

Sustainable Transformation of Plastic Waste for Fiberglass Formwork, Reducing Reliance on Wood in the Construction Industry

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Abstract

Medan, Indonesia's third largest city after the capital city of Jakarta and the city of Surabaya, is facing environmental challenges due in part to large amounts of non-biodegradable plastic waste. As a matter of fact, the city was considered the dirtiest metropolitan city in Indonesia based on the assessment of the Ministry of Environment and Forestry and the assessment of the Adipura 2020 program. Plastic waste can take 50 to 200 years to decompose due to the fact that plastic is formed from organic condensation or the addition of polymers. Therefore, this research proposes a sustainable approach, transforming plastic waste into fiberglass, a lightweight and durable composite material, to produce fiberglass formwork, providing a sustainable alternative to wood formwork in construction. Currently, wooden formwork dominates the industry, contributing to deforestation and environmental concerns. The extensive use of wooden formwork in construction contradicts the principles of "green" building practices due to its high environmental impact. The recycled plastic waste is used as reinforcing fibers and are then incorporated into the composite matrix along with a binder to form the final fiberglass product, creating the fiberglass formwork. Building upon existing literature that separately reports the feasibility of producing fiberglass from plastic waste, and the utilization of fiberglass for formwork manufacturing, this study seeks to establish a direct link between plastic waste management and fiberglass formwork production within the case study area of Medan, Indonesia. Fiberglass formwork offers several advantages compared to traditional wooden formwork, such as dimensional stability, quicker installation up to 80% leading to workforce reduction, water resistance, and extended lifespan up to 10 times. This translates to cost-effectiveness by 54%, improved construction efficiency, and environmental economic benefits, including reduced waste and deforestation, in the construction industry.

Keywords: Fiberglass formwork, Medan, construction industry, deforestation, sustainability, manufacturing, Indonesia.

1 Introduction

The generation of waste is an inevitable consequence of human activity. However, current global waste management practices are unsustainable and pose significant environmental and health threats. Improper waste disposal has a devastating impact on our

environment. For example, landfills leach harmful chemicals into soil and water [1], polluting resources essential to life; open burning of waste also releases toxins into the air, affecting respiratory health; and plastic pollution from landfills and littering ends up in the oceans, harming marine ecosystems and wildlife. The world is producing an alarming amount of plastic waste. According to the Organization for Economic Cooperation and Development (OECD), global plastic waste generation reached a staggering 353 million metric tons in 2019 [2]. With a growing population and increasing reliance on plastic products, this figure is expected to continue to rise in the coming years (figure 1) [3].

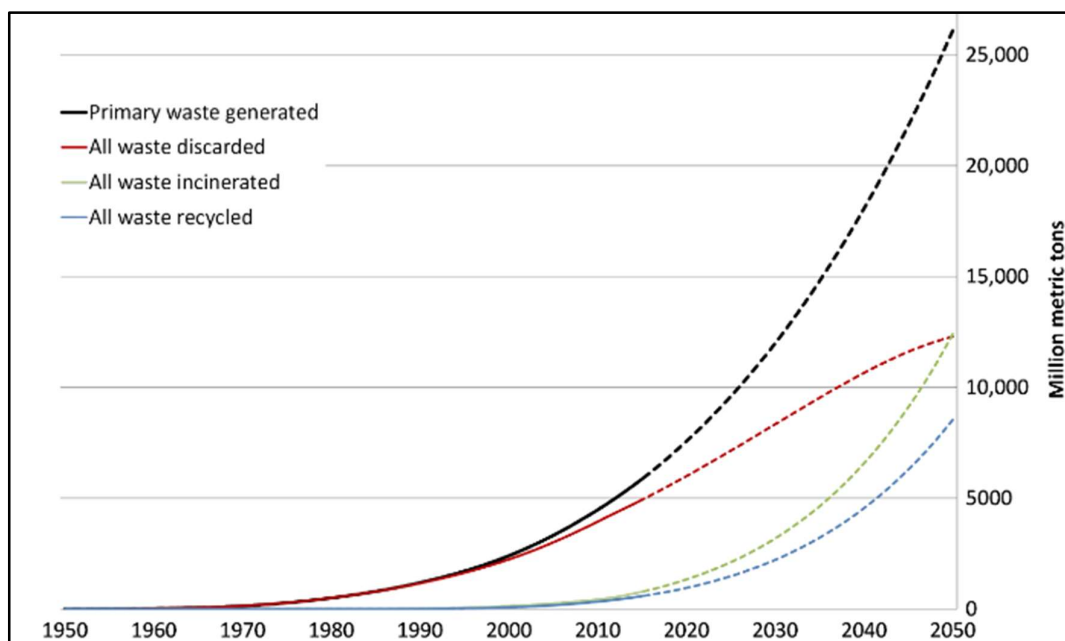


Figure 1. Total plastic waste generation and disposal (source: Geyer, et. al - Science Advances [3])

While Europe has implemented some of the most advanced waste management practices in the world, plastic pollution remains a significant challenge. Some of the key issues are: Inadequate recycling, although recycling rates in Europe are higher than in other regions, a significant proportion of plastic waste still ends up in landfills or leaks into the environment [4]; Microplastics, as the degradation of larger plastic items into tiny microplastics is a growing concern, contaminating water bodies, soil and even the food chain [5]. Asia is a major contributor to global plastic waste, primarily due to rapid economic growth and urbanization. Some specific challenges include Rapidly increasing plastic consumption, as disposable incomes rise, plastic consumption in Asian countries is sharply ascending. Limited waste management infrastructure, as many Asian countries lack adequate infrastructure and capacity to effectively collect, recycle, and dispose of plastic waste [6]; and Informal waste management systems, as informal waste collection practices often lead to improper disposal, contributing to environmental pollution [7].

In Indonesia, Medan City ranks as the third most populous urban center in Indonesia, following DKI Jakarta and Surabaya. Encompassing an area of 26,510 hectares, which constitutes 3.6% of North Sumatra's total area, it boasts a substantial population. As of 2020, Medan City's population stood at 2,524,321 individuals, resulting in a population density of

9,522.22 people per square kilometer [8]. Consequently, Medan City holds the status of a metropolitan area due to the significant size and demographic density of its population. According to the assessment conducted by the Ministry of Environment and Forestry (KLHK) in 2019 and the Adipura 2020 program, the city of Medan has been identified as the most polluted metropolitan area in Indonesia [9], [10], [11]. The main reason attributed to this designation by the KLHK assessment is the issue of waste management (figure 2). It is crucial to emphasize that waste management remains a pressing issue that requires concerted efforts from both government agencies and the local community as it remains unresolved. According to data provided by the KLHK, the city of Medan generates a staggering 2,100 tons of waste per day, or 63,000 tons per month (Medan City Sanitation Department 2016) [12], which is the root cause of the area's pollution problems. The situation is further exacerbated by the poor functioning of several drainage canals, which cause flooding in Medan City during periods of heavy rainfall, in fact the lack of proper primary drainage management results in excessive sedimentation, irregular drainage patterns, and clogging by debris, rendering the primary drainage system incapable of carrying the design flood flow for 2, 5, and 10 year return periods [13]. It's important to recognize that waste falls into two distinct categories: organic and inorganic. Organic waste comes from animals and plants, while inorganic waste includes materials such as glass, plastic, liquid or solid metals that are typically man-made. In general, organic waste is easier to manage because much of it can be reused as fertilizer due to its natural composition. Recycling inorganic waste, however, poses greater challenges. For example, plastics derived from organic condensation or polymer addition are particularly difficult to recycle [14]. Data from the KLHK shows that Medan generates a significant portion of the country's waste, more than 14% of the total. This translates to a staggering 10 million tons by 2020. In addition, plastic waste is a significant component of Medan's waste stream, accounting for 38% of the total waste disposed. This equates to a worrying 3.8 million tons of plastic accumulating in landfills.



