Doctoral Thesis

Study on recycling of disposable diaper as ecofriendly-concrete material for the application on building

Siswanti Zuraida

2020DBB409

Bart Dewancker Laboratory

Graduate School of Environmental Engineering

The University of Kitakyushu

Japan, September 2023

Abstract

Utilizing disposable diapers in concrete and cement-based materials has become an alternative to reduce waste capacity and environmental impacts. The findings of current research conclude that SAP (Super Absorbent Polymer) as an essential component in disposable diapers could improve the self-healing of concrete structures as well as increase yield stress values, flexural strength, plastic viscosity, and elastic modulus. However, the current research mainly elaborates on the materials' microstructure, making the application of the finding’s intangible. This doctoral research investigated the application of disposable diapers to replace the use of fine aggregates in concrete and mortar. This study is aimed at examining the feasibility of materials to be implemented as building components. Through theoretical analysis and experimentation, the study analyses the mechanical properties of materials, elaborates on environmental impact analysis, and estimates the availability of materials for the construction industry. For broad insight, the study also proposes a construction system for the materials by prototyping an actual house.

In Chapter 1, research background, problem and objectives were introduced as base of study.

In Chapter 2, theoretical background and literature reviews were elaborated to find the factors that influence the waste capacity of disposable diapers, indicators on environmental impact and the building standard.

In Chapter 3, the systematical methodology was introduced by conducting laboratory experiments, calculating simulation based on database and prototyping.

In Chapter 4, the results of the laboratory experiment were investigated with the findings on mechanical properties on concrete and mortar consist disposable diaper and its improvement, as well comparative study on similar materials.

In Chapter 5, feasibility study on environmental impact were assessed by analysis embodied energy, carbon emission and eco-costs.

In Chapter 6, feasibility study on construction system were proposed to find the proper implementation as building materials by designing the connection system and prototyping in actual scale of the house.

In Chapter 7, evaluation on all the findings based on Chapter 4, 5 and 6, were discussed to conclude the feasibility of using disposable diapers as a part of building materials component.

In Chapter 8, the main findings of the study were summarized and suggestions for future study.

Acknowledgements

Alhamdulillah, praise be to Allah the Almighty of God the Most Gracious and Merciful, first and foremost, the writer would like to thank God for His Blessing in the completion of this doctoral thesis. Then, praise is given to our Prophet Muhammad SAW, who has led us to a better life today.

To Prof. Bart J. Dewancker as a supervisor of this doctoral program and all members of Bart Lab.

To my husband - Romi Bramantyo Margono, as well to my sweety daughter - Ainara Ilma Nafia, for supporting, loving and caring during this doctoral journey.

To Ministry of Education, Culture, Sports, Science and Technology for MEXT Scholarship in doctoral program and PT. Awina Sinergi Internasional for funding the laboratory experiment.

Last but not least, to Muhammad Arief Irfan as a principal construction project of prototype housing, Anjar Primasetra as an architect who designing and constructing the housing prototype, Andrie Harmaji as an material engineer who contributes to research activities and laboratory, and Firman Fadhly AR as an architect who contributes to analyze the thermal environment of housing prototype, also Ilham as a civil engineer who contributes to structural analysis in constructing the housing prototype. The other contribution also comes from Ananda Setiyo Ivannanto and Ichsan who contribute to promoting and searching for funding to develop the research project.

Contents

List of Figures

List of Tables

List of Equations

Chapter 1

Introduction

1.1 Research Background

Up to 20 billion disposable diapers are thrown into landfills every year or more than 3.5 million tons of waste contribute to the disposal area and that number is increasing annually [1]. Based on a survey on people's preference for disposable diaper treatment, they threw the trash in the open or in any place [1] [2] [3]which is around 5- 40% of this waste is disposed of in landfills without further processing . Since disposable diapers contain dioxins and dyes - which are cancer agents that are harmful if released into the environment-, this habit causes contamination to water which is most likely to cause diarrhea, exacerbated by waste conditions that are difficult to degrade.

Due to the brief time required to burn the waste, incineration becomes a viable option for diaper waste management. However, the process also produces unfavorable outcomes, as the produced gas will harm the environment, as contaminants can accumulate in humans and animals. Additionally, landfills also give benefits due to the facilities are designed for long-term operation (50 - 100 years) but the results cause severe environmental issues, including methane emissions, water pollution, land use, and odors [4]. In addition, people typically dispose of used diapers by packaging them in plastic, which results in sluggish biological decomposition in landfills. To decompose, disposable diapers need oxygen and sunlight; however, this process does not work well in landfills, so it takes approximately 500 years [5] [4]. The virus excreted in the baby's feces eventually seeps into the local water supply, and the decomposition of disposable diapers can release high concentrations of explosive and flammable gases into the atmosphere [5].

To lessen the environmental impact of waste treatments for disposable diapers, the recycling process offers more environmentally friendly outcomes that can be utilized in a variety of ways. Recycling by biodegradation system produces no secondary pollutants, as opposed to incineration and landfill, while obtaining economically beneficial end products from bacterial metabolism, such as compost and soil fertilizer, an effective medium substrate for mushroom cultivation, and ethanol for use in biofuels. Moreover, compared to incineration, recycling by pyrolysis reduces the total amount of waste sent to landfills in a short period of time and limits the release of greenhouse gases into the atmosphere.

Despite its environmental benefits, the recycling process has limitations in terms of the additional costs required for diaper collection and in terms of its technical feasibility. For instance, recycling by biodegradation system necessitates a composter for efficient decomposition with excellent performance for only 100 percent biodegradable diapers and a lengthy procedure. Also, the system pyrolysis must be optimized in terms of temperature, thermal power, and particle size for various feedstock. The system configuration is costly and requires optimization. As a result of complicated process in collecting, shredding, sterilization and separating, only few companies are interested in recycling process such as Knowaste Ltd. United Kingdom [6], Fater Ltd. Italy [7] [8], Diaper Recycling Technology Pte Ltd. Singapore [9], Super Faiths Inc Unicharm Ltd. Japan [10], and PHS Group United Kingdom [11]. However, the existence of the companies reveals that diaper recycling technology is currently only available in developed countries. It is primarily the result of two factors: differences in levels of expertise and access to equipment between developed and developing countries and a need for more awareness in developing countries regarding the potentially harmful effects of diaper waste [4].

To tackle the limitations of recycling process in terms of technical feasibility, recycling disposable diaper as a part of concrete components is more visible since concrete is a widely used construction material. Primarily due to the ease of processing, relatively low construction costs, and lack of high-tech manufacturing requirements. Previous research has concluded that adding used diapers to concrete does not significantly diminish its strength. By adding one to ten percent used diapers to the concrete mixture, the findings conclude that concrete cubes containing 1% polymer baby diapers produce the best results [5]. Hydration for internal healing improves and yields positive results, and it has superior durability. Moreover, by conducting tests for shrinkage and compressive strength and drying shrinkage, with the compressive strength of concrete containing 5% polymer baby diapers exhibiting the highest strength at 28 days compared to other percentages [12].

Hence, due to the technical feasibility, this doctoral thesis is aimed at deep investigation on the application of disposable diapers on concrete. The study is investigating firstly the strength of concrete using disposable diapers for building components based on building standard and regulation. Secondly the feasibility study on environmental impact of the materials and source availability and third the construction system of materials as element of building. The findings will contribute particularly concerning the development of environmentally friendly and cost-effective materials. Further, concerning this paper's social and economic advantages, the development of materials can be accessed from low to high technology. The procedures are relatively easy to conduct and low-cost. It also gives a comprehensive perspective of utilizing disposable diaper waste as something valuable since it has ended up in the incineration process.

1.2 Research Questions

The need of deep investigation on the application of disposable diapers on cement-based material and concrete:

1. How can it be used in concrete and cement-based materials?
2. Does it better than common waste treatment and similar materials?
3. How is the sustainability of the source?
4. How can it be applied in the construction industry?

1.3 Research Objectives

Investigate the application of findings on utilization of disposable diapers on concrete by:

1. Analyze the mechanical properties of concrete and mortar consist of disposable diapers
2. Analysis on environment impact comparing to common waste treatment and similar materials.

3. Analysis the influence factors on source of disposable diapers
4. Estimate the utilization of materials for construction industry

1.4 Hypothesis

1. In a certain portion or percentage, the disposable diaper can improve mechanical properties of concrete and cement-based materials
2. Because recycling is environmentally friendly for waste treatment, the system for recycling disposable diapers may have the lowest impact.
3. The sustainability of source is feasible because the waste is produced from sanitary items used by babies (linear with the increase of population)
4. The materials are proposed for building element and for wider application may use for infrastructure

1.5 Research Outlines

Chapter 1: Introduction

This chapter consist of research background, research questions and objectives, as well include also hypothesis as a part of research frameworks.

Chapter 2: Theoretical background and Literature Reviews

To support the background, deep investigation on literature review elaborates more in this chapter included review on diapers products, properties and waste treatment, review on recycling disposable diaper to concrete and review on building materials standard. As well for comprehensive study, review on environmental impact assessment indicators on building materials becomes additional value.

Chapter 3: Research Methodology

This chapter focused on research methodology for conducting the research including qualitative by secondary data on literature review, quantitative approach by laboratory experiment and mixed method to evaluate the feasibility study to comprehensive findings.

Chapter 4: Laboratory Experiment

in this chapter, comprehensive analysis on mechanical properties of concrete and mortar consist of disposable diapers is elaborated deeply. it consists of result on result on application for building materials, result on application for building materials, and result on concrete mix design improvement. comparative study on mechanical properties with similar concrete materials also elaborate more to give broader insight of the findings.

Chapter 5: Feasibility Study on Environmental Impact Assessment

This chapter discuss about analysis on environment impact comparing to common waste treatment and similar materials, as well analysis the influence factors on source of disposable diapers to give quantitative insight on the availability of material resource.

Chapter 7: Evaluation

This part consists of comprehensive insight on analysis which include the evaluation on laboratory experiment and feasibility study on environmental impact as well construction system.

Chapter 8: Conclusion and Recommendation

This final part is summary of study and suggestion for development of future research.

