable quality of the cast concrete are achieved and must consider the following four main goals according to (Wong, 2015).

1. ***Quality***: - Forms must be designed and built with sufficient stiffness and accuracy so the size, shape, position, and finish of the cast concrete are attained within the required tolerances.

2. ***Economy***: - Since formwork is one of the three main materials of concrete work next to reinforcement and concrete, it has to be designed to be used efficiently and to maximum reuse of forms.
3. ***Safety***: - Forms must be built with sufficient strength and capable of supporting all dead and live loads without collapse or danger to workers and to the concrete structure.
4. ***Speed and Time: -*** Faster formwork cycle from erection to stripping would allow for faster overall project progress.

Nowadays generally, formworks exist in three major categories, namely, conventional formwork (the most traditional/oldest type of formwork used in the construction industry, which uses timber, bamboo), modern conventional formwork (similar to conventional one but more advanced materials such as steel props and various types of jacks (U jacks, T jacks) are used as supports in the formwork instead of timber supports and ply wood sheets are used instead of timber planks on slab decks, beams and columns) and system formwork which is modern formwork developed for improved features of concrete and has prefabricated components by patented manufacturers, (Sandip & Atterde, 2014).

In most of the local building construction industries in Ethiopia, targeting mainly at cost, and sometimes speed, often challenges the achievement of other quality aspects (Amare, 2015). It is a common practice to see additional treatments of concrete structures by chiseling and plastering structural elements in building construction projects because of problems such as misalignment, misplacement, deflective, cement paste grout and bulged concrete. Therefore, selection of an appropriate formwork system is a crucial factor for the success of the project. Selecting an appropriate formwork system affects the entire construction duration and cost, as well as subsequent construction activities. However, in practice, the selection of an appropriate formwork system has been done mainly on the intuitive and individual opinion of working level employees with low experience.

Additional treatment of concrete elements such as columns, beams, slab and staircase soffits by chiseling and plastering are being unnecessary in many countries which in turn saves time and cost of additional treatment by using system formworks.

1.2. Statement of the Problem

In today's building construction industry where the emergence of high rising buildings is increasing from day to day, old ways of construction and materials are replaced with newly innovated technologies to make the construction process safer, quality, economical and timely completed in different parts of the world. Concrete work is major in building construction which needs concern to produce quality surface finishing.

Nowadays concrete structures with high quality of surface finish are produced in building construction projects, which in other words means requirement to additional treatments of concrete surface to rectify imperfections after removal of forms, has been minimized. But most building projects in Ethiopia especially undertaken by local contractors are still in need of additional treatment to rectify defects such as bulging of concrete walls, offsets, rough and uneven concert surface, edges of structural elements not straight etc., by chiseling and plastering with mortar. Conventional ways of formwork construction have been practiced, where timber boards and steel panels are most widely used materials. "Steel panels and timber boards are the most commonly used formwork materials in Ethiopia. The quality of concrete surfaces is mostly not good as proper formworks are not designed and constructed accordingly, (Tarekegn, 2010)." The other problem in Ethiopian building construction is that formwork takes relatively longer time to erect and strip.

The type of formwork used and the way it is erected construction sites are among the key factors in determining the success of a construction project in terms of cost, quality, construction speed and safety of the projects (Wong, 2015). Usage and practices of low quality of formwork systems hence could result in poor appearance of concrete surface quality.

Generally, the problems are stated Table 1.1 below as main and sub problems.

Table 1.1 Research questions

Main Problem	**Formwork practices and effects on building construction projects: in what ways do current formwork practices affect the success of building construction projects in Addis Ababa?** This research evaluated the current formwork construction practice and how it affects the success of entire building construction projects in Addis Ababa.

Sub- Problems	**I. Which formwork types and materials are practically used currently and what selection criteria are set?** This will explain the type, material, cost, selection criteria and factors affecting the selection of formworks in building construction projects currently practiced in Addis Ababa.
	II. What are the main causes of the formwork reuse limitations and impacts on the concrete finishing surfaces? Common formwork defects, quality failures, causes of replacement, and impact on cost will be identified and evaluated here.
	III. Why are additional treatments required to the concrete surface of building structural elements in Addis Ababa? The purpose of this question is to identify main reasons additional concrete surface treatments and impacts of formwork.

1.3. Research Objectives

- To identify formwork types and materials used at building construction project sites in Addis Ababa undertaken by local and international contractors
- To identify formwork selection criteria and factors affecting formwork selection
- To identify major causes that affect formwork practices and impacts to the finishing surface of concrete structural elements.
- To assess economy of formwork.

1.4. Scope of the Research

This research is focused mainly on the current practices and trends of formwork in building construction projects in Addis Ababa. It is specifically focused on types, materials used, systems, erecting and removal (striking) of formworks, cost of formwork, treatments and release agents used.

Superstructures of building construction projects were given more attentions due mainly to their exposures to the public view, where effects of formwork on concrete surfaces are

visible after removal of formwork. Projects being undertaken by grade-1 and grade-2 contractors were studied considering that these top grade contractors have financial capacity and experience in the field which help to select appropriate formwork for a specific building project.

2. LITERATURE REVIEW

2.1. Definition of key terms

Form - Temporary structure or mold for the support of concrete while it is setting and gaining sufficient strength to be self-supporting.

Formwork - Total system of support for freshly placed concrete, including the mold or sheathing that contacts the concrete as well as supporting members, hardware, and necessary bracing.

Conventional/ traditional Formwork– The oldest formwork type which uses timber, bamboo, timber boards, timber props, masonry and carpentry

Modern Conventional Formwork - Similar to conventional but uses advanced materials such as steel props, plywood, steel sheets, different jacks (U jack, T jack) instead of timber boards and props.

System Formwork – Advanced formwork type which has modular (prefabricated) components with casting panels in large amount and developed for improved features of concrete construction for different structures.

Falsework -Temporary structure erected to support work in the process of construction; composed of shoring or vertical posting and lateral bracing for formwork for beams and slabs.

Joists- A comparatively narrow beam with closely spaced arrangements found directly under slab formwork

Formwork Engineer/Contractor - Engineer of the formwork system or contractor in charge of designated aspects of formwork design and formwork operations.

Shore - Vertical or inclined support member or braced frame designed to carry the weight of the formwork, concrete, and construction loads

Re-shores - Shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a full bay, requiring the new slab or structural member to deflect and support its own weight and existing construction loads to be applied before installation of the re-shores.

2.2. Formwork and Formwork Systems

Formwork is a temporary structure or mold for the support of fresh concrete until it sets and gains sufficient strength to support its own weight. Formwork is a temporary structure whose main purpose is to provide support and containment for freshly placed concrete until it can support itself and formwork system is the total system of support for freshly placed concrete, including the mould or sheathing that contacts the concrete as well as supporting members, hardware, and necessary bracing (Awad S. Hanna, 1999).

"Formwork means the surface of the form and framing used to contain and shape wet concrete until it is self-supporting (Australia code of practice, 2016)." The definition in this code of practice includes the forms on or into which the fresh concrete is poured to a desired shape and the frames and bracing which provide stability. Frames and bracings used as part of the formwork assembly, namely, the joists, bearers, bracing, foundations and footings are technically referred to as false work in this code of practice.

Formwork system can be generally classified as Vertical Systems (wall and column) and Horizontal Systems (slab and beam). The material serving as the contact face of forms is known as sheathing and it is used in both the vertical and horizontal systems.

Formwork system is among the key factors determining the achievement of a construction project in terms of cost, quality, safety and speed of works.

Formwork is the key factor determining the success of a building construction project in terms of speed, quality, cost and safety of the practice (Wong, 2015) and these factors are discribed as follows.

Speed: If a formwork system is not appropriately designed (if there is wrong selection, inefficient fixing method, difficult location of work, more labour intensive) to fit the actual site conditions, it will have low efficiency and affect the speed of work

Quality: Quality of concrete can be affected by formwork in the following ways:

a) The accurate shape of the formwork panel
b) Dimensional accuracy of the formwork

c) The verticality, leveling or alignment of the formwork
d) The tightness of joining of the panels
e) Whether the panel surfaces is in good condition

Cost: Cost of formwork include material, cost of cutting, material wastage, labour to assemble and erection, striking and transportation of formwork panels, replacement of reused panel.

Safety of works: In formwork construction dangers usually occur due to:

- Often need to work at height,
- Panels may be heavy for human workers and hence hoisting equipments should be used
- Unstable formwork erection will cause collapse and harm people working on it
- Working area nearby the formwork are usually congested and not easy to get access into.

Therefore, selecting the forming system, that is, making structural frames faster, simpler, and less costly to build, must begin in the earlier phase of the design work. It is also important to design for striking or removing the formwork easily considering re-use of the forms.

2.3. Requirements of Good Formwork

In order to successfully carry out its function, formwork must achieve a balance of technical, functional and economic requirements. The following categorical requirements of formwork were accessed from (theconstractor, 2018).

2.3.1. Technical Requirements

Formwork has to be technically sound and designed to achieve the desired specified quality of the concrete. The following are technical requirements of good formwork.

Containment: Formwork must be capable of shaping and supporting the fluid concrete until it cures.

Strength: Formwork should support the designed loads and any other applied loads during the construction period. Thus forms and shutters have to be designed to support dead weight, live load and hydrostatic pressure. Formwork for vertical concrete elements namely, columns and walls are subject to pressures (the hydrostatic pressure) on the form face caused by the fluid action of the fresh concrete. The pressure of the fluid concrete on the vertical faces increases proportionately with the depth of concrete and hence the maximum pressure being at the bottom of the form (theconstractor, 2018). Maximum pressure for the full depth of fluid concrete usually occurs when the concrete is placed very quickly (Metin, Osman, & Serkan, 2004). Therefore, the bracing must be strong enough not to be dislocated by impact of the hydrostatic pressure acting from any direction.

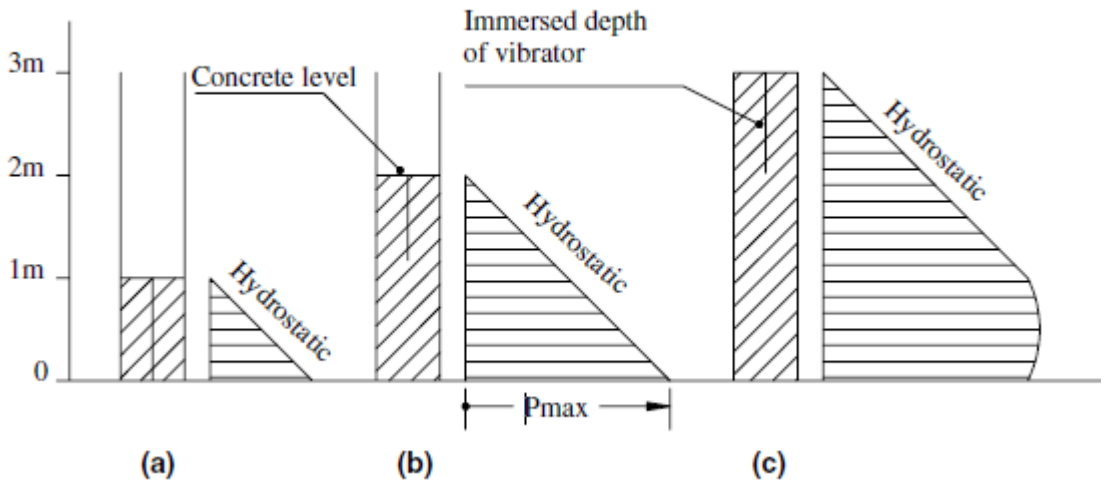

Figure 2.1 Impact of lateral pressure of vertical formwork (Metin, Osman, & Serkan, 2004)

Resistance to leakage: Concrete is placed in a mould or form while it is in its liquid state, from which cement and fine aggregates are prone to leak through form joints. The formwork therefore, must be designed and fixed to prevent leakage of cement and fine aggregate from the liquid concrete. The gaps between planks or form sheets must be tightly fitted to prevent the leakage of cement paste.

"All joints in form work must be either close fitting or covered with form tape to make them grout tight and smooth. If grout leakage occurs the concrete will leak at that point and finished surface of the concrete will need additional treatments to remove the grouts and fines. Leakages also cause honeycombing on the surface of hardened concrete (Sharmila & Christober, 2016)."

Figure2.2 Sealing gaps between form sheets with mastic tape to prevent slurry leakage (Ultratech Services, 2014)

Accuracy: Formwork must be accurately set out so that the resulting concrete product is in a right place and is of correct shape and dimensions. It shall also be carefully selected for required finish surface and linings to produce the desired concrete surface.

Rigidity: The mould into which the fresh concrete is poured must be rigid enough to resist bulging, capable of withstanding without distortion or danger the dead weight of the fluid concrete is placed on it, labor weight, equipment weight and any environmental loadings. Brace formwork and support to ensure that there exists no movement may take place under hydrostatic pressure when the concrete is being placed and vibrated (Metin, Osman, & Serkan, 2004).

Finish and reuse potential: The form or moulding material must be selected to be capable creating uniform, smooth, straight edges and desired concrete. At the

same time it should also achieve the required number of reuse for economical purposes. This may need minimizing nailing as much as possible to required, because nail holes may affect further use of timber formwork. The formwork material must be strong and capable of producing a good surface finish.

2.3.2. Functional Requirements

Ease of handling: Form panels and units should be designed so that their maximum size does not exceed that which can be easily handled by hand or mechanical means. In addition, all formwork must also be designed and constructed to include facilities for adjustments, leveling, easing and striking without damage to the form work or concrete (theconstractor, 2018).

Speed of erection and dismantling: The formwork design and the methods of assembly must be as simple as possible to reduce time spent in erection and dismantling. The formwork should be simple to remove without causing damage to the concrete surface and formwork itself (Barbosa, Gambatese, & Andre, 2014).

Access for concrete: any formwork arrangement must provide access for placing of the concrete. The extent of this provision will be dependent on the ease of carrying out the concrete operations.

2.3.3. Economic Requirements

For formwork construction to be economically feasible, the following procedures should be considered during selection (theconstractor, 2018);

- ✓ Formwork shall be made of low cost materials, energy and labor if possible.
- ✓ Formwork should be manufactured such that it can be repetitively used and shall be as adaptable as possible. It must be able to withstand a good number of reuses without losing its shape.
- ✓ Formwork must be designed so that the whole formwork can be assembled and dismantled with unskilled or semi-skilled labor.
- ✓ Formwork care and maintenance should be done according to specifications.

2.4. Formwork Selection and Considerations

2.4.1. Formwork selection overview

Formwork system is the key factor determining the success of a concrete construction project in terms of the well-known and important aspects, namely, quality, cost, time and safety of the project on hand. Formwork system plays a major role in finishing the structure with in stipulated time bound, specified quality, budget and safety.

To make the formwork selection easier by entering relevant information to the process, formwork is classified into vertical (e.g. columns & walls) and horizontal systems (e.g. Slab & beam). The vertical and horizontal formwork systems should be measured separately considering the information required to select each system which may not be the same, and they both have different functions, (Hanna, 1999). With proper selection of formwork systems, cost of construction can be significantly brought down, quality of the concrete can be great, the project will be completed within stipulated time and injuries can be minimized. Therefore, selecting the formwork system which suits for cast in place reinforced concrete is a critical decision that can affect the whole construction process. But in some of building construction projects formwork selection mainly depends on the intuitive and opinion of practitioners.

"Appropriate selection of a formwork system is a crucial factor in successfully completing most building projects. However, in practice, selection of an appropriate formwork system has traditionally depended mainly on the intuitive and subjective opinion of practitioners with limited experience, (Malvankar, 2013)."

2.4.2. Factors affecting formwork selection

The type and materials of formwork for building structural elements should be selected considering the type and purpose of the building. Different factors have to be considered for proper selection of formwork system to a specific construction project, so that the construction process will go smoothly and agreeing to the contract document. Proper selection of the formwork systems should also be a concern to all involved parties for optimum results (Hanna, 1989).

Hanna (1989) also has identified factors affecting the selection of formwork system into four major categories, namely, building design related factors, job specifications, local conditions and supporting organization as indicated in Figure 2.3.