Figure 2. Medan's Final Disposal Site (source: captured by author)

Waste management is also a challenge in the construction industry. Construction operations generate significant amounts of waste materials such as rubble, wood waste, concrete and metal. The construction industry focuses on building the structures and infrastructure that are critical to urban development. This includes buildings, roads, bridges, and other infrastructure elements within a locality or across multiple regions. Construction encompasses the full range of building activities, from the erection of structural components to the

completion of projects such as building construction, highway development, and bridge construction. Construction projects typically require significant investment and have long timelines. In construction, particularly projects utilizing concrete for structural elements like columns, beams, and slabs, precise dimensions and shapes are crucial. Fresh concrete, being wet and requiring curing time to solidify, necessitates a temporary mold to hold its form during this process, typically lasting around 30 days. These specialized molds, known as formwork, play a dual role which are shaping the concrete and supporting its weight. Without formwork, the heavy, liquid concrete would slump or deform under its weight, jeopardizing the structural integrity of the final element. Formwork, a key tool in construction, facilitates the forming of concrete into desired shapes and structures. Traditionally, formwork has been made from materials such as wood or aluminum [15]. However, in the context of Indonesia, particularly in the Medan City area, wooden formwork remains prevalent in construction practices (figure 3) [16]. While wood serves its purpose, it has several drawbacks. For example, wooden formwork is not durable enough for repeated use, requiring frequent replacement [17]. It is also time-consuming to erect and dismantle. In addition, the use of wood formworks generates significant waste, including wood scraps and nails [18]. The diminishing availability of wood due to deforestation exacerbates the problem and contributes to environmental issues such as global warming. The reliance on wood formwork undermines efforts to achieve environmentally sustainable construction practices, as evidenced by the negative environmental assessments received by ISO 14000-certified contractors [19].



Figure 3. Wooden Formwork in Construction in Medan (source: PT. Sinartech Beton Perkasa [20])

Given these challenges, there is an urgent need to explore alternative materials for formwork in construction projects. Utilizing fiberglass formwork in construction offers many advantages over traditional wood formwork, including cost effectiveness, time efficiency and environmental benefits [21]. In particular, fiberglass production can utilize inorganic waste materials, making it a sustainable option [22]. Given the abundance of organic and inorganic waste in the Medan metropolitan area, there is significant potential to utilize such waste for innovations such as fiberglass formwork. A shift from wood to fiberglass formwork is poised to bring positive change to Medan, potentially mitigating its status as the dirtiest metropolitan city. This shift would also relieve pressure on forest resources by reducing the demand for

wood, thereby lowering the carbon footprint of construction projects. By promoting a more sustainable construction practice, this shift can contribute to increased overall environmental and economic sustainability, benefiting both the environment and the local economy. This study aligns with Sustainable Development Goal 11 (SDG 11): Sustainable Cities and Communities. By proposing a solution to manage plastic waste and reduce deforestation in the construction sector, this research contributes to the creation of more sustainable and resilient urban environments. The process involves the conversion of plastic waste into a lightweight and strong composite material - fiberglass. This recycled fiberglass can then be used in the construction industry to make formwork, providing a sustainable alternative to traditional wood-based formwork systems.

2 Medan's Waste Management

In the city of Medan, waste management remains a major challenge, as evidenced by the inadequate handling observed by the Medan City Sanitation Department [23], [24] (Marpaung, 2018). Inorganic waste, mainly plastic, constitutes the majority of the waste stream, with about 80% of it posing potential hazards to the environment (Putra, 2020) [25], [26]. Plastic waste is further classified into six types: Polyethylene terephthalate (PET), high density polyethylene (HDPE), polyvinyl chloride (PVC), low density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), and other variants [27] (Hartulistiyoso, 2014). Among these, polypropylene (PP) plastic is particularly recognized for its strength and durability. Currently, more than 70% of the plastic waste generated consists of polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC), which are commonly found in items such as ice cream containers, straws, food packaging, and beverage bottles [28] (Wahyudi, 2018).

According to the waste management hierarchy outlined in European Union Directive 2008/98/EC [22], shown in Figure 4, the primary goal is to minimize waste to conserve landfill space. The hierarchy prioritizes waste management strategies in the following order: waste minimization/prevention, repurpose/reuse, recycling, incineration with or without energy recovery, and landfilling. The emphasis is on reducing the generation of waste, followed by promoting reuse, recycling, recovery, and finally disposal. It is essential to recycle, reuse and remanufacture plastic waste generated from various sources, as plastic waste can have a negative impact on the local environment by contaminating soil, air and groundwater, as well as spreading infectious diseases. It's important to note that landfilling and incineration are not considered recycling methods. In particular, incineration still results in 50% of the waste being converted to ash, which must be landfilled.



Figure 4. Waste Management Hierarchy (source: Medriva [22])

Observations from the Medan's final disposal data show that plastic waste is the predominant type of inorganic waste found in Medan City. Consequently, there is a growing interest in exploring the management of PP plastic waste by replacing the glass fibers in fiberglass with PP plastic fibers for use in fiberglass formwork. The primary motivation for switching from wood to fiberglass formwork is to reduce plastic waste, especially in the city of Medan. Furthermore, additional reasons are explained regarding the benefits of managing plastic waste in fiberglass formwork, which is more efficient in terms of cost and time.

3 Formwork in Construction

3.1 Wooden Formwork

For many years, wood has been the dominant material used for formwork, the temporary molds that shape concrete during construction. This widespread use has led to a significant increase in the demand for timber in the construction industry. To meet this demand, fast-growing tree plantations, such as those that cultivate Meranti wood, Axia, Sengon, Jabon, and Albizia, have become common (Rilatupa, 2016) [29]. While wooden formwork has the advantage of being reusable by being disassembled and reassembled for different shapes (Pratama, 2017), it also has some disadvantages. These conventional wood formworks have some limitations such as:

1. Limited lifespan: Despite its reusability, wood formwork deteriorates over time due to warping, cracking, and moisture absorption, as illustrated in figure 5. This necessitates frequent replacement, especially for high-volume construction projects, increasing overall costs [30].
2. Labor intensity: Wood formwork relies on on-site assembly and disassembly, which can be a time-consuming and labor-intensive process. This can be a disadvantage for projects with tight schedules or large concrete pours [31].
3. Environmental impact: The high demand for wood formworks has led to deforestation and the establishment of fast-growing timber plantations. While these plantations may seem like a sustainable solution, there are concerns about monoculture practices and potential ecological imbalances [32].

