T.C
BAHCESEHIR UNIVERSITY

GRADUATE SCHOOL OF EDUCATION

THE DEPARTMENT OF INDUSTRIAL ENGINEERING

APPLICATION OF GREEN, LEAN SIX-SIGMA METHODOLOGY IN FRAMEWORK CONSTRUCTION PROCESS TO REDUCE PLYWOOD CONSUMPTION IN KUWAIT

MASTER'S THESIS

DINA M J ISIED

ISTANBUL 2023

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ABSTRACT

APPLICATION OF GREEN, LEAN SIX-SIGMA METHODOLOGY IN FRAMEWORK CONSTRUCTION PROCESS TO REDUCE PLYWOOD CONSUMPTION IN KUWAIT

Dina M J Isied

Master's Program in Industrial Engineering

Supervisor: Prof. Dr. Ahmhet Beskese

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This thesis is performed with the aim of reducing waste in the Construction Industry in order to reduce project costs and the environmental impact of such waste. For this purpose, lean, green six sigma (LGSS) methodology is developed to reduce causes of construction waste if formwork construction. A case study in Kuwait, is performed to reduce the consumption of plywood due to formwork construction processes and standards. A large amount of plywood is wasted during the formwork process due to material properties. Using DMAIC problem-solving methodology for an in-depth understanding of the problem and process improvement. The process is visualized by a detailed Value Stream Map to represent plywood formwork process steps. The total plywood consumed for the formwork construction project is used to measure process performance and evaluate improvement. By identifying the main causes of the problem, we were able to implement waste reduction solutions to the formwork construction model. Using an integrated model of aluminum formwork system (AFS) and plywood in processes, Aluminum formwork is used in constructing elements with high wood consumption to help in minimizing waste and cost due to the material features and sustainability.

Keyword: Construction Industry, LGSS, Waste reduction, Value Stream Map (VSM), and Aluminium Formwork System (AFS)

ÖZ

APPLICATION OF GREEN, LEAN SIX-SIGMA METHODOLOGY IN FRAMEWORK CONSTRUCTION PROCESS TO REDUCE PLYWOOD CONSUMPTION IN KUWAIT

Dina M J Isied

Endüstri Mühendisliği Yüksek Lisans Programı

Tez Danışmanı: Prof. Dr. Ahmet Beskese

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Bu tez, İnşaat Endüstrisi'ndeki atıkları azaltma amacıyla proje maliyetlerini ve bu tür atıkların çevresel etkisini azaltmayı hedefleyen bir çalışmadır. Bu amaçla, kalıp inşaatında inşaat atıklarının nedenlerini azaltmak için "lean, green six sigma" (LGSS) metodolojisi geliştirilmiştir. Kuveyt'te bir vaka çalışması, kalıp inşaat süreçleri ve standartları nedeniyle kontrplak tüketimini azaltmak için gerçekleştirilmiştir. Malzeme özellikleri nedeniyle kalıp sürecinde büyük miktarda kontrplak israf edilmektedir. Sorunu derinlemesine anlamak ve süreç iyileştirmesi için DMAIC problem çözme metodolojisi kullanılmıştır. Süreç, ayrıntılı bir Değer Akış Haritası ile görselleştirilerek kontrplak kalıp süreci adımlarını temsil etmektedir. Kalıp inşaat projesi için kullanılan toplam kontrplak tüketimi, süreç performansını ölçmek ve iyileştirmeyi değerlendirmek için kullanılmıştır. Sorunun ana nedenlerini belirleyerek, kalıp inşaat modeline atık azaltma çözümleri uygulayabildik. Yüksek ahşap tüketimi olan unsurları inşa etmek için entegre bir alüminyum kalıp sistemi (AFS) ve kontrplak kullanarak malzeme özellikleri ve sürdürülebilirlik nedeniyle atık ve maliyeti en aza indirgemeye yardımcı olunmuştur.

Anahtar Kelimeler: İnşaat Endüstrisi, LGSS, Atık azaltma, Değer Akış Haritası (VSM), Alüminyum Kalıp Sistemi (AKS)

To My Parents.

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I would like to express my deepest appreciation to my supervisor Prof. Dr. Ahmhet Beskese for his encouragement and feedback throughout the research also would like thank him for all the provided knowledge.

I would also like to thank High City Contracting Est. for all the provided expertise and trust. Also, this endeavour would not have been possible without my project team members. Lastly, I would be remiss in not mentioning and thanking my family, especially my parents. Their belief in me has kept me motivated through this process.

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LIST OF ABBREVIATIONS

BIM	Building information modelling
CI	Construction industry
CW	Construction waste
CO2	Carbon dioxide
CTQ	Critical to quality tree
DMAIC	Define, measure, analyze, improve, control
GLSS	Green lean six sigma
KPI	Key performance indicator
LSS	Lean six sigma
LC	Lean construction
LCA	Life cycle assessment
LP	Labor productivity
MCDM	Multi-criteria decision making
TQM	Total quality management
VSM	Value stream map
VOC	Voice of the customer

Chapter 1

Introduction

The construction industry has a main and huge impact on a countries economic growth and employment rate. During the past three decades, Kuwait's CI has grown significantly and it has now one of the biggest employment rates among other private sectors in the country. Construction problems are constantly rising and it is in substantial need for development to keep momentum with other developed countries around the world. Kuwait is one of the developing countries that is struggling to address the current construction challenges in terms of productivity, sustainability, waste, and performance. Therefore, the development of construction industry has become one of the main priorities of the country, particularly after the launch of the new vision of their country, Kuwait 2035 (Al-Adwani & Fleming, 2019). The CI was valued at 5.66 billion USD in 2020 and the projected compound annual growth rate is 6.23% from 2021 to 2028 (Kuwait Central Statistical Bureau). Kuwait is currently inviting private sector investors from around the world, to invest in multiple significant construction projects over the country infrastructure, such as electrical power plants and metro lines, which will improve the country drastically, costing them around 74$ billion USD (Kuwait Construction, 2021).

Rapid growth of the private residential construction has become a huge attraction to both qualified and non-qualified contactors. Due to the lack and/or inadequate rules and regulation of the government about the contractor's qualification, it has encouraged an enormous number of small contracting establishments to work in the construction field, where most of the workers are unqualified for this profession and its' metric (Koushki, Al-Rashid, & Kartam, 2005). Moreover, Oxford Business Group published in (Oxford-Business, 2017) that is according to the Public Authority for Civil Information in 2016 there were 395,000 construction workers and only 21,000 of them with expertise. Unfortunately, due to the combination of a rapid rise in demand of construction, the inexperience and unqualified contactors, and the government rules and regulation, there has been a rise in conflict between owners, contractors, and material suppliers (Hafez, 2001).

Due to the increased amount of awareness of the environmental protection and sustainable development, the pressure has increased on organizations to improve their operations and make them more sustainable, and lower environmental impact (Siegel, Antony, Garza, Cherrafi, & Lameijer, 2019). Conventionally, the performance of construction projects was measured by time, cost, and quality. Recently, the measure of environmental factors has been added to the equation due to its' importance (Bossink & Brouwers, 1996). Based on the nature of the CI industry, it has become one of the main consumers for natural resources, time, and money. On the other hand, it generates a high level of waste, because of poor or inefficient management (Banawi, 2013). Statistics illustrate that CI has a major impact towards unsustainable development, and its economic and environmental impacts. Globally, construction consumes 40% of overall raw material, 40% of overall energy production, 25% of overall wood, and 16% of overall water consumption. Moreover, CI is accountable for 35% of CO_2 emission (Son, Kim, Chong, & Chou, 2011). A High level of waste is emitted in the CI because of the poorly managed projects, and a low level of awareness in terms of waste environmental impact and sustainability (AlSanad, 2015).

According to Kuwait Central Statistical Bureau, the amount of waste generated is increasing drastically and it has drawn a lot of attention, which has made the environmental studies become the focus of several agencies in the country. The amount of constructional waste in Kuwait takes the first place among other types of waste and garbage in the years between 2017-2019 as shown in table (1) (Kuwait Central Statistical Bureau, 2021). As clarification, and to scale the problem Kuwait is facing with CW, the amount of waste generated in Canada, which is the second largest country in the world, is around 9 million tons per year. The amount of waste generated in Kuwait is on average 15 million tons per year, which is a massive amount for such a small country (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013).

With the amplified demand of construction activities, the pressure of increasing the quality of the environment, and reducing cost, this has caused the country to face some challenges. Several studies in different countries confirmed that waste contributes in relatively recognizable proportion of overall production cost (Formoso, Soibelman, De Cesare, & Isatto, 2002). Additionally, the adoption of lean construction practice, help enhancing construction efficiency and reduce CW (Howell & Koskela, 2000). Kuwait's Government exercises minimal effort to waste management and sustainable development. Moreover, 90% of construction and demolish waste is disposed in landfills leading to unsustainable environment and pollution (Kartam, AlMutairi, AlGhusain, & AlHumoud, 2004). Although the government introduced some initiatives regarding waste management, they are not taking a positive measure to increase awareness among experts and construction firms, nor are they reassuring the development and the growth of sustainable and green construction. A questionnaire conducted by AlSanad (2015) among 504 participants in both private and government sectors was made to measure the level of knowledge and awareness in terms of sustainability and green construction in Kuwait. The result of the questionnaire shown in Figure (1) specifies that up to 72% of participants had a very low to moderate knowledge and awareness about the mentioned topic while, up to 27% had good to excellent knowledge and awareness

Table 1

Amount of Garbage and Waste Generated in Kuwait

Garbage and Waste	2017	2018	2019
Constructional Waste (ton)	15,851.493	12,679.097	15,743.415
Population Solid Garbage (ton)	1,696.923	1,786.079	1,857.840
Hazardous Medical Waste (ton)	4955.389	7010.654	6648.976
Agricultural Garbage (ton)	437.832	453.667	337.293
Commercial Garbage (ton)	411.896	485.712	730.340
Liquid Waste (gallons)	422.955	389.297	413,333

Source: Adapted from Kuwait Central Satistical Bureau, Kuwait Municipality and Health Ministry *Statistical review 2020-2021*.

In order to increase construction sustainability development, actions must be taken by the Government to increase and enlist public awareness of the mentioned issues as it plays a huge role in the matter of this aspect. Kuwait construction companies have unclear understanding of the problem and its' effect on the environment. The study conducted by AlSanad (2015) addressed that 88% of participants agreed that government intervention is required for the implementation of green construction in Kuwait. For example, by introducing mandatory set of standards and rules to be followed by construction firms, the matter of sustainable environment will be taken more seriously.

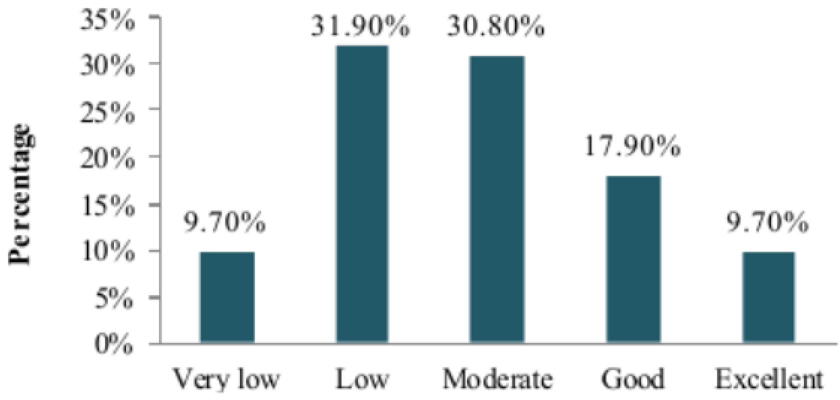

Figure 1 Level of knowledge and awareness of sustainability and green construction *(AlSanad, 2015).*

There are several challenges facing Kuwait CI, those challenges made the industry struggle to extensive improvements. The main challenges are low productivity, project management, waste management, and quality performance (Al-Adwani & Fleming, 2019). The production of high-quality goods with minimal resources thereby, little to no waste left behind is the outcome of well-managed process and continuous implementation of improvements along the line. In a previous study that has been conducted in Kuwait, Al-Adwani and Fleming found that the integration of lean construction (LC) and building information modelling (BIM) is able improve construction industry. However, based on the study findings, the implementation of the proposed model should be driven by the Government to assure proper implementation of the model and benefit the industry (Al-Adwani & Fleming, 2019). Using Six-sigma approach researchers have been able to address a significant improvement to internal finishes quality in construction by increasing sigma level from 2.66σ to 3.95σ (Pheng & Hui, 2004), Sigma levels will be explained further in this chapter. Additionally, a study conducted in the United Arab Emirates by Al-Aomar using lean construction to increase construction industry effectiveness by reducing error and defects together with variability in project schedules, cost estimations, and performance measures. The study was carried by in compliance with six-sigma methods to compliment lean construction practices (Al-Aomar, 2012).

While former studies focused on six sigma to increasing productivity, lean to reducing waste or, green to eliminate environmental impacts Figure (2), a few researches combined all three of the aspects together especially in the construction industry. The thoughts of integrating Green, Lean, Six-sigma (GLSS) have been known among academics and manufacturing industry (Cherrafi, Elfezazi, Chiarini, Mokhlis, & Benhida, 2016). Recently, the thought of the integrated model has gained popularity in the CI around the world based on its effectiveness in the matter of project improvement (Banawi, 2013).

Thereby, this research aims to integrate all three methods, green, lean and, six-sigma (GLSS) into the CI in Kuwait to reduce the high amount of CW generated in Kuwait annually, as was shown earlier in table (1). While there is great potential for improvement in the construction field, literature shows that there are many ways that we can apply to Kuwait CI to reduce CW. Based on prior studies, (Banawi, 2013; Aziz & Hafez, 2013) which discussed that by implementing GLSS to CI, it is able to improve construction productivity, while reducing waste and its' impact of the environment globally. The framework used to integrate GLSS is DMAIC methodology based on the theoretical elements of GLSS. DMAIC is a data driven methodology used for process improvement and it has become an essential methodology that drives and helps Six Sigma projects to thrive. The used methodology consists of five phases Define, Measure, Analyse, Improve, and Control.