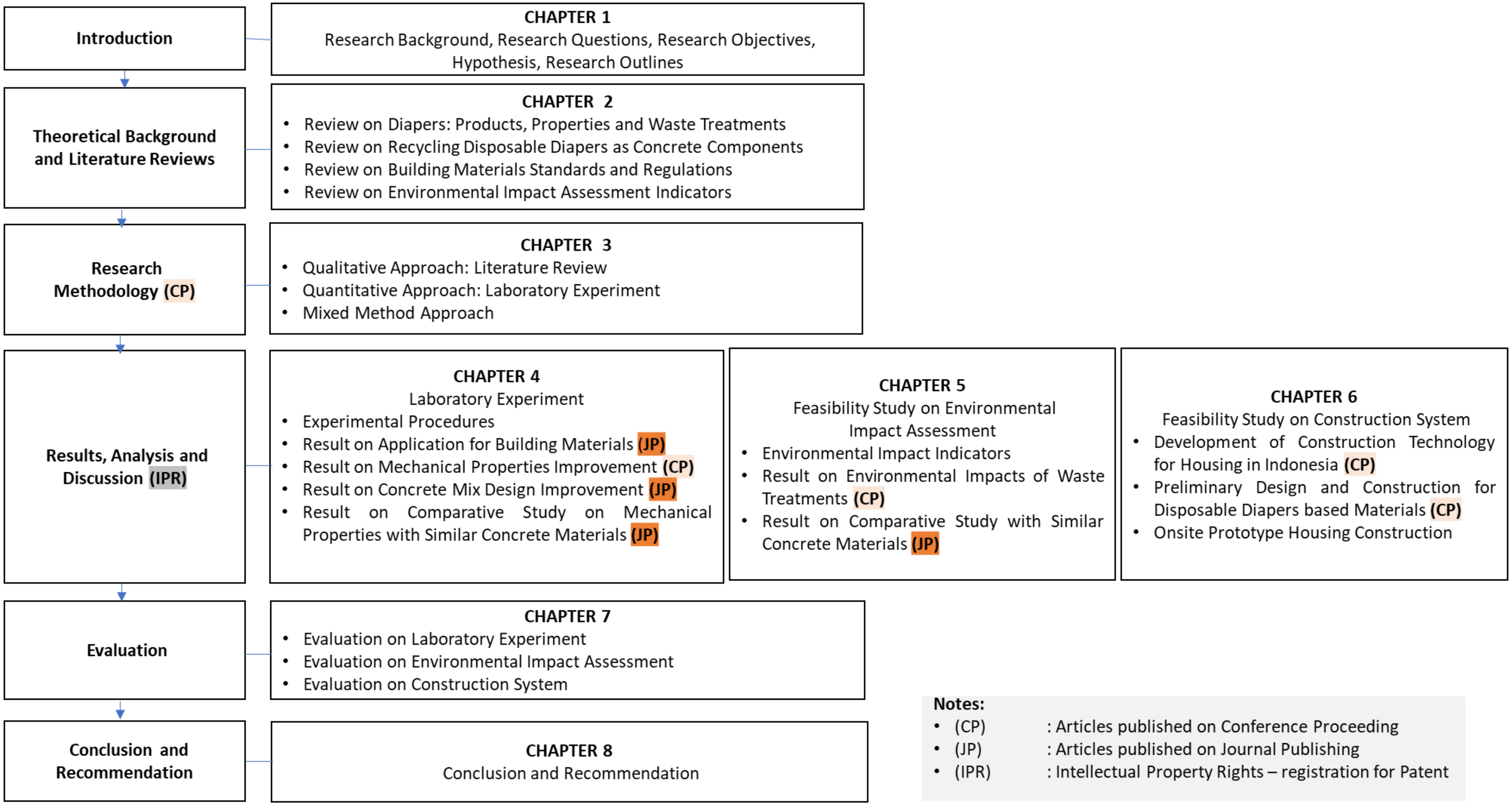


Figure 1. Research Frameworks

Chapter 2

Theoretical Background and Literature Reviews

2.1 Review on Diapers: Products, Properties and Waste Treatments

2.1.1 Brief of Diaper Products

Diapers Products

The use of cotton and linen did not cease until the early 1900s, when the first cloth diaper service was introduced which marked as the beginning of diaper marketing [13]. Before 1900s, parents diapered their children with animal skins, milkweed leaf wrap, and other natural materials [4]. In 1942, the first disposable absorbent diaper was created from unbleached cellulose tissue and was designed to be used just once. In the 1960s, tissue and paper were replaced with pulp and cellulose fibers to improve the performance of disposable diapers and marked as the beginning of the rapid evolution of disposable diapers [4].

Due to the convenience, currently there are three categories of diapers available for purchase: cloth diapers, disposable diapers, and diapers made from biodegradable materials [4]. The main material for cloth diapers is cotton which provides a plush pad that helps keep the user's skin from becoming irritated. While disposable diapers typically consist of a material called super absorbent polymer (SAP), which has a high capacity for absorbing water, and comfortable ties. Alternatively, the market for diapers has seen the introduction and acceptance of biodegradable diapers because it claims to be more eco- and skin friendly because of the use of natural materials and fewer chemicals in the production of one of their components. In 2013, disposable diapers contributed approximately 66% of the total market [4], and it is anticipated that this dominance will continue in the near future. Among these products, disposable diapers dominated the global market by contributing approximately 66% of the total market, following by and cloth diapers had the second largest market share and biodegradable diapers are expected to experience rapid growth due to rising environmental consciousness and shifting consumer preferences [4].

Cloth diaper

The oldest type of cloth diaper is called a flat cloth diaper, and it consists of a single layer of an absorbent material like cotton cloth that can be folded into a variety of shapes and secured with clips or safety pins [4]. The flat cloth diaper has been around for a very long time. One of the benefits of using cloth diapers is that they can be reused after being cleaned. The evolution of technology has allowed traditional cloth diapers to be transformed into their modern counterparts. A pocket diaper has two parts: the shell, which is called the pocket, and an insert, which is sewn into the shell. The diaper back sheet is made to be waterproof and has an adjustable snap that can be tailored to the wearer's specific needs. This contrasts with a pocket diaper, which requires the insert to be tucked into the cover.

The usage of cloth diapers results in a greenhouse gas emission footprint that is forty percent smaller than that of disposable diapers [14]. This is because the feces-containing materials that are found on cloth diapers may be rinsed off and disposed of in an appropriate manner into the municipal water treatment system [4]. This system filters the sewage water before it is returned to the clean river, while the feces-containing materials are converted into fertilizer. Another benefit of using cloth diapers is that they reduce the amount of chemicals, such as petroleum, that are utilized in the manufacturing process of disposable diapers [4]. However, using cloth diapers comes with a few drawbacks, the most significant of which are the reduced absorbency of the diaper itself, which necessitates more frequent diaper changes, and the need for a significant amount of water to properly clean the diaper.

Disposable diapers

The advent of disposable diapers was made possible by the discovery of a material called superabsorbent polymer (SAP) [15] with the chemical formula for SAP is $C_3H_4NaO_2$, which stands for *Sodium polyacrylate*. The development of superabsorbent polymer made it possible to improve the performance of diapers with a high absorbency while simultaneously reducing their weight [4] .The convenience of disposal, the prevention of feces discharge, and the maintenance of skin dryness are some of the additional benefits that are associated with the use of disposable diapers which contains: Polyethylene back sheet, hydrophobic polypropylene non-woven fabric, hydrophilic non-woven fabric, distribution layer, hot melts, spandex elastics, hook-and-loop tape, super-absorbent polymeric core, cellulose, moisturizer lotions, fragrance lotions, and sometimes wetness indicators [16]. The granular form of SAP has the potential to increase the capacity of diapers to increase their capacity to absorb and retain fluids by up to 100 times their own mass [17]. One kilogram of super absorbent polymer (SAP) has the capacity to soak up to 86 liters of water [4]. SAP can greatly improve the absorbency performance of diapers and minimize the amount of wood pulp fiber used in the manufacturing process of diapers. Between 1987 and 2005, there was a 40% decrease in the weight of diapers that were disposable [4] [16].

Biodegradable diapers

The biodegradable diaper is made up of wood fiber that does not contain chlorine, a non-toxic SAP, does not contain latex, and biodegrades in a partial manner [14]. The flushable and compostable (when moist) cotton inserts are combined with soft, reusable cotton covers to form the biodegradable diaper and feces-containing refills should be flushed rather than composted since up to eighty percent of the bio-solid waste that is produced by wastewater can be used as fertilizer for agriculture [4]. In terms of health, chlorine dioxide, which is a volatile bleaching agent and usually used to whiten diaper refills, this product can be deemed to be chlorine-free because the product uses polyurethane laminate (PUL), which is a fabric that is both waterproof and biodegradable, there is no longer a requirement for an additional outer covering [4]. The PUL is also biodegradable when compared to the vinyl cover, which is made of polyvinyl chloride (PVC). PUL, on the other hand, needs a substantial chunk of time before it can be entirely broken down. Therefore, biodegradable diapers manufactured from organic cotton, hemp, or bamboo are an even better option, as these diapers decompose quickly, and the raw materials required for diaper manufacturing grow quickly while requiring less fertilizers and pesticides [4]. In comparison, disposable diapers are more absorbent than cloth diapers, which means that they need to be changed less frequently and that they offer greater convenience to parents and make the product become a substantial source of garbage. They are responsible for up to 12 percent of municipal solid waste that is put into landfills [4]. Seventy percent of disposable diapers are made from wood pulp, while the remaining thirty percent are made from petroleum. Wood pulp and petroleum are both limited resources, and their combustion contributes to the acceleration of climate change. It is possible that the SAP contained in disposable diapers will not decompose for close to 500 years and has been linked in some cases to toxic shock syndrome and cutaneous irritation [18].

In comparison, disposable diapers are more absorbent than cloth diapers, which means that they need to be changed less frequently and that they offer greater convenience to parents and make the product become a substantial source of garbage. They are responsible for up to 12 percent of municipal solid waste that is put into landfills [4]. Seventy percent of disposable diapers are made from wood pulp, while the remaining thirty percent are made from petroleum. Wood pulp and petroleum are both limited resources, and their combustion contributes to the acceleration of climate change. It is possible that the SAP contained in disposable diapers will not decompose for close to 500 years and has been linked in some cases to toxic shock syndrome and cutaneous irritation [18].

In addition, according to [4], it argued that the use of disposable diapers can be more destructive to the environment, both in terms of cleanliness and environmental friendliness, whereas the use of cloth diapers can be less hazardous to the environment. The biodegradable diaper is more environmentally friendly than disposable diapers and more practical than cloth diapers because it is designed to degrade quickly in landfills. Switching from disposable diapers to cloth diapers can result in a large reduction in one's carbon footprint, as it will require much fewer trees to be cut down for disposable diapers production. However, when compared to the price of disposable diapers, the price of reusable diapers is much more expensive. It is possible to significantly cut down on the amount of waste that is produced by used biodegradable diapers and ends up in landfills.

In conclusion, it has been demonstrated that using cloth diapers results in an increased amount of laundry, but they are better for the environment than disposable diapers because they can be reused. The use of disposable diapers provides several benefits, including convenience and simplified diaper changes. However, there is currently no evidence that the biodegradable diaper is fully biodegradable, even though it offers several benefits, including ease of use and tolerance of the surrounding environment [4]. Used disposable diapers were the primary subject of this evaluation because of the extensive usage of disposable diapers, which would eventually become trash and cause problems for the environment if they were not properly disposed of.

2.1.2 Waste Treatment on Disposable Diapers

Landfilling

Before new landfills are established in most developing countries, existing landfills are normally erected and stuffed with garbage. In modern sanitary landfills are outfitted with well-designed engineering and management systems, which allow for the disposal of significant amounts of trash [4]. It is also monitored and operated in a way compliant with safety and ecologically friendly standards.

In order to stop the leachate from percolating through the landfill, modern sanitary landfills is originally lined with high-density polyethylene. The next step involves loading municipal waste and home garbage into the landfill cell. At any given time, there is only a tiny fraction of the landfill cell that is accessible and available for waste loading. Choong (2014 in [4]) says that as soon as waste is put on the ground, it is covered in layers and continues to be covered until it reaches the top of the landfill cell. In addition, the sanitary landfill is equipped with both a leachate treatment system and methane gas recovery wells. After the leachate has been collected, it is taken to a system that treats leachate contamination. In addition (Choong and Low (2014) in [4]) treated leachate that is discharged on-site through an extensive sprinkler system might be considered to have satisfied the necessary criteria. To generate power, the landfill gas, also known as methane gas, is collected, and then delivered to a well specifically designed for the recovery of methane gas. The gas would be vented, however, if the pace of gas extraction did not match the needs for either direct usage or the generation of electricity (Tai Hoe Resources, 2017 in [4]). A landfill that has reached its maximum capacity would, in the normal course of events, be closed; yet it would still require between 50 and 100 years of monitoring (Stauffer, 2012 in [4]).