The utilization of conventional wooden formwork in construction exacerbates the environmental impact through its contribution to deforestation. The causes of deforestation, such as unplanned expansion of agricultural areas, plantation expansion, forest fires, and rampant forest encroachment, are largely attributed to human activities (Kamilia, 2013). The increased demand for timber resources driven by construction practices further intensifies these destructive activities. As forests are cleared to meet the timber demand for wood formwork and other construction purposes, the natural ecosystem of these areas is disrupted. This disruption leads to irreversible damage, including loss of biodiversity, habitat destruction, soil erosion, and adverse climate effects. Therefore, the continued reliance on conventional wooden formwork perpetuates the cycle of deforestation, amplifying its detrimental consequences on both local ecosystems and the global environment.



Figure 5. Wooden Formwork Failure in Construction (source: Civil Engineering Forum [33])

To support the argument of deforestation caused by wooden formwork, the authors present a comprehensive analysis of wood consumption for this application. A typical two-story RC shophouse measuring 20 meters by 5 meters serves as the case study for this analysis. The details of this analysis are as follows

1. Amount of wood for formwork required for a 30cm*30cm with a height of 350cm column
 - 9mm multiplex panel $= 4*(30*350)*0.9 = 37800\text{ccm}^3$
 - Supporting wood $= 4*(280*4*6) = 26880\text{cm}^3$
 - Formwork Frame $= (4*2)*(350*4*6) = 67200\text{cm}^3$
 - Locking Wood $= (4*6)*(3*4*37) = 10656\text{cm}^3$
 - Support Base 15mm $= 4*(20*20)*0.15 = 240\text{cm}^3$
 - Total wood used $= 142776\text{cm}^3 = 0.142776\text{m}^3$
2. Amount of wood for formwork required for a 25cm*40cm with a length of 500cm beam
 - 9mm multiplex panel $= ((2*(25*500) + (2*(25*500)))*0.9 = 58500\text{ccm}^3$
 - Vertical Stud (22 members) $= 22*5*7*67 = 51590\text{cm}^3$
 - Horizontal Cross Beam $= 11*5*7*58 = 22330\text{cm}^3$
 - Horizontal Longitudinal Beam $= 3*4*7*5 = 525\text{cm}^3$
 - Scaffolding Lumber $= 11*8*12*350 = 369600\text{cm}^3$
 - Total wood used $= 502545\text{cm}^3 = 0.502545\text{m}^3$

3. Amount of wood for formwork required for a 500cm*500cm with a thickness of 12cm slab
 - 9mm multiplex panel $= 2*(500*500)*0.9 = 450000\text{cm}^3$
 - Girder Beam (10 members) $= 10*5*7*500 = 175000\text{cm}^3$
 - Scaffolding Lumber $= 50*350*5*7 = 612500\text{cm}^3$
 - Total wood used $= 1237500\text{cm}^3 = 1.237500\text{m}^3$

4. Amount of wood for formwork required for Continuous Footing

- 9mm multiplex panel $= 4*(30*500)*0.9 = 54000\text{cm}^3$
- Vertical Stud (22 members) $= 22*5*7*67 = 51590\text{cm}^3$
- Horizontal Cross Beam $= 11*5*7*58 = 22330\text{cm}^3$
- Horizontal Longitudinal Beam $= 3*4*7*5 = 525\text{cm}^3$
- Total wood used $= 128445\text{cm}^3 = 0.128445\text{m}^3$

Therefore, the total timber volume estimation for a simple shophouse project is as follows:

1. Columns (16 members) $= 16 * 0.142776 \text{ m}^3 = 2.284416\text{m}^3$
2. Beams (20 members) $= 20 * 0.502545 \text{ m}^3 = 10.0509\text{m}^3$
3. Slabs (6 members) $= 6 * 1.237500 \text{ m}^3 = 7.4250\text{m}^3$
4. Footings (20 members) $= 20 * 0.128445 \text{ m}^3 = 2.284416\text{m}^3$
5. Columns (16 members) $= 16 * 0.142776 \text{ m}^3 = 2.5689\text{m}^3$
6. Total $= 24.61363 \text{ m}^3 \approx 24.6 \text{ m}^3$

The wood commonly used for formwork is obtained from meranti trees, which usually have an average height of 30 meters and a diameter of 100 centimeters. Therefore, the calculation for the volume of wood produced in cubic meters from one meranti tree is $= \pi*0.5*0.5*30\text{m}^3 = 23.55\text{m}^3$. Additionally, the harvesting age of Meranti trees can be harvested for timber at 30-50 years old. Based on the above calculations, the required amount of Meranti trees to be cut down for the case studies is as follows:

1. a single simple shophouse (20m*5m) project require the use of one meranti tree for formwork manufacturing
2. RC four-lane divided highway (every 100m) require 1.2271m^3 of timber, equivalent to 0.06 meranti trees, 0.6 meranti trees for 1km, 6 meranti trees for 10km, and 60 meranti trees for 100km in formwork manufacturing
3. RC Flyover (every 50m) which considers support pillars, sidewalks, deck slabs, flyover floors, medians, prestressed beams, RC pavement, diaphragms, wingwalls, and piers require 50m^3 , equivalent to 2 meranti trees in formwork manufacturing
4. 40 story hotel (30m*30m) project require the use of 2050m^3 , equivalent to 88 meranti trees in formwork manufacturing
5. 10 story mall (75m*100m) project require the use of 5190m^3 , equivalent to 220 meranti trees in formwork manufacturing

3.2 Fiberglass Formwork

While wood has served the construction industry well for centuries, advances in materials and construction methods have led to the development of alternative formwork solutions such as steel, aluminum and even engineered plastics. These alternatives offer advantages in terms of reusability, speed of erection and reduced environmental impact. The

proposed alternative under consideration, which shows potential for constructing these structural formworks, involves the utilization of fiberglass.

In an industrial context, fiberglass is composed of fine glass fibers, commonly referred to as glass-reinforced plastic (GRP) (Swastika, 2015). Fiberglass typically consists of reinforcing and binding elements, which include:

1. Reinforcing components: Mat or woven material that acts as a binder for the fiberglass, giving the material strength and resilience and preventing it from becoming brittle.
2. Binding Components (Matrix): These binding components are made of the following materials:
 - a. Aerosil, which acts as an adhesive for the Mat to increase the strength and durability of the fiberglass, making it resistant to cracking and breaking.
 - b. Resin, which is responsible for fusing all the basic ingredients together during the fiberglass production process. Different types of resins offer distinct advantages and disadvantages, such as differences in hardness, flexibility, and strength.
 - c. Catalyst, which acts as a catalyst accelerating the drying and curing of the resin.
 - d. Pigment, which acts as a colorant to tint the glass fiber material during manufacture.
 - e. Talc, added to the glass fiber mixture to increase hardness and flexibility.
 - f. Acetone, used to thin thick resin to reduce drying time.
 - g. Cobalt, an active ingredient in catalyst blends that speeds up the drying process.
 - h. PVA, applied as a coating between the mold and fiberglass to prevent adhesion.
 - i. Release agent, which acts as a lubricant for the fiberglass material.
 - j. Putty, used to achieve a smooth and uniform surface finish on the fiberglass.