A. Define: During this phase, the project is defined from start to finish, mapping out the process, scope, and goal. Making clear opportunities for improvement, and knowing customer requirements whether internal or external.

   Such tools can be used in the define phase:

   - Project charter
   - Voice of customer (VOC)
   - Critical to quality tree (CTQ)

- Value stream map (VSM)

B. Measure: In this phase, a measure and assessment of performance in the process to reach desired goal is made. In addition, a measure of the problems faced and how often it occurs is taken.
    - Create and execute a data collection method and plan to examine current state.
    - Capability analysis – used to determine the efficiency of the process to reach expected outcomes.

C. Analyse: During this phase, determine where the failures and problems in process are and try to find the root of these underlying problems.
    - Conduct root cause analysis (RCA).
    - Pareto chart – used to analyse and determine the occurrence of problems and their causes.
    - Failure mode and effect analysis (FMEA) to determine possible process failures.
    - Develop plan for improvement.

D. Improve: Here in this phase, potential solutions are suggested for the addressed problems in order to eliminate them. All data collected in the analyse phase will be used and now it is time to start making improvements.
    - Brainstorm with team members to find potential solutions to the problem.
    - Evaluate alternatives and select the optimal solution.
    - Design of experiment (DOE) or Multi-attribute decision making can be used to determine the optimal solution.
    - Enforce Kaizen Events to enhance the process.
    - Develop implementation plan and implement.
    - Compare results to the baseline calculate in the measure phase to measure process improvement.

E. Control: Control phase is where process improvements are sustained to ensure effectiveness and long-term effect of implemented improvement.
    - Create a control plan to know what needed to be controlled.

- Statistical process control (SPC) to monitor the behaviour of process.
- Determine whether additional improvement is needed.

1.1 Statement of the Problem

Kuwait construction industry lack proper waste management and use of sustainability in their processes, which is leading them to lose valuable resources and increase their cost. The lack of implementation of sustainability and knowledge of how it is affecting our environment is causing a great deal of waste to be produced yearly. The harmful emission of gasses that is produced during the disposal process is affecting our environment in an extremely negative way.

1.2 Theoretical Overview

The framework used to integrate GLSS is DMAIC improvement model based on the theoretical elements of GLSS. DMAIC is a data driven methodology used for process improvement and it is an essential tool that drive Six Sigma projects, it consists of five phases as mentioned before, Define, Measure, Analyse, Improve, and Control.

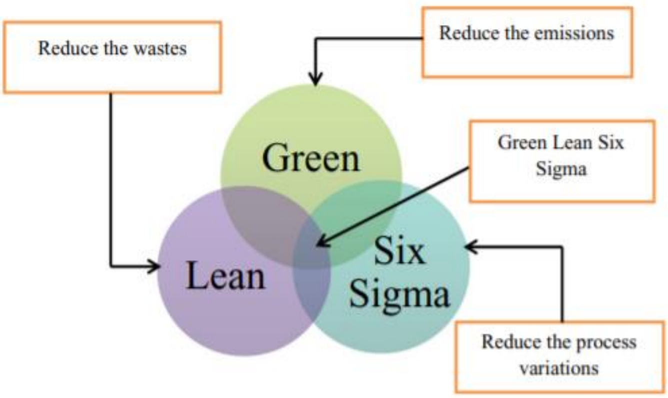

Figure 2 GLSS model
(Kaswan & Rathi, 2020).

1.3 Purpose of the Study

The purpose of the project is to decrease the waste generated during the construction processes, which has a huge negative impact on the environment. The goal is to illustrate that the integration of green, lean, and six sigma methods in the construction process of residential buildings structure in Kuwait, will minimize waste generated during formwork construction and reduce the construction cost.

1.4 Research Questions

- Why construction industry provides vas amount of waste?
- How to measure construction waste?
- How construction waste effect the environment?
- How we can make the construction process more sustainable?

1.5 Significance of the Study

If implemented, the study carried out will improve the amount of toxins and pollution caused by construction industry and it will decrease drastically. This will reduce the cost on many private and government sectors as there will be fewer materials to dispose of, meaning they are benefiting from sustainable materials and valuable lands rather than they get wasted. The reduced amount of waste will also mean the reduced carbon footprint of formwork construction. This improves the quality of the construction industry in an environmental aspect, which is to be more sustainable, and financially with cost reduction.

1.6 Limitations

Formwork construction has many limitations due to the nature and the standards of the projects. One of the most significant limitations project differences due to the different needs per project, carrying loads, and design elements. Also, long project duration is a critical limitation to the study, that limits the number of projects under study for data collection.

1.7 Definitions

- Value stream map (VSM): is a lean manufacturing technique to analyze, design and manage the flow of materials and information that are required to bring a product or a service to the customer.
- Construction Waste: is heterogeneous building materials generated from numerous types of construction activities.
- Sustainability: involves of fulfilling the current need of this generation but without compromising the need of future generations too, confirming an efficient balance between economic growth and environmental care.
- Life cycle assessment (LCA): is a process of evaluating the effect a product can have on the environment throughout its life entire life cycle.

Chapter 2

Literature Review

Construction industry played a huge role to the corporate sector and as a source of increased employment therefore, this industry has a significant impact on the economy. Over the years, maintaining an acceptable level of quality standards and cost in construction has been a challenge. As a result, substantial amounts of resources, both human and material are wasted (Siddiqui, S Q; Ullah, F; Thaheem, M J; Gabriel, H F, 2016). For example, the total CW is estimated to be 30% of the building total weight of building materials (Osmani, 2011). Accordingly, the problem of wasted resources in construction projects are associated with poor management. Previous studies have shown that improving the construction quality and process can reduce the amount of waste produced and relatively reduce cost (Bossink & Brouwers, 1996). It has been mentioned in (Howell & Ballard, 1998) that the main weaknesses of the current construction practice are low productivity, project duration, and waste. These weaknesses contribute in longer duration and preventable extra costs.

The two main factors that are influencing the development of CI are construction management and technology. Even though during the last four decades some innovative technologies have been applied, the efficiency of the CI is still relatively low (Aziz & Hafez, 2013). Due to the interdependences of activities and processes in each project performance, construction projects are extremely complex and exposed to high levels of uncertainty (Lukhele, T; Botha, B; Mbanga, S;, 2021). As an outcome of construction uncertainty, the project contractors follow a routine procedure in dealing with process changes, but with unfortunate poor planning and application. This can negatively influence the project, customer, company, and environment (Bruni, Beraldi, Guerriero, & Pinto, 2011).

Quality management is the key factor for companies to be successful with aim to compete and stay in business (Tang, Ahmed, Aoieong, & Poon, 2005). In the developing countries, the construction projects are primarily led and controlled by less educated people with no or few knowledge about project management and commitment (Stewart & Spencer, 2006). Construction projects need to be knowledgeably managed further more than the current management that only consider project budget and schedule where, it is equally important to consider quality and environmental impacts of projects (Formoso, Soibelman, De Cesare, & Isatto, 2002). Arditi & Gunaydin in (1997) addressed that the use of Total Quality Management (TQM) technique, has great potential to enhance process quality. The most important factor that leads to successful application of TQM is the commitment to continuous quality improvements from management and employees.

Implementation of developed technologies to CI in both design and construction phases helps to improve project quality and efficiency. In addition, former studies have shown significant improvement to construction strategies and processes by waste reduction strategies in general (Banawi, 2013). For example, integrated system of both Global Position System (GPS) and Geographical Information System (GIS) technology were used to help improving efficiency and reducing cost, while also reducing the construction material wastage (Li, Chen, Yong, & Kong, 2005). Construction projects early stages contain significant influences on the amount of generated waste in construction projects, such as pre-planning and design. For instance, A study by deMagalhaes, Danilevicz, and Saurin in (2017) addressed that the key factors contributing to amount of CW is the design choices and project management practice, by proposing design strategies with accordance to experts' guidelines it was possible to reduce the CW.

Nevertheless, former studies have addressed that CW dose not only effect the project outcomes in terms of efficiency, quality, and cost, it also has a huge impact on the global CO2 emission rate. Environmental protection has been considered as the fourth dimension in construction project management Figure (3) because this industry is considered as one of the major pollution generator sectors. Moreover, Environmental Process Assessment (EPA) was introduced to encourage construction sectors to improve their environmental performance by determining its current performance in achieving environmental standards continuously. Implementing EPA in CI was found to be problematic because of the lack of commitment from stakeholders and lack of legal enforcement (Tam & Zeng, 2004). Additionally, contractors should have more responsibility and must be involved in the early phases of the project with both client and designer to exploit their knowledge and help in reducing the amount of CW. The contractor's knowledge in transport, materials and other resources can be very beneficial to reduce pollution and minor impact on society originated from construction projects (Son, Kim, Chong, & Chou, 2011). Another study by Morel, Mesbah, Oggero, & Walker (2001) found that by sourcing local materials for building houses they were able of reduce the environmental impact of CW drastically. As a result of using local materials, they were able to reduce the amount of used energy in construction by 215% and the transportation impact by 453%.

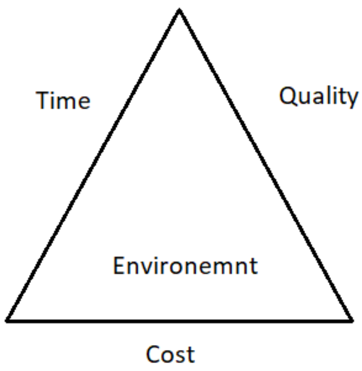

Figure 3 Fourth dimension of construction project management

Construction development has increased significantly leading to a massive amount of CW in the developing countries due to poor management. Construction sector is one of the highest resource consumers and it results in several types of waste that can be very harmful to the environment and increase project cost (Akhund, Memon, Memon, Ali, & Khos, 2019). CW is divided into four main categories design and documentation, procurement factors, operational factors and, materials storage and handling (Agyekum, Ayarkwa, & Adjei-Kumi, 2013). The detailed elements of each waste category are shown in Appendix A. Moreover, several studies adapted a waste generation measurement to find out the construction waste generation percentage with the following four measurement approaches, percent of purchased material, percent of the material required by the design, weight of material per unit area (kg/m^2) and, volume of material wasted per unit area (m^3/m^2) (Mah, Fujiwara, &

Ho, 2016). The use of more sustainable material during construction process helps drastically in reducing construction waste. Aluminium formwork system (AFS) is a modern formwork technique that is commonly used in mass housing projects such as high-rise building, row/block housing due to the high number of uses AFS can offer. Using AFS can provide best quality of housing with minimum time and cost also, it is easy to handle due to its light weight in comparison with other formwork materials. Aluminium has high strength where additional vertical support is not required, it is considered economical although it has high initial investment because it has very high scarp value (Shelke, Waghmare, Thorat, Wadekar , & Maske, 2021).

This project aims to use lean approaches to define waste in construction processes, where it is a very helpful approach to be used in CW management. The goal of the project will be carried via the use of lean and green approaches with an overall six sigma methodology scheme to help in improving the process performance along the way. The integration of lean and six sigma (LSS) has five key performance indicators (KPI) shown in Figure (4) that are recommended to measure construction project performance. KPI will help to address the problem and compare improvements to the baseline later in the project. The key performance indicators LSS are quality, cost, value, speed and, waste. Typical KPIs does not include the value and waste indices and it has been added to measure the influence of adapting lean six sigma in construction processes (Al-Aomar, 2012).

Figure 4 Lean Six-Sigma key performance indicators
(Al-Aomar, 2012).

2.1 Lean, Green, and Six-Sigma Integration

The integration model of the three elements green, lean and six-sigma will result in operational efficiency that will help in stimulating sustainability in process or service. The model is used to enhance the ability of delivering value to the customer, financial benefits to the business, and taking environmental precautious. In other words, the integration will minimize waste, rework and resulted emissions while conditionally increasing profit margin. The model usually is executed with the use of six sigma DMAIC methodology to help improve the effectiveness of integrated green lean initiatives as discussed by (Garza-Reyes, 2015). Each element of the model is discussed in depth in the following context below.

2.1.1 Lean practice. Organizations use lean management to their practice in order to eliminate waste and deliver superior customer value. Competition between organizations has increased drastically after the globalization, which forces organizations to implement modern management method into all levels within the organization to enhance their system, eliminate process waste, and reduce cost. Lean management is a modern management method, which was mainly used for manufacturing introduced by *Toyota Motor Company* in Japan. Therefore, the first system who worked in accordance to lean guidelines was Toyota Production System (TPS) (Dekier, 2012). The Lean management principles became well-known for its' effectiveness and have been used in many industries, such as manufacturing, software development, construction, and others. Moreover, according to (Womack & Jones, 1996) they established the five key lean principles for successful implementation:

1. Identify Value
2. Map the value stream
3. Create flow
4. Establish pull system
5. Continuous improvement

Implementing the lean management principles can have a huge impact when implemented correctly in productivity, cycle time, efficiency, scrap, and material cost. The first principle helps to identify what is the value. The value in lean is considered as what the customer is paying for and what adds value to the product such as quality assurance. The second principle assist in mapping the workflow and finding the value-added and non-value-added activities of the organization visually with the use of technical tools such as Value Stream Mapping (VSM). The third principle is creating a flow to detect and remove non-value-added-activities, such as detecting the cause behind bottlenecks in process. Establishing a pull system to avoid some lean wastes such as overproduction and inventory costs. The last principle is to assure continuous improvements by enhancing the activities that create most value to the consumer and eliminated as much as possible waste activities and materials (Crawford, 2016). Additionally, lean manufacturing system identify seven types of waste inventory, motion, overproduction, defect, waiting, transport, and over-processing.

2.1.2 Green thinking. Addressing the environmental impact of processes, products, and waste became very essential nowadays, businesses are trying to adapt new strategies and think out of the box to reduce the environmental effect. Although lean principles have the power to address waste in process, it does not address the environmental impact of the waste. Green thinking has the potential to help the environment by reducing the amount pollutants and environmental toxins produced by processes, product, waste, and more.