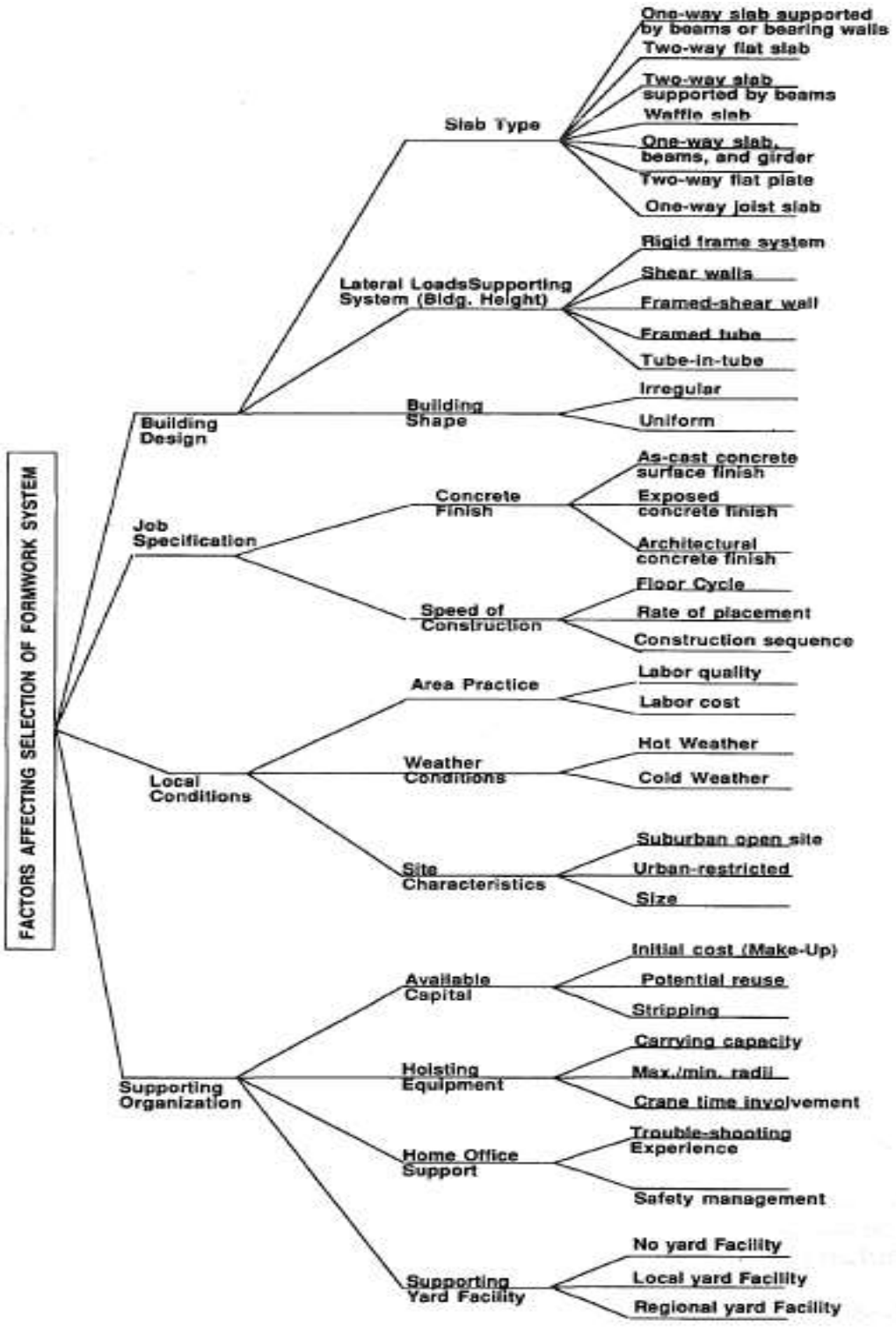

Figure 2.3 Factors affecting the selection of a formwork system (Hanna1989)

2.5. Form Work life-cycle and Management

2.5.1. Form Work Life-Cycle

For selecting formwork one must know the sequence of formwork construction activities, procedures or steps and methods to be followed so that the project will be proceeding in accordance with planned quality, time and cost. Following construction procedures and, or steps will always help to know inter dependency of the activities, specifications and additional requirements in placing concrete. This will allow us to practice appropriate formwork systems which fulfills the construction requirements.

The life-cycle of formwork is often integrated with life-cycle of the concrete construction, especially in the horizontal building structural elements such as slabs, beams and flat roof because the formwork cycle ends when the concrete cured and get enough strength to support itself. The process of providing formwork in concrete construction is to mould or place the fresh concrete till it gets self-supporting strength. Hence formwork and concrete life cycle is highly integrated (Hanna, 1999). But concrete mostly has stared to be cured after the removal of formwork in vertical structural elements such as columns and shear walls. Figure 2.4 indicates the integrated concrete/ formwork life cycle, where the left circle represents the formwork life cycle, while the right circle represents the concrete construction life cycle. The two intersection points represent the beginning and the end of concrete construction life cycle.

In some conditions as indicated in Figure 2.4 curing concrete and stripping formwork may be interchangeable if form is stripped after curing, for example in horizontal formwork for slabs and beams are removed after curing concrete, while in vertical concrete structural elements such as columns and walls, formwork should be stripped to cure concrete. This also indicates that curing and formwork stripping are not always interchangeable. “It should be noted that the phases ‘cure concrete’ and ‘stripping of formwork’ are interchangeable depending on the type of structural element. For example, columns and walls are cured after stripping the forms while slabs and beams are cured before and then stripped, (Malvankar, 2013).”

Formwork life-cycle starts with feasibility study (obtaining all necessary information) and ends with repairing, then reusing/ storing of the formwork while the concrete

construction life-cycle starts with placing reinforcement bars and ends with curing the concrete so that forms are ready to be stripped off the concrete as shown in Figure 2.4.

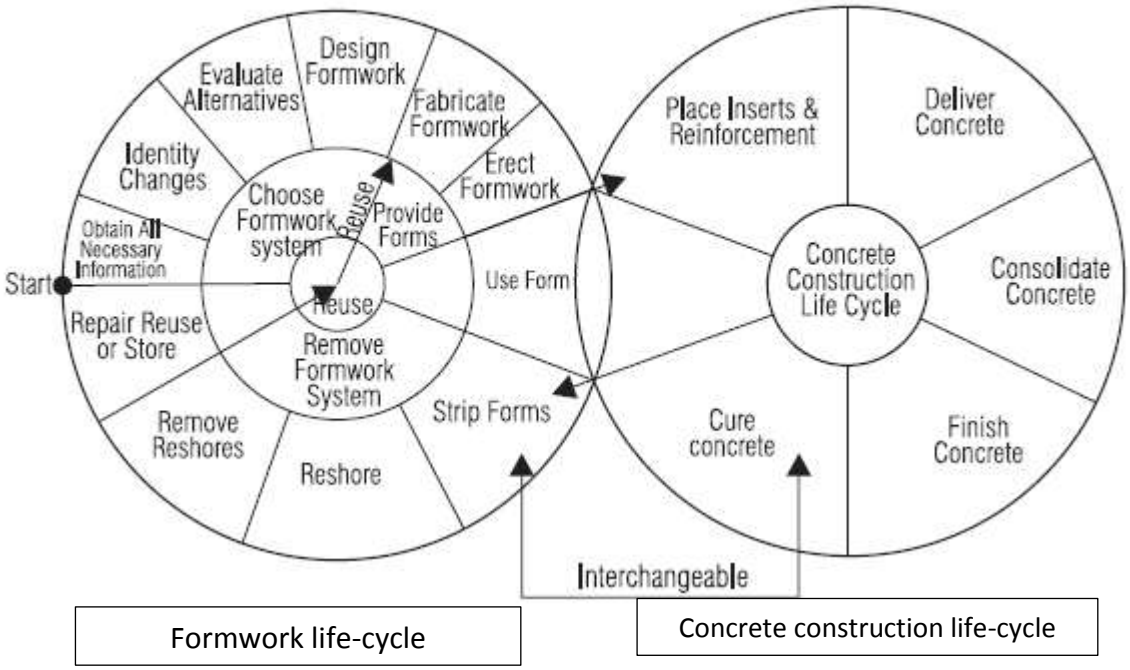

Figure 2. 4 Integrated formwork/concrete lifecycle (Hanna, 1999)

Barbosa (2014), on the other hand mapped the life cycle for vertical formwork on three construction sites, and identified and evaluated typical formwork construction procedures. They identified and evaluated that one general cycle of formwork use consists of about 18 steps explained in Figure 2.5.

Formwork has often taken a significant share of cost and hence it is the largest cost component in a typical multi-storey reinforced concrete building. In countries where labour cost is expensive such as united states, formwork accounts for up to 60% and even more in some cases, of cost of concrete and 10-15% the total construction cost, (ACI 347 R-04, 2004).

Therefore, apropriate practice of formwork construction, throughout every cycle will lead to the success of the construction project as required. Figure 2.5 demonstrates the mapped workflow of one formwork cycle which (Barbosa, Gambatese, & Andre, 2014) identified and evaluated.

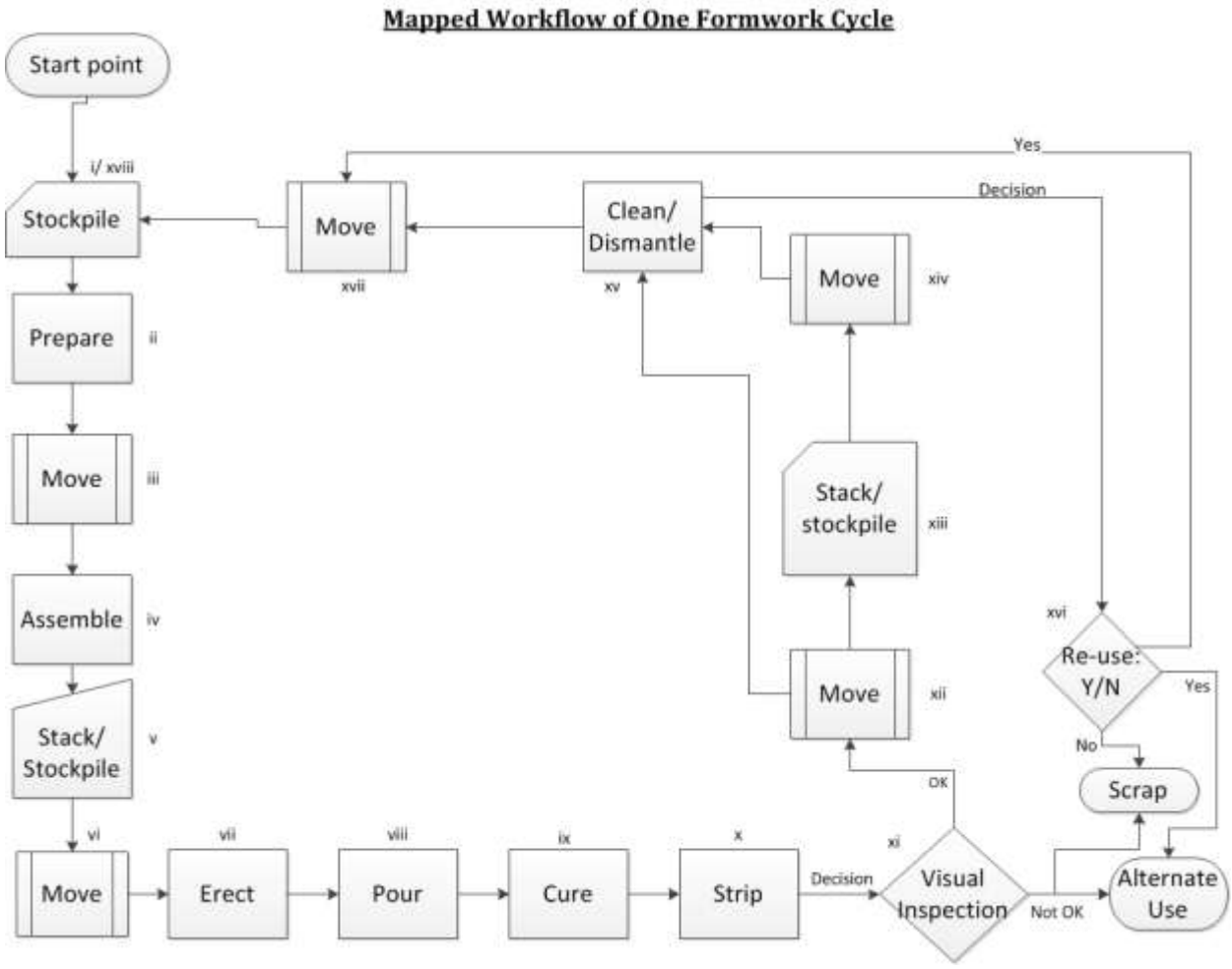

Figure 2.5 Mapped Workflow for One General Formwork Use Cycle (Barbosa,2014)

2.5.2. Form Work Management

Formwork significantly influences the success of a project in terms of quality, safety, and cost and completion time in high / mid-rise building construction with reinforced concrete structures. Therefore, managing the construction of formwork on one way or another can influence success of the total project.

Management of formwork construction throughout its life-cycle helps to achieve the required quality, safety, and cost and time effectively and efficiently. One of the effective ways for reducing the form work duration is to strip the forms without delay when concrete placed in the form is sufficiently cured to stand by itself.

Sengupta & Rajashi (2018), identified the following key reasons why formwork is highly important for any concrete construction project and need management for better progresses as described below.

I. **Time Management: -** Good formwork systems help to minimize floor to floor construction cycle time, thereby achieving substantial indirect cost saving for the project.

II. **Safety: -** Modern formwork systems provide designed solutions against all superimposed loads thereby ensuring structural safety. Also they integrate proper access and working platform arrangements in the scheme to ensure workmen safety.

III. **Quality:-**Surface finishing of any concrete is solely contributed by quality & type of formwork used. Superior surface finish imparted by modern formworks such as Aluminum formwork, Tunnel form and eliminates the need of plastering for any reinforce cement concrete surface.

IV. **Project Planning: -** Proper knowledge of formwork management facilitates on-time mobilization & demobilization of formwork resources, effective set movements, minimizes idling, maximize repetitions and minimize cost. It also helps in correct time & cost inputs for tendering process.

V. **Human Resource: -** Formwork activities require specialized skill sets for all levels of personnel involved. Hence proper skill assessment, training & effectiveness tracking are continual mandatory needs to maximize labor productivity.

VI. **Capital Management: -** Substantial quantum of Formwork materials owned by any construction company fall under asset category and travels from one project to the next. Hence accounting, physical verification, loss mitigation needs to be practiced meticulously to avoid unnecessary substantial cost impacts.

2.6. Economy of Formwork

One of the main features in terms of which formwork system is determining the success of a construction project is the cost. In countries where labor cost is high, the cost of formwork may take half, or even more cost of the concrete structures. On average about

35% of the total cost of any finished concrete unit or element can be attributed to its formwork; of this just over 40% can be taken for material for formwork and 60% for labor, (Patil, 2017). Formwork is the largest cost component for a typical multistory reinforced concrete building. Formwork construction takes a big share of construction cost which amounts 40-60% of cost of concrete structure and 10% of the total project cost according, (Hanna, 1999). In cast-in-place reinforced concrete building construction, formwork expenses can be as high as 50% of the total cost of the reinforced concrete structure, (Anthony, 1988)

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Therefore, economy should be considered in the planning stage of the formwork for a concrete structure. Economy of formwork encompasses many factors including the cost of materials, the cost of labor in erecting and removing the forms, and the cost of equipment required to handle the forms.

Economy of formwork also includes the number of reuses of the form materials where designing formwork to maximum reuses can save money, the possible salvage value of the forms for use elsewhere, and the cost of finishing concrete surfaces after the forms are removed. This means maximizing the number of reuses of formwork is one of the areas that make formwork activity economical. The main objectives are to obtain maximum reuse of forms and to permit use of standard material sizes with minimum cutting and fitting, (Hurd, 2005)

The formwork designer must therefore not only consider the maximum number of times that any form can be reused, but also produce a design that will minimize the time taken for erection and striking.

Economy in formwork begins with the design of a structure and continues through the selection of form materials, erection, stripping, care of forms between reuses, and reuse of forms, if any, (Peurifoy, 2011).

2.6.1. Economy in Designing, Planning, Building and Stripping Forms

In designing the formwork for a concrete structure, considerations of cost: materials, labor and the use of equipment required to assemble and handle the forms should be kept in mind. The formwork is an area where savings can be made in construction of a concrete structure.

Since the cost of concrete is fairly static, with existence of ready mixed concrete, there is little in savings to be had with the material itself. It is in the formwork practice that real economy can be achieved (iitarchie, 2011). Planning and practicing to reduce the combined cost of all these important items will reduce the cost of formwork construction in building construction industries. In some building construction projects, contractors have mainly targeted on cost of projects and compromised or gave little attentions to the quality and safety which may lead to uneconomical results or unnecessary costs would be incurred for rectifications.

The contractor therefore, should aim for maximum economy without sacrificing or affecting quality and safety in designing, planning and building formwork (Malvankar, 2013). Short cuts in design or construction that endanger quality or safety may not be economical. For example, if forms do not produce the specific surface finish, much hand chiseling of the concrete may be required to be plastered and if forms deflect excessively, bulges in the concrete may require expensive rectification measures.

Guessing could lead to very dangerous and expensive situations in any concrete construction that; if formworks are over-designed, they will be unreasonably expensive and if they are under-designed, they may fail, which also can be very expensive.

A number of methods effecting economy in formwork construction were identified (Peurifoy, 2011), out of which the following 11 points were taken for the purpose of this paper:

1) Design the forms to provide the required strength with the smallest amount of materials and the most number of reuses.
2) Do not specify or require a high-quality finish on concrete surfaces that will not be exposed to view by the public, such as the inside face of parapet, walls or walls and beams in service stairs.
3) When planning forms, consider the sequence and methods of stripping them.
4) Use the largest practical prefabricated panels that can be handled by the workers or equipment on the job.

5) Prefabricate form members (not limited to panels) where possible. This will require planning, drawings, and detailing, but it will save money.
6) Develop standardized methods of making, erecting, and stripping forms to the maximum possible extent. Once carpenters learn these methods, they can work faster.
7) Clean, oil, and re-nail form panels, if necessary, between reuses. Store them carefully to prevent distortion and damage.
8) Use long lengths of lumber without cutting for walls, braces, stringers, and other purposes where their extending beyond the work is not objectionable. For example, there usually is no objection to letting studs extend above the sheathing on wall forms.
9) Strip forms as soon as it is safe and possible to do so if they are to be reused on the structure, in order to provide the maximum number of reuses.
10) Create a cost-of-materials consciousness (awareness) among the carpenters who make forms. At least one contractor displayed short boards around his project on which the cost was prominently displayed.
11) Conduct jobsite analyses and studies to evaluate the fabrication, erection, and removal of formwork to increase productivity.