In the field of materials science, fiberglass falls under the category of thermoset polymer composites, which involves the combination of two or more materials on a macroscopic scale (Nugroho, 2019). Fiberglass composites have a wide range of applications due to their light weight, durability, flexural strength, impact resistance, corrosion resistance, and remarkable flexibility [34]. This versatility makes fiberglass suitable for various purposes, including the manufacture of household furniture and industrial tools such as fiberglass boats, pipes, and handicrafts. Research shows that an increase in the number of fiberglass layers correlates with an increase in tensile strength (Kristianto, 2018). According to the findings from the research article "Utilization of Waste Plastic Bags" [35], further experimentation is required to refine the production of fiberglass variations for achieving optimal research outcomes. It has been observed that PP exhibits greater resilience and adhesion to the material, suggesting its potential as a viable substitute for reinforcing fibers within fiberglass (Sulaeman, 2018).

Fiberglass formwork consists of a reinforcing component and a binder component, commonly referred to as the matrix. The reinforcing component, often referred to as fiberglass mat (figure 6), consists of fine glass fibers derived from molten glass and intentionally elongated to form strong and slender fibers. On the other hand, the binder component consists of a mixture of chemical substances, including erosion agents, resins, catalysts, pigments, talc, acetone, cobalt, Polyvinyl alcohol (PVA), mirrors, and fillers [34].



Figure 6. Fiberglass Chopped Strand Mat (source: GrechoFiberglass [36])

4 Environmental Impact Assessment

Life Cycle Assessment (LCA) is a thorough approach to evaluating the environmental impacts of a product or process over its entire life cycle. It begins with the extraction and procurement of raw materials ("upstream") and continues through manufacturing, transportation, use, maintenance, and end-of-life management (including disposal, recycling, or reuse) [37]. This holistic perspective recognizes the interconnectedness of each stage in shaping the overall environmental impact of the product. It's important to note that LCA goes beyond simply adding up the impacts of each stage; rather, it uses specialized methodologies to quantify and compare the various environmental impacts from inception to disposal. These assessments include not only overt factors such as energy consumption and emissions, but also latent factors such as resource depletion, water contamination, and land use change [37]. By providing a comprehensive and quantitative assessment of environmental impacts, LCA assists researchers, companies, and policy makers in several ways:

1. streamlining product design and process selection by identifying and mitigating environmental hotspots throughout the product's life cycle,
2. increasing environmental transparency by communicating the true environmental impact of products and processes to stakeholders, and
3. facilitating informed decision-making by guiding sustainable product development, resource management, and waste reduction strategies.

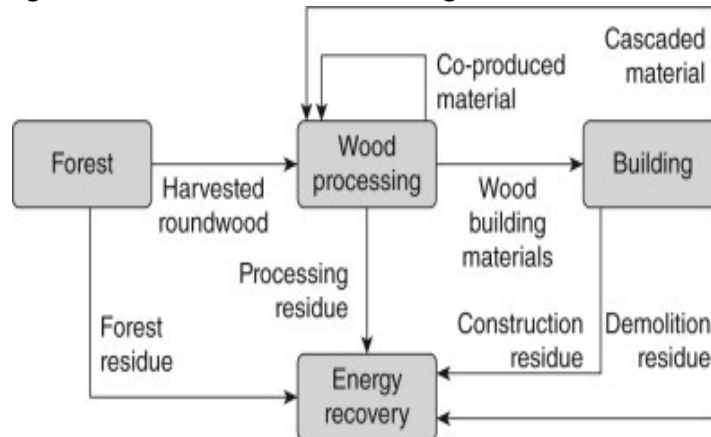


Figure 7. Life Cycle Analysis Wood Processing Hierarchy (source: Energy & Buildings – Leif G. [38])

This LCA diagram (figure 7) shows the environmental impact of wood products from forest harvesting to end-of-life management. The cycle begins with the removal of trees from a forest, followed by processing into usable lumber or other products in sawmills, which creates residual materials such as sawdust. These wood products are then used in construction, potentially creating more waste during construction and subsequent demolition. End-of-life options include energy recovery through combustion, recycling into new products, or unfortunately, disposal in landfills. Throughout the cycle, the diagram acknowledges potential environmental impacts such as air emissions, water pollution and solid waste generation, and emphasizes the importance of sustainable forest management and prioritizing recycling or energy recovery over landfilling to minimize the overall environmental footprint of wood products.

5 Method and Experimental Details

The method and experimental details consist of 2 stages (figure 8), which are detailed below.



Figure 8. Plastic Products Recycling Process for Fiberglass Formwork (Edited by the authors)

1. Preparation Phase. In the crucial pre-processing phase, plastic waste undergoes a series of steps where a series of treatments remove impurities, sort materials, and prepare the plastic for the recycling process.
 - a. Waste collection: First, collect PP plastic waste (figure 9) such as ice cream cartons, straws, and water bottles. This process can be accelerated through cooperation between waste management companies.



Figure 9. Plastic Waste Collection (source: The Times of India [39])

- b. Cleaning stage: The collected plastic is thoroughly cleaned to remove any contaminants, including labels, adhesives, or food residue.
- c. Size reduction stage: The plastic is crushed into granules (figure 10) approximately 1-4 mm in size. This resizing process increases the surface area of the plastic, making it easier to process and shape. Density testing is performed during this stage by floating the particles in a water tank to distinguish between denser and less dense particles. In addition, thickness, thinness, melting point, and color tests are performed on samples taken from each batch of plastic particles.



Figure 10. Resizing and Compounding of Plastic Waste (source: How to recycle polymer waste by Global Spec [40])

- d. Compounding: Small crushed particles are combined and processed into plastic pellets.
- e. Filament manufacturing and spinning: Plastic yarn filaments are made using an extruder machine (figure 11) equipped with a screw that pushes molten plastic pellets through a series of seven heating blocks. These blocks regulate the melting temperature to prevent damage to the plastic polymer bonds. The molten polymer is then ejected through a die head, forming a polymer sheet that is cut into filaments ranging in size from 1/300mm to 1/600mm. The filaments are spun using a winder (figure 12) and then woven into Mat sheets using a winding machine.

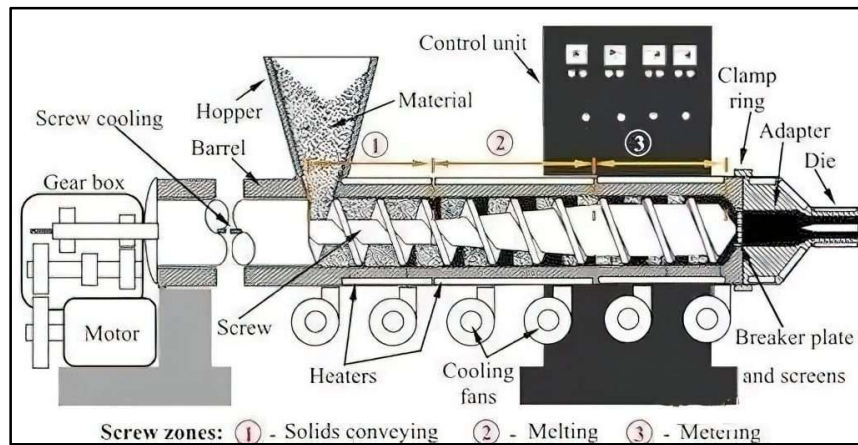


Figure 11. Melt Spinning Screw Extruder (source: SaludStyle Melt Spinning Process [41])