Life Cycle Assessment, (LCA) is a method used by leaders in the business world as well as scientist to achieve certain sustainability goals set by different countries and work places. There has been a dramatic change in global warming over the course of the last decade, and the environmental side of production has become a serious concern to many people and countries. LCA is a systematic measure for analysing the environmental impact and sustainability over the life cycle of materials or products, whether in the process of manufacturing these products, transportation, distribution, end-life phase, or construction using these materials as discussed here (BPF, 2018).

LCA has four main steps mentioned in (RIT, 2020), which are, goal and scope definition, inventory analysis, impact assessment, and finally interpretation, critical review, and reporting.

Step 1: Goal and scope definition

The first step is the key to your study. Here, you ask yourself why this study is carried out. What data you need, the quality of your data, how you will report and keep track of your data. You define your goal, objective and how you will apply it, and your audience.

Step 2: Inventory Analysis (LCI)

Here is where you collect all data that is relevant to your product/service. All input and output associated with the life cycle of the product, such as emission, material flow for each process, and energy requirements is collected here. You track the entire flow in and out of the system.

Step 3: Impact assessment (LCIA)

In this step the environmental impacts are calculated and studied. Data and information acquired from your LCI is analysed and made meaningful in context to the effect and impact of the environment, and how it is damaging, whether through the emission of gases, or transportation of products.

Step 4: Interpretation, critical review, and reporting

In the final step, you analyse your results with reference to you goal and scope (Step 1). You audit your data quality, check your limitations, and evaluate any opportunity to reduce the negative effects on the environment and to increase sustainability. A report can be created and analysed and finally asses where improvements to sustainability can be made

2.1.3 Six-Sigma. Six sigma is a technique known to improve business processes by providing tools and method to insure what is best for the process or product. (Kadry, 2018) discussed in his book how six sigma has evolved through the last two decades by proving the new ways of understanding and problem solving the sustainability issues. Nowadays there is an increased awareness in the importance of environmental sustainability that reflects on both business owners and customers requirement, where rare who can translate sustainability problems to be measurable so it can be improved. Using six sigma can increase the process performance and decrease non-value-added activities and wastes.

The main element in six sigma projects is to ensure the customer needs are carried by enhancing the process or service qualities. Essential tools and techniques that are used help in understanding the problem and obtain process improvement is shown in table (2). The tools are used throughout a six-sigma project starting from identifying customer requirement to making sure their requirements are delivered. Tools are obtained from data collected from the process or service, the, mentioned tools in Table 2 will help in visualizing the collected data and evaluate them.

Table 2

Tools and Techniques Used in Process Improvement

(Rehman, Asif, Saeed, Akbar, & Awan, 2012).

Illustrative process improvement tools and techniques	Purpose of use
Ishikawa/fishbone diagram	Root cause analysis of a problem. Identifying all the possible causes of a problem and sorting the most relevant one
Pareto analysis	Prioritization of problems. Isolating the vital few from trivial many
Scatter plot	To check the distribution of data
Histograms	To check the distribution of data with respect to control limits and mean of the process
Control charts	To track trends in a process
Process capability	To check the health of a process – how the data is distributed with respect to control limits and mean
Failure mode and effect analysis	To have better understanding of problem failures based on their severity, detectability, and occurrence
Design of experiment	Decision making through selection from a number of choices
Check sheet	Quantification of problems of various types

2.2 Construction Process

Construction process flows between owner, architect, engineer, and construction company as shown in figure (5) established by (Arditi & Gunaydin, 1997). The Design process of the project is based in customer requirements and specifications as an input element. After the design is submitted a plan of project specification is given to construction management to proceed. During the construction the project is performed by contractors and the constructed facility is given to the customer. The constructed facility maintenance can also be provided by construction company or the specialist contractor. Construction process goes from foundation to surface finish and everything in between, construction process is a very long process that requires a lot of time, materials, machinery, and effort. The main eight stages of construction process listed by (Parker, 2016) are foundation, substructure, superstructure, roofs, first and second fix, surface finishes, and external work. The construction project flow shown in figure (5) is the basic flow of any standard construction process. The construction process phase includes all the electric and pluming for the constructed facility. Project is performed based on customer requirement that are translated into drawings submitted to contracting company to be executed.

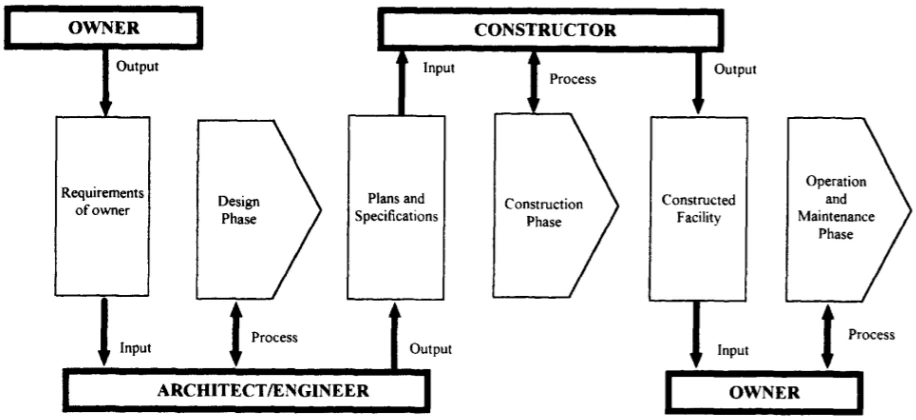

Figure 5 Construction project flow
(Arditi & Gunaydin, 1997).

2.2.1 Formwork structural classification. The structural classification of formwork consists of the following, wall formwork that has vertical upright structure which sheeting boards/panels are secured at the concrete facing side. Beam formwork is a three-sided box that is supported at right elevation and desired level, the striping of such formwork structure depends on the curing rate, humidity, and air temperature. Foundation formwork has several styles where, the size and height of the foundation defines which style the foundation is. Finally, column formworks are used for structures in order to strengthen the shape and form of columns for concrete pouring.

The structure for columns can be as simple as a small cylindrical column form or it can be extremely complex that requires different elements of wood and metal. The formwork structural classification elements are shown in the following figure (6).

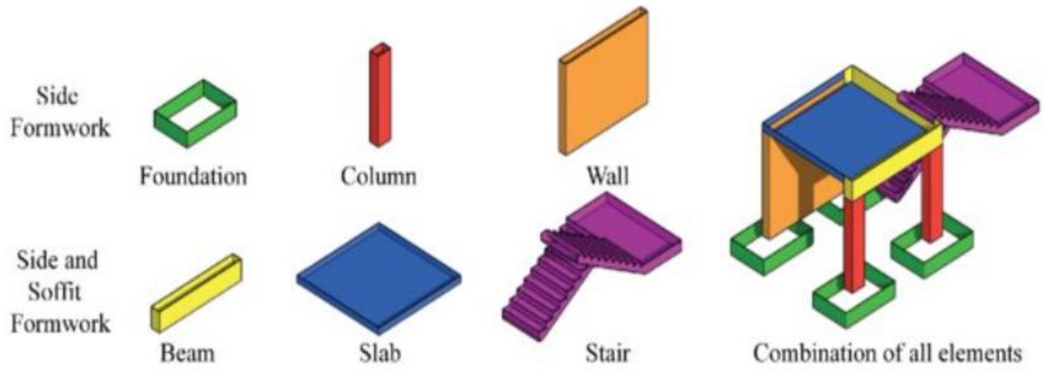

Figure 6 Formwork structural classification

2.2.2 Construction challenges. Construction process faces several challenges and the top challenges are discussed by (Leeds, 2017) are poor productivity and profitability where, due to high competition in the construction industry the profits margins are shrinking and productivity rates has remained consistent over the last 50 years. Low profit margins have restricted the investments in new technologies and better construction practices. Design complexity is another challenge facing CI where profit margins are very low there is no room for mistakes. Skilled labor shortage and limited skills as a very crucial challenge. Finally, Sustainability concerns where CI is the most industry consuming raw materials and it produces 25 to 40% of the world's carbon emissions.

2.2.3 Lean practice in construction process. Previous studies have shown a huge payback of integrating lean principles to construction processes, where the basis of lean construction is maximizing the delivered value to the customer and minimizing the non-value-added waste and activities at construction sites (CWG, 2021). Further study has shown that lean construction projects has led to easier project management, less completion time, less cost, and better quality. The reason for the circumstance that lean principles in construction is a new method of production management in this field that has an influence on both customer and project levels

(Aziz & Hafez, 2013). Numerous researchers identified that lean in construction projects leads to performance improvement for consumer, control the project life cycle, and enhance construction design. The frequently used methods in lean construction are FMECA, just-in-time, Kanban, 5s process, 5 whys, error proofing (Poka-Yoke), value stream map (VSM), fishbone diagram, standardisation, increased visualization, TQM, waste elimination, and standard operating procedures (SOP) to accomplish lean construction objective (Hussain, He, Ahmad, & Iqbal, 2019). For example, pervious study faced significant amount of constriction waste because of poorly managed projects, were able to analyse and reconstruct construction system using VSM to minimize waste (Yu, Tweed, Al-Hussein, & Nasseri, 2009).

2.2.4 Green practice in construction process. Majority of construction firm ignore the negative direct influence of CW to the environment. By the adaptation of green thinking into construction process, we will be able to reduce the environmental impact of construction processes by reducing the amount of wasted material. In other words, the goal of green construction management is to limit the environment disturbance (Banawi, 2013). The environmental matters in construction process occur in the initial steps of construction, when a project is designed, and plans are decided (Hussain, He, Ahmad, & Iqbal, 2019). Another study addressed that the environmental effect of construction process occurs throughout the construction project lifecycle, from the phase of design, raw material purchase, transportation of raw materials, inventory, delivery, and from project construction to the demolish of the project (Ding, 2008).

Construction industry consumes a significant number of resources where it accounts for one-quarter of total harvested wood, on-sixth of the worlds' freshwater withdrawals, and two-fifths of the worlds' energy and materials. The construction process has an impact beyond the structure limits, it influences air quality and watersheds that effects the ecological integrity (Shen & Tam, 2001). The high consumption of raw materials and energy has a positive proportional influence on global warming. Thinking towards sustainable construction is defined as creating a healthy building environment using resource efficient and ecological based principles. Sustainable construction involves the commitment to economic sustainability, environmental sustainability, social sustainability, in order to ensure an increase in profit, careful use of natural resources and responding to people (Kibert, 1994).

2.2.5 Six-Sigma in construction process. Six sigma principles can be used in effective ways to improve construction process performance easily. On account of the alarming construction performance six sigma became widely used in construction industry aiming to improve process that will consequentially reduce cost (Siddiqui, S Q; Ullah, F; Thaheem, M J; Gabriel, H F, 2016). Six sigma is a statistically based approach to problem solving regarding process or product quality by analysing data and root causes of the problem (Rehman, Asif, Saeed, Akbar, & Awan, 2012). The essential feature six sigma is to provide all the required information about the changes and the programs to execute the change to process improvement (Swami & Kadiwal, 2020). As an illustration, Swami and Kadiwal (2020) has identified and evaluated the key factors leading to defects in plastering finish using six sigma principles and methodology therefore, they were able of minimize the number of defects to increase process quality, customer satisfaction, and reducing the cost of rework.

Chapter 3

Methodology

The DMAIC methodology is widely employed in the construction industry to reduce constructional waste. By following the Define, Measure, Analyse, Improve, and Control framework, construction companies can systematically address waste-related challenges. The methodology begins by defining the problem and setting goals, followed by measuring the current state of waste and analysing its root causes. With this understanding, companies can implement improvement strategies to optimize resource utilization and streamline operations. The final step is to establish control measures that sustain the achieved improvements over time. Through the application of DMAIC, construction companies can effectively reduce waste, enhance efficiency, and improve project performance.

3.1 Research Design

During the past few years, Kuwait has faced a huge amount of waste generated by the construction field. Due to the lack of proper waste management and use of innovative solutions, waste has occupied a huge space of valuable lands in the region. Construction waste contributes in huge added costs to projects. That problem brings into our attention opportunity to implement new strategies to reduce the environmental impact of such waste and save cost on projects. The project consists of developing a proactive model and executing a case study to examine the validity of the suggested model. A GLSS Integrated model with an overall DMAIC methodology framework is used, DMAIC is best suited to improve the already existing process and enhance the process parameters.

The research methodology used is DMAIC to execute implementation of green lean six sigma. Figure (7) shows the elements of each phase in the used methodology throughout the preformed case study.

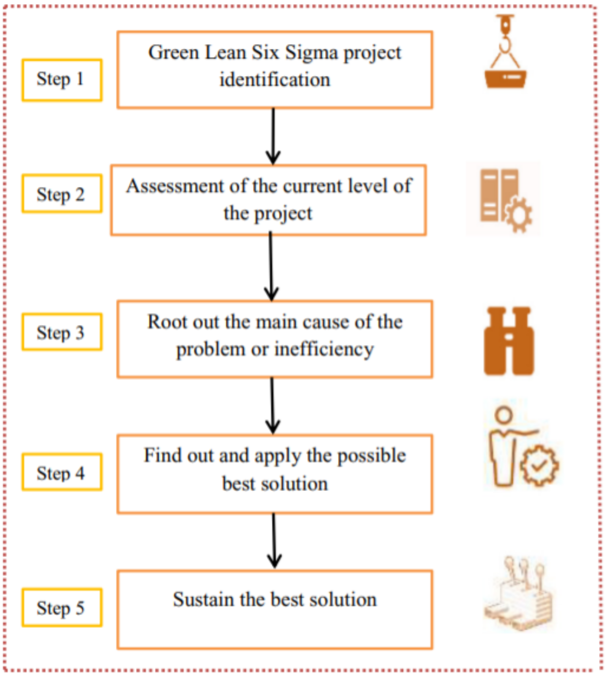

Figure 7 DMAIC steps
(Kaswan & Rathi, 2020).

3.1 Case Study

A case study was performed to visualize the validity of the integrated framework. The case study was performed at High City Contracting Est., Kuwait to lower plywood consumption in concrete formwork construction. Through the increased awareness of process development and sustainability, the company were able to envision room for improvements using more sustainable materials.