2.6.2. Aspect of Formwork Reuse and Caring for Reuse

Reusing formwork saves in construction costs, since concrete and reinforcement bars are often statistic. "Formwork is a large proportion of the total cost of a building structure, approximately 10% of total cost of the structure (Hanna, 1999)." Therefore, reusing formwork for concrete is one of the ways to reduce construction costs. The economic value or reusing formwork lies in the ease with which it can be stripped from concrete. With that in mind, formwork designers must be kept well-informed in advancing technology of formwork manufacturing so that quality can be maintained without ignoring its economic value in facing new challenges in reusing concrete formwork (Metin, Osman, & Serkan, 2004).

Formwork materials must be handled carefully and accidental dropping must be avoided as possible. Used formwork panels or sheets should be checked for damage before they are used again. Formwork highly affects the final appearance of the finished structure,

and hence any defect must be checked first and re-paired or removed; otherwise the formwork's defect will reflect on the finished surface of the concrete. After the formwork is repaired, any excessive concrete on the formwork surface must be removed also. Aluminum and steel formworks should be oiled to prevent from getting rusty and hence maximize life of the forms.

The other important activity within the life-cycle of the formwork which needs care is storage or stock piling. After the used formwork is repaired, excessive concrete removed and oiled, they should be stockpiled and covered with suitable material like canvas.

2.7. Quality Issues in Formwork Construction

It is the form which is responsible for the shape, alignment, size and texture of the concrete structure since fresh concrete, which is fluid, has no shape by itself. It is shaped and moulded by being placed in formwork. The formwork face in contact with the wet concrete determines the texture, shape, smoothness or roughness and sometimes the color of the concrete surface. Therefore, care must be given starting from planning up to the end activity of formwork so that the permanent concrete structure will be as planned.

"Although formwork and false work are classified as temporary structures, the same care must be taken in their design and construction as any structure of a permanent nature. Faulty design and construction of formwork and false work will reflect in the appearance of the finished concrete structure, and could result in partial or total collapse of structures with costly and sometimes tragic consequences, (Canadian Ministry of Transport, 1997)*."*

In designing and building formwork, the contractor should aim for maximum economy without sacrificing quality or safety. Size, shape and alignment of slabs, beams and other concrete structural elements depend on accurate construction of the forms.

Although the prime purpose of formwork is to shape and mould concrete by containing its flow in its liquid state to a desired alignment and smoothness, often the formwork materials that perform this function cannot be relied upon to give a satisfactory surface finish. The quality and selection of the formwork face is therefore critical in the visual appearance of finished concrete surface and it is the most important element in achieving concrete finishes. Even if the concrete mix is consistent throughout a project but the

formwork is poorly constructed and panel joints are badly fitted, the support system is not rigid enough to adequately resist the pressure from the liquid concrete; then the surface appearance of the concrete will be poor.

2.8. Factors Affecting Surface Quality of Concrete

In concrete construction, size, shape and alignment of slabs, beams, columns and other concrete structural elements mainly depend on accurate construction of the forms. The forms must be built to correct dimensions, must be sufficiently rigid under the construction loads to maintain the designed shape of the concrete, must be stable and strong enough to maintain large members in alignment, and must be substantially constructed so they can withstand handling and reuse without losing their dimensional integrity (Baxi, 2011). The formwork must remain in place until the concrete is strong enough to carry its own weight, otherwise, the finished structure may be damaged.

There are two major factors that decide how well the concrete will look in the final result. One is quality of the formwork and the other is how the concrete is placed and compacted.

2.8.1. Quality of Formwork Material and Workmanship

The quality of surface finish of the concrete is affected by the material of the form. The quality of the resulting concrete can be dictated by the quality of formwork materials and workmanship. A correct combination of form material and oil or other parting compound can contribute materially to eliminating air holes or other surface imperfections in the cast concrete. Many concrete surface problems such as discoloration, stains, and dusting are attributed to concrete formwork. Also, some deformed concrete surfaces are due to deformed formwork systems caused by repetitive reuse and inadequate support of formwork. The formwork and material quality has major impact on the off-form concrete quality unless it is designed and built accurately so that the desired size, shape position, correct location, quality and finish of acceptable quality of the cast concrete are attained.

(a) Smooth and flat concrete finish

(b) Honeycombing due to poor form quality

Figure 2.6 Effects of form materials on quality of concrete surface finishing(Kumar,2011)

2.8.2. Concrete Placement and Compaction

The impact of placing fresh concrete can vary depending upon the height of the forms or the height of the drop of concrete. Placing concrete into forms of small height will have low impact, but on higher structures, especially walls, the incoming concrete will apply additional force to the plastic concrete already in place which will transmit this added pressure to the forms (theconstractor, 2018). The faster the rate of placement the greater is the impact pressure likely to be on the formwork system. Unless necessary considerations of these additional forces are concerned, they could cause deflection of forms and hence, bulged concrete surface and alignment problems might be effects. Therefore, forms and ties should have sufficient strength to withstand these impact loads and the rate of placing should not be greater than their safe load capacity. The other related factor which has impact on the formwork is vibration and consolidation of concrete. Consolidation of concrete by internal vibration causes temporary lateral pressures. Although information on magnitude is limited, care should be taken not to damage or break any of the ties while vibrating because this would transfer more load to the other ties and load the forms unevenly. External vibration with form vibrators increases loads on formwork systems even higher and causes variation of lateral pressures (Construct-Ed Inc., 2019).

The forms materials in turn, affect the vibration of fresh concrete. For example wood forms tend to absorb vibration but steel forms tend to reflect the vibrations and bounce them back.

2.9. Current Formwork Types for High / Mid Rise Buildings

In today's concrete construction, the type and systems of formwork used to mould fresh concrete plays significant role. It influences the quality of work, construction time, site safety and cost of the project. Different formwork systems provide a wide range of concrete construction solutions that can be chosen to suit the needs of a particular concrete structure. The selection of formwork types and design of the layout for building concrete structures are some of the most complex tasks in formwork construction, especially if the sheets are to be reused many times to form different concrete structural elements to take economic advantages.

2.9.1. Conventional Formwork

Conventional formwork is the most traditional/oldest type of formwork used in the construction industry, which uses timber, bamboo, and carpentry or assembling to complete the concrete construction. It is a formwork type which is still being practiced and very much suitable for small houses or low-rise building construction projects, mostly two – three stories (Loganathan & Viswanathan, 2016).

Although this type of formworks has advantages for low initial cost, low labor experience requirements and low weight, high floor cycle wastage, low reusability, poor finish, and high labor requirement are on the other hand, the disadvantages. This is the type of formwork where most of the carpenters started as daily laborers and takes longer time to assemble and erect. Figure 2.7 shows conventional formwork systems for slab and stair case.

Figure 2.7 Traditional formwork constructions (Swapnali & Karke, 2016)

2.9.1.1. Features of Traditional Formwork

Traditional formwork construction has been practiced for a long period of time since the introduction of Portland cement and suitable for small house or low rise building up to three stories till these days. Swapnali & Karke (2016) have also identified the common features of traditional formwork as follows.

- ✓ Usually timber in the form of plywood, planking, batten and joist are used as the basic material
- ✓ Installation of the formwork is on a labor intensive basis. Human workers need to enter into every corner to perform the formwork installation works.
- ✓ The work operation is so designed to allow a single worker can handle his work basically by oneself. Size and weight of each formwork panel is so designed in the right combination to be moved and lifted for installation by a single worker Except for simple hand-tools, limited machinery is required in the installation process.
- ✓ Every work location requires care to be taken by human workers. Every small, difficult accessible and awkward shaped location can be taken care of by human worker
- ✓ Works are repeated from location to location or from floor to floor.
- ✓ For example, when workers completed the installation of formwork on the lower floor, they need to get up to the upper floor and repeated the works again though they are basically the same.

2.9.2. Modern Conventional Formwork

Modern conventional type of formwork is similar to the traditional slab formwork method but more advanced materials such as steel props and various types of jacks (U jacks, T jacks) are used as supports in the formwork instead of timber supports and ply wood sheets are used instead of timber planks on slab decks, beams and columns. These advanced materials can reuse for several times.

The advantages of this type are low initial cost, low skilled labor requirement and can use in places where there are a lot of deviations in the structure.

Figure 2.8, Modern conventional formwork in building construction

(Malvankar, 2013)

2.9.3. System Formwork

Existing of high rise and complicated building structures have now requiring modern, time saving and economical formwork which conventional formwork doesn't fit. System formwork is a specialized kind of formwork, sometimes referred to as modern formwork, developed for improved features of concrete construction for different structures (Chavan, 2016). It has modular (prefabricated) components with casting panels and can suit the required shape, alignment, size and quality of concrete structures. System formwork is much more important in today's concrete construction in achieving speed,

safety, quality and economy (Deb, 2015). Its high initial investment makes it uneconomical for low rise buildings but economical for high rise building constructions through maximizing reuse of the forms properly.

"The speedy and quality construction is the biggest advantage in system formwork type while high initial cost is the main disadvantage and hence this is not economical to use in low-rise buildings. But this is the most economical form of formwork type to be used in high-rise building construction. Most effective way to speed up the work is to reduce the cycle time provided that the interruptions and quality aspects such as deflection, misalignment and misplacement need to be taken care (Dubey & Sagar, 2014)."

"Reusing formwork for concrete is one of the ways to reduce construction costs. The initial cost of formwork materials will drop to 40 percent after five reuses. The economic value or reusing formwork lies in the ease with which it can be stripped from concrete, (Deb, 2015)."

System formworks are modular and prefabricated off the building construction sites with high precisions for advanced concrete finishes in special building structures and require skilled labor in fixing (Jha, 2014).

There are also other modern formworks of proprietary also called semi system formwork types for advanced concrete features produced by qualified manufacturers in different countries, some of which are Doka, PERI, Dunne, and MIVAN (Swapnali & Karke, 2016). These patented manufacturers are producing modern formwork systems which are much important and economical in mass or high rise building construction projects and are not economical in small project even though they permit greatest quality and speed of construction as they are designed to be economical through maximum reuse of the form systems. Some of the system formworks currently in practice across the globe are Tunnel Formwork, table (flying) formwork, Climbing formwork, Slab formwork, Column formwork system and some are discussed below.

2.9.3.1. MIVAN Formwork Technology

MIVAN is an aluminum formwork system used in cast in-situ concrete wall and floor slabs, and provides cast monolithic structural system in one continuous pour. Large room sized forms for walls and floors slabs are erected at site. These forms are made strong

and sturdy, fabricated with accuracy and easy to handle. They afford large number of repetitions (around 250 times). The system of Aluminum forms has been used widely in the construction of residential units and mass housing projects and it is fast, simple, adaptable and cost – effective. It produces total quality of work which requires minimum maintenance and when durability is the major consideration. Due to the fine tolerances achieved in the machined metal formwork components, consistent concrete shapes and finishes are obtained floor after floor, building after building, confirming to the most exacting standards of quality and accuracy, (Swapnali & Karke, 2016)

Figure 2.9 MIVAN Aluminum formwork (Swapnali & Karke, 2016)

2.9.3.2. Tunnel Formwork

Tunnel formwork system is the latest innovations in the formwork industry. It is a box sized steel fabricated form that allows the wall and the slab to be casted in a single operation in full or half tunnel sizes (Indian Ministry of Railways, 2017). Tunnel forms therefore, enable construction of walls and floors together which make the process ideally suitable for both high and low-rise mass housing projects. Once reinforcement is placed, concrete for walls and slabs can be poured in a continuous discharge. The use of repetitive cellular structures to construct both horizontal and vertical elements together is something that has got the potential to transform the construction industry.

Tunnel formworks are easy to clean and reuse and also enables high quality surface finishes. Engineers are also assured of high dimensional accuracy of structures. The repetitive nature of the construction work is another plus point with this type of formwork system, adding to its other advantage of requirement of a very small team on site. Tunnel forms can be either full or half tunnel depending on nature of the project as indicated in Figure 2.10 taken from, Report on Modern Formwork System, Indian Ministry of railways.

(a) Half tunnel systems (b) Full panel systems

Figure 2.10 Tunnel formwork systems (Indian ministry of rail ways, 2017)

2.9.3.3. Column Formwork

Modular in nature and allowing for quick installation on site, column formwork systems are now available in a variety of materials depending on the concrete finish requirement (Indian Ministry of Railways, 2017). Formwork systems for different column sizes can be easily assembled on site and entire working process is also simple. Once the concrete is poured and hardened, the formwork is then stripped and moved to the succeeding position.

Column formwork systems have great advantages because of the highly engineered nature of the formworks. They ensure greater control over the construction operations which automatically means reduction in wastage, time and labor costs.

Figure 2.11 High column formwork systems (Indian ministry of rail ways, 2017)

2.9.3.4. Table (Flying) Formwork

Table formwork systems are engineered slab formworks consisting of tables assembled to form larger area and reused on multiple stories of a building without being fully dismantled. The assembled sections are the either lifted per elevation or using cranes from one storey to another. The repetitive process ensures that there is almost negligible wastage comprises of slab formwork 'Fillers' used to fill gaps between the tables and walls. The mobility factor, along with the relatively easy installation means that these systems are widely used in construction projects where repetitive structures, where flat slab and slab layouts are involved.

Since the assembled units can be moved easily, it ensures fast track construction, in addition to the high quality surface finish. Also, the wastage generated is negligible as compared to the conventional formwork systems that are still used. Another key factor that should be noted is that with the table formwork system fast track construction is achieved, which in turn leads to cost savings, particularly in the case with structures with flat slabs.

Figure 2.12 shows the applications of table (flying) formwork, a) assembling the form, and b) lifting the table to the upper stories.

a) Assembling table form at site

b) Moving (lifting) the table to upper storey

Figure 2.12 Table (flying) formwork before erection in position (PERI handbook)

2.9.3.5. PERI and Doka Formwork Groups

Both Doka and PERI are proprietary formwork systems. These formwork types are classified also as semi system formworks (Sandip & Atterde, 2014). Doka is an Austrian company whereas PERI is German`s company which has established many products and system equipment on the market. Formwork Girders, various types of wall, column and beam formworks, patented concrete release agents, special formwork systems are among the main products of PERI. As compared to other formwork manufacturing firms, PERI has varieties of formwork systems.

Similarly, Doka Timber-beam floor formwork, Doka climbing systems, Doka formwork release agents and varieties of wall and column formworks are some of its products and share almost same methods with PERI (Tarekegn, 2010).

2.9.3.6. Jump /Climbing Formwork Systems:

Climbing formwork is one of the most internationally popular modern formwork systems normally used in construction of high rise building concrete elements. It consists of formwork systems complete with working platforms that support itself on the concrete cast earlier. It therefore does not depend on support from the building. Some of the concrete elements that are constructed using jump form systems include vertical concrete elements such as core walls, shear walls, bridge pillars and lift shafts. The use of jump form systems also helps saving costs of formwork construction by cutting down on labor

costs, especially in countries where labor is expensive and increasing construction efficiency, (Indian Ministry of Railways, 2017).

Figure 2.13 Climbing formwork systems for construction of vertical concrete elements (Indian ministry of rail ways, 2017)

Generally system formworks are more imperative nowadays to the success of construction projects in terms of quality, speed, safety and cost. Table 2.1 below describes the advantages and disadvantages of system formworks compared to conventional ones.

Table 2. 1 Advantages and disadvantages of system formworks over conventional (Assadi, 2017)

Advantages:	**Disadvantages:**
1. Number of times reusable than conventional formwork materials 2. Have lighter weight than conventional ones 3. Mechanization of construction is higher 4. Highest safety standard 5. Lesser labors requirements 6. Great accuracy and quality finish	1. Use of skilled labors is absolutely necessary as it is new technology and need of training to laborer and carpenters 2. This system is uneconomical and cannot be used in small projects since it is not profitable in such areas. 3. It is somewhat difficult to use this technology, when there is large variation

7. Higher productivity and lesser project duration
8. Economical in high rise building projects through large number of reusability

in forms since they are prefabricated off the site

2.10. Formwork Failures

In formwork designing and construction, the contractor should aim for maximum economy without sacrificing quality or safety. Short-cuts in design or construction that endanger quality or safety may be mistaken economy. If forms do not produce the specified surface finish, for example, minor failures such as excessive deflection of forms, bulges in the concrete, honey combing etc. may require much hand rubbing of the concrete ; or may require expensive chipping and grinding and major failure which is total collapse of structure may happen which is total loss to the contractor. Obviously economy measures that lead to formwork failure also loss their own purpose.

Generally, formwork failures are the cause of many accidents and building failures that occur during concrete construction, usually when fresh concrete is being placed.

Figure 2.14 Formwork Collapse Cases - Industrial Building in Kwai Fook Rord (Chung, 1995)

2.11. Causes of Formwork Failure

Among the accidents and failures that occur during concrete construction, many are formwork failures, which usually happen at the time concrete is being placed. A system of formwork filled with wet concrete has its weight at the top and is not basically a stable structure. An interesting aspect of formwork failures is that often the same design, or even the same form, has been used several times with no accident, perhaps in some cases this may be just a matter of luck and fortunately no strong lateral loads may occur. Then in another bay, probably under the same conditions, the concrete placement and vibration could lead the formworks unexpectedly collapse.

Generally, some unexpected event causes one member to fail, then others become overloaded or misaligned and the entire formwork. But, good practice in designing and constructing formwork, in handling and using it can provide safety as well as efficiency.

Construction project site human fault practices due to indifference, rush, or lack of knowledge also causes failures. One careless or irresponsible action may wipe out all the safety issues introduced in the design process.

Therefore, the formwork designer should plan systems that can be erected by the least skilled workmen likely to be available. At the same time, safe and correct work procedures should be enforced by job site supervision and training.