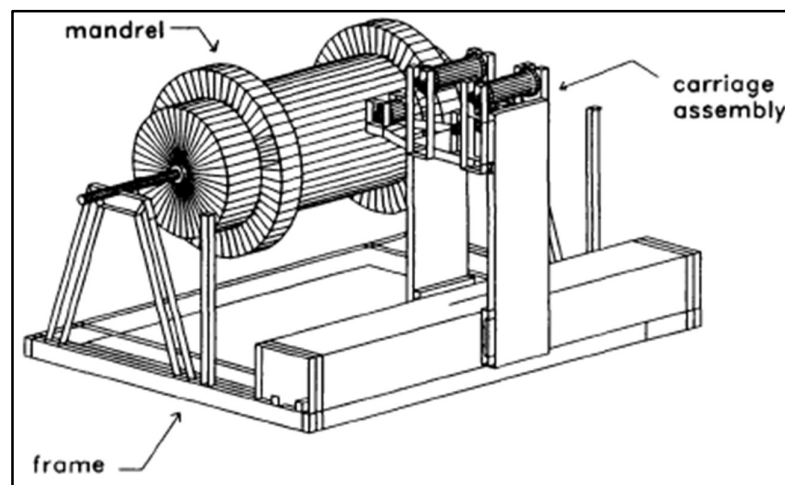


Figure 12. Filament Winding Machine (source: Mechanical System Design, N.K Kadir [42])

2. Fiberglass formwork molding

The production process of fiberglass formwork material can be divided into three stages:

- a. Making the main mold: The first step in the production of fiberglass material is to make the main mold, which serves as a container for molding fiberglass formwork and allows for easy shaping of the product. Typically, gypsum or fiberglass is used to construct the main mold. In this study, a fiberglass mold was used.
- b. Fabricating the Fiberglass Mold:
 - Prepare the main mold.
 - Use a clean container, such as used oil or paint cans, to mix and prepare the fiberglass dough.
 - Combine talc with resin in a ratio of 1.5 to 2 liters, making sure to mix thoroughly.
 - Add a catalyst in a 1:1/40 ratio and 400-500 grams of Aerosil to the resin-talc mixture. Add pigments or colorants at this time.
 - Adjust the consistency of the mixture by adding more catalyst if it is too thick or acetone if it is too runny. The ratio of catalyst will affect drying speed.
 - Apply a layer of mirror/lubricant to the inside surface of the main mold, distributing it evenly by rotating the mold until the coating is uniform.

- Once absorbed, wipe the surface with a clean cloth until it shines.
- Coat the mold surface with PVA to prevent adhesion to the fiberglass formwork. Alternatively, if mirrors and PVA are not available, floor cleaning fluid can be used.
- Place the 1/300 mm PP fiber Mat on the mold surface, followed by another layer of fiberglass dough.
- Apply a second layer of 1/600 mm PP fiber Mat on top of the first layer, following the 1:1 coating system (1/300 mm PP fiber: 1/600 mm PP fiber).
- Press the base dough during application to avoid bubbles, as bubbles can cause porosity in the fiberglass structure.
- Repeat the process for a total of four layers to ensure durability.
- Release the fiberglass form when the dough layer is dry and cured, as premature removal may cause shrinkage.



Figure 13. Geopanel Plastic Formwork (source: KARANASIOS [43])

- c. The final step is to finish the fiberglass form by leveling and smoothing it with sandpaper and grinding techniques (figure 13).

6 Results

6.1 Comparative Analysis of Material Potential

The comparative analysis of the material potential of fiberglass and wood, is shown in the table below:

Table 1. Comparative analysis of material potential: fiberglass and wood

No.	Formwork	Raw material	Availability	Resistance		Durability
				Water	Heat	
1.	Wood	Wood	Easily available	No	Limited	Limited
2.	<i>Fiberglass</i>	PP Fiber	Easily available	Resistant	Resistant	Durable

Table 2. Comparative analysis of material properties: fiberglass and wood

No.	Properties	Wooden Formwork	Fiberglass Formwork
1.	Tensile Strength (MPa)	27.6-34.5	206
2.	Shear Modulus (GPa)	1.67-3.32	29.1
3.	Thermal Conductivity (W/m*K)	0.21	0.36
4.	Modulus of Elasticity (GPa)	7-8.6	72.4

6.2 Cost Analysis

A. Fiberglass Formwork Production Cost Analysis

The following breakdown illustrates the cost of processing polypropylene plastic into fiberglass formwork.

Table 3. Production cost analysis of fiberglass sheets

No.	Information	Unit	Price (Euro)
1.	Recycling the PP plastics into pellets	Sheet	0.017
2.	Processing of pellets into woven 1/300 PP fiber	Sheet	0.035
3.	Processing of pellets into woven fiber PP size 1/600	Sheet	0.064
Total			0.116

Description: *Cost of recycling PP plastic into pellets (Pratt, 2017).

The following is the result of estimating the cost of making fiberglass formworks from 1x1 meter of PP fiber.

Table 4. Production cost analysis of fiberglass formwork

No.	Information	Unit	Cost/unit (Euro)	Cost (Euro)
1.	PP fiber x 4	m ²	0.116	0.464
2.	<i>Fiberglass</i> dough x 4	m ²	7.29	29.15
3.	<i>Fiberglass</i> Formwork Molding Fee [manufacturing and curing] (3 hours)	Per/hour	1.17	3.51
Total				33.124

Notes: *The compensation for the production of fiberglass formwork is determined according to the prevailing regional minimum wage in Medan City (source: kompas.com).

B. Wooden Formwork Production Cost Analysis

The production cost of a 1 square meter multiplex panel for fiberglass formwork applications is €7.29.

C. Comparative Cost analysis between Multiplex and Fiberglass for a 30 x 30cm concrete cast panel with a height of 4 meters.

An evaluation of panel area was performed for 30 x 30 cm columns at 4m height.

1. Cost of panels with wood formwork

- a. Price $1 \times 1 \text{ m}^2 = 7.29 \text{ Euro/ m}^2 : 10000 = 0.000729 \text{ Euro/ cm}^2$
- b. Price for formwork size $30 \times 400 \text{ cm} = 0.000729 \times 30 \times 400 = 8.748 \text{ Euro}$
- c. Cost of wood formwork for a $30 \times 400 \text{ cm}$ panel (required 4 pieces of panel) = $8.748 \times 4 = 34.992 \text{ Euro}$

2. Cost of panels with fiberglass formwork

- a. Price $1 \times 1 \text{ m}^2 = 33.124 \text{ Euro/ m}^2 : 10000 = 0.0033124 \text{ Euro/ cm}^2$
- b. Price for formwork size $30 \times 400 \text{ cm} = 0.0033124 \times 30 \times 400 = 39.7488 \text{ Euro}$
- c. Cost fiberglass formwork for a $30 \times 400 \text{ cm}$ panel (required 4 pieces of panel) = $39.7488 \times 4 = 158.9952 \text{ Euro}$

3. Cost Comparison of wooden and fiberglass formwork

For a more detailed comparison, the table below provides further insights

Table 5. Cost Comparison regarding usage amount between Multiplex Formwork and Fiberglass Formwork

No	Material	Usage Amount	Cost (Euro)	Cost Once Usage (Euro)
1.	multiplex	4 times	≈ 35.00	8.75
2.	<i>fiberglass</i>	40 times	≈ 159.00	3.975

The comparative analysis of panel cost between wood and fiberglass formwork shows that fiberglass shuttering is much more economical than wood formwork. While the cost of single use multiplex wood for framework is 8.75 Euro, the cost of fiberglass is 3.975 Euro. This indicates a 54% reduction in panel cost when using fiberglass as the base material for formwork.