Incineration

Incineration is a type of combustion that is completely oxidative and involves the burning of waste at temperatures ranging from 900 to 950 degrees Celsius [19]. In the beginning, incineration was utilized as a method for the management of hazardous waste and the reduction of waste volume through the transformation of the waste into ash [20]. Waste products such as solid ash and flue gas can be produced through the combustion of waste materials. The ashes are non-reactive and have the potential to be used in a wide range of products, such as cement, ceramics, and other building materials [21]. Incineration is a viable option for the processing of waste to energy, particularly in developed countries [20] since the availability of sophisticated technologies that control air pollution and toxic gas emission. The heat energy that is produced during the incineration process can be used either for the generation of electricity or for heating purposes caused the disposal method is gaining popularity as a means of dealing with waste [4]. Municipal solid waste is typically not sorted before being burned, so the fly ash that is produced, includes kitchen waste, wood, and PVC is burned contains a high concentration of the element's chlorine, potassium, and sodium [22]. The average lifespan of an incinerator is between 20 and 30 years, caused the incinerator maintenance and recovery construction may be required in order to extend the lifespan of incinerators [22].

Recycling

The main goal of diaper recycling is to disassemble the diaper and separate its plastic and organic fiber components. This necessitates carrying out complicated processes, such as collecting, shredding, sterilizing, and separating the materials. As a result of the complexity involved, there are currently only a select few businesses that have an interest in recycling used diapers. These businesses include Knowaste Ltd., Fater, Diaper Recycling Technology Pte Ltd., Super Faiths Inc Unicharms Ltd., and the PHS Group. Table 1 shows the process and result of recycling disposable diapers by companies.

Biodegradation

Fungi are examples of saprophytes, which are organisms that feed on cellulosic matter since its adaptability to a wide range of cellulosic substrates, the oyster mushroom, also known as *Pleurotus sp.*, is one of the most cultivated edible mushrooms [4]. Cellulases are enzymes that hydrolyze cellulose and are produced by the fungus *Pleurotus sp*. are helpful in the process of degrading cellulose. The research conducted by [23] demonstrated that mushrooms have the capacity to degrade diaper waste by converting the cellulosic components of used diapers into glucose that can be used as a food source to significantly cut down on the weight of used diapers due to the deterioration of wood pulp and cellulose [24]. Although the mushrooms were technically edible after a period of two and a half to three months, researchers have not yet determined that this method is a viable method for cultivating the fungus for human consumption [25].

In a separate line of research, the fungus *Pleurotus ostreatus* was grown on a substrate made of wheat straw and diaper cores resulted in a reduction of as much as 80 percent of the substrate and was adequate for three rounds of oyster mushroom harvesting [26]. The harvested mushrooms did not contain any human disease-causing pathogens, and they appeared and contained the same amount of nutrients as commercially available mushrooms and has the potential to degrade used diapers with a high cellulose content while simultaneously producing products that can be put to good use [4].

The transformation of used diapers into soil fertilizer or compost is biologically possible because of the activities of microbial enzymes has been discovered that the cellulosic components of used diapers can be easily broken down by the enzymes produced by microbes [27]. Separating the cellulose pulp from the diaper cores and then mixing them with other organic materials required the use of a bioreactor that contained used diapers in the composting of yard waste produced encouraging results without causing any unintended adverse effects [4]. This small-scale composting system can reduce approximately 87% of the mass of diapers and turned used diapers can be recycled into high-quality compost [27].

Pyrolysis

Pyrolysis refers to a heating process in which organic material is subjected to thermochemical decomposition in an environment without oxygen and result in the production of three distinct products: gas, a liquid oil product, and a solid char product with a high concentration of carbon [28]. Incineration and pyrolysis are examples of thermal degradation processes used for soiled diapers but pyrolysis more environmentally friendly option compared to incineration. The incineration of waste results in the emission of carbon dioxide and fly ash into the atmosphere because it involves the combustion of waste, in contrast with Pyrolysis which results in a decreased emission of greenhouse gases into the atmosphere [29]. The process of pyrolysis results in the production of char that has a porous structure that is useful for a variety of applications, including acting as an adsorbent, soil additive, and catalyst [30] [31]. The char can function as a microwave absorbent that efficiently absorbed microwave energy and quickly reached a high temperature [30]. In addition, the pyrolysis process can produce biochar and synthetic diesel fuel that can be used as a secondary source of revenue for the generation of electric power, power supply, and heat (Hamilton (2007) in [4]).

As a summary, Table 2 shows the details on waste treatments for disposable diapers. In conclusion, It argued that [4] even though most countries have many landfills, not all are up to date hygienic because the system take up to 500 years for disposable diapers to completely disintegrate, the human waste that is trapped inside of soiled diapers would be left in landfills for a significant amount of time would result in the breeding of germs, which has the potential to spread disease (by dirty diaper) to individuals living nearby and personnel at the dump. However to rely on the incineration, ashes produced from the incineration of used diapers would contain potentially toxic substances, such as dioxin and heavy metals [22] since the diaper itself contains a trace amount of dioxin (DeVito and Schecter, 2002 in [4]). The prominent levels of moisture that are present in used diapers require more time and energy to evaporate, which in turn delays the ignition time [32] resulted the performance of an incinerator that burns used diapers could be drastically reduced.

In other hand, it argued that even though biodegradation does not degrade the outer plastic layer and composting used diapers requires specialized equipment and scientific processes the biodegradation of cellulosic material could reduce the amount of waste that is disposed of in landfills [4]. Recycling the organic material that is contained in used diapers offers an appealing alternative for the management of both waste and resources [27]. However, it was found that there are limitations, such as the requirement for additional costs for removal or separation of the diaper core and plastic packaging, health concerns for workers who are constantly exposed to waste and feces, and the fact that the global end market for finished compost is underdeveloped, which is a significant obstacle in recycling used diapers [4]. Other limitations is a need for additional costs for removal or separation of the diaper core and plastic packaging may could be handled if appropriate facilities as well as safety and health precautions for recycling management are in place, composting used diapers is a promising option for recycling used diapers on a small scale [4].

Similarly, pyrolysis has the potential to help reduce the number of diapers that end up in landfills by converting them into three products that have a variety of uses by offering environmentally friendly method. However, the feedstock obtained from used diapers is unreliable because of the variable waste composition (such as: urine, feces, resin, plastic, and fiber) present in each batch of diaper waste [4]. It argued that the consistency of the feedstock is important because it directly impacts the efficiency with which high-quality gas, oil, and char are produced mechanically is necessary to optimize the pyrolysis process factors to fix a broad feedstock range [4]. Some of these factors include the pyrolysis temperature, the heating rate, and the particle size.

Table 1. Summary of Review on Disposable Diaper Recycling Company (modified from [4])

Company	Recycling Process	Recycling Result	Capacity
Knowaste Ltd. UK	The diapers used are chopped, stirred with a dehydrating agent, sterilized by autoclaving technology, and separated into plastics and fibers.	- Plastic components can be used in composite materials to replace concrete and steel, while the recovered fiber can be used in pet manure, concrete and asphalt additives, brick making, and insulating materials. - This process is reported to significantly reduce carbon emissions by 71% compared to the landfill and incineration processes	- Time processing 1.5 hours - Up to 36,000 tons
Fater Ltd. Italy	The recycling process involves sterilizing and deodorizing the diapers under high pressure steam, and this is followed by the mechanical removal and separation of superabsorbent materials, plastics and pulp.	- The super-absorbent material can be used as an anti-flood barrier and for gardening due to its adsorption properties. - Plastics can be used in the production of pallets, benches, and other products while pulp material can be used as recycled paper, biofuel, cat litter and anti-flood agents.	- Up to 10,000 tons
Diaper Recycling Technology Pte Ltd. Singapore	Focuses on manufacturing a diaper recycling facility using vertical-stacking technology which reduces floor space and is suitable for small factories.	- Plastic purification and pulp – SAP separation. - Exhibits a high recovery rate for superabsorbent materials, plastics and pulp, promising viable technology.	- Up to 99 % recycled
Super Faiths Inc. Japan	Using the exhaust system called SFD conversion system. Shredded made as a strip free of bacteria after being dried in a high temperature, then printed out as pellets.	As a source of biomass boiler fuel	- High calorific value of about 4.186 kJ/kg - 300 kg and 600 kg

Company	Recycling Process	Recycling Result	Capacity
Unicharm, Japan	- Creating ozone processing component (OPC) technology that improves AHP's recycled energy efficiency by using the electricity generated to power other parts of the system. - This system includes the extraction of high quality, recyclable, and safe cellulose pulp from used diapers. - Also includes the digestion of the pulp with water and the sterilization of byproducts using ozone.	Applying microbial fuel cells to generate electricity from wastewater obtained from recycling used diapers.	
PHS Group, UK	- Involves mechanical separation, chemical treatment, and conversion of plastics to Refuse Derived Fuel (RDF). - Plastics are converted to RDF by burning in a biomass plant.	To produce hot water and electricity	

Table 2. Summary of Review on Waste Treatment on Disposable Diaper (modified from [4])

Methods	Landfilling	Incineration	Recycling	Biodegradation	Pyrolysis
Advantages	- Waste may remain out of sight for a short period of time because they are covered after being buried. - Facilities are designed for long-term operation (50 - 100 years).	Wastes can be completely incinerated in a brief period of time.	Separating diaper waste into plastic and fiber materials for other uses	- Environmentally benign with no secondary pollutants, such as those produced by incineration and landfill. - Can be recycled and returned to the earth	- Reduces the total amount of waste sent to landfills in a brief period of time. - Limits the release of greenhouse gases into the environment compared to incineration.
Limitations	- Waste continues to exist underground and requires time to decompose anaerobically. - At maximum capacity, landfills must be closed, and post-closure monitoring is required.	- A portion of the produced ash is hazardous. - The Incinerator maintenance is necessary to maintain combustion efficiency.	Additional costs are required for diaper collection.	- Requirement of composter for efficient decomposition - Excellent performance only with 100 percent biodegradable diapers - Time-consuming procedure	- The system must be optimized for various feedstock in terms of temperature, thermal power, and particle size. - The system setup is expensive and requires optimization.
Potential by-product and secondary product	Electricity generation	The ashes are inert and can be further converted into various products such as ceramics, construction material and cement	- The plastic component can be used in composite materials to replace concrete and steel, production of pallets, benches, - Fiber can be used in pet litter, concrete and	Obtain economically beneficial end products from bacterial metabolism, such as: - Recycle into compost and soil fertilizer	- Produce three useful by-product: gas, liquid oil product, solid char product. - These three by-product can be used in various application such as fuel source, absorbance, catalyst, soil additive

Methods	Landfilling	Incineration	Recycling	Biodegradation	Pyrolysis
			tarmac additive, brick manufacture, and insulation materials. - The superabsorbent material can be used as anti-flooding barriers and for gardening, recycled paper, biofuel, cat litter	- Effective medium substrate for mushroom cultivation - Ethanol production for use in biofuels	
Examples	Bukit Tagar Sanitary Landfill, Malaysia	Shibuya Incineration Plant, Japan	Knowaste Ltd, United Kingdom	Dycle	Knowaste Ltd, United Kingdom
Current Status	- Daily operation rate: 2500-3000 ton/d - Daily operation rate on diaper waste: 300-360 ton/d - Operating cost for one ton of waste (USD): $12.72	- Daily operation rate: 159 ton/d - Daily operation rate on diaper waste: 19.08 ton/d - Operating cost for one ton of waste (USD): $10.94-12.50	- Daily operation rate: 98 ton/d - Daily operation rate on diaper waste: 98 ton/d - Operating cost for one ton of waste (USD): $60	- Applicable in residential and domestic settings. - Promote the use of 100% biodegradable diapers and the invention of a diaper that contains no petroleum. - Growing fruit plants with soiled diapers	- Utilizing pyrolysis, successfully construct an AHPs recycling system. - Convert coal product into pellets and sell them as fuel for stoves, biomass boilers, and nearby energy sources.