In general, the following are some of the main causes of formwork failures from past experiences (Nemati, 2007):

I. **Improper stripping and shore removal: -** Premature stripping of forms and shores results from a desire for economy, and careless practices in re-shoring have caused various failures or deficiencies in the completed concrete structure.
II. **Inadequate bracing: -** Inadequate cross bracing and horizontal bracing of shores is one of the factors most frequently involved in formwork accidents. Investigations of cases involving thousands of dollars of damage show evidence that the damage could have been prevented or held to a minor

amount if only a few hundred dollars had been spent on diagonal bracing for the formwork supports.

III. **Vibration: -** Forms sometimes collapse when their supporting shores or jacks are displaced due to vibration caused by passing traffic or the movement of men and equipment on the formwork, or the effect of vibrating concrete to consolidate it.

IV. **Unstable soil under mudsills, shoring not plumb:-** (A plank, frame, or small footing on the ground used as a base for a shore or post in formwork),

V. **Inadequate control of concrete placement:-** Failure to regulate properly the rate and order of placing concrete on horizontal surfaces or curved roofs may produce unbalanced loadings and consequent failures of formwork

VI. **Lack of attention to formwork details: -** Even when the basic formwork design is soundly conceived, small differences in assembly details may cause local weakness or overstress leading to form failure. This may be as simple as insufficient nailing, or failure to tighten the locking devices on metal shoring.

2.12. Common Defects of Concrete and Quality of Formwork

The quality and surface appearance of the concrete structures is normally dedicated by the quality of formwork materials and systems. Using formwork materials with inferior quality usually leads to unsatisfactory result and defects. Failures to achieve the required results in concrete construction may cause additional treatments and elongated time frame to rectify the defects on the surface of concrete after removal of the formwork, which could lead to uneconomical activity. Honey combing, poor construction joints, uneven concrete surface, staining of concrete, bonding of forming material are some of the most common defects in concrete construction caused by poor form quality of formwork materials (Jha, 2014).

Therefore, formwork systems need to be designed & built accurately so that the desired size, shape position, correct location, quality and finish of acceptable quality of the cast concrete are attained.

(a) Honey combing

(b) Poor Construction Joint/Offsets in Concrete

(c) Plywood Grains Stuck on Concrete Surface

(d) Forms stuck on concrete surface

Figure 2.15 Common defects due to poor formwork quality

2.13. Formwork Treatment and Release Agents

Formwork surface treatments are nowadays common with various types, from applied coatings to form liner systems. Many face contact materials have their own individual texture and absorbency characteristics which require differing treatments to ensure the

best possible results. A form coating or release agent is often applied inside surface of formwork (surface of the form which has direct contact with the surface of concrete) to the concrete from bonding to the formwork elements. Coating can be applied by spraying, brushing, or by roller. Form coating facilitates the operation of removing the formwork after the concrete has gained enough strength to support itself, (Mohit, 2016)

2.13.1. Function of Release Agents

The general functions of the formwork release agents are assisting clean and easy stripping of a mould / formwork from concrete without damaging the concrete or the formwork and ensure high quality fair faced stain free concrete. In order to achieve the satisfactory concrete release from a mould / form, it is imperative to choose the correct release agent.

Another function of coating is sealing the surface of the wooden elements which prevents the water in freshly placed concrete from being absorbed by the wood. Form release agent should not affect or react with the finished concrete. Form release agents are generally used for the following three main reasons according to (Sengupta & Rajashi, 2018):

1. To prevent forms such as plywood, from sticking to the concrete surface.
2. To produce good finish to the exposed concrete surface after removal of forms.
3. To facilitate longer life and more repetitions of the moulding member of the formwork especially, timber products like plywood.

2.13.2. Applications of Form Release Agents

It is not only the type of form release agent which affects the formwork construction, but also the amount of the release agents applied on the surface of the form materials/ mould. “Too much release agent is as bad as too little amount (Eastern Petroleum, 2018)”

•**Too little** –surface damage to concrete and formwork (surface plucking / mould stick: where patches of the concrete surface stick to the form and are then pulled off the face during formwork removal.

•**Too much**–blow holes, staining, colour variation, efflorescence, dusting, even retardation of the concrete. Excess oil can also cause ground contamination. Excessive application results in 'pooling'. If there is an over application, distribute it to the whole surface of the form with a clean cloth for good and uniform results.

2.13.3. Form Materials

Forms made of absorptive material must be saturated with water prior to use so that the fresh concrete does not cause the form to swell upon contact. Saturating the wood or other absorptive material may have to be repeated if it becomes dried out by exposure to air and sun before use. Oiling is also necessary between uses to help tighten joints, provide a better finish and make stripping of forms easier.

Reuse of forms with high absorbency is a questionable practice because some become too nearly saturated and begin to affect the color of the concrete (Metin, Osman, & Serkan, 2004). Materials with a plastic surface provide more constant and predictable treatment of the concrete surface. Proper care and coating with form release materials can increase their life potential.

Steel-faced forms produce uniform color, but sometimes cause blowholes to form in the concrete during vibrating. Rust- preventing oils should be used on steel-faced forms to avoid discoloration of the concrete surface from iron oxides.

2.14. Formwork Construction in Ethiopia

Building construction industry is one of the sectors, where mass construction is taking place in Ethiopia, especially in urban areas, and where many labours are employed. Many high rise buildings are constructed in urban areas of the country, especially in the capital Addis Ababa, by local and international contractors. Clients choose contractors based on the performance of the contractors and their own financing capacities. Most of the banks building constructions in Addis Ababa are awarded to foreign contractors and proceeding with visible success in terms of quality, faster construction time and safer site conditions while it is not a case by local contractors. The quality of work reduces the requirement of additional treatments of concrete surface, speed of construction allows the

owner early utilizations of the building structure and safe practices also play great role in reduction of injuries and form failures (Amare, 2015).

Concrete work is the major of the building constructions and formwork is by which the success of construction is determined in terms of quality, construction time, cost and safety. Despite the development and continuity of high rise building constructions in Addis Ababa especially, by local contractors; quality, time, cost and safety still requires improvement. Most of concrete elements are in need of additional treatments to make the concrete surface straight and smooth by chiseling and plastering with cement mortar of lesser strength than the removed concrete which is also time taking and costly.

Considering contractors use ready mixed concrete, the type of formwork used and the way it is erected determines success of concrete construction in terms of quality, construction time, cost and safety. As per the classification of formwork for the purpose of this research, conventional and modern conventional types of formwork are the majority taking place in Ethiopian building construction industry with a highly labor intensive manner, lower productivity, high wastage, long time and low quality of output (Amare, 2015).

(a) Timber & steel props, plywood form

(b) Steel column panels store poorly at site

(c) Unsafe column casting (d) poor finishing/ pieces of forms bonded on surface

Figure 2.16 Types of formwork and concrete finishing quality of buildings in Addis Ababa by local contractors;

2.15. Need for System Formwork in Ethiopia

Although the conventional formwork systems which are made of wooden scantlings and timber runners have often permitted easy forming and erecting at site, they tend to be labor intensive, take substantial time of construction, and mostly concrete surface needs additional treatments after removal of the formwork which needs additional time and finance. The other most common problem of such formwork systems is, they tend to lose their structural and dimensional properties over a period of time and lead to safety problems after repeated usage which in turn leads to maximized wastage of forms. "Many of the accidents take place in Reinforced Cement Concrete (RCC) constructions are because of inferior formwork and scaffolding, (Chavan, 2016)."

Developing the formwork situation parallel to the booming occurrence of mass building constructions is significant in today`s construction, generally in the Ethiopian building construction sector and specifically in the high rise building constructions in Addis Ababa. Some of the high-rise building constructions, mostly bank buildings, in Addis Ababa by the international contractors have often being preceded with a fast tracking, safe and quality manner. Usually the formwork scenario in Ethiopian building construction industry especially in local construction companies can be stated as:

- Conventional and modern conventional forms are most commonly practiced which is labor intensive, time taking, unsafe and with surface finishing in need of additional treatment.
- High wastage of formwork materials; the timber material reusability is limited because of unplanned and repeated nailing even where nailing is not required, for example nailing pieces of corrugated iron sheet on plywood to stop leakage of concrete paste through the joints.
- Low labor productivity and limited circulation spaces through props and braces due to closely fixed bracings and propping, especially when timber products used.
- Higher wastage of concrete due to leakage through sheeting materials and one of the additional treatments is removing the cement grout through the sheeting joints by chiseling which then followed by plastering to level the surfaces and which is also false economy, unsafe and poor quality.
- Higher wastage of form materials and limited reusability due to unplanned nailing and poor storage.
- Unskilled labor due to lack of willingness in construction companies to give training, fearing laborer would leave at the end of training, and hence have chosen to continue with low productivity labor.

In today's building constructions across the globe, overall economy saving, faster construction time and high quality off-form concrete are met through innovations of modern (system) formworks. Modern formwork systems are designed for speedy and efficient construction and permits placing fresh concrete in larger amount with a single pour.

In building construction projects some costs of resources like material cost are considered unique based on the type and design of the building. But the cost for most of the resources such as labor, equipment and machinery, safety, waste materials handling, finishing quality and the duration of the project are directly affected by the technologies and the construction methods practiced in the project. The speed of the project is directly affected by the formwork type used in the project. This is the most critical in high-rise building construction. When using latest technologies, the labor requirement and the time duration can be minimized in the project, mainly for the super structure, (Gunatilaka &

Wijesekara, 2016).Although labor cost is not considered as expensive in Ethiopia's construction industry, the general method of construction with labor intensive and low productivity usually makes the project duration elongated which intern makes the total project cost increased. Because when considering a construction project, there are many cost components contributing to the total cost of the project as described above. According to researches preliminary cost is a key cost component when comparing the total cost of a project, and the duration of the project is the governing factor for the preliminary running cost. This means as the duration of the building construction increases, the preliminary cost increases which also mean total project cost increases, (Sandip & Atterde, 2014)

Total Project Cost = Materials and labor + Preliminary cost + Machinery & equipment + Waste material handling + Safety + Finishes + etc.

Preliminary Cost = Salaries + Electricity + Telephone + Welfare + Security + etc.

Making the building construction with latest formwork technologies has been giving lots of advantages through improving quality, saving cost by maximum reuses, minimizing safety problems, minimizing additional treatments of finished concrete surfaces, fast tracking construction and hence early utilization of the building etc.

"Now focus has to be shifted to other key factor "Formwork", to face the challenges for the completion of fast track projects. By going in for system formwork, substantial savings are possible by faster return on investments (Chavan, 2016)."

Modern formwork systems are also stiffer and stronger than conventional formwork, amenable to systematic design, allow big number of repetitions, can be easily and speedily erected and dismantled by less skilled crews, as they are designed to be so. According to Chavan (2016) these systems are pre-engineered to provide increased accuracy and minimize waste in construction and most have, built-in health and safety features. Better quality buildings at faster speed of construction rate, cost effective and environment friendly manner can be achieved by using advance formwork systems.

Rapid improvements in formwork system, along with the innovations in concrete as a material have led to a radical change and quality, safer, faster, sustainable and more efficient construction is possible nowadays.

This formwork is an important enabling work, which has to keep pace with the modernization of concrete construction. "As time progressed, the use of advanced techniques of formwork for construction of structures has gained wide acceptance. In the present competitive market, speed and efficiency are of prime importance; thus by use of advanced technology, the duration of project is reduced by using latest materials, equipment's and techniques which are effective, durable and intensify the pace of construction, (Kazi, 2015).

Therefore, having known the impact of formwork on the process of the whole building construction in terms of cost, quality, time and safety, lots of improvements have been done on the formwork construction across the globe which Ethiopian building construction is in need of. Most of the researches done in formwork construction in Ethiopia have focused on productivity, comparison of form materials (Amare, 2015), application of modern formwork (Tarekegn, 2010), and they revealed low productivity, requirement of additional treatment, no matter whether the form material is steel or timber as far as it is conventional, and limited applications of modern form systems. Table 2.2 shows the major characteristics of system and conventional form woks in general.

Table 2.2 Characteristics of system and conventional formwork construction (Karke, 2016)

Ser. No.	Characteristics	System formwork	Conventional formwork
1	Speed of construction	1-4 days cycle per floor	21 days min. cycle time
2	Quality of surface finish	Excellent, no plastering	Bad, plastering needed
3	Preplanning of formwork system	Required	Not required
4	Type of construction	Cast-in-situ Cellular construction	Simple RCC framed construction
5	Wastage of formwork materials	Very less	In great amount
6	Accuracy in construction	Accurate construction	Less accuracy

Ser. No.	Characteristics	System formwork	Conventional formwork
7	Coordination between agencies	Required	Not necessarily required
8	Resistance to earthquake	Good	Less than modern
9	Removing of floor slab forms without removing props	Possible	Not possible
10	Need of any timber or plywood	Not required	Are main components
11	Re-usage value of formwork	250 - 350	Maximum 50
12	Suitability for high rise construction	Very much suitable	Not suitable
13	Initial investment in the system	High	Less
14	Economy in construction	Economical for mass housing	Economical on small scale construction

2.16. Removal of Formwork (De-shuttering)

The time for removal of formwork mainly depends on the type of concrete structural elements. Forms for vertical members, which are non-load bearing parts, such column and concrete walls can be removed after 16 hours as per BATCODA specification in Table 2.3 below. Formwork removal should be given adequate considerations when forms are being selected for better result. Hammering against the face of forms could leave marks in face or edges of forms and cause spots in the concrete the next time the forms are used (Deb, 2015). Therefore, proper striking of forms can help reduce damage of forms and hence increase reuse values.

Finishing of concrete may require treatments after form removal. The most common treatments are grinding of fins, patching tie holes or honeycomb and correcting surface defects such as bulging and offsets. De-shuttering (form removal) must be designed for easy operations so that form materials will be used many times to make the process

economical and safe. Forms shall be fabricated for easy removal without hammering or praying against concrete surfaces. Provide crush or wrecking plates where stripping may damage cast concrete surfaces.

"The best form carpenters are ones who plan to strip before they plan to build, (Baxi, 2011)*."*

2.16.1. Ethiopian standards recommendations for formwork removal

The most common Ethiopian standards in building construction are BATCODA (1991) specification and EBCS. The minimum periods required to strip formwork for building structures are indicated in Tables 2.3 and 2.4 as per BATCODA and EBCS-2 respectively. The time of form removal is determined mainly by the strength development of the concrete and the function of the formwork. "No undue deflection or damage whatsoever shall be caused to a structure by the removal of formwork. No formwork shall be removed until the concrete has hardened sufficiently (BATCODA, 1991)." In the absence of more accurate data, the following minimum periods are recommended.

Table 2. 3 Minimum periods for Formwork Stripping as per BATCODA (1991)

Vertical formwork to columns, walls & beams	16 hours
Soffit formwork to slab	21 days
Props to slabs	14 days
Soffit formwork to beams	21 days
Props to beams	14 days

Table 2. 4 Minimum periods for Formwork Stripping as per EBCS-2 (1995)

For non-load bearing parts of formwork (e.g. vertical formwork of b~; formwork for columns and	18 hours

walls)	7 days
For soffit formwork to slabs	14 days
For props to slabs	14 days
For soffit formwork to beams	21 days
For props to beams	

2.16.2. ACI Recommendation

(ACI 347 R-04, 2004), a guide to Formwork for Concrete, recommends that engineer specified criteria based on strength gain is used to determine form removal time. In the absence of such criteria, the guide contains recommendations for the length of time that formwork should remain in place when the air temperature is above 10^{o}C as indicated in Table 2.4.

Table 2. 5 ACI General Guidelines for Form Stripping

Members	**Time**	
Walls	12hrs	
Columns	12hrs	
Sides of beams and Girders	12hrs	
Joist, beams, girder or bottoms	Where design live loads are:	
Under 10ft(3m) clear span	<Dead load	>Dead load
10 to 20ft clear span	7days	4days
	14days	7days
	21days	14days
One way floor slabs		
Under 10ft(3m) clear span	4days	3days
10 to 20ft clear span	7days	4days
Over 20ft clear span	10days	7days
Two-way floor slabs	*Contingent on re-shores being placed immediately after striping*	

2.17. Summary

The building construction industry in Ethiopia has been massively developing in the past decades. Buildings of different purposes or infrastructure projects are being constructed in large amounts every year in cities of the country, especially in the capital Addis Ababa.

According to Wong (2015) formwork is one of the key factors that guarantee the success of these building construction projects in terms of quality, safety, cost and time. It contributes a most important part of cost in most of the building construction projects. The selection and effective use of formwork can lead to the success of a project. An appropriate formwork system is always cost and labor effective, suitable to handle, fulfilling requirements, and most significantly, it have to be safe to use all before, during and after concrete placement.

Although the main purpose of formwork is moulding or holding freshly placed concrete until it hardens and supports its own weight and to a specified shape, size and alignment, the continuous need of achieving better concrete surface features, construction time and cost minimizations, and safety makes the construction industry keep continuous improvements of formwork for concrete.

The currently available formwork types are categorized into three major parts, namely, *Conventional formwork* which is oldest type and uses timber props, bamboo, and timber planks etc., *Modern Conventional formwork* which is advanced conventional and uses steel props instead of timber, plywood and steel sheets instead of timber plank or panels, and *System Formwork* which is a modular or prefabricated type of formwork designed for advanced concrete features.

The quality and surface appearance of the concrete structures is normally dedicated by the quality of formwork materials and systems. Using formwork materials with inferior quality usually leads to unsatisfactory result and defects which is the case in Ethiopia especially by local contractors (Amare, 2015). Failures to achieve the required results in concrete construction may cause additional treatments and elongated time frame which is false economy.