6.3 Comparative Analysis of Productivity, Assembly and Installation Time

This case study examines the formwork requirements for a typical two-story shophouse under construction. The building has a footprint of 20 meters by 5 meters and a total height of 7 meters (two stories at 3.5 meters each). The main structural components are reinforced concrete (RC) columns measuring 30 centimeters by 30 centimeters, RC beams measuring 40 centimeters by 25 centimeters, and a concrete slab 15 centimeters thick. A table details the specific amount of formwork needed for casting these RC elements.

Table 6. Example of required amount of Formwork for 2 Story Shophouse RC Structure

No.	RC Structure	Dimensions (cm)	Length (m)	Span (m)	Amount	Required Formwork (cm ²)
1.	Column	30*30	3.5	-	16	67.2 cm ²
2.	Beam	40*25	5	-	20	130 cm ²
3.	Slab	15	-	5*5	6	21.6 cm ²
Total						218.8 cm ²

To assemble and install the formworks, in this case study it requires 4 groups, each composed of 1 craftsman and 6 workers. The groups are required to erect formworks with the amount of 218.8m². Additionally, the foreman is capable of overseeing 6 workers, hence the productivity analysis is calculated as follows:

Table 7. Productivity Rate of Formwork Assembly for 2 Story Shophouse RC Structure

	Wood	Fiberglass
Craftsman	0.083	0.017
Worker	0.5	0.1
Foreman	0.083	0.017
Productivity 1 group (m ² /day)	12	60
Productivity 4 group (m ² /day)	48	240
Duration (days)	4.55	0.91

This analysis of formwork assembly productivity for a two-story reinforced concrete (RC) commercial building highlights the significant advantages of fiberglass. Fiberglass formwork has a much faster assembly rate compared to traditional wood formwork, achieving up to a 5x increase in productivity. This translates into a dramatic reduction in installation time: fiberglass requires only 0.91 days to form columns, beams and slabs, compared to 4.55 days using wood for the same elements. Consequently, based on both productivity and installation time, fiberglass formwork offers an impressive 80% speed improvement for RC construction projects.

6.4 Life Cycle Cost Analysis

In this subsection, IdematLightLCA software is used to perform a Life Cycle Cost (LCC) analysis of the formwork materials used in this study. For the wood formwork scenario, the LCC of meranti wood, a commonly used type of wood for formwork construction in the Medan region, is evaluated. In the case of fiberglass formwork, the analysis focuses on the primary material relevant to the case study, which is polypropylene (PP) plastic. The LCC results for both wood and fiberglass formwork are presented in the table below.

Table 8. Life Cycle Cost Analysis for Wood and Fiberglass

	Wood	Fiberglass
Base Material	Meranti	Polypropylene
Eco-costs (€)	8.06	1.25
Carbon Footprint (kg)	2.97	2.86
Waste Treatment & Open Loop Recycling (kg)	0.79	1.23
Closed Loop Recycling (kg)	-1.01	0.25

7 Discussion

7.1 Material Potential

Due to its availability and relatively low cost, the use of wood for wooden formwork, using multiplex and plywood, is a commonly used formwork material, making it an attractive option for various construction projects. However, its susceptibility to water absorption poses significant challenges. This sensitivity can lead to swelling, which affects the structural integrity of the formwork. In addition, the need for additional concrete mix water due to water absorption by the wood can affect the properties of the concrete. Despite its affordability and availability, the limited reusability of wood formwork, coupled with its combustible nature, which poses fire safety risks, highlights the need for careful consideration of alternatives.

Fiberglass formwork, on the other hand, offers several advantages over wood. In particular, fiberglass is known for its exceptional durability, as it is resistant to water, corrosion and chemicals, making it suitable for use in demanding environments. In addition, fiberglass has superior strength properties, including higher tensile strength and stiffness compared to wood. This results in a more robust formwork system capable of withstanding greater loads during concrete pouring. In addition, fiberglass formwork offers increased reusability due to its resistance to water damage and wear, allowing for multiple uses on different projects. In addition, its superior fire resistance enhances overall construction safety, making fiberglass a compelling alternative to traditional wood forms.

Although not directly addressed in this comparison, the environmental impact of formwork materials should also be considered. Wood formwork often requires the harvesting of new trees, potentially contributing to deforestation. Fiberglass production also has an environmental impact, but its reusability helps mitigate this concern. Further research into the life cycle assessment of both materials is required for a comprehensive environmental analysis.

7.2 Environmental and Economical Sustainability

While the initial cost of Multiplex wood appears to be lower at €35 for a set of four 30cm x 400cm panels, its reusability is limited to a maximum of four uses. This translates to a cost of €8.75 per use for wood forms. In contrast, fiberglass formwork, despite a significantly higher initial cost of €159 for a similar set of panels, offers a much higher reusability factor of up to 40 uses. This translates to a cost of €3.975 per use for fiberglass formwork. This represents a significant 54% cost advantage over wood over the long term.

A. Economic Considerations

The results show a clear economic benefit associated with fiberglass formwork. While the initial investment is higher, the extended reusability translates into significant cost savings over multiple construction projects. This underscores the importance of considering the total lifecycle cost of formwork materials, rather than focusing solely on the initial purchase price.

B. Environmental Sustainability

In terms of the environmental impact of formwork materials, wood formwork requires the continuous harvesting of trees, potentially contributing to deforestation. Fiberglass, on the other hand, is a more sustainable option because it requires less raw

material over its long life. In addition, the reduced number of formwork changes required with fiberglass minimizes waste generation and disposal.

C. Limitations

It is important to recognize that the cost and environmental advantages of fiberglass formwork can vary based on several factors. These factors include the size and complexity of the project; smaller projects with fewer formwork requirements may reduce the initial cost advantage of fiberglass. Also, the maintenance and repair costs of fiberglass formwork compared to wood alternatives must be considered. Disposal considerations are also important; although fiberglass formwork offers reusability advantages, proper recycling or management is essential to mitigate environmental impacts.

7.3 Productivity, Assembly and Installation Time

The results show a significant advantage for fiberglass formwork in terms of construction speed. Studies suggest a productivity rate of 12 m² per crew per day for wood formwork due to the time-consuming nature of assembly, including proper formwork setting, nailing of sections and ensuring structural integrity for heavy concrete loads. Fiberglass formwork, on the other hand, has a much faster erection rate, with studies suggesting a productivity rate of 60 m² per crew per day. This improved efficiency is due to the inherent properties of fiberglass. Its stiffness, high tensile strength and simpler locking mechanisms allow for faster assembly compared to traditional wood components. The case study example reinforces these observations. Using four crews, it takes an estimated 4.55 days to install 218.8 m² of wood formwork. Conversely, the same job using fiberglass formwork and a similar crew size can be completed in just 0.91 days. This represents a remarkable 80% reduction in installation time achieved with fiberglass formwork.