2.2 Review on Recycling Disposable Diapers as Concrete Components

Because it can absorb up to one thousand times its dry weight, the super absorbent polymer (SAP) that is the highest component in disposable diapers is said to have a structure like that of a hydrophilic network. As water absorbents, SAP and hydrogel polymer have very comparable levels of performance as the absorbent layer of baby diaper. This layer is designed to lock and store urine within its polymeric structure. SAP also have found use in a wide variety of applications, including those that involve the use of admixtures and additives in concrete.

Based on some studies, the utilization of SAP in concrete and cement-based materials can be separated into SAP pre-soaked processes [33] [34] [35] [36] [37] [38] [39] [40] and SAP dry-mixing processes studies [41] [42] [43] [44] [45] [46]. The pre-soaked processes can improve workability, while dry-mixing processes can ensure uniform polymer dispersion [47] [48].

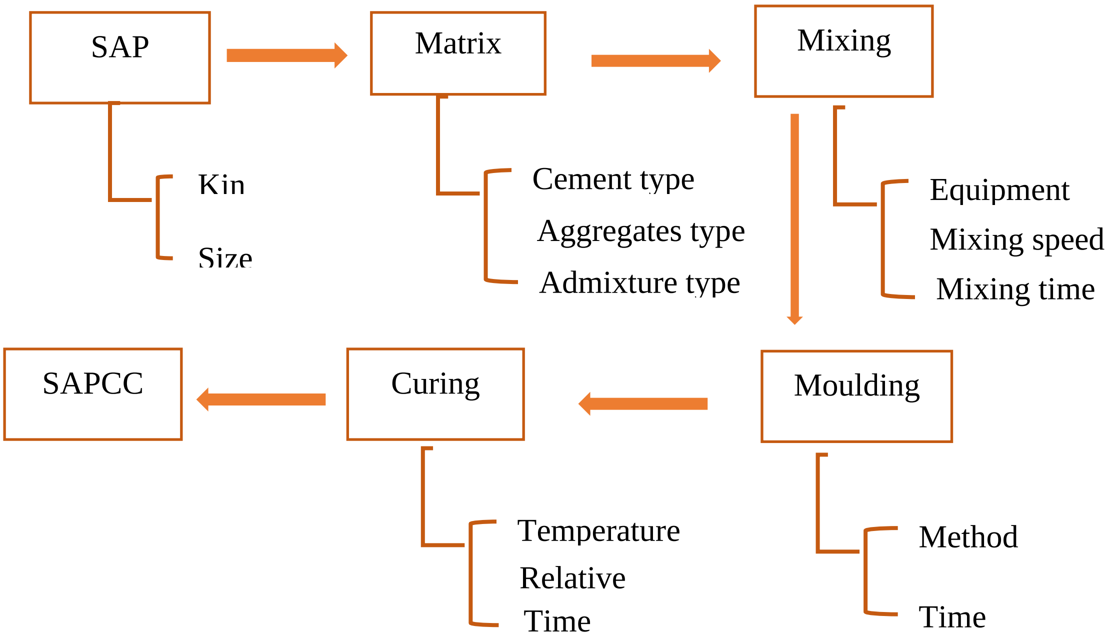


Figure 2. Processing SAP-modified cement-based composites (re-drawing from [47])

The experimental precision for predicting the absorption capacity of SAP is crucial for the mix design of an internally cured concrete, as the strength or workability can be diminished if the prediction is inaccurate. To comprehend the absorption kinetics of SAPs on concrete pore solution, the designed tea-bag method and cement-based artificial pore solution were utilized [49]. The use of SAPs as a chemical admixture in concrete technology effect on the rheological properties of fresh cement-based pastes as well as their varying effectiveness in mitigating autogenous shrinkage [50]. In addition, producing mortars containing SAP can significantly reduce autogenous shrinkage, particularly when ground granulated blast-furnace slag (GGBS) content is increased since SAPs can provide water for prolonged GGBS hydration [51]. It is also noted that using superabsorbent polymers necessitates the consideration of additional water if the global microstructure is to remain essentially unchanged. However, the additional water will cause subsequent hydration. Cement pastes containing SAPs and containing no additional water exhibit a slight decrease in the micro- and mesoporous range and have the same microstructure as cement pastes containing the same proportion of effective water to cement [52]. The result was no significant difference in the micropore range between cement pastes containing SAPs and those containing additional water, but there is a slight increase in the mesopore range [52].

Further, the effect of mechanical pressure on the absorption of SAPs was evaluated and found to significantly influence the absorption behavior; this demonstrates the importance of considering the constraint effect of the cementitious matrix during initial mixing [53]. For the SAPs and mix designs examined in this study, it was found that the incorporation of SAPs decreased the compressive strength of the cement pastes, particularly when SAPs increased the formation of macro voids in the cement paste [53].

In summary of Table 3, it concludes that adding SAP to cement based materials, significantly change the rheology of the material, yield stress values and plastic viscosity, but it decrease water-cement ratio that cause additional water is needed to produce cement-based materials with good workability. In addition, SAP improve the self-healing efficiency of concrete and help retain the watertightness of concrete structures, increase shrinkage in the process of promoting cement hydration also could close the cracks due to the swelling of the SAP particles in the cracks, and the water penetration resistance was remarkably improved. However, SAP increases the number of macroscopic pores in the matrix, resulting in a decrease in the mechanical properties of cement-based materials and the carbonation depth of concrete containing SAP was lower than the ordinary concrete.

Table 3. Summary of Review on Properties of SAP on Disposable Diapers to Concrete and Cement based Materials

(Summary and modified from [47])

Properties	Result	Source
Rheological Properties	- Significantly change the rheology of the material - Decrease water-cement ratio - Additional water is needed to produce cement-based materials with good workability - The yield stress values and plastic viscosity increased significantly, while the open testing time was shortened but changes in temperature have an effect on yield stress - Under the same conditions, addition of SAP have greater plastic viscosity and yield stress than those without SAP. - The thinning behavior of SAP was more effective than cellulose methyl-hydroxypropyl (MHPC), because SAP particles are spherical and do not interact with the chains of the plasticizer. - The large SAP particle size increased yield stress, plastic viscosity, and thixotropy significantly. - Finer SAP seemed to be more effective than coarser SAP in improving the flowability and reduce the superplasticizer demand - Pre-soaked SAP could improve the static stability and passing ability of self-consolidating lightweight concrete (SCLWC) and prevent the addition of water to compound and increase the slump of concrete.	[54] [52] [55] [56] [57] [58] [41] [59] [43] [60] [39] [34] [61]
Mechanical Properties	- Increases the number of macroscopic pores in the matrix, resulting in a decrease in the mechanical properties of cement-based materials - the strength increased slowly in the first 7 days less than that of the control concrete at a curing age of 28 days. - 15–20% lower than that of the mortar without adding SAP under the curing condition of 95% RH. However, the compressive strength of mortar with SAP was only 5% less than that without SAP at 30% RH - SAP-containing mortar did not change significantly compared to 0.45 w/c mortar. SAP (w/c = 0.55) would decrease the mortar's early strength, but the internal curing effect would help cement hydration and partially recover it. - SAP increased mortar early tensile strength when w/c = 0.45, but decreased when w/c = 0.55 - The compressive strength of the samples cured in room was generally lower than that of the samples cured in water - Increasing of nano-SiO_2 content, the strength increased, mainly due to the volcanic ash effect of nano-SiO_2 - Specimens with SAP had 13–27% lower compressive strength than the SCLWC standard after 28 days.	[54] [55] [62] [63] [64] [65] [66] [67] [68] [69] [42]

Properties	Result	Source
	- Coarse SAP had lower compressive strength than fine SAP under identical conditions. - No significant difference in flexural strength, but the compressive strength decreased compared to control mortar. - The compressive strength with SAP at 7 days was 0.93 times less than that of control mortar but at 28 days it was 1.2 times higher. - The combination of SAP and PP fiber increased the compressive strength by 20% compared to the control mortar (with only PP fiber). - The mortar with SAP and PP fiber exhibited slightly increased flexural strength and elastic modulus. - The compressive strength with 20% calcium sulfate aluminate (CSA), shrinkage reducing admixture (SRA) and SAP was approximately 60 MPa at 28 days and the elastic young's modulus was approximately 35 GPa at a curing age of 3 years.	
Shrinkage	*Chemical shrinkage*: increased chemical shrinkage in the process of promoting cement hydration *Autogenous shrinkage* - decreased and induced an expansion right after set. - significantly reduce the autogenous deformation of cementitious materials, regardless of whether additional water was introduced and regardless of whether fly ash and blast furnace slag were used as supplementary cementitious materials. - The dosage of SAP should not exceed 0.6 kg/m^3. - The internal curing increased and should be sealed and cured in the first 7 days to reduce shrinkage without potential strength underestimation. - SAP could reduce the autogenous shrinkage and drying shrinkage of UHPC, thereby reducing the risk of cracking. *Drying shrinkage* - drying shrinkage of concrete increased with increasing w/c without SAP, - the addition of SAP pre-soaked with water increased the drying shrinkage but could reduce drying shrinkage under the same (w/c) - w/c was between 0.5 and 0.6, SAP could effectively reduce the drying shrinkage. - compact structure and a low w/c decrease the strain of drying shrinkage.	[70] [71] [54] [46] [72] [73] [44] [49] [34] [43] [54] [74] [46] [37] [49] [56]

Properties	Result	Source
Self-healing	- improve the self-sealing efficiency of concrete and help retain the watertightness of concrete structures. - SAP in the modified cement-based materials had a reswelling capacity and could be used to prevent water from flowing into cracks. - Self-healing properties when the relative humidity in the environment was greater than 60%. - the addition of 1 m% of SAP produced the best results, exhibited an excellent self-healing capacity and did not exhibit diminished mechanical properties. - main healing products were $CaCO_3$ and a small amount of $Ca(OH)_2$, CSH and CASH - enhanced the water permeability resistance and effectively sealed and healed cracks. - the effectiveness of SAP can be improved by increasing its reswelling rate and particle size.	[75] [76] [77] [78] [79] [80] [81]
Durability	*Permeability* - SAP could close the cracks due to the swelling of the SAP particles in the cracks, and the water penetration resistance was remarkably improved. - when w/b was 0.45, the increase in SAP with FA and GGBS of mortar content could reduce the OPI value whereas the increase of SAP containing SF did not affect the OPI (a higher OPI value indicates lower permeability) - has no significant effect to the chloride conductivity index (CCI) compared to mortar containing GGBS with w/b of 0.45 (a lower CCI value indicates better chloride resistance - Increasing impermeability of the mortar - the addition of SAP without additional water increased the chloride ion penetration resistance of concrete compared because the initial w/c in the mixture was reduced. - the chloride ion penetration resistance of the concrete would improve only if the degree of hydration was sufficiently increased, which w/c was <0.42 and only applicable to specific amounts of SAP. - the chloride ion diffusion coefficient of the concrete with SAP was lower than concrete without SAP. - the pore structure tends to become finer and the connection among the capillary pores is cut off, which effectively limited the chloride ion diffusion and enhanced the resistance to chloride ion penetration. - the chloride ion diffusion coefficient with large SAP particle size was less than that of the mortar containing a small SAP particle size. - the internal curing agent of SAP played a more significant role in improving impermeability under relatively dry conditions	[82] [83] [84] [85] [86] [87] [88] [89] [90] [91] [92] [93] [94] [95] [96] [97]