Selection of the formwork system which suits for cast in place reinforced concrete is a critical decision that can affect the whole construction process. With proper selection of formwork system then, cost of construction can be significantly brought down, quality of the concrete can be great, the project will be completed within stipulated time and injuries can be minimized.

3. RESEARCH METHODS AND MATERIALS

3.1. Introduction

This chapter is intended to present the methods and materials used in this research as well as to introduce the research approach and procedures used. It targets at explaining the methodological process used to carry out this research based on the objectives of the study. This includes, limitations of the research, the detail section which describes how data are collected, questionnaires survey made, and detail processes how the analysis of the data was made.

3.2. Research Limitation

This research is limited to the current practices and trends of formwork systems particularly in building construction industries in Addis Ababa. It specifically focuses on formworks used in superstructures of the building construction projects; practical procedures throughout the life-cycle of the formwork systems and their outputs.

3.3. Research Design

Three procedural stages are applied in this research, namely, the secondary data examination from literatures on formwork, primary data collection from current formwork practices and trends, through observations at building construction project sites in Addis Ababa and questionnaire method, then evaluation of the two data from the two sources.

The populations for this research are Grade-1(GC or BC) and Grade-2(GC or BC) contractors, registered from Hamle 01, 2009 to Tir 24, 2010 E.C as per ministry of construction. Data is collected from building project sites ran both by local and international contractors to clearly examine the procedures and trends in the formwork construction before, during and after placement of fresh concrete.

3.4. The Research Questionnaire Design

The questionnaire was designed based on a combination of examination of past researches dealing with the materials, types, methods, practices and economy of

formwork systems for concrete in building construction and researcher's knowledge on the current formwork practice of local contractors.

The questionnaire, which was accompanied by a cover letter, consisted of six parts starting with general information of the respondents and ended with asking what the future of formwork construction in Ethiopia would be. The questionnaire was a mix of organized (close ended) and open ended type of questions to let the respondents give brief information.

3.5. Rationale of Research Questionnaire

As aforementioned in section 3.4, a questionnaire of six sections is prepared to explore the current formwork practices on the selected building projects. The questionnaire is intended to gather information based on the ongoing practice in the selected projects in the capital perceiving it is representative of building projects in the whole country.

The first and second sections are intended to assess the status of the respondent and the company considering that it would help in getting actual information about the ongoing formwork construction systems in Ethiopia, particularly in Addis Ababa.

Section 3 covers on formwork Types, Materials and methods given that there are three main categories of formwork, namely, conventional, modern conventional and system formwork currently across the globe. This is to make it clear to the respondents so that actual information could be collected.

Section 4 is dealing mainly with the formwork design and selection criteria of construction companies, allowing the respondents to explain their formwork selection criteria and to rank influential factors provided in table, also letting them to add any influencing factors.

Section 5 is provided about to deal with the current practice of formwork in the construction companies regarding the number of reuses, limitations and replacement. This section is provided to collect information on the situations of the companies, concrete finishing standards, production and cost factors, cost distributions, advantages of contractors` vast experience in selecting formwork etc.

The last section is about to collect information on economic considerations and cost components of formwork currently being practiced. This section is consisted of 2 questions focusing on the market situations and detailed cost components.

3.6. Location of the Research

Although the increased population and business activities lead to fast urbanization across different towns and cities of Ethiopia, where vast high rise buildings are developed, it is found important to conduct this research paper in Addis Ababa city. Because the capital Addis Ababa is a city where massive multistory building developments are taking place both by local and international contractors, and majority of the contractors reside. Hence the location for this research is set for projects in Addis Ababa building construction industries.

3.7. Target Population

The term population denotes the collective or entire entities, units, subjects, or members that conform to a set of conditions and target population is the population from which the researcher is going to take data for a specific problem. Populations might be small or big which forces the researcher choose a system of conducting the research by; either to consider the entire population or part (portion) of it depending on the economy and time. A smaller population can be studied more concisely and with higher precision at a fixed cost and time than a larger population (Cochran, 1963).

The populations for this research paper are set to be contractors of grades 1 and 2 (GC &BC) considering the experience and financial capacities they have, which affects the process of formwork selection, and time and economy for the research.

3.8. Research Sample Size Determination

Many researchers reflect in research activities that it is believed investigation would be better, if all elements or member of the population could be investigated. But due to different constraints in the real areas such as time and economy, representative units (samples) of a population are commonly measured. The advantage of using a sample

(proportion of population) is that it is more practical and less costly than collecting data from every members of the whole population although some errors might be expected.

"In addition to the purpose of the study and population size, three criteria usually will need to be specified to determine the appropriate sample size: the level of precision, the level of confidence or risk, and the degree of variability in the attributes being measured (Michener, 1976)."

For larger populations hence, it is important to decide what portion of the population is really of important to investigate. The accuracy may not be as of small populations, where entire population is investigated, and hence larger margin of error is expected.

A number of formulae are available to determine sample size one of which is based on a proportion. For populations that are large, (Cochran, 1963) developed an equation to yield a representative sample for proportions.

$$n_0 = \frac{Z^2 pq}{e^2} \quad \text{.....Equation 3.1}$$

Where;

Z = Z value (e.g. 1.96 for 95% confidence level)

n_0 = required sample size,

p = proportion of the population having the characteristic (0.5 is used)

q = 1-p =1-0.5= 0.5

e= the margin of error or degree of precision (10% is used here).

Researchers recommend that proportion of the population (p) may be known from prior research or other sources; and in case of no information or if it is unknown to use p = 0.5 which assumes maximum heterogeneity (dissimilarity) (i.e. a 50/50 split). The degree of precision is the margin of error (e) that is acceptable.

$$n_0 = \frac{1.96^2 * 0.5 * 0.5}{0.1^2} = 96.04 \approx 96$$

But this sample size may take long time and higher cost to cover and Cochran also developed a formula for finite population correction for proportions.

$$n = \frac{n_0}{1+\frac{(n_0-1)}{N}} \quad \text{.....Equation 3.2}$$

Where;

n = the sample size,

n_0 = required sample size, and

N = the population size.

Contractors are working in Ethiopia, registered as GC, BC, RC, SC and PF. As per ministry of construction, assessment and company certification bureau 109 BC1 & GC1, 35 BC2 & GC2 were registered from Hamle-1, 2009 to Tir-24, 2010 E.C for 2010 budget year and found in Addis Ababa. Therefore, a total of 144 grade 1(BC1 & GC1) and grade 2 (BC2 & GC2) contractors are taken as a population (N) for this research.

Therefore, the new sample size is;

$$n = \frac{96}{1+\frac{(96-1)}{144}} = 57$$

Therefore, based on the above sampling method and criteria, 57 samples were selected. The sample projects to be studied here are building projects being undertaken in Addis Ababa area. To understand the impact of formwork on the building construction industry, superstructure parts with minimum height of G+6 are given more emphasis. This is because the impact of forms is more important in the superstructures and repetition of forms are practiced in high rise building projects which allows maximum reuses if forms are used properly.

3.9. Data Collection Methods

In this research, data collection methods include questionnaire of 6 sections explained above in section 3.5, site case studies (observations) and personal interviews at sites and offices. The site visits involved observations and interviews to find out the practice of formwork, such as how materials were being stored, handled, assembled, erected and dismantled; treatments of forms, and concrete surfaces related to formwork, sequence and methods of construction, number of formwork reuses, areas of formwork failures and improvement necessities, reasons of materials selection and methods of construction, form type and floor cycle and cost of the formwork construction in the selected building construction projects.

The main aim of the data is to know the current formwork construction activity in Addis Ababa, Ethiopia, and understand the progress of formwork to the building construction industry.

From a total of 57 copies of questionnaires distributed to building construction projects located in Addis Ababa, 36 copies were returned. The questionnaires were distributed to grade one and two, specifically to general and building contractors.

This is mainly because these top grade contractors could have financial capacity and experience on big buildings formwork constructions which help to select appropriate formwork.

Table 3. 1 Location of questionnaire distributions and rate of return

S. No	Locations of questionnaires distribution	Questionnaires distributed	Questionnaires returned	Rate of Return (%)
1	Megenagna and 22 areas	9	6	67%
2	Around Lancha and Gotera	5	3	60%
3	Piassa and Arat kilo areas	8	4	50%
4	Around stadium and Flamingo	7	4	57%
5	Around Dembel and Wollosefer	7	4	57%
6	Around Ayat	6	5	83%
7	Bole areas	8	6	75%
8	Around Gerji	3	2	67%
9	around CMC	4	2	50%
	Total	**57**	**36**	**63%**

The total return rate as indicated in Table 3.1 above is 63% of distributed questionnaires. Return rates with higher percentages would minimize error or level of precision but it was a challenge to collect distributed questionnaires due mainly to respondents` time to fill necessary information and willingness, and the researcher conducted the analysis with returned data.

3.10. Method of Data Analysis

As described above this research is considering to questionnaire, case study and interviews to collect data. The method of analyzing the collected data is based on ranking the frequencies of responses to the factors (requirements) which have influences or

significance of formwork design and selection. And the ranking is based on relative importance index (RII) or Likert scale, which is expressed as follows.

$$RII = \frac{\sum W}{A*N} = \frac{5n_5+4n_4+3n_3+2n_2+1n_1}{5*N} \quad \text{.....Equation 3.3}$$

Where,

W—weighting given to each statement by the respondents and ranges from 1-5;

A—Higher response integer (in this case 5); and

N—total number of respondents

n_i - the variable expressing the frequency of the i^{th} response

The levels of responses are:

1= little influence, 2=moderate influence, 3 = high influence, 4 = very high influence, 5 = extremely high influence

3.11. Summary

Generally, the procedures followed here in this research are illustrated in figure 3.2 below.

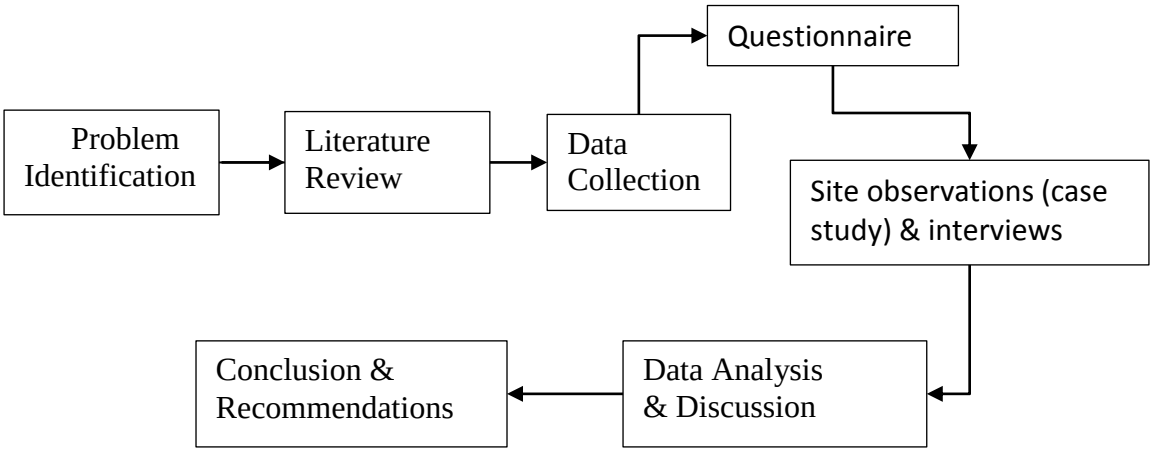


Figure 3. 2 Flow chart of Research Methodology

4. DATA ANALYSIS AND DISCUSSION

4.1. Introduction

This chapter is where the gathered data through questionnaires, site observations (case studies) and unstructured interviews on the current formwork construction practices in Addis Ababa building construction sites, are to be analyzed and discussed.

4.2. Data Analysis and Interpretations

Information collected from the building construction sites in Addis, the research study area, are discussed complying with the objectives of this research set at the beginning. And the objectives were;

- To identify formwork types and materials used at building construction project sites in Addis Ababa undertaken by local and international contractors;
- To identify formwork selection criteria and factors affecting formwork selection;
- To identify major causes which affect formwork practices and impacts to the finishing surface of concrete structural elements;
- To assess economy of formwork.

4.3. Profiles of Respondents and Selected Building Projects

4.3.1. Profiles of Respondents

Respondents to the returned questionnaires have 2 years to 25 years of experiences in the construction industry in different positions as indicated in Table 4.1. 42% of the respondents, which is highest rate of Reponses, have a position of site engineers and they were the one to reply nearly for each of the questionnaire than anyone else.

About half (50%) of the total respondents have 0-5 years of experience in construction industry while the remaining have more than 5 years on the field.

Table 4.1 Profiles of respondents

S. No.	Respondents profiles	Frequency	Rate (%)
1	**Position**		
	Owner		
	Project manager	6	17%
	Office engineer	11	31%
	Site engineer	15	42%
	Other	4	11%
	Total	**36**	**100%**
2	**Experience in construction industry**		
	0 to 5	18	50%
	5 to 10	10	28%
	10 t0 15	5	14%
	15 to 20	2	6%
	20 to 25	1	3%
	Total	**36**	**100%**

4.3.2. Profiles of Selected Companies and Building Projects

From the respondents, 81% were grade-1 contractors while the remaining are grade-2 contractors as indicated in Table 4.2. Contractors of grades 1 and 2 are selected for this research due mainly to perceptions the researcher had, that these two higher grade contractors have greater finance and experience in the construction industry which affects the selection and design of the formwork practices undertaken currently; and not to conclude lower grade contractors can`t select and build in a better way.

Table 4. 2 Profiles of selected companies and building projects

Grade of contractors	Frequency	Total	Rate (%)	Minimum height of bldg. (floor)	Owner	
					Private	Public
GC-1	19	29	81%	G+10	13	6
BC-1	10			G+9	7	3
GC-2	5	7	19%	G+8	2	3
BC-2	2			G+8		2
Total	**36**				**22**	**14**

4.4. Types of Formwork Used

As mentioned in Section 2.9, the literature review part, the types of formwork currently on use are generally classified into three for the purpose of this research, namely, conventional which is the most traditional/oldest type and uses timber, bamboo, and carpentry; modern conventional, which is similar to conventional but uses steel for supporting members and sheeting, plywood and different jacks; and system formwork, which is a specialized kind of formwork and has modular (prefabricated) components developed for improved features of concrete structures.

Data are collected based on these three general types of formwork, allowing the respondents to choose, which type they are currently using for their building construction projects, after clear clarifications of each type. And according to the respondents, illustrated in Figure 4.1, 36% use conventional or traditional, 58 % use modern conventional (combination of plywood and steel supporting members) and 6% are using system or modern formwork type (but these forms are laminated plywood, which international contractors use, considering as modern formwork, according to site observations).

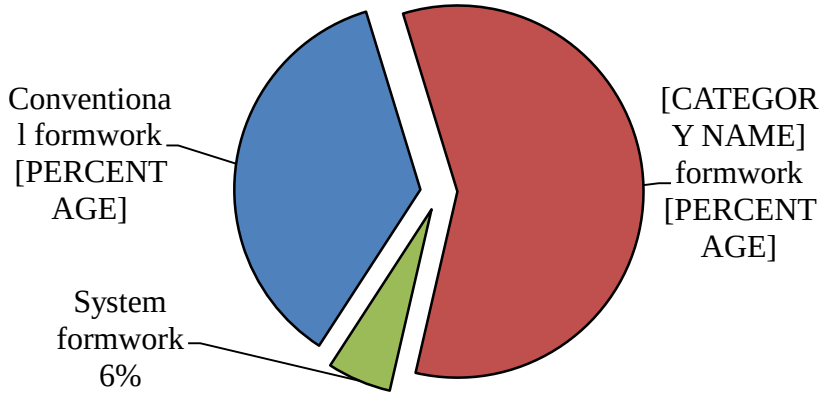


Figure 4.1 Types of formwork currently used at building constructions site in Addis Ababa

For an open ended question, "Why do you prefer this type of formwork", 22% of the responses (highest percentage of given answers here) shown that the initial cost of materials takes more concerns while safety took the least consideration, only 4%, as indicated on Figure 4. 2. This indicates that contractor give more concerns to initial cost of the form materials to select formwork for building construction projects.

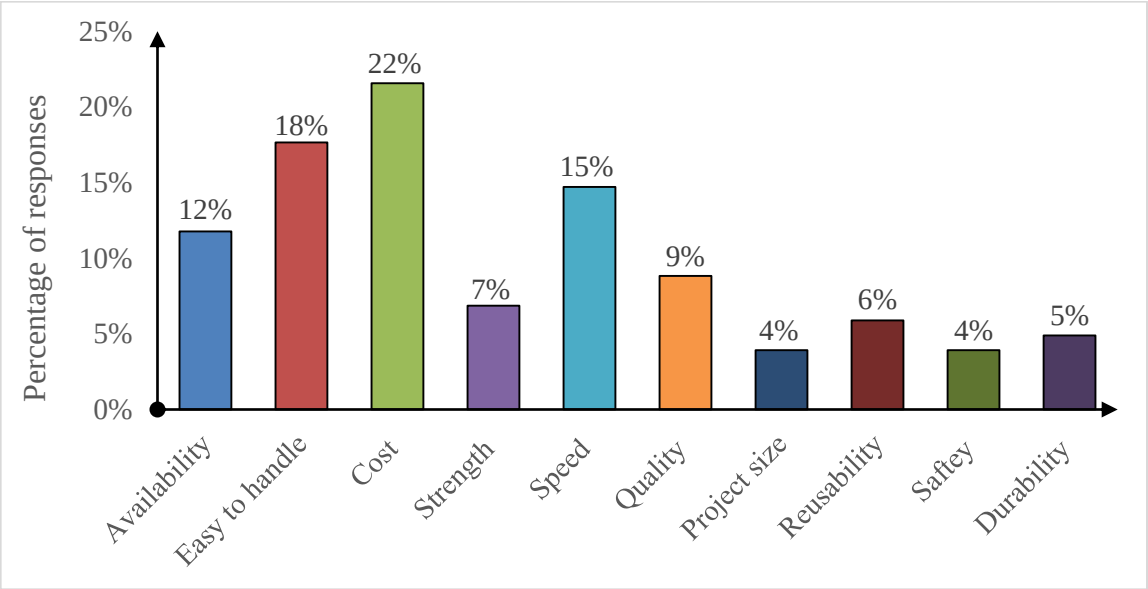


Figure 4.2 Major reasons why contractors chose the type of formworks they are currently using

4.5. Materials Used for Vertical and Horizontal Formwork

Formwork materials are one of the most important factors on the quality required in the finished concrete surface, speed of construction, safety of both the concrete structures and labors during the construction process, and the cost of construction. Therefore, the selection of appropriate materials for formwork should be based on these objectives.