Preceding the framework application, on-site visits were conducted to different projects throughout the years 2020 to 2022 for the sake of collecting the voice of the process (VOP) and establishing a baseline. During the visits critical data were collected and captured where also, the suggested framework was introduced, explained and, discussed with the project manager and engineers. The on-site visits helped identifying major root causes of the intended problem by investigation. Main contracts of the project were submitted by the company with cost break down to validate financial benefits of the study. The data under study is collected from the process of constructing plywood for concrete formwork construction, data from different projects were collected to help in drawing a baseline for the plywood consumption performance. The process of formwork construction was studied by different projects were analysed in order to ensure the accuracy and consistency of the measurement instrument that is represented in this case study.

Theoretically by successful implementation of lean green six sigma we will be able to reduce the amount of plywood used by 40%. Therefore, it will drastically reduce generated waste and project costs while using green perspective to reduce the environmental impact. Each project has its' own identity based on size, design complexity, carry loads and, other specifications. The average savings per project is 17,000 KWD where, it can be extremely higher or lower depending on project identity mentioned. Plywood takes on average 15% of the project budget and, construction company takes only (10%-15%) profit margin per project.

3.1.1 Define. In the define phase of the research problem, data have been collected and observed between the years 2020-2022 for the purpose of plywood waste in formwork construction process here in Kuwait. Construction industry presently generates a large amount of waste and the evolution towards sustainability in this industry is very low. Green management involvement has a very little impact in construction industry.

The current research project aims to improve construction process to have minimum wood waste in the first place. By implementing innovative solutions to formwork construction process the target is to be able to save 40% of plywood cost by reducing its' consumption. The performance measure unit in this study is number of plywood sheets used. The company profit is around 10% of the project total on the other hand, the wood cost on average 15% of the project total cost. The number of plywood sheets used might vary from project to another based on the project size, design, load, and other structural requirements. The data is statistically analysed using Microsoft Excel, and other statistical tools. The used tool throughout the project is lean and six sigma tools to help in process improvement.

The project charter is shown table (3) states that project does exist and there is possible room for waste reduction and financial benefits. The charter describes the project goal, objectives, and resources to develop better understanding of the project with team members.

Table 3

Project Charter

Project Charter		
Problem Statement	**Business Case**	**Project Scope**
High amount of waste is generated yearly from formwork construction process in Kuwait. In addition to added cost and harmful emissions is produced from the disposal of non-sustainable material.	Reducing the plywood consumption in formwork construction process will save cost on projects and reduce its' environmental impact by developing green lean six sigma model.	The scope is to reduce plywood consumption in concrete formwork construction process. Project team are focus on the purchasing of plywood per project and the use of plywood in construction by historical and observed data.
Core Team Members:		**Project Plan**
Name	**Role**	By choosing more sustainable material in high wood consumption elements and train the operators on the new material to guarantee minimum waste. The complete results will be available after 22 months.
T. A S. H K. Z I. A	Project Manager Civil Engineer Process Operator Transport worker	
Goal Statement		
Aiming to reduce the number of plywood sheets used from concrete formwork construction by 40%		
Project Constraints	**Summary Project Status**	
1.Time Constraint 2.Budget Constraint 3.Resource Constraint	Project Start Date Project Completion Date Overall Process Impact Potential Financial Budget	14 November 2020 26 December 2022 New process changes KWD 35,000.00
Sponsor	HIGH CITY CONTRACTING EST.	

3.2.1.1 Voice of the Customer (VOC). The customer in this study will be the construction company itself Internal Customer) where, this study will focus in waste reduction and material sustainability that will significantly help in cost reduction. The voice of the customer is collected by face-to-face interviews with 16 different workers from and observations that helped in an in-depth understanding and personalization of customer needs that may lead to innovative ideas. Based on the understanding of the problem we developed a questionnaire and asked the customers from upstream and downstream the following questions:

- What is your perception of the current plywood consumption situation?
- What are your expectations based on the industry standards?
- How important is the assessed dimensions?
- What factors affect the plywood consumption?

Based on the conducted face-to-face interviews we were able to support our business case by identify that construction industry currently produce vast amount of plywood waste that can be prevented and/or reduced significantly. The expectation bar is set very high due to the innovative solutions out there in the construction field. Developed technologies helped in putting out new innovative solutions to minimize waste where needed. The interviewees also mentioned the importance of reducing plywood waste in terms of cost reduction and environmental impact due to its lack of renewability. That will help in improving construction process to stay in competition with other companies in the industry.

3.2.1.2 Critical to quality. Customer need is translated using Critical to Quality (CTQ) tree a diagram-based tool as shown in figure (7). The tool is used to ensure better understanding of process performance requirements that are derived from customer critical needs. CTQ tree shows that reducing plywood waste in construction industry will help in increasing customer satisfaction because it will reduce project cost and reduce environmental impact. The quality drivers were identified by finding what factors must be present to meet customer need of reducing plywood waste. The three main factors are using sustainable formwork materials, reduce plywood cutting, and implement waste management plan. Based on industry standards and limitations we identified the measurable performance requirements.

The performance requirements of the CTQ tree are the following, Use of renewable formwork materials (1), reusable formwork materials ($x \geq 70$), reduce plywood cutting (x ≤ 30), proper waste management of plywood with toxic glues (formaldehyde) that produce potential harmful gasses (1), reduce and controlling waste generation processes (1).

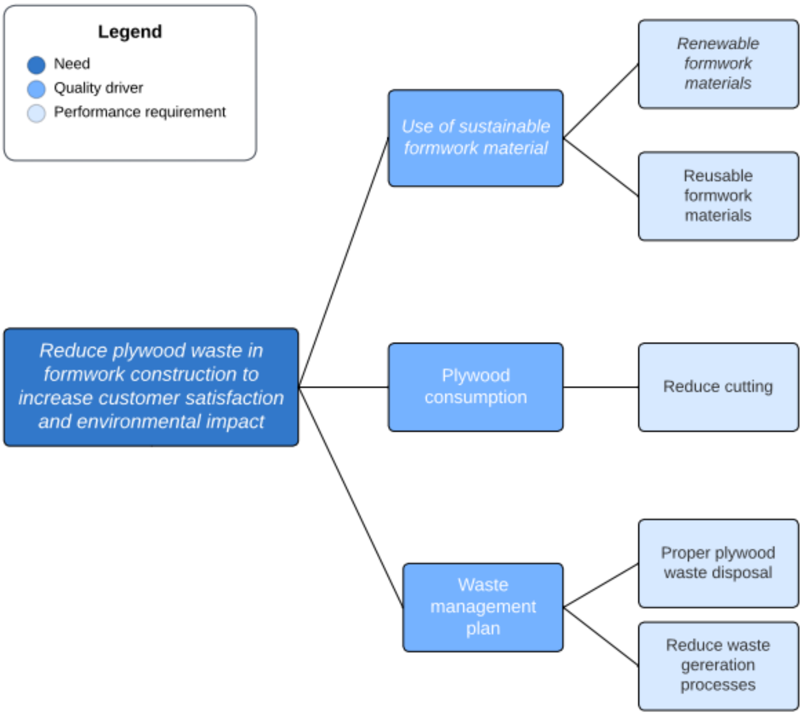

Figure 8 Critical to Quality (CTQ) tree

Most of the plywood can be replaced with more developed sustainable materials that can be used for many times that will reduce the waste significantly by more than 40%. By fully implementing new solutions and management strategies we might be able to reach 30% of total plywood consumption and its' environmental impact. By satisfying customer performance requirement, the plywood consumption can be minimized by 40% during the assessed project theory. As to meet the theoretical values the main scope is the waste generation elements in the construction process.

3.2.1.3 Voice of the Business (VOB). The voice of the business is mainly derived from the company financial data and internal quantitative data to state the importance of the case study needs. Expectations, and preferences. Based on the collected data from the company we were able to understand the financial impact of the aspect under study. Zero waste process is always what businesses are seeking towards to reduce non-value-added costs on projects. The occurrence of large amount of waste in formwork construction contributes in loss of valuable resources and added costs that can be avoided by using developed technologies and more sustainable materials. The prices of plywood have increasing significantly during that past year that makes company stakeholders seek to exploring process improvement ideas. Implementing developed techniques will not only help the company save cost it will also help the company grow financially and sustainability.

3.2.1.4 SIPOC. The SIPOC diagram considered as high-level process map. Moreover, SIPOC documents the business process from start to finish before implementing any process improvement. The diagram shown in figure (9) shows the high-process map of plywood formwork construction. There are two suppliers in the process that supplies the project one plywood and the other for process accessory. Inputs of the process are formwork design from civil engineers, plywood, carpenters, and required tools to machine the moulds. The processes are obtained by site visits and worker interviews. The process outputs are formwork mould ready for concrete pouring, plywood waste and scrap, and warehouse occupancy. The warehouse stores such material as used plywood, scaffolding, and support system that are transported to project site. Finally, the customer direct of the formwork mould process is the contracting company that consumes waste and deal with disposal process, and the other customer is the project owner that is affected by plywood waste indirectly by added cost on project total.

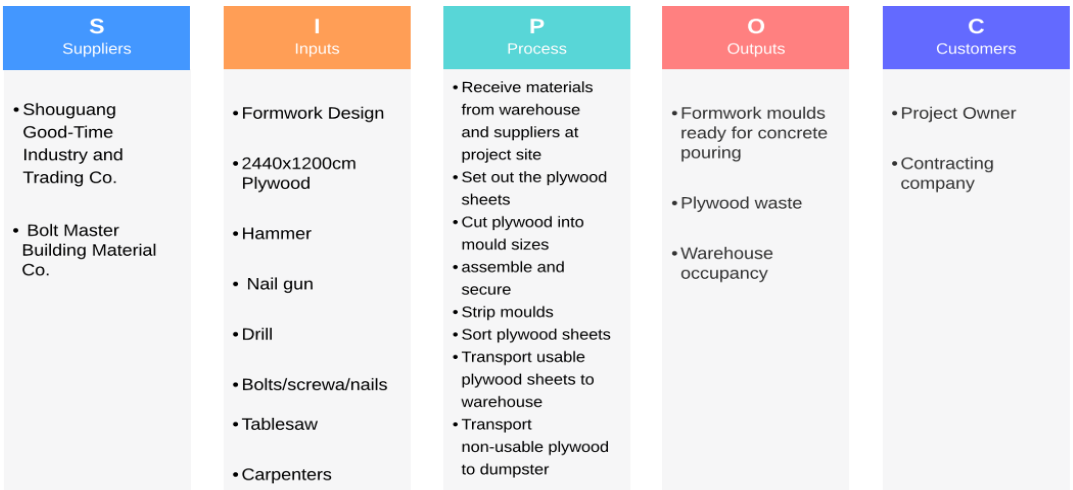

Figure 9 SIPOC diagram

3.1.2 Measure. During this phase of the project, we were able to confirm the current state of plywood formwork process flow by the identified inputs and outputs to the process. Also, the collected data from process walk-ins and submitted contracts are used to expose the primary cause of the problem. The current state of the process flow is illustrated using value stream map (VSM). Data collection plan is preformed to determine the baseline of the project.

3.2.2.1 Value stream map (VSM). The current value stream map shown in figure (10) is constructed based on the formwork mould construction steps, materials, and information flow. After the project contract is accepted and the formwork design is approved the construction managements calculate and order the required plywood amount for the project while, taking into consideration the available materials in the warehouse. After the materials are set out for transportation, workers unload the required materials at the unload station. Machining plywood formwork into mould size comes after works has already built the support. The next process in the formwork moulds consists of assembling, securing, and make them ready for concrete pouring.

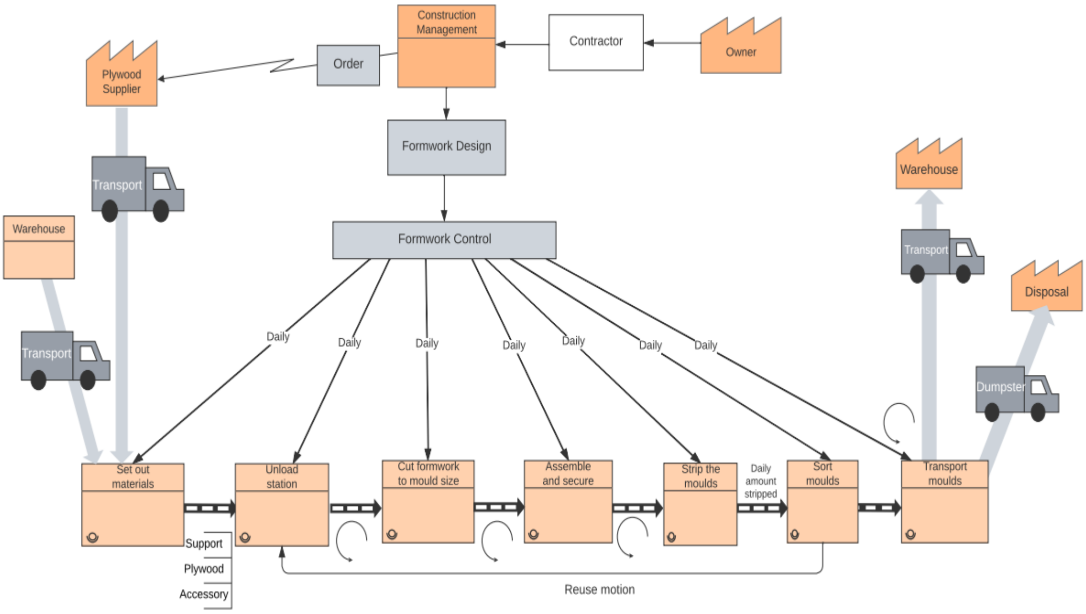

Figure 10 Current-state value stream map (VSM)

Concrete is poured into formwork moulds and workers must wait for concrete to dry for 24-48 hours before stripping the moulds. After the stripping process is done the striped material is sorted. Due to the standard structure of formwork and the used material a huge amount of plywood is wasted occurs during machining and striping the mould. Moulds are stored into two categories, usable and non-usable. Since plywood can be used up to 3-time, usable material can either be used if the project is still in construction or transported to the warehouse. Non-usable plywood is transported by $10m^3$ dumpster to get disposed.