Properties	Result	Source
	Freeze-thaw resistance - during the hardening of SAP-modified cement-based composites, the water absorbed by SAPs releases into the matrix, leaving air voids. These voids can protect concrete such as air entraining agents during freezing and thawing. - a certain improvement to the freeze-thaw performance of ordinary concrete would be obtained with the addition of SAP, whereas its effect of freeze-thaw resistance was not as significant as that of the air entrainment. - the freeze-thaw resistance of highly ductile short-fibre reinforced concrete was greatly improved through the addition of SAP by introducing specific micro-defects into the structure. - SAP acted as an additive, which increased the freeze-thaw resistance of cementitious composites and as an internal curing agent. - frost resistance of SAP with a large particle size was not as good as that of concrete with air entraining agents, and it was considered that SAP with large particle size could not improve the frost resistance of concrete. - the void volume of SAPs with different particle sizes was similar in concrete, and it was considered that the difference in absorption capacity did not cause the difference in frost resistance. - Cement-based materials modified with SAP were more stable in mixing and transportation than those containing air entrainment agents.	
Carbonation	- the carbonation depth of SAP-modified mortar with a large particle size was significantly lower than that of the SAP-modified mortar with a small particle size. - the carbonation depth of concrete containing SAP was lower than that of the ordinary concrete. - Adding dry or presoaked SAP conducive to the formation of a compact matrix with a lower carbonation dept	[98]

In conclusion the characteristic of SAP in concrete and cement-based materials is listed below: (summary from [47])

1) The hydration process affected to raw material feeding sequences mixing times, molding techniques, and curing conditions.
2) The complex cement hydration process makes it impossible to completely control the water release process of SAP in the cement matrix.
3) Additional water to maintain the mixture's workability, and the additional water intake increases the number of capillary pores, leave a significant number of voids in the cementitious matrix after it has hardened caused reduce the mechanical properties. Mechanical properties can be enhanced through the addition of fibers or additives.
4) The effects of SAP on the mechanical properties of cement-based materials are dependent on the proportions of the mixture, curing conditions, and testing age.
5) The addition of SAP increases drying shrinkage, but the reduction in autogenous shrinkage helps to reduce the total shrinkage resulted have a high resistance to cracking.
6) The water swelling of SAP prevents corrosive materials from entering resulted the improved of self-healing capability, but different curing conditions have different effects on the self-healing effect.
7) In addition to preventing further water and chloride ion penetration, increasing the permeability of the matrix due to the water swelling of SAP promotes the hydration of cement by filling the capillary pores of the cementitious matrix and thereby obstructing the path that chloride ions use to diffuse through the matrix.
8) Effectively improve the frost resistance because voids left by SAPs after water release can act as air-entraining agents to protect cement-based materials from freeze damage.
9) Due to SAP's further hydration, the addition of SAP can effectively enhance anti-carbonation, and the uniform distribution of voids after SAP water release will also inhibit the diffusion of CO_2.

2.3 Review on Building Materials Standards and Regulations

In order to be used as construction materials, the experiment's results must fulfill the appropriate building material criteria. The use and specifications for concrete based on compressive strength are displayed in Table 4. The standard distinguishes between three strengths of concrete, ranging from low to high. Low strength, with a minimum of 10 MPa, is often used for light building structural components, whereas high strength, with a minimum of

41 MPa, is employed for prestressed concrete and heavy building structural components. The experimental outcome will be categorized as the compressive strength of the samples.

Table 4. Standard of Strength and Utilization of Concrete [99]

Concrete Type	Compressive Strength (fc') MPa	Strength Code	Utilization
High Strength	≥ 41	K400 – K800	Generally, be utilized for prestressed concrete such as pile, girder, concrete plat for runaway plane, high rise building, etc.
Medium Strength	21 - 40	K250 - < K400	Generally, be utilized for reinforced concrete, such as concrete plat for bridge, girder, precast curb, culvert, abutment, middle rise building, etc.
Low Strength	15 - < 20	K175 - < K250	Generally, be utilized for normal concrete, such as cyclopean concrete, paving and housing with max 2 floor.
	10 - < 15	K125 - < K175	Light structural component for building, landed housing, and base floor.

Table 5. Mortar Type and Utilization on Building Components [100]

Placement	Building component	Mortar Type			
		Rec.	Fc' MPa	Alt.	Fc' MPa
Outdoor, surface level	Load bearing wall	N	5,2	S / M	12,5 - 17,2
	Wall nonstructural	O	2,4	S / M	12,5 – 17,2
	Supporting wall	N	5,2	S	12,5
Outdoor, under level	Foundation, bearing wall, tunnel, pedestrian ways	S	12,5	M	17,2
Indoor	Load bearing wall	N	5,2	S / M	12,5 - 17,2
	Partition nonstructural	O	2,4	N	5,2
Indoor and outdoor	Shelter and decorative wall	O	2,4	N	5,2

Note:
Rec.: Recommended
Alt: Alternative
Fc': Compressive Strength
Mortar type composition:
M: Portland cement: burnt lime = 2: > ¼ - 1 ¼
N: Portland cement: burnt lime = 1: > ¼ - 1 ¼
S: Portland cement: burnt lime = 1.5: > ¼ - ½
O: Portland cement: burnt lime = 1: > 1 ¼ - 2 ¼

The standard relates to concrete bricks and paving blocks whose strength is categorized into four categories for architectural components. The sample in this experiment followed a solid concrete brick between two types of concrete bricks: solid and hollow. Level I is the strongest, having a minimum strength of 10 MPa, and is commonly used for structural components such bearing walls. The lowest level is level IV, which has a minimum strength of 2.5 MPa and is suitable for non-structural components such as wall partitions. The highest level for paving blocks is A, which has a minimum strength of 40 MPa and is used for public roadways. The lowest level is D, which has a minimum strength of 10 MPa and is suitable for dwelling floors or garden pavement. **Error! Not a valid bookmark self-reference.** contains more information on architectural components and their applications.

Table 6. Standard of Strength Level and Utilization of Concrete Bricks and Paving Blocks [101] [102]

Strength Level	Average gross fc'		Gross fc' for each sample		Average gross fc'		Gross fc' for each sample		Utilization
	Kg/cm^2	MPa	Kg/cm^2	MPa	Kg/cm^2	MPa	Kg/cm^2	MPa	
Bricks	Solid Concrete Bricks				Hollow Concrete Bricks				
I	100	10	90	9.0	70	7.0	65	6.5	Structural component, fits for exposed structure
II	70	7.0	65	6.5	50	5.0	45	4.5	Structural component, for covered structure
III	40	4.0	35	3.5	35	3.5	30	3.0	Non-structural components, covered condirion and fit for unplastering/exposed finishing
IV	25	2.5	21	2.1	20	2.0	17	1.7	Non-structural components, covered condition and plastering
Paving Blocks									
A	400	40	350	35					public street
B	200	20	170	17					pavement for vehicle parking
C	150	15	125	12.5					pedestrian ways
D	100	10	85	8.5					Floor or pavement for garden

Thus, for the mortar standard of building is based on SNI 03-6882-2002 Mortar Specification for Building Materials, which the specification of mortar type is shown in

Table 5.

2.4 Review on Environmental Impact Assessment Indicators

The evaluation of environmental quality as a result of the use of building materials has received increased focus in recent years as a result of the numerous environmental harms caused by construction activities [103]. According to [104], civil works and building construction consume sixty percent of lithosphere-derived raw materials. The issuance of international standards to assess environmental quality, also known as the Life Cycle Assessment (LCA) [105], was undertaken in an effort to evaluate environmental damage. LCA analysis examines the entire life cycle of a building, from the extraction of building materials to its demolition. Studies of embodied energy and carbon emission are frequently employed in the LCA method. By calculating the amount of embodied energy and carbon emissions produced during the production and construction of materials, these two measurements are utilized not only in LCA but also in the vast majority of environmental damage assessment research. The research on the quality of building materials, which frequently links these two dimensions, muddles the definitions of both, despite the fact that they have distinct implications when used for research. In addition, the accuracy of the use of research parameters and methods in discussing the issues of embodied energy and carbon emission has a significant impact on the reliability of the research results.

One of the most important aspects of using embodied energy and carbon emission as parameters for evaluating material quality is understanding when and how these two can be used as LCA research parameters. Understanding the relationship, position, and characteristics of embodied energy and carbon emission can assist researchers in assessing the environmental quality of materials. This part reviews the parameters and methods used to measure embodied energy and carbon emission by examining various precedents to clarify the characteristics of these two parameters as they relate to the formulation of research problems.

LCA is associated with several research trends concerning embodied energy. The findings are categorized based on research evaluated embodied energy using the LCA method [106] [107] [108] [109] [110] [111] [112]. In the meantime, Goggins et al. (2010) [113] assessed embodied energy by measuring the fuel used in the production and transportation of materials. Pellegrino et al. (2011) [107] and DongHun & Gabbai (2011) [108] make embodied energy an LCA parameter by incorporating cost as a metric for calculating embodied energy. Vogtlander et al. (2010) [114] added Eco-cost (cost) as one of the factors that must be considered in LCA in order to evaluate sustainable materials.

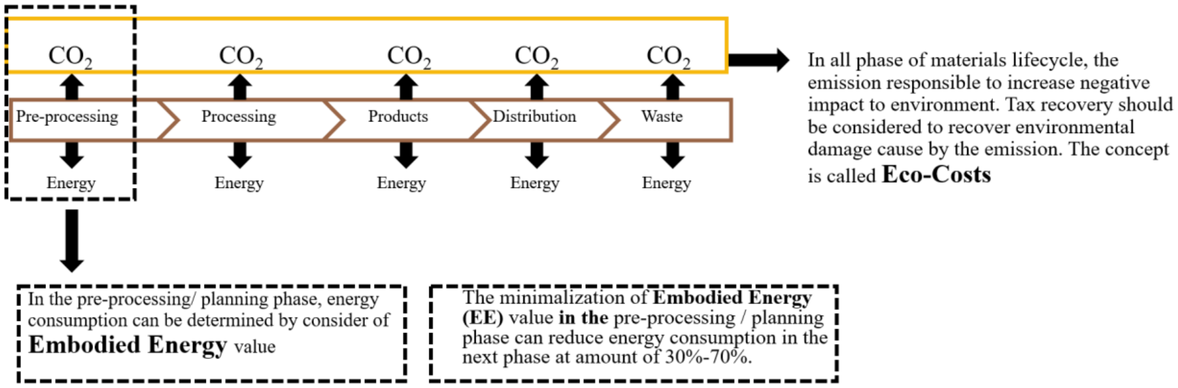


Figure 3. Diagram on Relation between Embodied Energy, Carbon Emission and Eco-costs on Materials Lifecycle (adapted from *[115]*)

Moreover, the characteristics of research methods based on embodied energy depend mostly on primary data with semi- or non-experimental research designs, as there is no standard for measuring embodied energy, making pure experimental research designs difficult to execute and time-consuming. To calculate embodied energy, therefore, mathematical modeling or analysis is used. The use of primary data in embodied energy research makes this research easier to conduct because researchers can observe directly, ensuring the data's validity and reliability. Moreover, the object of study in the form of a material makes it easier for researchers to interpret the characteristics of the material compared to the use of secondary data in which the characteristics of the material are not clearly known, so the measurement of embodied energy is more appropriate for evaluating the process of making a material.