4.5.1. Vertical Formwork

Materials used for the construction of concrete formwork in Ethiopian building construction industry right now are mostly modern conventional (the system used a combination of traditional with modern materials such as timber, steel and plywood. Vertical structural concrete elements of a building are columns (rectangular or circular), lift houses, shear walls and sides of beams. The formwork materials for theses vertical elements at building construction sites in Addis Ababa currently being undertaken are circular steel mould for circular columns and plywood for rectangular elements as illustrated in Figure 4.3. The bracing and supporting materials are mixtures of steel and timber (mostly eucalyptus).

Figure 4.3 Formwork materials for rectangular and circular vertical members

4.5.2. Horizontal Formwork

Timber products are the most widely used materials for concrete construction applications as forming material in the horizontal structural elements. According to respondents and observations made for this research, plywood is the most widely used moulding material for horizontal (slab and beams) by local contractors and laminated board by international contractor. Supporting and bracing materials are mixture of steel and eucalyptuses as well as vertical members in most of the building constructions projects.

Three types of timber products used for moulding, supporting and bracing are identified to be used currently in Addis Ababa building construction industries during this research, by questionnaires and observations.

The first product of timber is raw timber, mostly eucalyptus, used for supporting and bracings. It is the widely available, despite the arguments to deforestations, and more suitable to cut and fix for supporting and bracing formwork in small spans.

The second wooden product formwork material is plywood used for moulding fresh concrete to the desired shape and size. Availability of plywood in a variety of thicknesses, lengths, ease of handling, cut and fix during construction makes it preferable for shuttering material for building constructions in Addis Ababa.

Plywood is produced and supplied in a relatively larger size of sheets (1220 X 2440mm) than steel sheets (1000 X 2000mm). Availability of plywood in relatively large sizes is important in reduction of construction time, cost of building and at the same time have provided smooth surface which in turn reduces cost of finishing of concrete surfaces. Most of the higher grade local contractors are using plywood formwork aiming at getting a flat and smooth concrete surface finishing which avoids additional plastering.

The third wood product currently used for concrete formwork, which is sheathing material, is structural laminated board, also called laminated plywood. This sheeting material is very smooth and special type of wood product which produces excellent surface finishes as indicated in Figure 4.4 (d).

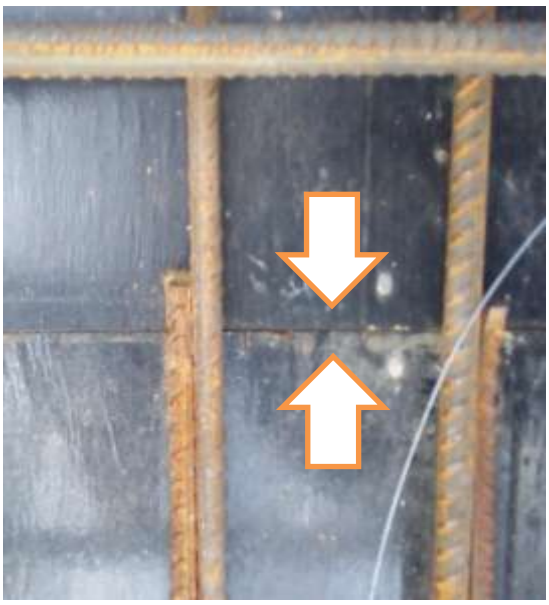
According to observations made and interviews through the consultant side, laminated plywood is watertight and does not intake water compared to the normal plywood forms as Figure 4.4 (c). It is covered on both sides with special smooth black plastic like films, and the ends are also treated with impermeable paints.

"The surface of the laminated plywood is characterized by high resistance to aggressive media, temperature extremes and excellent moisture-resistant qualities, making use while working with concrete surfaces. The formwork of plywood is also fairly light compared to the standard shuttering boards (Beams-rion, 2019)."

According to observations and interviews made for this research, this type of formwork is currently used by the international contactors in Addis Ababa, and needs no releasing agents, especially in the first two usages, because of the material`s smoothness it is covered (coated) with. It easily releases and does not bond to the concrete when removing due to its very smooth surface. Figure 4.4 shows the laminated plywood and resulting concrete slab surface.

The other benefit of laminated plywood form is that, the edges are straight which make the joints very tight, nearly closed and hence no leakage of cement paste through, to appear when the forms removed.

(a) Very smooth surface



(b) Very tight joints

(c) Water tight

(d) Smooth and uniform surface finish

Figure 4. 4 Laminated plywood (laminated board) and resulting concrete slab surface

4.5.3. Steel Formwork Materials

Steel formwork materials are also one of the main formwork materials currently used in big building projects as supporting and bracing members (false work). Steel, currently used mainly as shores, joists and bracings rather than sheeting, when other materials like timbers are impossible to use because of their low strength and span of construction and also when higher reuse is needed. Steel formwork has major advantages on concrete construction to form longer spans and its higher potential for reuse when handled with essential cares.

Steel formworks are available in fabrication of four main different formwork components.

i. Steel panel for columns or beams, and steel sheets for slabs,
ii. Lateral or diagonal shores for walls or columns, and vertical shores for slab or beams,
iii. Steel components used for joists in horizontal and struts for vertical formwork,
iv. Steel pipes for formwork bracing.

Of these four main components, where steel formworks are mainly used, steel sheets for slab concrete placement are currently not preferable, despite their flexibility and higher

reuse capacity, in the building construction projects. Rather plywood is the most widely shuttering material especially for slab construction as described in Section 4.4.2.

Because the target populations of this research are 1st and 2nd grade contractors, the materials described here are those used and practiced by these contractors. Most of the steel formwork materials currently used as shuttering material are circular column panels and rectangular columns are constructed using plywood.

According to site observations and interviews (unstructured) for this research, steel sheets are less preferable than plywood and laminated plywood due to the following main reasons.

- Initial cost of steel sheets is higher
- Steel sheets are heavier than plywood
- Plywood is easier to handle, cut and fix than steel sheets
- Steel sheets cause discolorations (staining) due to rust and inadequate release agent
- Carpenters prefer to work with plywood for nailing easily than steel sheets

Amare (2015), had also discovered that steel formwork systems cause more discoloration or staining than timber formwork systems which make steel formwork inferior with regard to the quality aspect of the finished concrete product.

Although not specifically an objective of this research and stated by any of the respondents, the other importance of plywood over steel sheets is that it has relevant water absorption capacity, which is very important to improve the concrete uniformity and compressive strength and also durability at the surface. It is because from the fact that some water and entrapped air migrate to the interface of concrete and could be absorbed by the formwork material such as plywood, or allowed to escape. Water absorption of formwork material therefore, seems to have an influence on concrete compressive strength. The greater the water absorption of formwork material the greater the concrete density and compressive strength, (Rubaratuka, 2013). Rubaratuka also has put the following two main results from his study which didn't consider the concrete mix ratio, but the formwork materials alone;

i. Formwork material has an influence on the compressive strength and durability of concrete. The surface strength varies with the rate of water absorption of formworks.

ii. There is a need to reduce/absorb excess water at the concrete surface in order to ensure concrete uniformity and improve the concrete compressive strength at the surface and hence concrete durability.

4.5. Formwork Selection Criteria, Design and Treatment

4.5.1. Formwork Selection Criteria Being Practiced Currently

One of the most important factors on the success of completion time and cost of many building projects is formwork practice. Results from questionnaires, observations in three sites and interviews, for the purpose of this research, from building construction projects in Addis Ababa indicated that the impact of formwork on the cost and duration of the projects is high. This indicates that proper selection of formwork to building projects can play a great role both to the owners of buildings and the contractors themselves. Because on time completion of projects helps the owners to take advantages of early usage of building structures and a one-time concrete finishing would make the contractors economically advantageous.

The main problems studied here in the current formwork construction practices, especially by the local contractors, are desires to choose materials with low initial costs. But some of the material costs are minor compared to total cost of concrete structures, for example form release agent.

Improper selection of formwork and form release agents together with poor workmanship resulted in a concrete surface which needs additional treatment, which is common in most of the building construction projects in Addis by local contractors, although striving to minimize and eventually avoid it. The additional treatments currently practiced as per questionnaire survey for this paper, are chiseling and plastering the defect area or whole surface with mortar, a material of weaker strength compared to the concrete chiseled away. An average minimum cost of 101 Birr/m^2 is required to treat a defect concrete surface as indicated in Table 4.3.

Therefore, proper selection of formwork material and types can save a minimum of 101 Birr/m^2 plus the time required for the treatment activity which means a lot both to the contractor and owner of the building structures.

Table 4. 3 Average minimum unit cost of additional treatments (chisel and plaster)

Treatment cost components		**Average unit cost (Birr/m^2)**
Chiseling		15
Plastering (2nd coat)	Material	46
	Labors	40
Total		**101**

For the close ended question respondents were asked to rank amongst five major factors in formwork selection process, namely, cost, quality, speed of construction, safety and stock availability of materials, most of them ranked quality to fulfil the first priority as illustrated in Figure 4.5. Speed of construction took the least priority of these factors at the building construction project currently on progress in Addis Ababa.

This part is aimed at knowing the priorities of main factors in formwork selection and practice at building construction projects in Addis Ababa. The rank is made by calculating the Relevance Importance Index (RII).

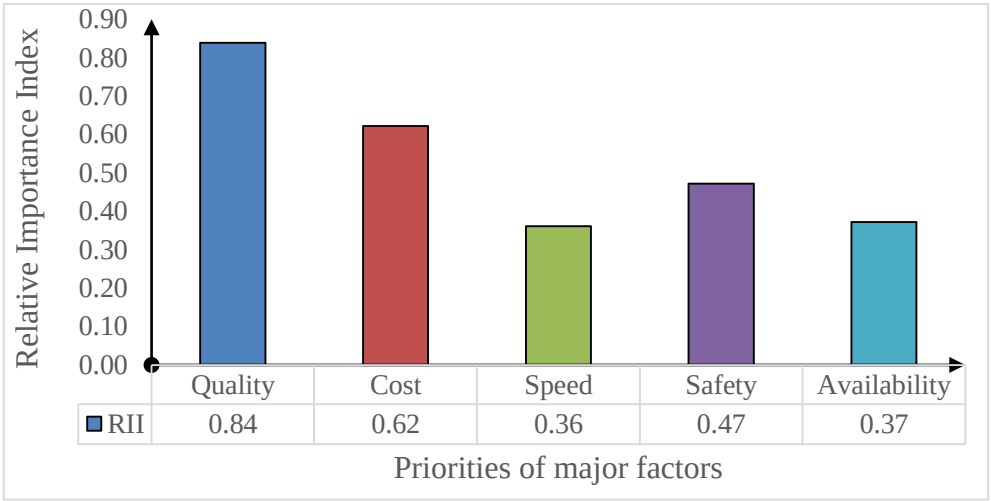


Figure 4. 5 Priority of quality, cost, speed, safety and availability in formwork selection.

A total of 29 factors identified from literature studies were distributed to companies to prioritize the influence level. Evaluation of the given factors using Lickert scale, or relevant importance index (RII), as per respondents indicated that financial capacity of contractor ranked top indicated in Table 4.4. Considerations are given to each of the factors not in the same way during formwork selection in different companies. But average rank indicated also those factors such as weather conditions, location of sites; available codes and standards are less influential in formwork selection process.

Table 4. 4 Factors and their influence on formwork selection for building construction projects

Ser. No.	Factors influencing formwork selection	Sum product (∑W)	A*N	RII = (∑W)/A*N	Rank
1	Financial capacity of the company	138	180	0.77	1
2	Availability of the material in the company	135	180	0.75	2
3	Availability of the material in the market	133	180	0.74	3
4	Formwork strength	129	180	0.72	4
5	Quality of formwork material	123	180	0.68	5
6	Initial cost of the material	122	180	0.68	6
7	Shape of building	122	180	0.68	6
8	Concrete surface finish	122	180	0.68	6
9	Cost of labor	121	180	0.67	9
10	Formwork accuracy in construction	120	180	0.67	10
11	Life cycle cost of the material	120	180	0.67	10
12	Availability of labor	119	180	0.66	12
13	Formwork cycle time	119	180	0.66	12
14	Repetition cycle (number of reuses)	119	180	0.66	12
15	Productivity of labor	119	180	0.66	12
16	Formwork and personnel safety	118	180	0.66	16
17	Skill of labor	117	180	0.65	17
18	Type of floor slab	116	180	0.64	18
19	Wastage of materials	116	180	0.64	18
20	Height of the building	114	180	0.63	20
21	Size of building	112	180	0.62	21
22	Absorption capacity of the formwork material	111	180	0.62	22
23	Repetition cost	107	180	0.59	23
24	Variation of floor areas	105	180	0.58	24

25	Environmental effects of the materials	103	180	0.57	25
26	Location of the project	99	180	0.55	26
Ser. No.	**Factors influencing formwork selection**	**Sum product (∑W)**	**A*N**	**RII = (∑W)/A*N**	**Rank**
27	Terms and specifications in the contract document	99	180	0.55	26
28	Available codes and standards	96	180	0.53	28
29	Weather condition	89	180	0.49	29

According to the questionnaire survey for this research, a total of 11 responses were given for an open ended question "What major requirements have you put for the formwork materials to fulfill, with regard to safety of both the concrete structure and labor?", where the highest percentage of responses (21%) indicates that the formwork should be strong enough. Figure 4.5 shows the major formwork selection criteria with regard to safety of both concrete structure and labor according to questionnaire survey.

But the questionnaire analysis here indicated that responses for, "why do you choose this type of formwork?", where due to "initial cost of material" is prior as indicated in Figure 4.2, mismatches with the requirements set for the formwork to fulfill with regard to safety of structure and labor, where "strength of material" is top an shown in Figure 4.6. I believe the responses should agree.

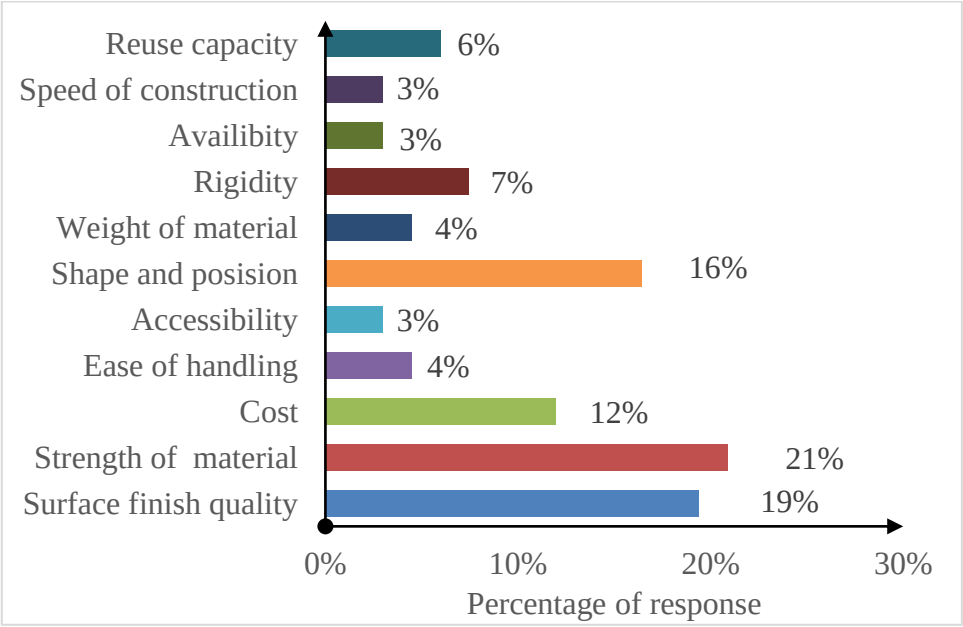


Figure 4.6 Formwork selection criteria for safety of formwork and labor.

This means the criteria the construction companies have, as per the responses, indicated that the first requirement the formwork is needed to fulfill is strength in Figure 4.6, while the reason for selecting the formwork they are currently using is due mainly to its initial cost as indicated on Figure 4.2. But the selection criteria should be followed for good results.

4.5.2. Formwork Design Procedures

The other thing that good formwork should do is to support all the applied loads without collapse or excessive deflection. Because the objective of formwork design is to determine the adequate spacing for each form component such as sheathing, joists, runners and shores; it is very important to ensure that each component has adequate strength to resist the loads and applied pressures.

Questionnaire surveys for this research show that formwork materials are selected by two methods, intuitive or by experience of contractors and, design and inspection approvals by architects/engineers. Table 4.5 describes the method of formwork selection currently practiced, design standards used, responsibility of formwork design and concrete finishing standards they have.