Table 4

Formwork Construction CT and # Of Workers

Activity	Cycle time	# Of workers	Total hours
Set out materials	1 day	2	4
Unload station	1 day	4	8
Cut formwork to mould size	4 days	7	224
Assemble and secure	7 days	10	560
Strip the mould	7 days	7	392
Sort mould	1 days	4	32
Transport mould	1 day	2	4

Delay in cutting formwork because of support set up after foundation phase is done the setup time 4 days, mould is strip lead time is 2 days based on concrete drying time. Before moving to the next floor concrete must fully cure for about 14 days and then there is setup time again 4 days to build the second floor. The mould transports occur after the formwork is complete. The number of workers is listed in table (4) below. The process cycle time for two storey house each of 570-meter square using plywood formwork is 2400 hours which is 300 working days, and the lead time is 339 days in total. The labour productivity 3.8-meter square per worker day which means that each worker can finish up to 3.8-meter square in 8 hours.

3.2.2.2 Data collection plan. Determining what best factors represents the performance of the process to draw the process baseline. The process baseline is represented in terms of plywood waste per meter cube of concrete poured into formwork. This baseline can be interpreted by percentage of plywood consumption during the formwork mould process shown in the current-state of the VSM. The balanced inputs and process variables shown in figure (11) will help in quantifying the overall performance. Performance is measured by how well needs and requirement of both customer and business were met. The output measures are customer satisfaction, cost, plywood waste, and environmental impact.

Figure 11 Input vs. output data

3.2.2.2.1 Measurement selection matrix. Measurement selection matrix shown in table (5) is identified in order to find the most strongly linked measures to reach customer needs. The output measure that has highest correlation with customer requirements will be measured as performance baseline that improvement can be evaluated by. The y-axis in the matrix represents voice of the customer (VOC) data that are used to identify what are the critical to quality requirements (CTQ). On the other hand, x-axis represent the output measures that are collected from brainstorming, SIPOC, and other collected data. The matrix has been discussed with project team members to classify the correlation between all measures with corresponding customer requirement: strong, moderate, weak. After the correlation is made the matrix will show which output measures powerfully associated with customer requirement. The measurement selection matrix shows that the amount of plywood waste and environmental impact are strongly linked to all customer requirement. The two measures that found highly correlated with CTQ are amount of plywood waste and environmental impact.

Table 5

Measurement Selection Matrix

Customer Requirement	Output Measures: Number of uses	Cost of plywood	Amount of plywood consumed	Amount plywood per formwork element	Environmental Impact
Renewable formwork					●
Reusable formwork	●	●	●	○	□
Reduce cost	●	●	●	●	
Reduce cutting			●		□
Proper waste disposal					●
Reduce waste generation process	□		□	●	●

CONTRIBUTION ● Strong □ Moderate ○ Weak

3.2.2.2.2 Data collection instrument. The data collected for the selected significant measurements are obtained with the use of different tools. Table (6) show data measure, how it is obtained, unit of the data, and the data type. Construction company has submitted the project contract where it has valuable information about the project area, amount of concrete required, and formwork design. The company also submitted the purchase order (PO) of materials that include the following data; quantity, cost, and reusability of plywood. The quantity purchased of plywood is obtained by the required amount of plywood minus the available amount in the warehouse. The number of materials that got transported from the warehouse and back is obtained by the foreman records of the project. Amount of plywood waste is measured by the total of plywood transported to the project-site minus the amount of plywood transported back to the warehouse. Number of filled dumpsters is observed during the project final stage, where the dumpster size is $10\ m^3$.

Table 6

Data Collection Plan Information

No.	Data	Obtained by	Unit	Data type
1	Formwork design	Contracts obtained from the company	N/D	N/D
2	# Of plywood needs to be purchased	PO $(required/3 - available)$	Sheets	Attribute
3	Purchased plywood cost	PO	KD	Variable
4	Plywood reusability	PO	times	Attribute
5	# Of plywood transported to project site from warehouse.	Foreman records	Sheets	Attribute
6	Amount of plywood out for disposal	# Of filled dumpster observed	m^3	variable
7	Amount of plywood back to the warehouse after the project is over.	Foreman records	sheets	Attribute
8	Amount of concrete poured into formwork moulds	Contracts obtained from the company	m^3	Variable
9	Plywood consumption	$\frac{Out}{Total\ In} x100$	Percent	Variable
10	Used plywood per formwork element	Total element area	m^2	Variable
11	Volume of plywood sheet	$h\ x\ w\ x\ t$	m^3	Variable
12	Emission	Literature	$kgCO_2e$	Variable

3.2.2.2.3 Data collection procedures. The data collected using different procedures to assist the baseline performance of plywood consumption in formwork mould construction. The data collection procedures are performed six times, based on the number of projects we are analysing. The project design and contract and is approved between the two of customer and contractor the construction process starts. The detailed formwork design and the amount of concrete poured data is submitted in the project contract by the company. Information about the plywood dimension, cost, and reusability is collected from the purchase order submitted to the plywood supplier. The number of plywood sheets transported to the project site and back to the warehouse is counted by the foreman and submitted as a form of two Kanban, one for the number of sheets transported to project site and the other one for the number of sheets transported back to the warehouse. Amount of disposed plywood is collected from the number of dumpsters filled during project and transported to landfills. In order to get accurate data about the disposed plywood, we designated dumpster for only wood waste. The percentage of plywood consumption is calculated using this formula $\frac{Out}{Total\ In}x100$, out is the total amount of disposed plywood, total in is the total amount of plywood transported to project site from both warehouse and supplier. Finally, the amount of emission is measured based on LCA of hardwood plywood product literature review, in terms of kilograms carbon dioxide equivalent $KgCO_2$ per 1 m^3 of plywood. The emission will be calculated for the total amount of used plywood per project. The emission includes the amount of $KgCO_2$ released in production and stored in 1 m^3 of plywood.

3.2.2.2.4 Data analysis procedure. The collected measure data is analysed using statistical tools to come up with critical values to the process performance. Process performance is calculated based on customer requirement. The collected and calculated data then will be analysed to measure the process baseline performance to help in measuring the performance improvements. Measuring improvements based on process baseline to note how well is the process in meeting the customer CTQ. A value steam map is constructed base on process observation and workers interviews. VSM helped in visualizing the formwork mould construction. A measurement selection matric is created to find the mostly link data to measures to reach customer needs. The matrix shows the correlation between the output measures and customer by ratings obtained from interviews. The mostly liked data then will be analysed to find the baseline of process performance. Moreover, data collected about amount of plywood transported from-to warehouse are obtained by the project foreman, the data is analysed to help identify amount of plywood consumed by the project formwork construction. The purchase order (PO) of plywood is submitted by the company to identify the amount of wood goes into the project. Also, PO include valuable information about the plywood such as cost, and dimensions. The consumption of plywood per formwork elements is tracked to help in accurate implementation of the solution, and the causes of such high rate of consumption is discussed with the team members.

3.1.3 Analyse. During this phase we were able to identify potential causes of the problem by visually analysing the process flow. The process of plywood formwork moulds starts after the digging, shuttering, scaffolding, rebar work is done in that phase. Then the carpenter measures the size of the moulds that needed to be constructed from plywood for each formwork element such as, foundation, columns, slabs, beams, grids, walls, and stairs, shown previously in figure (6). The plywood is cut and dry fitted to size to assure accuracy of the mould. The next step is to support and secure the mould in place using screws and bolts, after the first phase (storey) mould elements are done the moulds will be ready for concrete pouring. Afterwards, concrete curing takes 14 to 21 days to fully cure and mould are ready to be stripped and transported to the next phase of the project to be used again if possible or disposed. Plywood moulds construction per each 1000 m2 takes approximately around 7-9 days to be constructed and mould stripping takes 7 days. Each 200m3 of poured concrete needs approximately 336 sheets of plywood and the plywood can be re used for 3 times only or 1-2 times in case of cutting for an odd shape, each sheet costs 6.5 KWD in 2019 to 2021 and it went up to 7.5 KWD in 2022 up to now. Each meter cube of concrete is charged 2 KWD for plywood fabrication. Here in Kuwait each project demands that 80% of the used plywood must be new and the old 20% of plywood can be used only in construction the project foundation. Also, as we already mentioned that formwork construction using plywood consume up to 80.6% of plywood on average as shown in Table (7). The data in the table shows the amount of concrete poured into six different projects and the purchased amount of plywood sheets. The consumed number of sheets is calculated from the plywood sent back to the warehouse after each project is over and the number of dumpster trips to consumed plywood disposal.

Root causes analysis is conducted by brainstorming with team members and the company stakeholders we were able to identify the root causes that generates high amount of plywood waste during the formwork mould construction. Brainstorming the causes of the problem were approached using one of the well-known lean manufacturing tools ‘fishbone diagram’ to present the data visually. There are six different categories causes the main problem and each category contains several sub-categories. The categories are design, manpower, material, method, measure, and mother nature as shown in figure (12). Each of the team members contributed on what may affect the high plywood consumption in formwork mould construction and then, we again brainstormed and searched for the causes with high potential. We found that complex designs contribute to higher wood consumption were also, it leads more to design errors.

Table 7

Plywood Consumption for Each Project

Project	Year	Reinforced Concrete m^3	Req. # of sheets	Cost of plywood	Consumed # of sheets	Consumption Rate
A	2019	8901	7475	KWD 29,900	6055	81%
B	2019	3229	2712.5	KWD 10,850	2306	85%
C	2020	3652	3065	KWD 12,260	2452	80%
D	2022	808	680	KWD 4,080	530	78%
E	2020	14159	11891	KWD 47,564	9751	82%
F	2022	4119	3550	KWD 21,300	2840	80%

The excessive use of beams and grids other than slabs in designs contributes to higher consumption based on the size of the sheet where it will need to be cut to fit the design of grids and beams. The second category is manpower where workers can affect the consumption and state of the plywood by the way they are handling it. The main causes of manpower category are lack of expertise where they can damage a large amount of resources also, incompetent workers can damage the used material based on they carelessness. Another factor in this category is lack of communication between workers and engineers where it may cause change in design during construction and/or engineers can implement unnecessary complex elements that will increase the plywood consumption during construction.

Material is one of the main factors that influence the consumption based on its' properties. The problem is deeply influenced by the material reusability where plywood can be used only 3 times and the be disposed, plywood has a standard size and that will increase the need for cutting it to fit desired mould size. Plywood can be easily damaged because of its' properties, it can be damaged from transportation, securing using screws/nails and, stripping that will reduce that lifespan of the sheet. The next category discussed for increase of plywood consumption is method where it can include construction method, lack of other construction techniques and materials, poor waste management, rework method, mould stripping technique. One another important category is measure where, poor plywood utilization and wrong measurement can highly affect the plywood consumption in any means. Finally, mother nature and poor environment can affect the plywood quality and damage it bases on the known wood properties such as expanding if exposed to highly humid environment for long time.

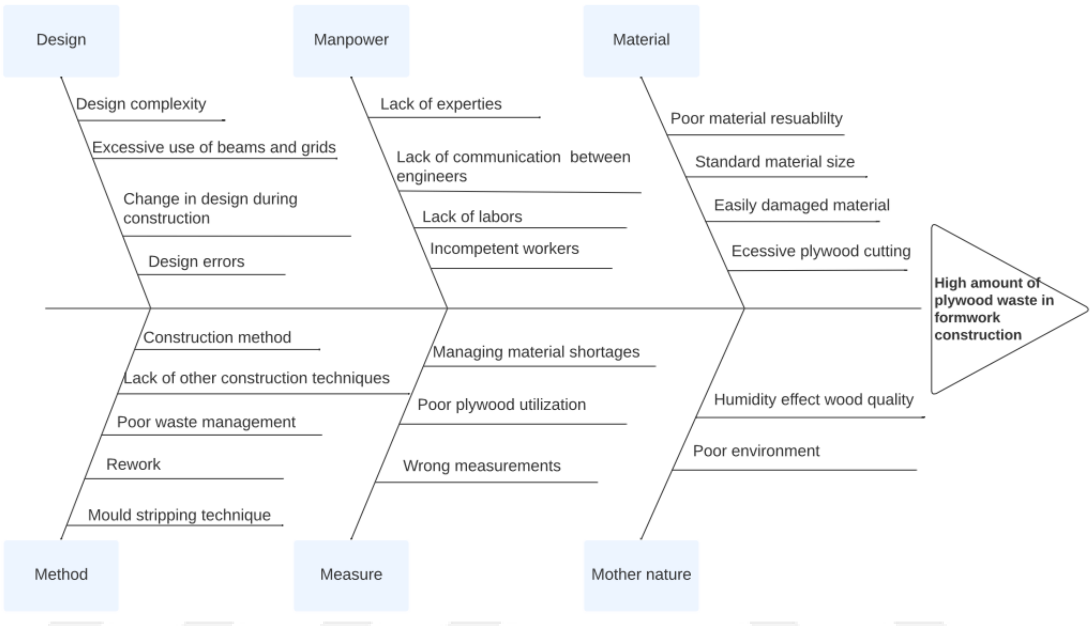

Figure 12 Fishbone diagram

Using brainstorming, prioritization, and selection techniques alongside project team members we were able to narrow down the search for significant root causes of the problem. Pareto chart is constructed as shown in Figure (13) where, it has shown that plywood cutting and the number of uses is the main causes of plywood waste. Plywood cutting occurs during formwork construction in order to make perfect size moulds based on the project dimensions and requirements. Excessive cutting occurs in the formwork structural elements such as beams, stairs, grids, and columns construction. After tracking the causes of high plywood consumption, we found that the company uses GRADE-C plywood that has a very low reusability rate. Low grade plywood can be used 3-4 times maximum based on the low quality of used wood and film-face. The plywood durability also is a factor contributing in hight amount of waste, the used grade of plywood used can be easily damaged after several uses. Based on the properties of wood it can be bend during formwork de-shuttering, nailing into the wood for assembly purpose has also affect plywood consumption rate. Design related elements such as curved surfaces and domes produce vast amount of waste where plywood can be used very few times and a lot of errors can occur in constructing complex shapes.