The research by Monahan & Powell (2011) [106] [116], Tingley & Davison (2012) [112], and Crishna, et al. (2011) [111] demonstrate the characteristics of research based on carbon emission in assessing LCA, which is associated with embodied energy. As LCA parameters, these studies utilize embodied energy and carbon emission. Taehoon, et al. (2012) [117], Salmi & Wierink (2011) [118], Sun Jeong, et al. (2012) [119], and Junghoon, et al. (2012) [120] conducted additional studies that only link carbon emission with LCA. The only LCA parameter used in these studies is carbon emission. Taehoon, et al. (2012) [117] and Junghoon, et al. (2012) [120] used the cost and strength of materials to measure carbon emission more precisely, whereas Salmi & Wierink (2011) [118] used fuel during the manufacturing process and transportation as a measure of carbon emission.

Other studies by [121] [122] [123] [124] [125] [126] only assess carbon emission without relating it to the LCA. This carbon emission assessment focuses on fuel consumption during the manufacturing process [121] [123] [122] [124] [125] as well as costs [121] [126]. The assessment of carbon emission that is predominately based on fuel is rational because fuel contributes a significant amount of carbon emission.

Table 7 shows that most of the research methods used to assess carbon emissions rely on secondary data from related institutions. While primary-data-based research is always associated with embodied energy. Similar to the research design for assessing embodied energy, the research design for assessing carbon emission is difficult to conduct purely experimentally due to time constraints. It takes a long time to assess carbon emission in the process of making materials due to the large number of influencing variables, making modeling or mathematical analysis simpler. done. In addition, the majority of research on carbon emissions uses secondary data because it is easier to obtain data on fuel capacity for material production from institutional databases than through direct observation. As a result, carbon emission measurements are more focused on this material.

Various types of materials contain varying amounts of embodied energy. Using materials with a high embodied energy can result in a high future energy demand for heating, ventilation, and air conditioning [103]. Selecting environmentally acceptable materials can reduce energy consumption and environmental impacts [127]. Wood structures, for instance, have lower embodied energy and CO2 emissions than concrete, steel, and brick structures, as wood has significantly less embodied energy than other materials [127]. Crushing and grinding the clinker in Portland cement requires a great deal of energy [128]. Portland cement is a widely used material. Using concrete tiles as opposed to ceramic tiles could save up to 1.93 MJ-Eq/kg of energy [103].. Utilizing renewable energy or recycled materials could result in energy savings [129]. Multiple forms of renewable energy, such as those derived from the sun, wind, ocean, and hydropower, etc., could significantly reduce a building's energy consumption [130]. In addition, recycled concrete contains recycled aggregate derived from construction and demolition waste, a material alternative to virgin concrete. According to [131], the use of recycled concrete could reduce the consumption of natural resources and solve the problem of landfilling. In different phases of a building, the effects of a particular material on energy consumption may vary (or even be contradictory) [129]. For example, a high insulation value may save energy during the operational phase, but it may incur high embodied energy costs [129].

Table 7. Summary of Review on Environmental Impact Indicators for Building Materials Assessment

Indicators	Variable	Case of study	Research methods	Sources
Embodied Energy	• Fuel on processing • Fuel on transportation • Costs	Building materials, Façade Bricks and glass, Concrete	Primary sources, observation-non participant Experimental, modelling, quasy-experimental, mathematic analysis	[107] [108] [116] [113] [115] [132]
Carbon Emission	• Fuel on processing • Fuel on transportation • Costs • Strength of materials	Concrete Steel and iron Wood and Concrete Steel and zinc Building construction Geopolymer, OPC, cement, concrete Building elements Building materials	Secondary sources, insitution record, earlier research, Primary sources, observation non participant and participant Quasy-experimental, modelling, scenario analysis, Comparing study, Non experimental, literrary study, comparing study, modelling	[121] [117] [126] [120] [118] [106] [116] [133]
Eco-Costs	• Fuel on processing • Fuel on transportation • Costs • Strength of materials • Maintenance	Concrete Steel and iron Wood, bamboo, ceramic	Primary sources, observation, participant, quasy-experimental, modelling, Non experimental, literrary study,	[134] [135] [136]

2.5 Conclusion

The incorporation of SAP as the highest component in disposable diaper expected to improves the autogenous shrinkage, self-healing, and impermeability of cement-based materials, thereby extending the service lives of concrete structures and reducing their maintenance costs. With the advancement of science and technology, it is undeniable that SAP-modified cement-based composites are capable of exhibiting significant benefits in practical applications. By linkage with the waste treatment and environmental impact that caused by disposable diaper, recycling the waste as concrete and cement based materials is predicted has a lowest environmental impact.

Chapter 3

Research Methodology

3.1 Qualitative Approach

The objectives of qualitative analysis are:

1) To find out the factors that influence the waste capacity of diapers.
2) To decide the indicators on environmental impact for the material
3) To summarize the building standard that used for laboratory experiment.

This study employs a secondary source in the form of literature reviews extracted from international journals and collects data using a technique of purposive sampling in which data reduction is accomplished by focusing on the search for precedents with related to the topics. This research topic reveals the research parameters that are typically employed by researchers to evaluate the topic of concrete consist of disposable diapers or SAP. Hundred research examples were sampled with an emphasis on data analysis of the parameters and methodology employed in the research study area. The most recent research years for the used precedent no more than 10 years lately. To maintain data validity, it is necessary to consider the year of publication in literature studies. Each research topic is mapped to a table-based precedent as part of the data analysis procedure. Then, a descriptive analysis containing the interpretation of the analysis by table is conducted.

3.2 Quantitative Approach by Experimental Study

The Objectives of quantitative analysis are:

1) To analysis the capacity of disposable diaper waste that can be used for building materials
2) To evaluate the application of building materials based on standards and regulation.

3.2.1 Standard on Concrete Mix Design

To calculate the quantity of disposable diapers that can be used as construction components a laboratory experiment was undertaken to conduct a direct inquiry. Experimental study involved two kinds of utilization of composite materials, the concrete composite for structural elements such as column and beam and mortar composite for architectural elements such as non-bearing wall and floor. The standard of building materials is in accordance with Indonesian building standards and regulations (*Standard Nasional Indonesia*/SNI) as follows:

1) SNI 2847:2019 Structural Concrete Requirements for Buildings [137]
2) SNI 7656:2012 Mixed Design Procedures for Normal Concrete, Heavy Concrete, and Mass Concrete [138]
3) SNI 03-2834-2000 Technical Mixed Design for Normal Concrete [139],
4) SNI 03-6882-2002 Mortar Specification for Building Materials [102]
5) SNI 03-0349-1989 Concrete Bricks for Wall and [100]
6) SNI 03-0691-1996 Paving Block / Concrete Block [101]
7) And other relevant standards.

The objective of designing a concrete mix is to establish the proportions of cement, fine aggregate, coarse aggregate, and water that meet the specified criteria for workability, strength, durability, and final appearance. The proportions produced by the design must also be optimal, in the sense that the minimum number of materials must be used while still meeting technical requirements. Considering the varying properties and characteristics of the constituent materials, the formulation of concrete mixtures is a complex issue. Consequently, the nature and characteristics of each of these materials will result in a wide range of concrete production.

In addition, it is necessary to understand several other factors that influence the work of creating concrete mix designs, such as the working conditions, the planned concrete's strength, the ability of the executor, the level of supervision, the equipment used, and the building's designation.

To achieve a certain concrete strength, the design must produce a proportion of mixed materials whose value is determined by the following factors:

Water-cement-ratio

The value of the ratio of water to cement or what is called the water-cement ratio (w/c) has a strong direct influence on the strength of concrete. It should be understood in general that the higher the w/c value the lower the quality of the concrete, but the higher of workability of concrete.

Type of cement

The use of various types of cement will necessitate different values for the water-cement ratio. In Table 8 there are various types of cement that currently use in Indonesia.

Table 8. Types of Cement that Use in Indonesia

Type of Cement	Descriptions	Compositions
Portland Cement	A fine powder produced by heating limestone and clay minerals in a kiln to form clinker, grinding the clinker, and adding small amounts of other ingredients. Several types of Portland cement are available, the most common of which is called ordinary Portland cement (OPC), which is gray in colour, but white Portland cement is also available.	Depends on type.
Portland Cement I Type (Ordinary Portland Cement)	It is used for all types of construction when special properties are not required. The properties of Ordinary Portland Cement are between those of moderate heat cement and high early strength Portland cement.	5% MgO and 2.5-3% SO3
Portland Cement II Type (Moderate Heat Portland Cement)	For construction applications that require moderate resistance to Sulphate and hydration heat, usually used for harbour areas and buildings around the coast.	20% SiO_2, 6% Al_2O_3, 6% MgO, and 8% C_3A
Portland Cement III Type (High Early Strength Portland Cement)	Used in emergency and winter situations, also used for the production of compressed concrete. It has a higher C3S content compared to other types of cement making it hardens and releases heat faster. This type of cement is very suitable for the	6% MgO, 3.5–4.5% Al_2O_3, 35% C_3S, 40% C_2S, and 15% C_3A

Type of Cement	Descriptions	Compositions
	construction of large buildings, hazardous works, foundations, cold air concreting, and prestressed concrete which requires high initial strength.	
Portland Cement IV Type (Low Heat Portland Cement)	Excellent for preventing cracks in buildings with low heat hydration, such as large and thick concrete structures. It contains less C_3S and C_3A, resulting in reduced heat loss. This cement is frequently used for manufacturing or engineering hydraulic applications requiring low hydration heat.	6.5% MgO, 2.3% SO_3, and 7% C_3A.
Portland Cement V Type (Sulphate Resistance Portland Cement)	Possesses a high resistance to sulfur and a lower C_3A content than other types; it is commonly used for buildings in areas with high sulfate content, such as ports, tunnels, drilling at sea, and buildings in the summer.	6% MgO, 2.3% SO_3, and 5% C_3A.
White Cement	It is produced from limestone raw materials that contain less than 1% iron oxide and magnesia oxide, necessitating additional supervision to prevent contamination with Fe2O3 during the manufacturing process. The use of gas as a combustion fuel in rotary kilns is intended to reduce contamination of the combustion ashes and manganese oxide so that the color of the white cement is not altered. White Cement is utilized in construction and decoration.	24.2% SiO_2, 4.2% Al_2O_3, 0.39% Fe_2O_3, 65.8% CaO, 1.1% MgO, and 0.02% Mn_2O_2.
Oil Well Cement	Portland cement is blended with retardant substances such as lignin, boric acid, casein, sugar, or organic Hydroxide acid. to ensure that mortar can be pumped into oil or gas wells, the retarder's function is to reduce the rate of cement setting or to prolong the cement setting time. This is used to protect the space between the oil well's frame and the surrounding rock or soil, as well as the oil well's frame from the corrosive effects of water.	6% MgO, 3% SO_3, 48-65% C_3S, 3% C_3A, 24% C_4AF + $2C_3A$, and 0.75% N_2O
Colored Cement	Cement that matches the color of the material or materials to be glued is frequently required. When white cement is ground, 5 - 10% dye (pigment) is added to create colored cement. The colorant added to the cement must not affect its storage or use.	-
Cement Paint	Cement flour is produced by grinding portland cement with dyes, filters, and water-repellent agents. Typically, titanium oxide or zinc sulfide is used to make cement paint white. Typically, a water-repellent agent or silica material is utilized as a filter, whereas $CaCl_2$ is utilized as an accelerator and calcium or aluminum stearate is utilized as a water-repellent agent.	-
Masonry Cement	For this purpose, a hydraulic cement containing one or more blast furnace slag cement, portland pozzolan cement, natural cement or hydraulic lime and	-

Type of Cement	Descriptions	Compositions
	additives containing one or more of the following ingredients: slaked lime, limestone, chalk, calculous shell, talc, slag, or clay. The characteristics of this cement include high plasticity and low compressive strength.	