Analysis from questionnaire data for this paper indicated that Ethiopian Building Codes Standards (EBCS) and American Concrete Institute (ACI) design standards are considered to be the most widely used standards in designing formworks for building projects being undertaken in Addis Ababa. And for the responsibility of formwork design 23 respondents replied as contractors are responsible for the form designs at their sites while 10 other said consultant or architect takes the responsibility of the formwork design.

For a, Yes or No Question respondents were asked whether they have a concrete finishing standards or not, 27 replied “no” and other 8 replied “yes” as indicated in Table 4.5 below.

Table 4.5 Method of form selection, design standards used, design responsibility and finishing

Se. No	Items	Responses given	frequency
1	Method of selecting formwork	Intuitive/ opinion of contractor	12
		Using design and inspection approvals (engineer/ architect)	23
2	Design codes (standards) commonly used	EBCS	32
		ACI	4
3	Responsibility of formwork design	Contractor	23
		Architect/Engineer	10
4	Concrete finishing standard	Yes	8
		No	27

For the design of formwork, a total of 24 factors were identified from literature reviews in three categories; namely, technical, functional and, loads & pressures, then distributed to construction companies. Factors are ranked both individually and by category using relative important (RII) method. The categorical comparison is done by average relative importance index (ARII). Technical factors ranked first and functional second while loads and pressures are least influential of these three categories as indicated in Table 4.6.

Table 4.6 Factors influencing formwork design for building construction projects

Ser. No.	Cate-gory	Factors considered during formwork design	RII = (∑W)/A*N	Individual Rank	Category rank
1	**Technical**	Containment (shape and support)	0.78	3	**1**
2		Strength	0.92	1	
3		Leakage resistance	0.68	10	
4		Accuracy(consistence in bldg. dimensions)	0.76	4	
5		Rigidity	0.82	2	
6		Surface finishing quality	0.74	5	
7		Reuse potential	0.68	10	
8		Internal layout	0.62	20	
9		Architectural features on building	0.71	7	

		exterior			
10		Span and head room	0.73	6	
Average			**0.74**		
11	**Functional**	Ease of handling	0.65	14	**2**
12		Speed of erecting and dismantling	0.65	14	
13		Possibility of introducing alternative design	0.56	22	
14		Accessibility to concrete work	0.64	16	
15		Area or volume of cast per pour	0.66	12	
Average			**0.63**		
16	**Loads and pressures**	Type of cement	0.55	23	**3**
17		Type of release agent	0.58	21	
18		Concrete pour / placement rate	0.63	18	
19		Height of concrete pour	0.71	7	
20		Weight of concrete	0.70	9	
21		Slump of concrete (W/C ratio)	0.66	13	
22		Temperature	0.53	24	
23		Vibration	0.62	19	
24		Machines and labor loads	0.64	16	
Average			**0.62**		

Type of cement and temperature are found least influential factors as per their rank 23rd and 24th respectively, from questionnaire survey indicated in Table 4.6. The impact of cement type and temperature is considered in the strength development of concrete which will also have impact on formwork loads. Ordinary Portland cement (OPC) is commonly used in Addis Ababa and hence impact on formwork loads through strength development is more or less constant and less influential factor to be considered in formwork design.

4.5.3. Formwork Treatments and Release Agents

Formwork is one of the most important investments in concrete constructions which has great role on the quality, time, cost and safety of the concrete structure. Therefore, it is vital to treat formwork with a relevant release agent so that it can be removed easily after the concrete has set. Taking care of the formwork systems extends formwork life and reusability; improve surface quality, which in turn contributes to economic advantages to the contractor.

Failure to use a proper and adequate release agent is the main cause to result in the formwork sticking to the concrete surface at some building construction sites in Addis Ababa. This has led to damage both to the concrete surface and plywood when it is removed.

Proper application of formwork release agents has greater impact on cost reduction by increasing the life of forms and maximizing repetition, creating good concrete surface finishes, easy removal of forms and minimizing form clean up times.

Form release oils are basically used for the following main reasons:

1) To help easy removal of the formwork at the time of de-shuttering by reducing of adhesion in the inner surface of the form and the concrete.
2) To provide a good finishing surface after removal of forms
3) To help in the repetitive use of plywood, which otherwise would get swell easily and become unfit for good quality of concrete surface

Although discoloration of concrete constructions seems to decrease nowadays in Addis, because contractors use plywood (a material with less tendency of staining concrete surface) for shuttering, bonding of plywood sheets to the concrete structures is still a problem. The cause of form bonding to the concrete is mainly inadequate form release agents. This bonding of forms to the surface of concrete structure has been observed to reduce the reusability of the forms after removal.

It is recommended for the form oil not to contain too much carbon, for example burnt oil. But burnt oil is the most widely used form oil in most projects in Addis Ababa as shown in Table 4.7, due mainly to its low cost and availability. “If carbon content is more in formwork release agent, i.e. burnt oil, it would patch over the concrete face and react with the outer surface, which may affect the properties of concrete (Mohit, G.J., 2016).”

Some of the respondents answered, no release agent, for the type of form release agent they are currently using. Other 50% of the responses have revealed that used oil is the most widely used release agent. The cost of used oil ranges between 5 and 7 Birr per litter, while machine or diesel oil is about 19 Birr per litter.

According to observations and interviews, some of the contractors choose burned oil as a form release agent perceiving to compensate their low bidding amount reduced to be least bidder during bid competitions. But researches and experienced professionals on the field revealed that costs of release agents are minor proportion of the total cost of the formwork and therefore its omission could be false economy.

Table 4. 7 Types of form release agents currently used in Addis Ababa building construction projects sites.

Type of Release Agent used	Frequency of Responses	Rate (%)
No release agent	5	16%
Burned oil	16	50%
Machine/ diesel oil	9	28%
Mould oil	2	6%
Total	**32**	**100%**

Contractors who responded 'no release agent' are those who use wide thin plastic sheets mainly to protect leakage of cement grout through the form joints as illustrated on Figure 4.7, and the international contractors who use laminated plywood, which releases by itself because it is made to do so. But this practice of using thin plastic has caused curing problems according to interviews. Because it holds and protects evaporation of water from concrete slab soffits which some other contractors have taken as an importance to the concrete.

Figure 4. 7 Thin plastic sheets applied over plywood to protect paste

Although form release agent has great role on formwork constructions, most of the contractors are still considering the single cost of the oil itself rather than the cumulative economic advantages. Figure 4.8 shows the major concerns of selecting the type of form release agents, contractors are currently using and 43%, which is the highest percentage of the responses, have selected based on the initial cost of the oil.

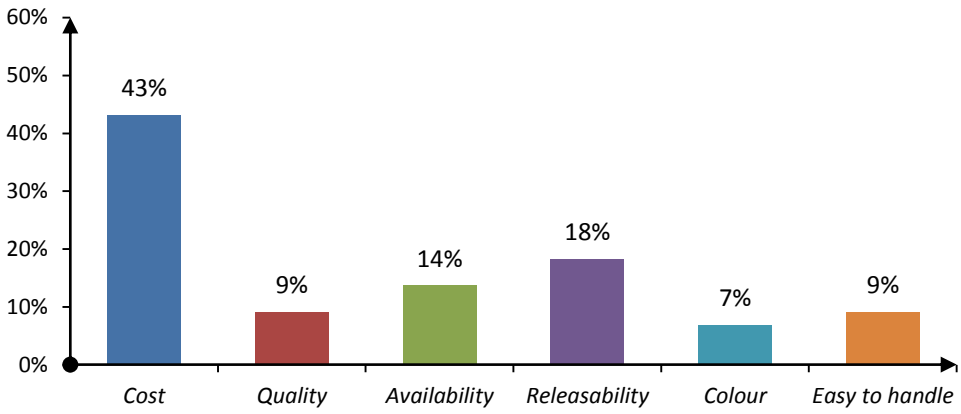
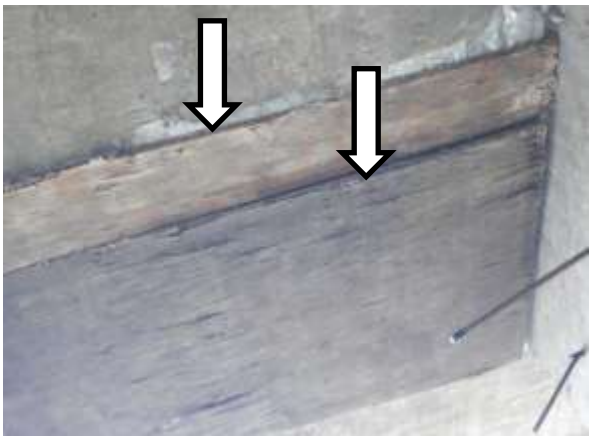


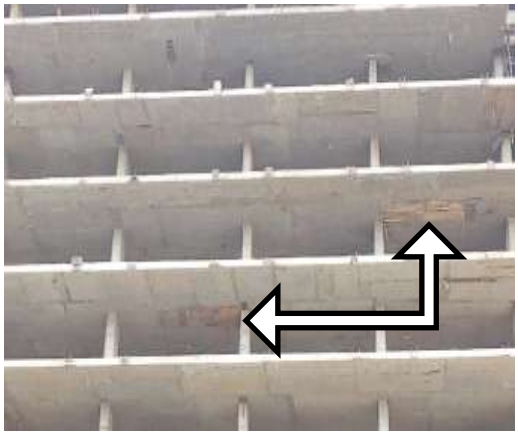
Figure 4. 8 Major selection criteria of the form release agents currently used

Lack of appropriate release agent applications to the formwork surface has caused defects both to the concrete and formwork. In some locations forms remained bonded to the concrete surface during removal need to be chiseled away, which damages both the surface of concrete and the form.

But considering the initial cost of form release agent, which is minor compared to the cost of the concrete structure; has a great impact on the quality, time and cost of building construction projects.



(a) Plywood bonded to concrete surface



(b) Plywood layers remained on surface

Figure 4.9 Improper selection and practice of form release agent

One of the main causes for wastage of formwork materials in the building construction sites, according to respondents, is lack of adequate form release agent. As illustrated in Figure 4.9 inner layers of plywood bonded to the surface of the concrete slab which is even visible from a reasonable distance of the building structure, while proper selection and application of release agent could improve the process.

Though widely used in current practices of building construction projects in Addis, burnt oil is even applied not in an adequate amount. Penetrations of water and damp made the plywood panels swell after about 3 or 4 repetitions. Figure 4.10 shows the impact of inadequate application of form release agent and its impact to the finishing surface of the concrete slab.

(a) Inadequate application of form oil

(b) Impact on surface of concrete slab

Figure 4. 10 Improper selection and application of form work release agents

4.6. Formwork Life-Cycles

Three building project sites undertaken in Addis Ababa had been observed for this research. Site 1 is undertaken by international (chines) contractor while the other two sites by local contractors of the same grade. According to observations on these three building project sites being undertaken in Addis Ababa, the cycle of formworks is more or less similar despite the difference in shuttering materials and applications. Construction of solid flat slabs with minimum thickness 230 mm and maximum 260mm are being undertaken which help to reduce the area of forms since there are no beams. This type of slab also reduced time required to cut and fix beam formworks. This process therefore, led contractors to economic advantages and ease of erecting forms to concrete slab where beams are built in together with the slabs.

All of these contractors have used modern conventional type of formwork and accessories except the shuttering materials. Laminated plywood, which needs no form oils in the first two uses, once each side, but resulted with very fine, smooth and uniform surface finishing as indicated in Figure 4.3. The local contractors on the other hand are using a 1220x2440mm plywood, which results with fair finishing surface, especially in the first two uses (once each side of the form) but depends on workmanship and applications of different form oils which affect the process differently.

The times of form removal for all the three sites are, 16 hours for vertical members i.e. for columns and shear walls, and minimum of 21 days for horizontal members. But the Internationale contractors use the forms quickly after removal while locals do not same way.

The average formwork cycle currently practiced in the building construction sites is illustrated in Figure 4.10. The costs of formwork are 32%, 23% and 52% of the concrete structures in site-1, site-2 and site-3 respectively as indicated in Table 4.8.

The contractor undertaking site-3 supplies only formwork materials and all other materials are supplied by the client. Therefore, the formwork cost is 52% of the cost of placing reinforcement bars and casting concrete to the building structure.

Table 4. 8 Current practices of formwork construction in three project sites in Addis Ababa

Item	Projects observed		
	Site 1	**Site 2**	**Site 3**
Location of site	Dumbbell	Piassa	Bole
Type of concrete slab	Solid & flat	Solid & flat	Solid & flat
Type of formwork	Modern conventional	Modern conventional	Modern conventional
Concrete forming materials	Laminated board	Plywood	Plywood and steel panel only for circular columns
Form oil	No	Burnt oil	Diesel oil
Average cost of formwork (birr/m2)	526	238	235
Average cost of concrete including casting (birr/m3)	4800	2643	675
Average cost of reinforcement bar (birr/kg)	57.5	33	5
Rate of formwork cost to concrete structure	32%	23%	52%
Requirement of additional treatment	No	Yes	Yes
Type of additional treatment		Chisel and plaster	Chisel and plaster
Location of treatment		Only defect area	Only defect area
		Uneven & rough	Uneven & rough
Possible causes of treatment		surface, cement gout, bulged vertical members	surface, cement gout, bulged vertical members

Item	Projects observed		
	Site 1	Site 2	Site 3
Possibility of finishing on time and budget	Likely	Unlikely	Unlikely
Materials supplied by contractor	All	All	Only formwork

All unit costs of the international contractors are higher than the local contractors and need higher initial investment by the client. But the quality, safety and time of construction allows the client an early access of the building structures, which pays the investment back quickly.

Although comparatively lower construction costs are practiced by the local contractors, improper selection and applications of formworks made projects need additional treatments. Additional treatments take additional materials, time and hence cost, which also extend the access of the building structures.

4.6.1. Number of Reuses and Limitations in Current Formwork Practices

The number of reusing formwork materials depends on a number of factors in different building construction sites in Addis Ababa. According to site observations and questionnaire responses, both plywood and laminated board used for a minimum of 3 times, with maximum reuse of 6 times if properly used for plywood. Laminated board is used 4 times (twice each side) with careful handling and repair. Figure 4.11 shows the different factors that affect quality and reusability of formwork materials, as per experiences of the respondents to the construction industry. Poor workmanship at construction sites is one of the factors that 21% replied. More also observed in some sites, carpenters and labors practice carelessly and prefer to use new materials than used ones because of its simplicity to cut, fix and nail.

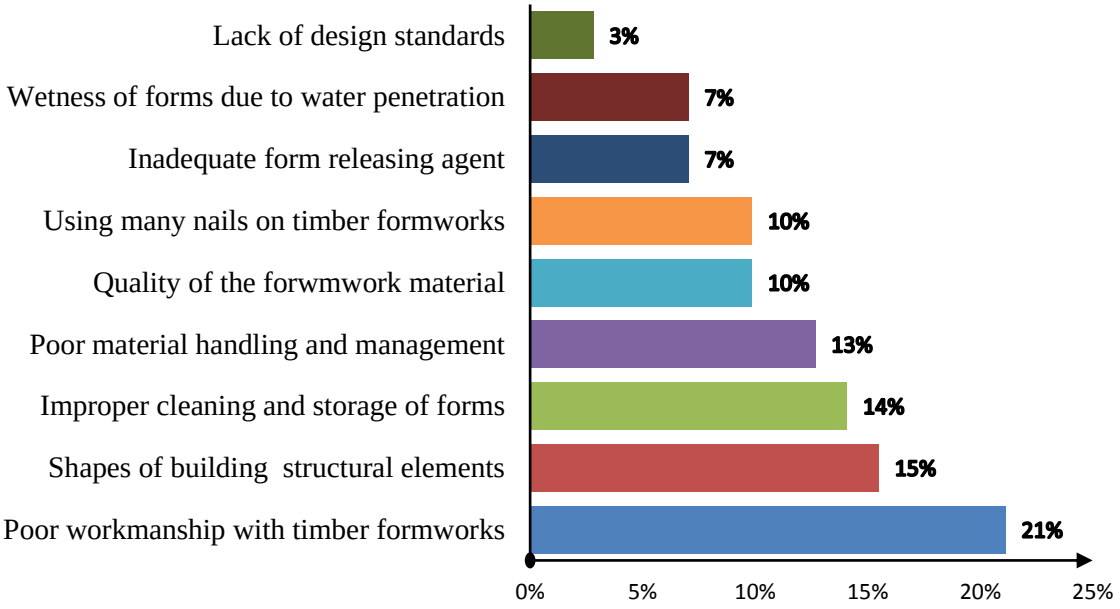


Figure 4.3 Factors which reduces number of repetition for formwork materials

4.6.2. Formwork Materials Handling, Storage and Erection

One of the main issues that have great impact on formwork is the workmanship practiced in the building project sites in Addis Ababa. Proper material handling, maintenance and storage can improve the life and reuse of formwork. Plywood is prone to penetration of water and dampness, which makes the surface layer swell and weak. Dampness and water penetration through the edges affects the reusability and quality of the resulting concrete finishing surface.

The other factor that greatly affects the form life and number of form reuse is improper erection and fixing of the formwork, especially at the form joints. Mastic tape is widely used in other countries to protect leakages of slurry through form joints. But what is currently practiced in Addis Ababa in some projects is cutting a used corrugated iron sheet longitudinally to cover the gaps or joints of forms by nailing to the edges. But this practice has been observed to cause defects both to the formwork and the concrete surface after the de-shuttering. The pieces of corrugated iron sheets remained boded to the surface of slabs most of the times.