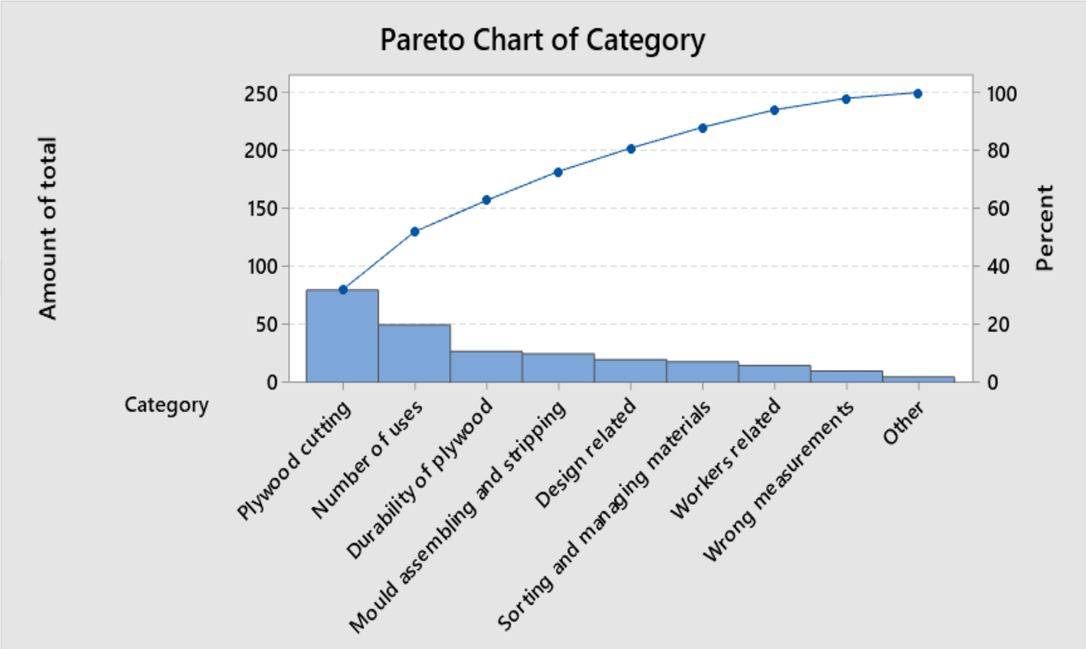

Figure 13 Pareto chart

3.1.4 Improve. The focus in this phase is to identify potential solutions, evaluate, select, and optimize the best solution for the problem under investigation. The potential solutions are evaluated by using multi attribute decision making, that will help in selecting the best solution to be implemented. Using the collected data from different project we were able to identify the main causes of high plywood consumption during the formwork construction. Know the main causes of the problem helped to identify a wide range of potential solutions aiming to reduce plywood consumption. The optimum solution in theory will be building formwork moulds at minimum cost with material that have infinite number of uses, zero environmental impact, and smooth surface finish. The alternatives will be ranked using one of the Multi-Criteria Decision Making (MCDM) models called Simple

Additive Weighting (SAW) method. Using normalized decision matrix each alternative will be assessed regarding every criterion finding the performance score of each alternative to be ranked from best to worst solution.

3.2.4.1 Potential solutions. There are many formwork materials out there, potential solutions are generated based on the construction industry standards to solve the problem of hight plywood consumption.

A. Higher grade plywood

The higher the grade of plywood the more reusability rate it has. High quality structural plywood is well known for its;' durability and number of uses. Grade-C plywood can be used 12-15 times and the standard dimensions are 2440x1220mm. This type of wood is preferable to be used in construction a building of 7 floor and higher in order to get full use of it. the cost of grade-c plywood is 15KWD.

B. Plywood inner face treatment with shuttering oil

Shuttering oil treatment is mineral oil used to the inner face of the plywood formwork moulds before concrete pouring. Shuttering oil prevents water absorption by plywood and works as a releasing agent to prevent the plywood from sticking to the concrete therefore it protects the plywood so it can be used several times. Moreover, shuttering oil reduce concrete defects by providing good surface finish. If the plywood has no barrier paint, is it recommended to use three coats of shuttering oil before plywood is used for the first time. Correspondingly, shuttering oil can contaminate the reinforcement rebar where, it is advised to use the shuttering oil and give it time to cure before assembling the moulds are erected.

The area covered by 1 Litre of shuttering oil can cover 35 to 45 m2 of plywood formwork. For 1000 m2 slab concrete shuttering oil required = 1000/35 = 258.5 litres. The cost of shuttering oil is 450fils per 1 Litre here in Kuwait, making the cost of shuttering oil 116 KWD to cover concrete slab of 1000 meter square. The procedure of applying oil to plywood will significantly affect the process time of formwork construction, where it will also require cleaning the boards before using them again. Also, concrete must be cleaned after formwork moulds are stripped for removing any shuttering oil residues that will also add to the process time. The estimated process time of applying the oil to 1000m2 of plywood is 12 hours in total and the estimated time for cleaning concrete surface is 8 hours. Since a vast amount of plywood consumption in construction process is due to plywood cutting, the use of shuttering oil will not help preventing the main cause of plywood consumption. But, the use of shuttering oil will increase the number of uses for the grade of plywood used by two times. but eventually it will get deposed to landfills and replaced increasing environmental impact by the added material to it. A very important information is shared by the company engineers that the use of shuttering oil in this region will cause the film face of the plywood to be ripped due to the high heat here in Kuwait.

C. Aluminium formwork system (AFS)

The aluminium formwork system is established in the late 1970's in developing regions for the cause of constructing low-cost housing units. A study was conducted by (de Abreu & Lordsleem Jr, 2019) mentioned that AFS provides a continues concrete pouring where, all the formwork structure elements such as walls, slabs, stairs, also openings for doors and windows are poured in a single operation. This type of systems designed for the use in a large-scale construction project such as commercial, industrial, or residential buildings. It is most effective in repetitive construction projects that has identical units being constructed. The use of such system ensures higher quality, accurate dimensions, and very smooth concrete surface finish. The study shows that using AFS can significantly increases the rate of productivity, the execution pace of each floor is 4 to 6 days. Most of the projects that used AFS have a work cycle of 4 days per floor. As the floor plan is divided into four sections after structural designer consultation and the activities are carried out for one section per day is concreted. A project that consists of ground floor and four storey levels can be accomplished in 20 working days only. Moreover, aluminium formwork system has less material waste than other conventional formwork system such as plywood and it can be reused for more than 300 times.

The AFS involves a smaller number of works and less skill is required than other methods. Each worker can install 20-to-30-meter square of aluminium panels per day without the need for lifting tower. The high quality of formwork and the low execution time are the main factors for using AFS is multiple countries. Since the used material for this type of formwork is aluminium, it is very light weight that will be easy to handle and assemble. The lightness of the AFS will reduce the number of trips to transport the material where it will help in reducing emission. Additionally, aluminium is the most environmentally friendly metal on earth and it can be infinitely recyclable and it has 40% recycling value. The initial cost of AFS is 22 KWD per meter square and each time the material used the cost will be lowered. For example, by using the material 50 times the cost per meter square will be 0.44 KWD and the more you use the materials the less it will cost overtime. The hardest part of using this type system is creating shell drawing, formwork layout, formwork elevation, and formwork BOQ (Bill of quantities) using computer software. Also, the use of thumbnail BOM (Bill of material) using SolidWork software add-in to give the assembly information is relatively required. When using the aluminium formwork from old project to build new project only 10%-20% of the non-standard formwork materials will need to be replaced. The aluminium material has a high reselling value of 50% of the purchasing cost.

Figure 14 Aluminium formwork system (AFS)

D. Integration of plywood formwork and aluminium formwork systems

The use of both plywood and aluminium and plywood together is under investigation for effective material waste reduction. Since the main causes of high plywood consumption is plywood cutting and the number of uses this model is developed. The basic number of uses for the current used grade of plywood is 3 uses the cutting process lower that number even more. This model focuses on replacing the formwork mould material where excessive cutting occurs and change the grade of plywood used. The main elements in the formwork that contributes in large amount of plywood consumption are stairs, beams, and columns. Based on the shape and size of these elements and the size of plywood a vast amount of cutting is requiring. The current type of plywood (GRADE-C) can be used up to 3 times and if the plywood needed to cut the it will be used 1 or 2 times only, by changing the grade of plywood used to GRADE-B that can be reused 12-15 times we will be able to reduce the plywood consumption dilemma. The higher grade the plywood the more expensive it gets; the cost of the new plywood is 15KWD per sheet.

Nowadays, there are manufacturing companies that supplies and adjustable column formwork, that can be adjusted base on the design requirements. the adjustable column structure can be adjusted using the pegs in the structure itself. The size of column can be adjusted from 600mm to 1200mm based on the project requirement and the sizes can be change based on order. This type of adjustable column is preferable to be used for square columns and still it is not certified to be implemented in formwork construction here in Kuwait. Breaking down the columns in to several aluminium panels to construct one column is helpful to insure well reusability of the panels. For example, a column of 600x1200mm will be assembled by two panels of 300mm and two panels of 600mm on each side. This method will reduce the high labour productivity the system has, but it will be more financial to the company.

The beam size can vary depending on the carrying load but, for a company works with residential buildings the beam dimensions is 225mm x 300mm according to the **SI code** where the span can be up to 5 meters. Therefore, a fixed size be can be implemented in residential buildings and small housing units. The depth and width of the beam depends on the area between two reinforced columns, the distance range between 3 to 4 meters for small buildings 6 to 9 meters for large building where large free space is required. For the common structures 5 meters space between columns is reasonable where the maximum and minimum distances are 7.5 and 2.5 meters respectively. The beam depth rule of thumb is the clear span between two columns divided by 10 or 12 and the ratio of depth and width of the beam should be greater than 0.4 to 0.45 as IS13920. For most project these distances are applied where, it will limit the options of beam dimensions and that will be helpful to increase the reusability of the material throughout other projects.

Stairs is another main factor that highly consume materials using conventional formwork due to its' shape that required a lot of material cutting. The design of staircase is influenced by height of the celling, riser, depth, width, thread, flight angle of the stair, load applied and other aspects. But. there are standard dimensions for stairs components that can be followed for stairs construction such as thread, riser, width, and flight angle that are majorly used in small housing units' construction. In Kuwait the basic standard stairs dimensions for two to three storey houses are depth 30cm, width 110cm, riser 18cm, and 30-45 angle

3.2.4.2 Ranking alternatives using MCDM. In this study the evaluation criteria are derived from customer requirement, business needs, and environmental impact as the following:

1. Number of uses
2. Labour productivity (LP)
3. Cost
4. Material weight
5. Salvage value
6. Environmental impact – Carbon footprint

Using Multi-Criteria Decision Making (MCDM) methods to assess alternatives and select the optimal solution based on our selected evaluation criteria. The selected solution will be compared with the IPAFS model for performance evaluation. One of the most common and useful method used in MCDM is Simple Additive Weighting (SAW) that is going to be used in the case to select between alternatives. The basic concept of SAW method to find the weighted performance rating for each alternative on all the evaluation criteria. The method will help in easily ranking the alternative to find optimal solution among others. The Evaluation criteria for the current used formwork material and suggested alternatives are shown in table (7). Beneficial evaluation criteria are number of uses, labour productivity, and salvage value. The beneficial criteria indicate to where higher values are desirable also known as positive criteria. On the other hand, the non-beneficial criteria are plywood consumption, cost of material, weight, and environmental impact where lower values are desirable also known as negative criteria.

The criteria are weighted using direct rating method in according to their importance to the study, scale of 1 to 5 is used where 1 being least important and 5 being most important. The criteria assigned to be most important given the value 5 are the number of uses, and cost of formwork material. Environmental impact of the chosen material given the value 4 for being important, and labour productivity and weight of the material are assigned to be 3 as moderately Important. Finally, 1 for salvage value being less important.

Table 8

Evaluation Criteria

Criteria	Unit	Plywood-C	Plywood-B	Shuttering oil	AFS
Number of uses	times	4	12	5	300
Labour productivity	m2/day	3.8	3.8	3.76	10
Cost	KWD/m2	2.5	4.5	2.5128	24
Weight	Kg/m2	7.726	7.726	7.726	18
Salvage value	%	5	5	0	40
Environmental impact	KgCO2e/kg	2.11	2.24	2.134	8.14

The environmental impact is measured by kilogram of carbon dioxide equivalent per kilogram of the used material for formwork. The data is collected from literature, KgCo2e/kg for aluminium is obtained from (Winnipeg-Canada, 2012), and for plywood is obtained from (Wilson, Johnson, Puettmann, & Oneil, 2013)

After the direct rating method is done, the data values are normalized to obtain the weighted criteria as shown in table (9). A1 is assigned to the current plywood formwork material Ply-C, A2 is assigned to the use of higher grade of plywood Ply-B, A3 is for using shuttering oil with the plywood, and A4 for using aluminium formwork system.