Durability

Durability considerations will require values of minimum strength, maximum water-cement ratio, and minimum cement content.

Table 9. Values of Minimum Strength, Maximum Water-cement ratio, and Minimum Cement Content [139]

Conditions	Minimum cement content per m^3 of concrete (kg)	Maximum water-cement ratio
Indoor		
a. Non-corrosive circumstance	275	0,6
b. The corrosive circumstance is caused by condensation or corrosive vapors	325	0,52
Outdoor		
a. Not protected from rain and direct sun	325	0,6
b. Protected from rain and direct sun	275	0,6
Underground		
c. alternating wet and dry conditions	325	0,55
d. Under the influence of alkaline sulfates from the soil or groundwater	Table 10	
Continues contact with water	Table 11	
e. Freshwater		
f. Sea water		

Table 10. Provisions For Concrete in Contact with Groundwater Containing Sulfates [139]

Sulphate Concentration (SO3)			Type of cement	Minimum cement content (kg/m3)			Maximum water-cement-ratio
Underground		SO3 in ground water (g/lt)		Max Size Aggregate (mm)			
SO3 Total	SO3 in the mixture of Water : soil = 2:1(g/lt)			40	20	10	
<0,2	<0,1	<0,3	Type I with or without Pozzolan (15-40%)	280	300	350	0,5
0,2 – 0,5	1,0 – 1,9	0,3 – 1,2	Type I without Pozzolan	290	330	380	0,5
			Type I Pozzolan (15-40%) or Portland Pozzolan Cement	270	310	360	0,55
			Type II or Type V	250	290	430	0,55
0,5 – 1,0	1,9 – 3,1	1,2 – 2,5	Type I with Pozzolan (15-40%) or Portland Pozzolan Cement	340	380	430	0,45
			Type II or Type V	290	330	380	0,5
1,0 – 2,0	3,1 – 5,6	2,5 – 5,0	Type II or Type V	330	370	420	0,45
>2,0	>5,6	>5,0	Type II or Type V and protective layer	330	370	420	0,45

Table 11. Minimum Requirements for Watertight Reinforced/Prestressed Concrete [139]

Contact with:	Maximum water-cement-ratio	Type of cement	Minimum cement content (kg/m3)	
			Max Size Aggregate (mm)	
			40	20
Freshwater	0,5	All type 1 to V	280	300

Sea water	0,45	Type I with Pozzolan (15-40%) or Portland Pozzolan Cement	340	380
	0,5	Type II or Type V	290	330
Brackish water	0,45	Type II or Type V	330	370

Workability and Portion of Water

The nature of the concrete mixture's viscosity and consistency can be used to describe the workability of concrete, which is expressed as a slump value. The amount of water required will be influenced by the slump value that, for a given aggregate size and construction type, is anticipated to facilitate workability. To avoid using concrete mixtures that are too viscous or too thin, it is advised to use slump values within the following parameters:

Table 12. Slump Value Standard of PBI-Indonesia

Structural Elements	Slump value (mm)
Mass concrete	25 - 75
Foot plate foundation, basement construction, caisson	25 - 90
Reinforced concrete for road pavement	50 - 75
Foot plate foundation, reinforced foot plate foundation	50 - 125
Floors, beams, columns, and walls	75 - 150

Table 13. Slump Value Standard [138]

Structural Elements	Slump value (mm) *with vibrating	Slump value (mm) *other than vibrating
Mass concrete	25 - 50	50 - 75
Road pavement and floor	25 - 75	50 - 100
Reinforced concrete foundation (walls and foot plate)	25 - 75	50 - 100
Foot plate foundation, wall basement, caisson	25 - 75	50 - 100
Beams and reinforced walls	25 - 100	50 - 125
Columns	25 - 100	50 - 125

Concrete consistency testing must be determined by measuring the slump according to SNI 1972:2008. Meanwhile, according to the General Specifications for Highways 2010-revision 3, the range of slump values that must be met are:

- For concrete that will be formed with slipforms: 20 - 50 mm

- For concrete to be spread with a fixed form (fix form): 50 - 75 mm

Aggregate Specification

The maximum aggregate grain size should not exceed:

- One-fifth the smallest distance between the side planes from molds;

- One third of the plate thickness;

- Three quarters of the minimum clear distance between bars or beams.

Table 14. Estimated Free Water Content (Kg/m^3) Required for Several Levels of Concrete Workability [139]

Maximum Size of Aggregate(mm)	Type of aggregates	Slump (mm)			
		0-10	10-30	30-60	60-180
10	Natural	150	180	205	225
	Crushed	180	205	230	250
20	Natural	135	160	180	195
	Crushed	170	190	210	225
40	Natural	115	140	160	175
	Crushed	155	175	190	205

Notes:

• Correction of temperature above 200°C, every 50°C increase must be added 5 litres of water per m^3 of concrete mix

• Surface conditions: for a rough aggregate surface, ± 10 litters of water per m^3 of concrete mix must be added

Table 15. Coarse aggregate size arrangement limits [139]

Size of sieve (mm)	Percentage by weight of the portion that passes through the sieve		
	Nominal size of aggregate (mm)		
	38 - 4,76	19,0 - 4,76	9,6 - 4,76
38,1	95-100	100	-
19,0	37-70	95-100	100
9,52	10-40	30-60	100
4,76	0-5	0-10	0-10

Portion of Cement

Minimum cement requirements are set to prevent concrete from being damaged by special environments, for example: corrosive environments, brackish water and sea water. The minimum cement value can be determined using Table 9. The minimum cement value is then compared to the required amount of cement, if the value is greater than the required amount of cement, the minimum cement amount is taken.

Table 16. Estimated Compressive Strength of Concrete with W/C 0.50 [139] [140]

Type of Cement	Type of course aggregate	Compressive Strength (MPa) on age (day)				Specimens form
		3	7	28	91	
Type I, Type II Type V	Natural	17	23	38	40	Cylinder
	Crushed	19	27	37	45	
	Natural	20	28	40	48	Cube
	Crushed	23	32	45	54	
Type III	Natural	21	28	38	44	Cylinder
	Crushed	25	33	44	48	
	Natural	25	32	46	53	Cube
	Crushed	30	40	53	60	

Variability

Variability in concrete will influence the planning value for compressive strength. The standard deviation value essentially reflects the significance of concrete strength variation. If a number of data are collected from the results of the concrete compressive strength test, the data will indicate that the resulting values will fluctuate around a mean value with a specified standard deviation. The planning assumption is that the distribution of concrete strength will be normal during the implementation period.

$$M = k \times S \qquad \text{…………} \qquad \textit{Equation 1}$$

The standard value of k for the 5% acceptable reject/defective portion is 1.64. The *k x S* value is also known as the added value (margin) and security value in design. It should also be understood that the minimum number of samples must be considered when calculating the standard deviation value. A correction number must be applied to the standard deviation value if the tested object falls short of the minimum number.

The test result data to be used to calculate the standard deviation must be:

- Represent materials, quality control procedures and production conditions similar to proposed work.
- Represents the required concrete compressive strength, f'c, which is within ±7 MPa of the f'c value which is determined.
- It consists of at least 30 consecutive test results or two groups of consecutive test results a minimum of 30 test results taken into production for a period of not less than 45 days
- If a concrete production only has 15-29 test results that meet the requirements, then the standard deviation value is the multiplication of the standard deviation calculated from the test results data with the multiplier factor from Table 17.
- If the field test data to calculate the standard deviation that meets the requirements of item above is not available, then the targeted average compressive strength f'cr must be taken not less than (f'c+12 MPa)

Table 17. Multiplier factor for standard deviation when available data is less than 30

Samples	Multiplier factor
Less than 15	not less than (f'c+12 MPa)
15	1,16
20	1,08
25	1,03
30 and more	1,00

3.2.2 Procedure of Mixed Design for Concrete

In Indonesia, concrete mix design is based on two standards [140]:

1) SNI 03-2834-2000 Technical Mixed Design for Normal Concrete which is adapted from DOE method -British, and
2) SNI 7656:2012 Mixed Design Procedures for Normal Concrete, Heavy Concrete, and Mass Concrete which is adapted from American Concrete Institute (ACI)

In general, the two methods are based on empirical relationships, charts, graphs, and tables, but there are differences in their procedures.

In its mixed design procedure, the SNI 03-2834-2000 method adopts the following assumptions [140]:

1) This procedure is applicable to Ordinary Portland Cement (type I), Rapid Hardening Portland Cement (type II), High Early Strength Cement (type III), and Sulphate Resistant Portland Cement (type V).
2) This method differentiates between crushed aggregate (crushed stone) natural aggregate (gravel), which affects the quantity of water used.
3) Consider the gradation of fine aggregate by zone and assume that the gradation of fine aggregate will impact the concrete's workability.
4) The optimal ratio of coarse aggregate volume to concrete volume depends on the nominal maximum size of coarse aggregate and the fine aggregate grading.
5) The only factor affecting the water content of the concrete mixture is the level of workability, as measured by the slump test.
6) It is assumed that the nominal maximum size of the coarse aggregate has no effect on the mix proportions.
7) The method utilizes a concrete mixture with a water-to-cement ratio (w/c) of 0.50.

While the SNI 7656:2012 method adopts the following assumptions [140]:

1) This method does not differentiate between the type of hydraulic cement (it applies to all types) and the type of aggregate.
2) It is believed that the consistency of the mixture affecting its workability depends solely on the free moisture content of the mix proportions, as expressed by the slump test.
3) The optimal ratio of coarse aggregate volume per cubic meter of concrete is solely dependent on the nominal maximum size of coarse aggregate.
4) The type of compaction has an effect on the suggested slump height.
5) It is possible to estimate the volume of mixed concrete ingredients using either weight equivalent or absolute equivalent.
6) This method does not specify a minimum acceptable concrete content.
7) This method reduces the amount of water in concrete mixes containing natural coarse aggregate/gravel by 18 kg/m3.

Testing

The mix design of concrete is based on the assumption that the properties of hardened concrete are highly dependent on the properties of the mixture composition. Concrete must be compacted uniformly in order to achieve the desired hardness. Whether a concrete mixture can be adequately compacted depends on the properties of the fresh concrete itself. This test measures the slump or consistency of the concrete mixture. After the concrete has hardened or the hydration process has ceased, a solid and hard object with particular characteristics is formed. These properties must be understood in order to use them in planning or to assess the intended strength.

Fresh concrete

Good properties can be attributed to a fresh concrete mixture if it satisfies the primary requirements of the mixture, which is the ability to provide workability, i.e., if the mixture remains uniform during the transport, molding, and compaction processes. The nature of ease of craftsmanship is a complex problem because it combines the influence of natural properties and other random factors that occur during craftsmanship. Concrete's workability is the primary performance of fresh concrete. Even if a concrete structure is designed to have high compressive strength, the objective will not be met if the design cannot be implemented in the field due to its complexity. The concrete mixture will be easy to work with if it possesses at least the following three properties [140]:

1) Compatibility, i.e., concrete can be compacted to eliminate or reduce air pockets.
2) Mobility, or the ability for concrete to flow into the cast concrete mold.
3) Stability, or the capacity of concrete to maintain a homogeneous mass during work and vibration without segregation of the main components.