The other defective practice by the local contractors that leads the concrete surface finishing to additional treatments, is placement of improper and weak spacers between

form and reinforcement bars. Failure of spacers has made the bars rest directly on the form surface, which are then exposed when forms are removed as indicated in Figure 4.12 (a).

The international contractors use laminated plywood which has straight and treated edges. Forms made no joint gaps and hence no need of mastic tapes or pieces of other things to protect slurry leakages. Forms which used more than required and cannot be used as a whole panel are cut and fixed where they fit. This practice also helps to use the resources to the optimum level and hence economical.

Some of the formwork practices by the international and local contractors are pictured in Figure 4.12 to see the effects on the life and reusability of formwork.

a) Poor form joint treatments and resulting concrete surface in some sites by local contractors

b) Tight form joints and resulting smooth concrete slab surface by international contractors

Figure 4. 4 Effects of form joint managements to the form and concrete surface finishing

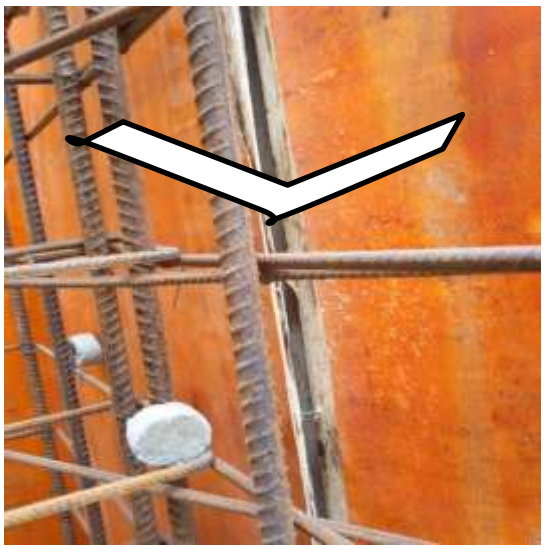
Using nails while tie rods are preferable, shape of building structural elements and improper maintenance and storage of formwork, mostly plywood, are the most commonly experienced factors that affect the formwork process as clearly shown in Figure 4.13.

Corners of structural elements and surfaces at the form joints, through which slurry leaks, are the most common imperfection areas by the local contractors. And hence chiseling and plastering these areas is necessarily required to make them straight, smooth and uniform.

(a) Nailing to plywood

b) Using tie rods

c) Angled shape of column



d) Shape of column damaged plywood

Figure 4. 5 impacts of shape of building structural elements and workmanship

Proper treatment and cleaning can extend the life cycle of concrete formwork panels which makes them more economical. Forms must be given cares and well treated before, during and after the concrete construction process so that it will be able to reuse panels as much higher as possible, (Peri Group, 2017). Proper guidelines and check lists shall be prepared and practice in the building construction sites.

4.7. Formwork Economy

As indicated in Table 4.4, financial capacity of the construction company is one of the leading factors that affect the selection of formwork for a specific building construction project in Addis Ababa. Formwork is the area that contractors can save costs, if selected and practiced properly.

Flat slabs are currently preferable by most of the designers in Addis Ababa. These slabs have reduced the area and complexity of formwork; which in turn reduces costs and wastages of forms. This is because beams are casted in slabs and only soffit area is added to slab area. Form areas that would be required for both sides of beams are omitted, which reduces the cost of formwork.

The other importance of flat slab is that it allows using the whole shuttering panels to all rooms with no cut requirements which plays great role to the formwork economy by reducing wastage. But the same factors that affect reusability of forms discussed in Section 4.5.3 and 4.6.1 affect the cost of formwork currently practiced despite the advantages of flat slabs.

According to the questionnaire survey and observations in some building projects in the city, the minimum cost of formwork is 23% and 32% of concrete work by local and international contractors respectively. Construction of formwork involves considerable costs in terms of material, labor for assembling, erection and removal of. The average cost of forms including these costs are 522 Birr/m^2 for plywood, 1475 Birr/m^2 for steel sheets and 1153.7 Birr/m^2 for laminated plywood respectively. Table 4.9 indicates costs of forms currently used, up to 6 repetitions for plywood, which is maximum and 10 repetitions for steel sheets, which is nearly minimum in most of the sites.

Table 4. 9 Cost of different formwork materials currently practiced and reuses

Number of uses	Total unit cost of formwork		
	Plywood	**Steel sheets**	**Laminated board**
1	522.0	1475.0	1153.7
2	261.0	737.5	576.8
3	174.0	491.7	384.6
4	130.5	368.8	288.4
5	104.4	295.0	230.7
6	87.0	245.8	192.3
7	-	210.7	-
8	-	184.4	-
9	-	163.9	-
10	-	147.5	-
Contract cost/m^2	**235**	**235**	**526**

According to the respondents, the minimum number of uses for plywood and laminated board is 3 times. But plywood is used up to 6 times in some building projects sites while laminated board is up to 4 times. Steel sheets on the other hand, are said to be used for a minimum of 8 and more times depending on conditions of the project sites.

Costs of formwork have gone down to 174 Birr/m^2 for plywood and 384.6 Birr/m^2 for laminated boards after the minimum number of uses, i.e. 3 times for both as indicated in Table 4.9. Laminated boards are used up to 4 times and hence the cost decreased to 288.4 Birr/m^2 at this point. But those local contractors who are using plywood up 6 times could reduce the cost to 87 Birr/m^2 compromising quality of the concrete surface finishing if forms are not cleaned and repaired properly. The cost of steel sheets can also be reduced 184.4 Birr/m^2 and below after 8 repetitions, which is the minimum currently practiced number of uses.

The contract amount currently practiced are 235 Birr/m^2 for plywood and 526 Birr/m^2 laminated board considering the cost of materials, labors, form treatment oils and number of uses.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The main objective of this research is to study and evaluate the current formwork practices and situations undertaken by selected contractors in the building construction industry in Addis Ababa. This helps to come up with an awareness of what current formwork practices look like compared to past activities and future requirements needed. Building projects undertaken by local and international contractors were studied to compare their practical impacts to quality, safety, time and cost of projects. Having analyzed the results in previous chapter, the following conclusions were made:

- As per the types of formwork categorized for this research, 58% of the respondents are using modern conventional, 36% conventional and 6% system formworks.
- Plywood is the most widely used formwork material by local while laminated board is used by international contractors as form material.
- From the respondents, 81% of revealed that formwork has great impact on cost and duration of total project. The minimum costs of formwork according to this research, are 23% and 32% of the concrete structures, for local and international contractors respectively.
- Corners of structural elements and surfaces at the form joints, through which slurry leaks, are the most common imperfection areas by the local contractors. And hence chiseling and plastering these areas is necessarily required to make them straight, smooth and uniform.
- Selection of formwork is highly affected by the financial capacity of the contractors followed by availability of formwork material in the company and market.
- One of the root causes for poor formwork practices by some of the local contractors in Addis Ababa is, striving to compensate the low bid amount by low cost materials, for example, used oil which highly affects the formwork.
- Poor workmanship, shape of building structures and, selection and application of improper form release agents are the most common practices which limit number of reusing forms and cause defects on the finishing surface of concrete.

- Form removal time is a minimum of 21 days and maximum of 28 days for slabs; but similar for other structural elements in most of the projects except few contractors who start stripping at 8^{th} day after post tensioning the slab. Reshoring is mostly practiced when forms are removed below 21 days starting from 8^{th} day.
- Improper selection and applications of formwork materials and form release agents are currently costing a minimum of 101 Birr/m^2 of concrete surface for additional treatments plus the cost of reduced reuse value of the form. This also makes the owner not to take the advantages of early usage of building structures, which are higher sources of income in Addis Ababa.

5.2. Recommendations

Based on the results of this research, the following recommendations are forwarded to insight what the current practice of formwork construction in Addis Ababa needs in the future.

As known from interviews, most of the local contractors lower the bid amount during biding competition of projects to win by being least bidder. Of course most of them have used plywood aiming to produce a uniform concrete surface ready to paint though not effective. Some of these least bidders have practiced to use low cost materials, especially burned oil. But unlike our perceptions, the benefit gained from one additional reuse of forms is incomparably higher than the cost saved from initial costs of form oils. The other problem faced is poor workmanship. Therefore:

- Formwork materials should be selected considering safety of both the concrete structures and labor.
- Contractors should consider cumulative cost savings from extended life of formworks rather than initial costs which are minor compared to cost of concrete structures, for example burnt oil, which affects life of forms.
- Contractors should train the laborers to make them more effective and efficient for economical results.
- Government of Ethiopia should prepare concrete finishing standards and checklists which will help to select suitable formwork materials and workmanship.

- Financial capacity of contractors has made them select formworks of inferior quality which affects the safety of both concrete and the labors. Therefore, government of Ethiopia should also either support financially through long term loans, or prohibit them from upgrading their levels unless they have good performances on the area.
- Regulations, design standards and code of practices, which order the type of formwork and materials considering height of buildings and safety should be prepared and enacted to formwork constructions by the federal, state or local governments.
- Wooden materials, especially used for supporting and bracing members should be replaced with steel or equivalent materials to building projects which need higher repetitions, for the safety of the building structures and labor; and also to decrease environmental impact by saving trees.

Recommendations to further studies

1. Impacts of types and applications of form release agents on concrete surface finish.

2. Impacts of unskilled labor on formwork practices during construction of concrete structures.

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Appendix

Section 1: Respondent`s (personal) Information

1. Job position in the company:

   Owner ☐ Project manager ☐ office engineer ☐ site engineer ☐ other ☐
2. Experience in construction industry: _____years.
3. Experience in building construction: _____years.
4. Number of building projects you have participated: _____
5. Highest number of stories (tallest building) you have practiced: G+____.

Section 2: Project Information

1. Grade of the contractor in this project, BC or GC 1, 2…_____
2. Experience of the contractor in building construction industry: _____ Years
3. Grade of the consultant in this project:_____
4. Project delivery type for this project_____
5. Owner of this project: Private ☐ Public ☐
6. Building area:_____
7. Height of building:_____
8. Number of typical floor slabs (slabs with same area):_____
9. Average slab area:_____
10. Types of floor slab areas (A_1, A_2…, how many slab types):_____
11. Planned duration to complete one floor concrete work: _____days.
12. Actual duration to complete one floor concrete work: _____days.
13. Estimated Total Cost of this project:_____
14. Estimated total project Duration:_____
15. Current performance (% completed)_____
16. Probability of finishing within specified time and budget _____
17. How important is the impact of formwork on the duration and cost of the project? _____

Section 3: Formwork Types, Materials, methods

Note: For the purpose of this research and to make it clear to the respondent, formworks currently in practice are categorized into three types.

a. **Conventional/ traditional »»** uses timber, bamboo, timber boards, timber props, masonry and carpentry
b. **Modern conventional »»** similar to conventional (a) but uses advanced materials such as steel props, plywood, steel sheets, different jacks (U jack, T jack) instead of timber boards and props.
c. **System (Modern) Formwork »»** has modular (prefabricated) components with casting panels in large amount and developed for improved features of concrete construction for different structures. Eg. Table, climbing, tunnel formworks are some of system forms.

1. Which formwork type is most practically used in your company (a, b or c)?___
2. What major reasons make your company choose this type of formwork?_____
   _____
3. Are there any regulations specific to formwork construction you are practicing? Yes ☐ No ☐, please specify if yes_____
   _____
4. What type of form releasing agent have you used in your projects most commonly and what makes you select this release agent?
   Form release agent name;_____
   Reason to choose;_____
   _____
5. What major requirements have you put for the form materials to fulfill, with regard to safety of both the concrete structure and labor?_____
   _____

Section 4: Formwork Design and Selection Criteria

1. How have you practiced in selecting the formwork systems in your building projects?
   a) Using intuitive and opinion of practitioners (contractor)
   b) Using design and inspection approvals by professionals (engineer/ architect)

c) Other method (please specify)_____

_____

2. Which design codes (standards) have you commonly used in designing formwork for your building projects? ☐ **EBCS** ☐ **ACI** ☐ **BS** Others, please specify__
3. According to ACI, responsibility for the design of the formwork rests with the contractor or the formwork engineer hired by the contractor to design and be responsible for the formwork. Who is responsible for the design of formwork in most of your contract documents?

   Contractor ☐ **Architect/ Engineer** ☐ **Other**, please specify,_____

4. Do you have a concrete finishing standard planned and designed to achieve?

   Yes ☐ No ☐

   If yes please describe your concrete surface finishing standards_____

   _____

5. Please rank the following factors according to their priority in your formwork selection criteria from 1-5.

   Quality ☐ ***Cost*** ☐ ***Speed*** ☐ ***Safety*** ☐ **stock availability of material** ☐
6. How significant are the following basics in your formwork design for your building construction projects? Please thick in front of each factor according to its influence level and feel free to add factors you consider in your formwork design.

   Level of significance; *1= little influence, 2=moderate influence, 3 = high influence, 4 = very high influence and 5 = extremely high influence*

Formwork design considerations		**1**	**2**	**3**	**4**	**5**
Technical	Containment (shape and support)					
	Strength					
	Leakage resistance					
	Accuracy(consistence in bldg. dimensions)					
	Rigidity					
	Surface finishing quality					
	Reuse potential					
	Internal layout					
	Architectural features on building exterior					

	Span and head room					
Functional	Ease of handling					
	Speed of erecting and dismantling					
	Possibility of introducing alternative design					
	Accessibility to concrete work					
	Area or volume of cast per pour					
Loads and pressures	Type of cement					
	Type of release agent					
	Concrete pour / placement rate					
	Height of concrete pour					
	Weight of concrete					
	Slump of concrete (W/C ratio)					
	Temperature					
	Vibration					
	Machines and labor loads					

7. Researchers agree that "Contractors' vast experience in construction can help to select the best suitable formwork system". How important is your experience in the building construction industry to select the best suitable formwork for your projects?
   a) Importance of your experience on selecting best suitable formwork type_____
   _____
   _____
   b) In what basis, the formwork type you have selected is best suitable for your project (what are your formwork suitability measurements)? _____
   _____

8. Which factors have you experienced with, in selecting the type of formwork for your building construction projects? Please tick in front of the factor according to its influence level in your projects. You can also add any factor missed, which you may think it, to be added, below in the table. The influence levels supposed here in this table are;

   1= little influence, 2=moderate influence, 3 = high influence, 4 = very high influence and 5 = extremely high influence.

No	Factors affecting formwork selection in your company	Influence				
		1	2	3	4	5
1	Availability of the material in the company					
2	Availability of the material in the market					
3	Financial capacity of the company					
4	Initial cost of the material					
5	Availability of labor					
6	Skill of labor					
7	Cost of labor					
8	Quality of formwork material					
9	Formwork accuracy in construction					
10	Type of floor slab					
11	Wastage of materials					
12	Life cycle cost of the material					
13	Formwork and personnel safety					
14	Formwork cycle time					
15	Shape of building					
16	Size of building					
17	Variation of floor areas					
18	Location of the project					
19	Weather condition					
20	Height of the building					
21	Terms and specifications in the contract document					

No	Factors affecting formwork selection in your company	Influence				
		1	2	3	4	5
22	Available codes and standards					
23	Environmental effects of the materials					
24	Absorption capacity of the formwork material					
25	Repetition cycle (number of reuses)					
26	Repetition cost					
27	Formwork strength					
28	Concrete surface finish					
29	Productivity of labor					

Section 5: Formwork number of reuses, limitations and replacement

1. For how many times of repetitions have you designed formwork and how many times are they actually used? Please fill in the table below missed materials.

Formwork materials		Designed number of reuses		Actual number of reuses	
		Minimum	Maximum	Minimum	Maximum
Sheeting	Timber panels				
	Plywood				
	Steel sheets				
	Aluminum, if any				
Supporting and bracing	Timber				
	Steel				
	Aluminum				

2. Which parts of the concrete structural element need quick formwork replacements?

   Column ☐ Shear Wall ☐ Beam ☐ Slab ☐ Stair case ☐

3. If the formwork materials are not used as much repetitively as designed, what major factors have you observed/ reported which limit/ restrict the number of reuses in your site? _____

4. What major reasons increase formwork wastages in your company throughout the life-cycle? _____

5. What remedial actions have you taken to increase life of the formworks?_____

Section 6: Economic Considerations and Cost Components of formwork

1. The market situation commonly affects the price of material and the cost of labor in different construction companies. How does it affect your company?

   In terms of material_____

   In terms of labor_____

   In terms of overall construction cost_____

2. The following table is prepared to know your company`s current Production and cost factors and please fill the real costs so that this research can produce real current situations of formwork in building construction projects in Addis Ababa.

Production and cost factors	Unit cost for the Formwork types		
	Timber (plywood)	Steel	Modern (system) formwork
Average cost of framing and propping materials (Birr/m^2)			
Average labor productivity of propping and bracing (m^2/day)			
Number of reuses of propping and bracing materials (numbers)			
Average cost of sheeting or panels (Birr/m^2), (Birr/m^2/day if rented)			
Number of reuses of sheeting materials			
Average sheeting productivity of labor (m^2/day)			
Average labor cost for sheeting (Birr/m^2)			
Average unit cost of form releasing agent (Birr/lit) (numbers)			
Average stripping and re-shoring labor cost (Birr/m^2)			
Average stripping and re-shoring labor productivity (m^2/day.)			
Additional treatments of concrete surface			
Unit cost of chiseling concrete surface (Birr/m^2)			
Productivity of chiseler (m^2/day)			
Unit cost of plastering material (mortar), (Birr/m^2)			
Unit cost of plastering laborers(Birr/m^2)			
Productivity of plastering laborer(m^2/day)			
Number of plastering coats			