Table 9

Criteria Weights Using Direct Rating Method

Criteria	Explanation	Rate	Weight
C1	Number of uses	5	0.25
C2	Labour productivity in m2/day	3	0.15
C3	Cost of material in KWD/m2	5	0.25
C4	Weight in Kg/m2	3	0.1
C5	% of Salvage value	1	0.05
C6	Environmental impact in KgCo2e/kg	4	0.2

After finding the criteria weights, the alternative values are obtained, the alternative values are normalized using the following equations:

$$v_{ij} = \left\{\frac{x_{ij}}{Max\ x_{ij}}\right\} \quad \text{and} \quad v_{ij} = \left\{\frac{Min\ x_{ij}}{x_{ij}}\right\}$$

The calculation of the previous equation shown in the table (10):

Table 10

Normalized Decision Matrix

Normalized Matrix						
Type	B	B	NB	NB	B	NB
	Criteria					
Alternative	C1	C2	C3	C4	C5	C6
A1	0.013333	0.38	1	1	0.125	1
A2	0.04	0.38	0.5	1	0.125	0.94196
A3	0.016667	0.376	0.994906	1	0	0.98875
A4	1	1	0.104167	0.429222	1	0.25921

Next is finding the alternative preference using the following equation:

$$A_i = \sum_{j=1}^{n} w_i\, v_{ij}$$

Using the formula above large value of A indicates that A3 is the best solution, A1 is the second-best solution and V2 is the last. In other words, using the SAW method V3 is the optimal solution shown in table (11)

Table 11

Ranking Alternatives

Alternative	Ai	Rank
A1	0.572833	2
A2	0.457402	4
A3	0.557044	3
A4	0.599346	1

3.2.4.3 Implementation plan. The implementation plan will integrate the best two alternatives Aluminium and plywood formwork into construction process of formwork structure. Full implementation of AFS was initially considered but, due to the high initial cost of the aluminium formwork system execution was stopped for the mean time. AFS will be used where excessive plywood cutting occur, this model is introduced to help in minimizing the waste of plywood. The first steps to execute this model will start from analysing the approved engineering drawings submitted by the owner to the contracting company. The engineering drawing will help in determining the number of materials needed to be purchased to build the concrete formwork. The detailed engineering structure drawing is analysed by calculating the number of each column and beam size in every level, the slab dimensions are also considered to calculate the required amount of formwork materials. The slabs, beams, and walls are preformed using structure plywood formwork. On the other hand, columns are preformed using aluminium formwork materials. The number of columns formwork required from each size will be the maximum number in all levels to insure one concrete pour per floor. For example, the number of column C-1 is 18 in ground floor, 12 in first floor, and 8 in the second floor; the number of column C-1 formwork is purchased is 18. This method will help in purchasing less of the aluminium material but still pour all the columns in a single floor at once. The required number of columns and its' dimensions are sent to the fabricator to produce the required materials and components. To assemble the column formwork the required components are stub pins, wedges, and corner panels. The required tools to assemble aluminium formwork are panel puller, hole bari, hammer, pre-treatment mould oil and steel tape. The project engineer will help in explaining to the workers how to assemble the columns, what tools and components are needed, what are the precautions to be taken, and how to sort the materials after de-shuttering.

When the excavation, levelling, and foundation is done with the use of plywood where appropriate the workers will proceed into columns rebar process. Afterwards, the aluminium columns will be assembled then checked for elevation and vertical alignment, ready for concrete pouring. When concrete cures column de-shuttering is done, the other formwork elements such as beam, slab, and wall will be executed using the current conventional formwork - structural plywood sheets. The amount of plywood required will be calculated from the design structure and be purchased. structural formwork elements using plywood are poured, the rebar work starts and column formwork is assembled around it again in the next level ready for another concrete pour.

The rate of plywood consumption will be calculated by comparing the standard required number of plywood sheets per project without the use of aluminium formwork columns and with. The difference will measure how well does the implementation of aluminium formwork will reduce the consumption of plywood and other materials. In order to assure less material wastage and damage to the aluminium panels, panels must be cleaned and well sorted to increase its' life cycle. Well sorting of the panels using Kanban card will help in easy access to the material and less purchases in next projects.

The environmental impact of the purchased materials required for the project is calculated by the reference value of KgCo2eq produced by Kg of each used material. The aluminium formwork material has higher emissions in comparison to plywood per Kg, but the amount of plywood purchased for each project is significantly higher. Since AFS has higher reusability value the amount of emission produced will be divided by the number of uses of the material.

3.2.4.4 Implementation. The suggested model is implemented in formwork structure construction of a building here in Kuwait that is performed by High City Contracting Est. The detailed engineering and architectural drawings of the building are done by AL-Jazera Consultant, and submitted to the company by the owner after approval. The total amount of concrete required to accomplish this project is 1622m3 of concrete in total. The suggested model will be using aluminium formwork to construct the concrete columns in category C, and plywood for the other elements in category A and B shown in Table (12). Category A consist of the formwork elements that require excessive plywood cutting, while category B consist of the elements that has minimal cutting required.

The columns total concrete volume is 180m3 poured into 336 columns in total for three storeys. Table (13) shows the columns number, count per storey, and dimensions where the ground floor, first floor, and second floor consist of 141, 138, and 57 columns respectively. The building plan and dimensions are sent to the fabricator to customize the required panels for the column's formwork. Colum panels came in the following widths in millimetre 200,250,300,400,500, and 600. Where the height of the panel is 2100mm so, double panels are required to be aligned vertically in order to accomplish the required celling height that is 4200mm per storey T.O.T (top-to-top). Boundary wall columns referred to as BWC in table (12) has a hight of 2100mm will be executed in two phases in order to save in aluminium materials cost, where that will not reflect negatively to the project timeline.

Table 12

Structural Formwork Elements and Concrete Volumes

Category	Elements	Thickness	M3
A	Footing	ref. drawing	183
	G-Beams	ref. drawing	176
	Beams	ref. drawing	293
	Stairs	ref. drawing	22
B	Plain Concrete	0.1	96
	Slab on Grade	0.15	170
	Pump Wall	0.2	35
	Pump Slab	0.2	7
	Core Wall	0.2	39
	Solid Slab	0.12	50
	Solid Slab	0.16	237
	Solid Slab	0.18	2
	Solid Slab	0.2	101
	Solid Slab	0.25	31
C	Columns	ref. drawing	180
Total			1622

Table 13

Numbers and Dimensions of Columns in Each Elevation

Columns Schedule						
Column No.	# C in GF	Dimension in cm	# C in FF	Dimension in cm	# C in SF	Dimensions in cm
C1	7	30x70	7	25x70	7	25x60
C2	2	50x40	2	50x40	2	50x40
C3	8	30x70	8	25x70	8	25x70
C4	22	30x60	22	25x60	22	25x60
C5	4	30x90	4	25x90	4	25x90
C6	18	30x50	18	25x50	0	-
C7	10	40x60	10	40x60	10	40x60
C4-A	4	30x50	4	25x60	4	25x60
C8	1	30x70	1	25x70	0	-
C9	8	30x40	8	20x40	0	-
BWC	57	30x30	0	20x30	0	-
C-N	3	30x30	0	-	0	-
TOTAL	141		111		57	

The number of aluminium panels purchased for each panel width derived from the factory BOQ is shown in the following table (14) to cover a total surface of concrete which is 1484.7-meter square. In order to achieve the required column dimension, the panels are paired using stub pins and wedges. For example, to assemble C5 the width will be 300mm panel on each opposite side and the depth will be 500mm and 400mm combined on each opposite side to form a column. The use of smaller panel width assembled to construct a column will help in increasing the panel reusability in other projects and target less purchase of materials, where column sizes will vary in size from a project to another based on project size and carrying loads.

The initial investment in aluminium formwork system is 29,694KWD for the total of 1484.7 meter-square of aluminium panels. The purchased aluminium panels can be used more than 300 times, where in this project itself most of the panels were used 2-3 times with no waste occurring from column construction. The cost of column formwork using plywood would be 2,760KWD for the purchase of 370 plywood sheets, where for the aluminium formwork columns it will breakeven with plywood formwork after 12 uses. The cost will decrease every time the panels are in use as shown in figure (15)

Table 14

Number and Size of Panels

Number of Aluminium Panels per Size			
No.	Panel Width	Count	Surface Area
1	200mm	86	58.8
2	250mm	256	134.4
3	300mm	926	617.4
4	400mm	272	228.48
5	500mm	200	210
6	600mm	232	292.32
Total		1972	1484.7

The required amount of plywood sheets for the other formwork elements were calculated using the given dimensions in the engineering drawing. The grade of the structural plywood is Grade-C due to the size of the project as discussed earlier, higher plywood grade will have on average a noticeable 40% cost and 60% waste reduction in a bigger scale project. In smaller projects higher grade plywood will reflect negatively on project budget. The number of plywood sheets purchased to construct elements in category A and B is 822 Grade-C sheets costing 6,165KWD.

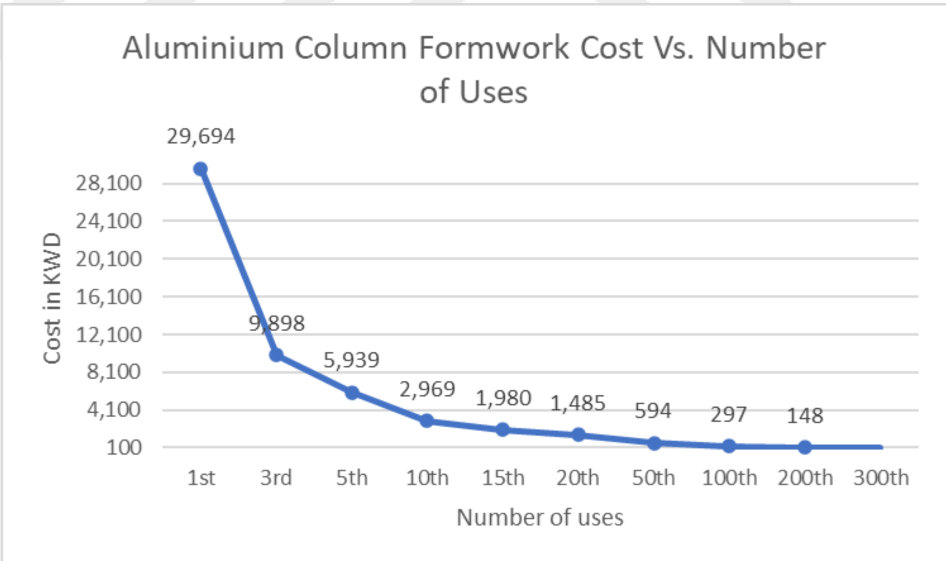

Figure 15 Aluminium column formwork cost vs. number of uses

The formwork materials and tools transported to construction site; it was unloaded to the site. Plain concrete foundation, ground beams, footing, and core walls is poured into plywood mould, afterwards, workers sorted the aluminium panels for each column number for the ground floor at ground level 0. After rebar work is over the columns assembly 3 workers were able to assemble 114 aluminium column formworks with shoring in 8 days for ground floor ready for concrete pouring. Where 87 of the columns for building structure purposes and 27 for the boundary columns. Worker has assembled the 111 columns for the first floor in 7 days for the first floor where, 27 columns for boundary and 84 columns for structure needs. The second floor took 3.5 working days with 3 workers to assemble 57 columns. The total columns assembled are 282 columns using hammer, pins, and wedges ready for concrete pouring. The Assembly of columns in Ground floor is shown in figure (16). Vertical props and horizontal bracing are set to support the construction of beams and slabs formwork of the ground floor celling. Three workers were able to assemble 16 columns in one working day, one worker were able produce 5.33 columns per working day that consist of 8 hours. As the cycle gets repeated moving from one floor to another the workers must refer to the engineering drawings after the concrete is cured and formwork de-shuttered to get the columns dimensions for the next floor. The panels are cleaned to be assembled again and when the project is over the panels are cleaned, checked for damage, and sorted by size ease the process and to be transported to the warehouse at the end of the project.

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Figure 16 Assembly of aluminium column formwork

After the project was over the number of usable plywood sheets transported back to the is 167 sheets, that makes the number of disposed sheets is 655 for constructing the volume of concrete in category A and B. Most of the waste is generated in the construction of the elements in category A

The implementation of the aluminium column formwork was able to reduce the reduce the purchase of plywood by almost 33% in this project. Investing in durable and high reusability rate material has a positive impact of project timeline and resource consumption rate. The aluminium columns are very easy to use and does not require skilled labour.

3.1.5 Control. The focus of this phase is to sustain the performance at a targeted level. The implemented solution was able reduce the amount plywood purchase for formwork construction. In order to sustain the process improvement, the company must keep track of material in hand to avoid repurchasing using Kanban cards. For future projects the company is asked to purchase the required aluminium panels taking into consideration the materials in hand. When new projects are submitted to the company, the company must break down the measurements of the required columns into smaller panel sizes to insure high reusability rate of the panel. Purchasing higher grade plywood for projects that has more than four stories is required to lower the consumption rate further.

The kanban card is used to improve inventory system and reduce cost of repurchasing an existent material. The kanban card should include the following information shown in figure (17) about the material. The part description will include the panel size, part number as stated in the PO, quantity, order date, supplier/origin, kanban is issued by who, number of uses, location of the material in the warehouse, inspection note for any visible dent or deformation.

The use of kanban card will ensure proper material management, and reduce project cost. If panels are deformed or dented the inspector will note that in the kanban card so material can be fixed or sold to be recycled, where that will avoid any deformation to the formwork being constructed.

KANBAN CARD	
Part Description:	Part Number:
	Order Date:
Quantity:	
Supplier/Origin:	Number of Uses:
Issued by:	
Location:	
Inspection Note:	
Submit Kanban Card to:	

Figure 17 Kanban card

3.2 Limitations

Construction formwork has different dimensions based on design requirements and carrying loads therefore, the full implementation of AFS was restricted in smaller size projects. Full implementation of aluminium formwork was not feasible for the project size and budget therefore, the AFS was implemented in column formwork where it has hight plywood consumption. Another important limitation for the project was the unawareness of sustainability in construction industry and old mentality of the company stakeholders. Kuwait has very few aluminium formwork fabricators that has restricted the verity of the materials available on the market. Most of the purchased material was transported from India and that increased the waiting time and shipping cost for the material to be arrived. AFS has large initial investment where construction industry has a lot of competition. The profit margin is lowered due to the competition and that restricts the room for implementing innovative solutions and developments.

Chapter 4

Findings & Discussion

4.1 Findings

Construction industry is one of the top global consumers of raw materials. The industry produced 20-40% of the global carbon emission. Wood is the most consumed material in conventional formwork construction. plywood has a limited number of uses and standard sizes where that will increase the waste of the material. By developing potential solution and evaluating them we found that aluminium formwork is the best solution to reduce the amount of material waste and lowers the environmental impact of the formwork construction. Aluminium formwork system is well suited for larger projects such as high-rise buildings to reflect positively of the project budget. The use of aluminium formwork materials has a positive impact on our resource consumption and labour productivity rates. Integrating aluminium formwork with plywood formwork is well suited for all project sizes. Using aluminium formwork for column construction by breaking down the depth and width of the of column to different panels to insure high reusability rate through different upcoming projects.