The faster assembly times associated with fiberglass formwork provide several practical benefits to construction projects. These include increased productivity, as reduced formwork erection times directly translate into increased overall construction efficiency. This results in faster project completion schedules and potentially earlier occupancy of structures. In addition, the streamlined assembly process of fiberglass forms can require fewer workers compared to wood forms, potentially reducing labor costs and promoting a more sustainable construction process by minimizing the use of labor resources.

7.4 Life Cycle Cost

The comparative LCC analysis reveals contrasting environmental impacts associated with Meranti wood and PP for formwork applications. While both materials have comparable carbon footprints (2.80-3.00 kg CO₂ equivalent), the environmental cost associated with wood is demonstrably higher, estimated to be approximately six times that of PP plastic. While wood has the advantage of faster biodegradation at the end of its life, its environmental impact is exacerbated by deforestation pressures. Meranti trees require extended growth periods (30-50 years) to reach maturity for construction purposes, resulting in significant resource depletion. In addition, the reusability of meranti wood forms is inherently limited (approximately 4 uses) compared to fiberglass forms (over 40 uses). This limited reusability results in an increased environmental cost due to the unsustainable use of natural resources.

8 Conclusion

This study addresses two interrelated environmental challenges in Medan, Indonesia: plastic waste management and deforestation. The city faces a significant burden of non-biodegradable plastic waste, while the construction industry's heavy reliance on wooden formwork contributes to deforestation. The research proposes a novel solution: using recycled plastic waste as reinforcing fibers in fiberglass composites for formwork production. This approach directly links plastic waste management with a sustainable alternative to traditional wooden formwork. The proposed fiberglass formwork offers potential benefits including faster installation times (up to 80% reduction), improved durability (up to 10 times longer life), and water resistance. This shift to fiberglass formwork could not only reduce plastic waste, but also alleviate deforestation pressures in Medan and promote a more environmentally responsible construction industry.

Based on the discussion of the problems above, it can be concluded that:

- A. The proposed solution to the problem of inorganic plastic waste in the city of Medan is to use this waste as the primary material for the production of fiberglass formwork.
- B. In the process of converting inorganic waste into fiberglass formworks, Group 5 plastic, specifically PP, is used due to its superior strength compared to other plastics and its resistance to temperature variations.
- C. By using PP plastic waste as a substitute for glass fiber in fiberglass production, an alternative is presented to reduce the reliance on wood materials in construction projects and mitigate deforestation in Indonesia.
- D. The management of PP plastic into fiberglass formwork involves several stages, beginning with the collection of PP plastic, followed by washing, resizing, pelletizing, filament forming and spinning. Next, the mold is manufactured through mold forming, PP fiberglass production, and finishing.
- E. The effectiveness of using fiberglass as formwork lies in its resistance to weather and water, which allows for multiple uses compared to wood formwork, which is susceptible to water damage and has a limited life of four uses. Fiberglass formwork also offers a significantly faster installation time, requiring only 0.91 days compared to 4.55 days for wood formwork, reducing overall project duration. This represents a remarkable 80% reduction in installation time achieved with fiberglass formwork. Fiberglass formwork also proves to be more cost effective, with a single production cost of €3.975 as opposed to €8.75 for wood formwork made from multiplex. This represents a 54% reduction in panel cost when fiberglass is chosen as the base material for formwork.

By using plastic waste as an alternative resource in the city of Medan, the goal is to reduce waste generation, mitigate pollution, and improve environmental conditions, ultimately improving air quality and overall resilience.

9 Recommendations

This study acknowledges limitations in the understanding of fiberglass formwork compared to traditional wooden formwork. Further research is recommended to address knowledge gaps, particularly regarding the case study's focus on plastic waste management for fiberglass production. While existing literature supports the concept of recycling plastic waste

into fiberglass, limited data exists on the mechanical properties of such recycled materials. The authors suggest expanding the investigation to explore the incorporation of various plastic types beyond polypropylene (PP). Given the abundance of polyethylene terephthalate (PET) from bottled plastic and polystyrene (PS) from plastic bags, research is warranted to assess the mechanical properties of fiberglass composites utilizing a blend of recycled plastics. This broader investigation should be accompanied by a comparative life cycle cost analysis (LCCA) to comprehensively evaluate the environmental and economic sustainability of such approaches.

References

- [1] “Basic Information about Landfills.” Accessed: Mar. 15, 2024. [Online]. Available: <https://www.epa.gov/>
- [2] “Plastic pollution is growing relentlessly as waste management and recycling fall short, says OECD.” Accessed: Mar. 14, 2024. [Online]. Available: <https://www.oecd.org/>
- [3] R. Geyer, J. R. Jambeck, and K. L. Law, “Production, use, and fate of all plastics ever made,” *Sci. Adv.*, vol. 3, no. 7, p. e1700782, Jul. 2017, doi: 10.1126/sciadv.1700782.
- [4] “Plastics Europe: enabling a sustainable future.” Accessed: Mar. 13, 2024. [Online]. Available: <https://plasticseurope.org/>
- [5] M. Bergmann *et al.*, “Plastic pollution in the Arctic,” *Nat Rev Earth Environ*, vol. 3, no. 5, pp. 323–337, Apr. 2022, doi: 10.1038/s43017-022-00279-8.
- [6] “Solid Waste Management.” Accessed: Mar. 16, 2024. [Online]. Available: <https://www.worldbank.org/>
- [7] M. Margallo, K. Ziegler-Rodriguez, I. Vázquez-Rowe, R. Aldaco, Á. Irabien, and R. Kahhat, “Enhancing Waste Management Strategies in Latin America Under a Holistic Environmental Assessment Perspective: A Review for Policy Support,” *Science of The Total Environment*, vol. 689, pp. 1255–1275, Nov. 2019, doi: 10.1016/j.scitotenv.2019.06.393.
- [8] “Badan Pusat Statistik Indonesia (Indonesia’s Central Bureau of Statistics).” Accessed: Dec. 03, 2024. [Online]. Available: <https://www.bps.go.id/id>
- [9] “Kementerian Lingkungan Hidup dan Kehutanan Indonesia (Indonesian Ministry of Environment and Forestry).” Accessed: Dec. 03, 2024. [Online]. Available: <https://www.menlhk.go.id/>
- [10] “Kompas News.” Accessed: Dec. 03, 2024. [Online]. Available: www.kompas.id/
- [11] “CNN Indonesia.” Accessed: Dec. 03, 2024. [Online]. Available: www.cnnindonesia.com/
- [12] S. Saragi, K. Sinaga, and B. Purba, “The Role of the Government in Community Empowerment Through Waste Bank Management,” *IJSSEH*, vol. 1, no. 2, pp. 130–143, Jun. 2020, doi: 10.46576/english.v1i2.724.
- [13] R. Harahap, B. Budi, and S. Rahmadani, “Study Of Drainage Analysis As Flood Control In Setia Budi Area Medan City,” in *Proceedings of the 4th Annual Conference of Engineering and Implementation on Vocational Education, ACEIVE 2022, 20 October 2022, Medan, North Sumatra, Indonesia*, Medan, Indonesia: EAI, 2023. doi: 10.4108/eai.20-10-2022.2328879.