Column formwork construction takes the second place in hight plywood consumption where the first is the construction of beams, and stairs takes the third place. By replacing the plywood for aluminium in column formwork construction we were able to reduce the amount of purchased plywood by 31%. The amount of wasted material can be reduced by 33% by integrating the aluminium with plywood in formwork construction data is shown in figure (18). Construction of all three categories using conventional formwork will result of wasting 980 plywood sheets where, by using both aluminium and plywood it will be 655 plywood sheets.

The productivity rate has increased in comparison with plywood column formwork from 2 columns per worker day to 5.33 per worker day. The total days required for 3 workers to accomplish 282 columns for ground, first, and second floor using aluminium formwork is 18.5 days in total and 47 days for plywood formwork, data shown in table (15). This means that the implementation of aluminium into column formwork will decrease the column mould construction from 47 days to 18.5 days in other words the time of mould construction will reduce by 60.6%.

Table 15

Plywood vs. Aluminium for Column Formwork

Description	Plywood	AFS
Cost of columns formwork	2,624	29,694
Column per worker day	2	5.33
Reusability	3	300
Total days req. for completion	47	18.5
Salvage Value	5%	40%

Aluminium is more expensive than plywood as shown in table (15) because it is a durable and sustainable material that can be infinitely recycled without losing its' quality. Therefore, it has high salvage rate and reusability in comparison with plywood. Where is 40% for aluminium and 5% for plywood.

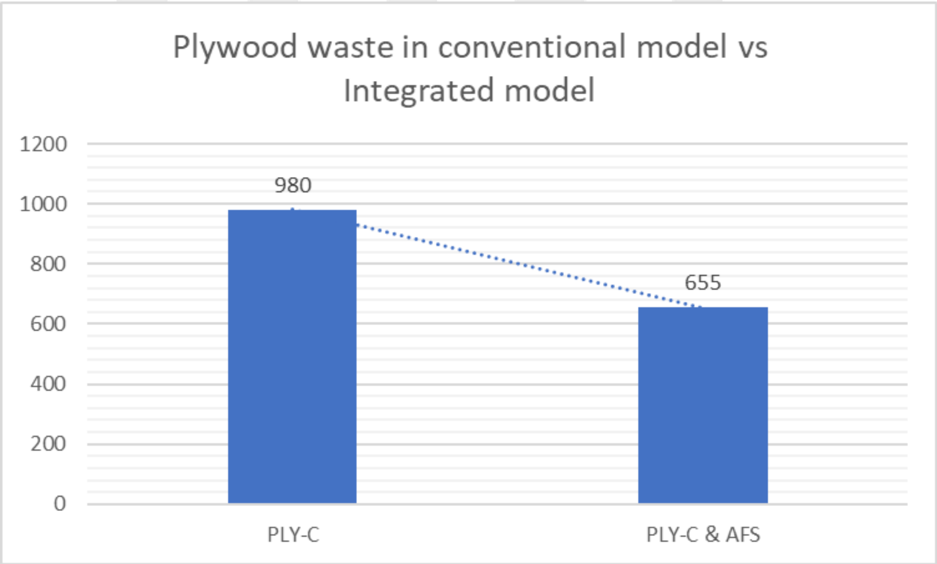

Figure 18 Waste of plywood vs. plywood & aluminium formwork

By integrating the aluminium formwork to the conventional plywood formwork, we were able to reduce the plywood waste from 980 to 655 sheets during this project shown in figure (18). The reduction of plywood waste will reflect positively on the environment by reducing the emission rate generated plywood since it is non-sustainable material due to the glue used in the construction of plywood sheets. Aluminium is a sustainable material that will reduce the overall produced emission if implemented in formwork construction projects due to the high number of uses.

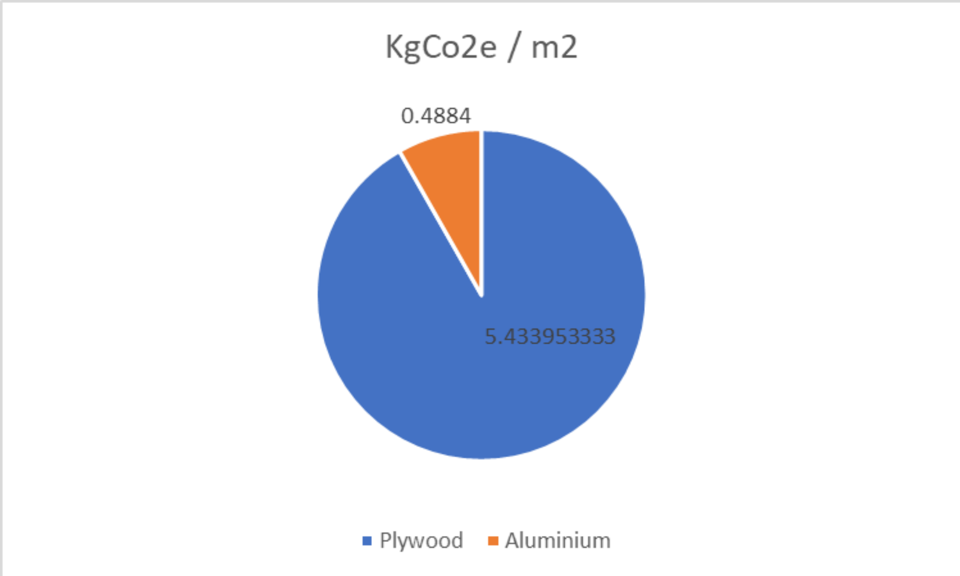

Figure 19 Carbon footprint per meter-square of plywood vs. aluminium

By integrating more sustainable material with conventional formwork construction projects it will significantly reduce the carbon emission being produced. The carbon footprint of one meter-square of aluminium is 0.4884 and 5.434 KgCo2e for plywood shown in figure (19) also taking into consideration the total number of uses for each material.

The use of aluminium as a formwork material to construct column is the project being studied will help in reducing the carbon footprint as shown in figure (20). Since aluminium has high number of uses that is on average 300 times, it has less environmental impact due to its sustainability. Aluminium is highly recyclable material and by doing so, we can save 95% of the energy used in its' production from raw materials. There is a significant difference due to the number of uses per assigned material.

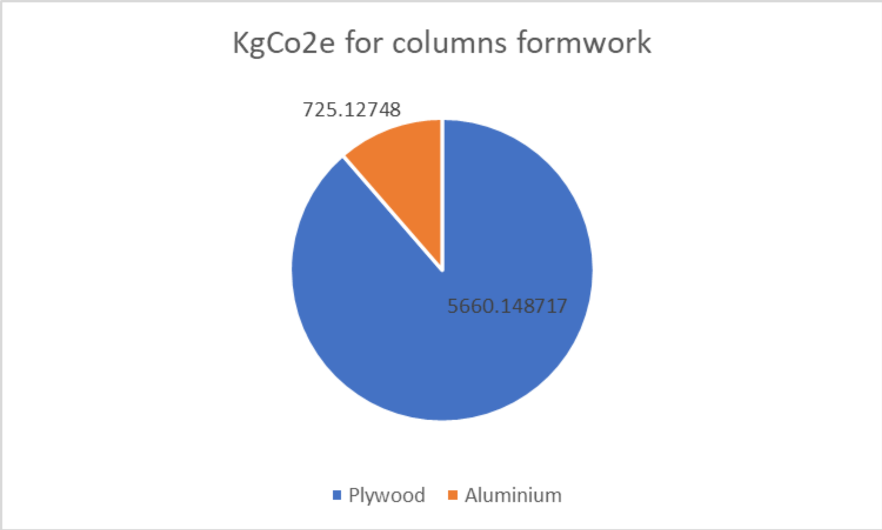

Figure 20 Carbon footprint of plywood vs. aluminium formwork

Initial investment for the aluminium column formwork is very high in comparison to the cost of plywood column formwork. On the other hand, it can help in reducing process time and waste. Also, it has a very high salvage rate and number of uses. The cost reduction values are calculated using the following equations:

Calculate the cost per use of the old and new material:

$$\text{Cost per use of the old material} = \frac{2{,}624}{3} = 874.67 \text{ KWD}$$

$$\text{Cost per use of the new material} = \frac{29{,}694}{300} = 98.98 \text{ KWD}$$

Calculate the total cost savings from using the new material instead of the old material:

$$\text{Total material cost saving} = (Cost\ per\ use\ of\ old\ material\ - Cost\ per\ use\ of\ new\ material) * No.of\ uses$$

$$= (874.67 - 98.98) * 300 = 215{,}569 \text{ KWD}$$

Calculate the cost of waste reduction:

$$\text{Cost of waste reduction} = (\text{Waste of plywood formwork} - \text{Waste of the integrated model}) * \text{Cost of plywood}$$

$$= (980 - 655) * 7.5 \text{ KWD} = 2{,}437.5 \text{ KWD}$$

Calculate the process time reduction:

$$Time\ saving = \ Plywood\ process\ time - Aluminium\ process\ time$$
$$= 47\ days - 18.5\ days = 28.5\ days$$

Cost of time saving: Given three workers per day for column formwork construction 15 KWD per worker day

$$\text{Cost of time saving} = \ \text{Time saving} * (\ \# \text{ of workers} * \text{cost per worker day})$$

$$= 28.5 \text{ days} * (3*15) = 1{,}282.5 \text{ KWD}$$

Total Cost reduction from implementing the new material is calculated to the project:

$$Total\ cost\ reduction = Cost\ saving\ from\ material +$$

$$Cost\ of\ waste\ rediction + Cost\ of\ time\ reduction$$

$$= 775.69 + 2{,}437.5 + 1{,}282.5 \approx 7{,}709\ KWD$$

The total amount saving of this project is 7,709 KWD if the material got in use for 300 times as expected. The cost reduction values due to the implementation of aluminium column formwork is very noticeable and effective. The aluminium material has high re-usability rate where in each upcoming project 10-15% repurchase is expected due to project differences. The repurchase rate expected for project with small to medium floor plan. The amount saving will vary from project to another due to project differences.

4.2 Discussion of Findings for Research Questions

1. Why construction industry provides vas amount of waste?

The main cause that construction industry produces a large amount of waste is the use of non-sustainable material. In the formwork structure construction, the highest amount of waste produced is plywood waste where it is on average 80.6% of the total purchased plywood. The main causes for plywood waste are cutting, number of uses per sheet, and durability respectively. Structural plywood is a non- sustainable material used in conventional formwork construction, the material has a very limited number of uses and require a vast amount of cutting depending on the structural element being molded into. Shuttering and de-shuttering the plywood reduced its' life span based on the material properties with low durability regarding this process.

2. How to measure construction waste?

The focus of this study is the amount of plywood waste generated from formwork construction. The amount of plywood waste can be measured in two ways, one being accurate than the other. The first method is the number dumpster trips observed, and the second method is the total number of sheets required transported from the warehouse and/or purchased from supplier.

3. How construction waste effect the environment?

Construction waste has a significant impact on the environment by producing large amount carbon dioxide (Co2) to the atmosphere and being the largest consumer of the natural resources. Due to the high demand of structural wood an illegal deforestation was highly spotted in one of the largest forests on planet. The disposal of constructional materials waste unrevealed the stored carbon dioxide, where also materials need to be replaced due to unsustainability reasons. The harvest, manufacture and transport of the new material produce a vast amount of carbon dioxide. The Co2 levels are higher than ever been before because of fossil fuels that people are burning. Plants pull the Co2 of the atmosphere and convert it to oxygen, and by cutting the trees to use as building material and process it we produce more and more carbon dioxide influencing global warming.

4. How we can make the construction process more sustainable?

By using more sustainable materials that has a hight number of uses and/or recycled materials to reduce the materials carbon footprint. Sourcing the required materials locally and consolidating suppliers will reduce the environmental impact of transportation. Observing high waste generator process during construction and develop suitable solutions that will reflect positively on the process and environment.

Chapter 5

Conclusions

5.1 Conclusion

Planning and performing out a formwork construction project is definitely very challenging, where many different resources must come along to perform structural formwork that includes many steps and design elements to follow. The formwork construction must be carried in a cost effective and minimum waste as possible. Materials used to perform a project formwork is accounted for 15% of the total construction cost. the current practice in formwork construction uses plywood as main material to mould the structural elements, where plywood machining and assembly generates a large amount of waste. On average a project consumes 80% of the total plywood required to complete a project.

For this purpose, this research adapts green, lean, and six-sigma in order to reduce the amount of plywood waste and its' environmental impact while increasing customer satisfaction. The amount of plywood consumption was calculated from six different projects and the main causes of plywood waste were examined. The lean green six-sigma model indicates that the main causes of structural plywood waste is plywood cutting, the number of uses, and durability of the material. Plywood cutting highly occurs in the construction of the following structural formwork elements beams, columns, and stairs respectively. The number of uses for the structural plywood grade in use is 3 times known as Grade-C structural plywood that has also low durability over time. The replacement of the material on the elements that require cast amount of cutting will be able to reduce the amount of plywood waste.

By integrating the optimal solution from the suggested alternatives with the current formwork construction method we will be able to reduce the amount of plywood required by 31% per project. The model uses aluminium and plywood as a formwork material, where aluminium is highly sustainable material that has a very high number of uses. Full aluminium formwork structure is well suitable and most effective for large scale buildings that requires high number of repetitions of the same elements. The implemented solution in this research aluminium formwork is used to construct the column formwork and plywood is used for other structural elements. The construction of columns using aluminium instead of using plywood will reduce the KgCo2 by 91% per meter square of material. This integration will help in minimizing the generated carbon dioxide by using more sustainable material.

5.2 Recommendations

This research makes the following recommendation for reducing the plywood waste in formwork construction and material purchasing.

5.2.1 Waste management:

- Ensure proper disposal of waste
- Navigate the waste generator processes and try to reduce or eliminate the cause.
- Recycle the aluminium used in formwork construction to reduce environmental impact.

5.2.2 Material purchasing:

- Breakdown the column formwork into smaller panel sizes to ensure high reusability rate
- Purchase adjustable aluminium column formwork for square columns with dimensions between (250mm-900mm), shown in Appendix C
- Higher grade plywood is recommended for buildings with 4 or more stories to reduce material cost and amount of waste.

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