- [14] F. H. Puspitasari, S. Supriyadi, and M. Al-Irsyad, "Analysis of Organic and Inorganic Waste Management Towards a Green Campus at Universitas Negeri Malang:," presented at the 3rd International Scientific Meeting on Public Health and Sports (ISMOPHS 2021), Malang, Indonesia, 2022. doi: 10.2991/ahsr.k.220108.014.
- [15] V. Rajeshkumar, S. Anandaraj, V. Kavinkumar, and K. S. Elango, "Analysis of factors influencing formwork material selection in construction buildings," *Materials Today: Proceedings*, vol. 37, pp. 880–885, 2021, doi: 10.1016/j.matpr.2020.06.044.
- [16] P. L. A. Luthan and N. Sitanggang, "Supervision Indicator of Formwork on Reinforced Concrete," *J. Phys.: Conf. Ser.*, vol. 1477, no. 5, p. 052005, Mar. 2020, doi: 10.1088/1742-6596/1477/5/052005.
- [17] M. Shazwan Ahmad Shah, N. Md. Noor, A. Beng Hong Kueh, and Mohd. N. Tamin, "A review on wooden formwork for concrete casting," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 513, p. 012036, Apr. 2019, doi: 10.1088/1757-899X/513/1/012036.
- [18] Dr. D. C. Tsang, "CICR05-13-Recycling Used Timber Formwork into Lightweight, Thermal-insulating Cement-bonded Particleboards_RS_011.pdf." Construction Industry Council, Hong Kong SAR. [Online]. Available: www.cic.hk
- [19] "International Organization for Standardization (ISO) - ISO 14000 Environmental Management." Accessed: Mar. 12, 2024. [Online]. Available: <https://www.iso.org/standards/popular/iso-14000-family>
- [20] "Harga Upah Jasa Borongan Pekerjaan Bekisting Murah di Medan." Accessed: Mar. 03, 2024. [Online]. Available: <https://sinartechbetonperkasa.wordpress.com/>
- [21] "Report on Modern Formwork Systems." Research Design and Standards Organization, Lucknow.
- [22] J. Qureshi, "A Review of Recycling Methods for Fibre Reinforced Polymer Composites," *Sustainability*, vol. 14, no. 24, p. 16855, Dec. 2022, doi: 10.3390/su142416855.
- [23] H. Ridho, M. A. Nasution, . Subhilhar, and M. Amin, "Challenge of Waste Management in Medan City:," in *Proceedings of the 3rd International Conference on Social and Political Development*, Medan, Indonesia: SCITEPRESS - Science and Technology Publications, 2019, pp. 13–17. doi: 10.5220/0010001700130017.
- [24] R. Marpaung, "Pengelolaan Sampah di Kota Medan (Studi Kasus Kecamatan Medan Baru)." Universitas Sumatera Utara, 2018. [Online]. Available: <https://repositori.usu.ac.id/handle/123456789/5878>
- [25] B. Jiang, J. Yu, and Y. Liu, "The Environmental Impact of Plastic Waste," *j. of environ. & earth. sci.*, vol. 2, no. 2, pp. 26–35, Nov. 2020, doi: 10.30564/jees.v2i2.2340.
- [26] H. P. Putra and Y. Yuriandala, "Studi Pemanfaatan Sampah Plastik Menjadi Produk dan Jasa Kreatif," *jstl*, vol. 2, no. 1, pp. 21–31, Mar. 2010, doi: 10.20885/jstl.vol2.iss1.art3.
- [27] P. Eyerer, "Plastics: Classification, Characterization, and Economic Data," in *Polymers - Opportunities and Risks I*, vol. 11, P. Eyerer, Ed., in *The Handbook of Environmental Chemistry*, vol. 11. , Berlin, Heidelberg: Springer Berlin Heidelberg, 2010, pp. 1–17. doi: 10.1007/978-3-540-88417-0_1.
- [28] J. Wahyudi, H. T. Prayitno, and A. D. Astuti, "Pemanfaatan Limbah Plastik Sebagai Bahan Baku Pembuatan Bahan Bakar Alternatif," *JL*, vol. 14, no. 1, pp. 58–67, May 2018, doi: 10.33658/jl.v14i1.109.

- [29] J. Rilatupa, “Pemanfaatan Kayu Pada Bangunan Di Permukiman”.
- [30] R. L. Peurifoy and G. D. Oberlender, *Formwork for concrete structures*, 4th ed. New York: McGraw-Hill, 2011.
- [31] N. Mine, S. H. Wai, T. C. Lim, and W. Kang, “An Observational Study on the Productivity of Formwork in Building Construction,” presented at the 32nd International Symposium on Automation and Robotics in Construction, Oulu, Finland, Jun. 2015. doi: 10.22260/ISARC2015/0112.
- [32] “Deforestation and Forest Degradation.” Accessed: Mar. 13, 2024. [Online]. Available: <https://www.worldwildlife.org/>
- [33] “Causes of Formwork Failures.” Accessed: Mar. 16, 2024. [Online]. Available: <https://www.civilengineeringforum.me/>
- [34] D. B. Miracle and S. L. Donaldson, Eds., *Composites*. ASM International, 2001. doi: 10.31399/asm.hb.v21.9781627081955.
- [35] B. Sulaeman, “Pemanfaatan Limbah Karung Plastik,” *JIIIT*, vol. 3, no. 1, p. 93, Mar. 2018, doi: 10.51557/pt_jiit.v3i1.173.
- [36] “Fiberglass Chopped Strand Mat White Fibreglass Cloth Fiberglass Mat.” Accessed: Mar. 15, 2024. [Online]. Available: <https://www.grechofiberglass.com/>
- [37] E. Sanyé-Mengual and S. Sala, “Life Cycle Assessment support to environmental ambitions of EU policies and the Sustainable Development Goals.” Integrated Environmental Assessment and Management, European Commission, Joint Research Centre (JRC), Ispra, Italy.
- [38] L. Gustavsson, A. Joelsson, and R. Sathre, “Life Cycle Primary Energy Use and Carbon Emission of an Eight-Storey Wood-Framed Apartment Building,” *Energy and Buildings*, vol. 42, no. 2, pp. 230–242, Feb. 2010, doi: 10.1016/j.enbuild.2009.08.018.
- [39] “Kochi: Plastic waste collection to resume in corporation limit today.” Accessed: Mar. 09, 2024. [Online]. Available: <https://timesofindia.indiatimes.com/>
- [40] “How to recycle polymer waste.” Accessed: Mar. 20, 2024. [Online]. Available: <https://insights.globalspec.com/article/14792/how-to-recycle-polymer-waste>
- [41] “Polyester Yarn Manufacturing Process - From Chips to Yarn.” Accessed: Mar. 07, 2024. [Online]. Available: <https://www.saludstyle.com/>
- [42] N. K. N. KADIR, “Mechanical System Design, Design and Development of Small Scale 2axis Filament Winding Machine.” Faculty of Mechanical Engineering, Universiti Malaysia Pahang (UMP), Apr. 2016.
- [43] “Geopanel Plastic Formwork.” Accessed: Mar. 06, 2024. [Online]. Available: <https://karanasios.gr/>