Workability can be determined by the consistency of the concrete mixture, which is equivalent to its plasticity. The more flexible the concrete, the simpler it is to manipulate. The consistency of the concrete mixture is affected by the factors listed below [140]:

1) Water content: More water will make the concrete mixture easier to work with.
2) Cement content: If the cement-to-water ratio remains unchanged, adding more cement necessitates adding more water, resulting in greater plasticity.
3) Aggregate gradation: Aggregate that satisfies the gradation requirements will make concrete easier to work with.
4) Aggregate grain shape: Concrete with round aggregate grains is easier to control.
5) Maximum aggregate grain: Using the same quantity of water, a larger maximum aggregate will result in a greater degree of simplicity.
6) Method of compaction and equipment for compaction: Correct use of a compactor will influence the final condition of the wet concrete after compaction, allowing the hard concrete quality target to be met.

The test method that can be used to measure the workability of concrete is the slump method [141] (SNI 1972:2008 Concrete slump test method).

Procedures

A 300 mm high, 200 mm base diameter, and 100 mm top diameter truncated conical mold is filled with concrete in three layers, with each layer pierced 25 times with a 16 mm diameter tamping rod. The distance of the concrete surface settlement, as measured from the initial concrete surface level, is the slump value of the tested concrete mixture.

- *True slump*: This type of slump is derived from a homogeneous and cohesive concrete mixture, so the measured slump value corresponds to the actual slump value.
- *Shear slump:* If shear failure occurs on one side or portion of the concrete mass, the test must be repeated using a different portion of the same mix. Then, if two consecutive tests on a single concrete sample demonstrate shear failure, it is possible that the concrete mixture is less plastic or less cohesive; therefore, it must be declared as a mixture that does not meet the workability requirements.
- *Collapse slump:* For normal concrete without the addition of a superplasticizer, the slump value obtained from such a mixture will exceed the maximum slump value limit; therefore, it must be declared as a concrete mixture that does not meet the workability made possible by the use of excessive water.

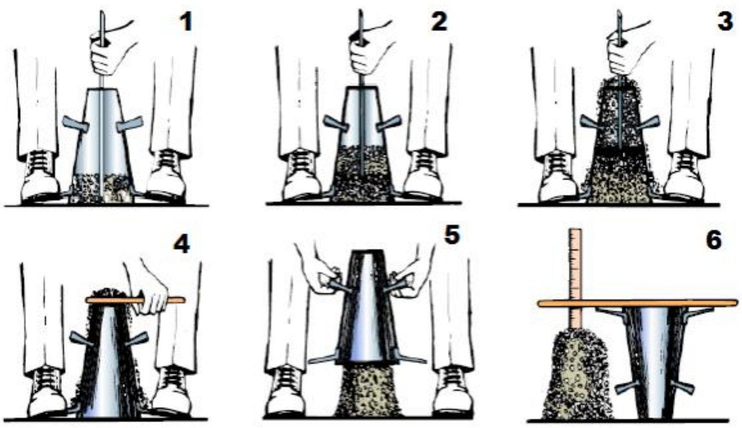


Figure 4. Procedure of Slump Test for Fresh Concrete [140]

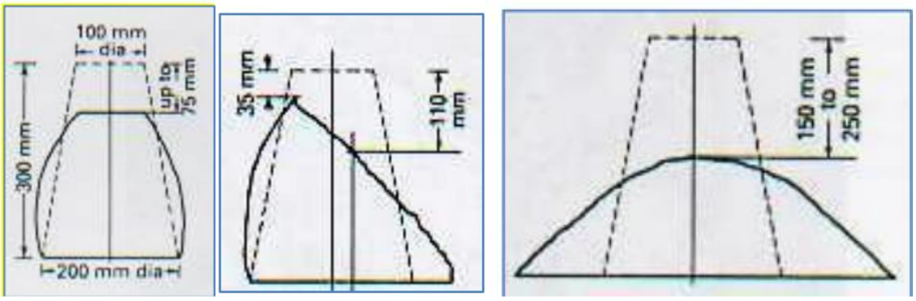


Figure 5. Parameters of Slump Collapse [140]

Hard concrete

Concrete strength is the most essential property of hard concrete. The strength of concrete is determined by calculating the maximum load that a concrete cross-section can support using specimens of a specific shape. A concrete's strength is affected by four primary factors: a. The proportion of constituent materials with a specific material quality; b. Formulating and mixing method; c. Conditions at the time of molding; and d. Maintenance.

It is common knowledge that the higher the w/c ratio, the weaker the concrete strength. However, the lower the w/c ratio does not always indicate a stronger concrete. A too-low w/c ratio will make it difficult to compact the concrete mixture, which will result in concrete with less strength because the density is not optimal. Typically, the w/c ratio for concrete is between 0.40 and 0.65. However, for high-quality concrete, a lower w/c ratio can be used in conjunction with additives that facilitate workability.

When the concrete mixture is in its plastic state, it has no strength whatsoever. After hydration, concrete strength begins to develop; then, as concrete ages, its strength increases. Significant changes in the increase in concrete strength occurred up until the age of 28 days, after which the increase is insignificant, and the concrete strength is considered to have reached its maximum value. If at 28 days the concrete's strength is considered to have reached 100 per cent, the strength of the concrete at ages other than 28 days is typically converted as follows:

Table 18. Comparison of The Strength of Concrete at Various Ages

Concrete properties	Age (days)						
	3	7	14	21	28	90	365
Concrete using ordinary Portland cement	0,4	0,65	0,88	0,95	1,00	1,20	1,35

Concrete properties	Age (days)						
	3	7	14	21	28	90	365
The concrete uses Portland cement with high early strength	0,55	0,75	0,90	0,95	1,00	1,15	1,20

Concrete compressive strength test

On a cube-shaped specimen measuring 150 mm x 150 mm x 150 mm, or on a cylindrical specimen with a diameter of 150 mm and a height of 300 mm, the compressive strength is measured. When the specimen is capable of supporting the maximum compressive load, the maximum stress value can be used to determine the compressive strength of concrete.

$$fc = P/A \quad \ldots\ldots\ldots\ldots \quad \textit{Equation 2}$$

fc = concrete section stress

P = compressive axial load

A = cross-sectional area that carries the load

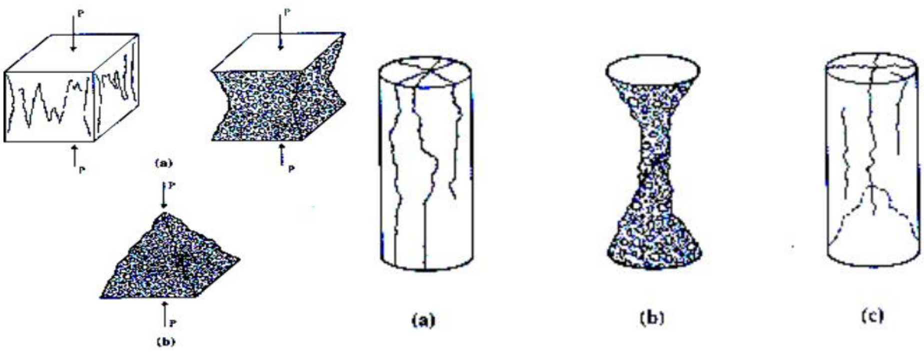


Figure 6. Cube specimen for compressive strength test and cylindrical specimen for the thesis test [140]

According to the shape of the test object, the characteristic compressive strength is stated. Due to the different shapes of the specimens, it is common practice to compare the compressive strength of the specimens in the following manner:

Table 19. Compressive Strength Comparison

Specimens	Compressive strength comparison
Cube 150 x 150 x 150 (mm)	1,00

Cube 200 x 200 x 200 (mm)	0.95
Cube 100 x 100 x 100 (mm)	1,07
Tube ϕ150 mm height 300 mm	0,83

Procedures for the manufacture and maintenance of concrete specimens in the laboratory

Table 20. Procedures for the manufacture and maintenance of concrete specimens in the laboratory SNI 2493:2011 [142]

Tools	- Mold - Tamping rod/internal vibrator/external vibrator - Slump Test Equipment - Mixing bowl/mixer - Air Content Test Equipment - Scales - Concrete Mixer - Rubber hammer - Shovel
Mixing Procedures	Prepare the mold to be used 1) Weigh each material according to the amount of material specified from the results of the concrete mix design 2) Mix all the ingredients that have been weighed by hand or machine mixer (mixer) 3) Mixing using a mixer (mixer) is carried out with the following steps: o First, operate the mixing machine, then add coarse aggregate and a specific amount of mixing water, or adjust it according to the type of mixing machine. o If additional ingredients are added to concrete, they are first combined with the water mixture or adjusted according to the instructions. o Include fine aggregate material, cement, and the remaining water in the mixture. o If these ingredients cannot be added while the mixing machine is in operation, the mixing machine can be stopped beforehand. o After all the ingredients have been added to the mixer, the concrete is stirred again for three minutes. o Stop the machine for 3 minutes, and during the pause in stirring, the mixing place (mixer) must be tightly sealed. Continue stirring for another 2 minutes, or until the ingredients are thoroughly combined. o The concrete mixture is then extracted from the mixing machine. o Once all of the concrete mixture has been removed from the mixer, clean any remnants of the mixture that are still attached to the mixer; Stir the concrete mixture again with a stirring spoon or shovel until it is uniform. 4) After the mixture is uniform and homogeneous, conduct the slump, bulk density, and air content tests.

	5) After the slump test, bulk density, and air content have been completed, return the concrete to the mixing bowl. Re-stir the mixture with a spoon or shovel until it is uniform and smooth. 6) Mold the test object with the following conditions: o Where the concrete will be poured, a shovel or stirrer is placed beneath the top surface of the mold. o Layer the concrete mixture into the mold according to the type of specimen. o Compact the concrete by choosing the appropriate compaction method based on the slump value if: - Slump value is greater than 75 mm, the material is compacted by tamping rod - Slump values between 25 and 75 millimeters, compaction by tamping rod or internal vibration. - Slump value 25 mm; vibration-based compaction o In addition, tamping rods are used to level the concrete prior to initial compaction. In the final layer, concrete is added until it exceeds the surface of the mold, so that it will not need to be added again once the concrete has hardened. 7) Cover the test sample with a material that is resistant to water absorption, nonreactive, and simple to use, but also capable of retaining moisture until the test sample is removed from the mold. 8) After 20 hours and no later than 48 hours following molding, remove the specimen from the mold. 9) Perform maintaining on the test object until the time of testing.
Compaction by tamping rod	1) The diameter of tamping bar and the number of punctures are listed in Table 20 if compaction is accomplished by tamping rod. 2) Pierce the bottom layer until it reaches its depth. 3) The holes are evenly distributed across the cross-section of the mold surface 4) For each top layer, the tamping rod may penetrate the underlying layer to a depth of 12 mm (for layers 100 mm thick) or 25 mm (for layers > 100 mm thick) mm. 5) After each layer has been pricked, the exterior is lightly tapped with a rubber hammer to close the air holes. 6) After all layers have been pierced, the surface of the mold is flattened with a tool until the specimen's surface is smooth and uniform.
Compaction by vibrator	1) The duration of vibration is dependent on the workability of the concrete and the vibrator's efficiency. (In general, enough vibration is done until the concrete surface becomes smooth). 2) Continuous vibration is applied to each layer until sufficient concrete density is achieved. 3) Excessive vibration will result in aggregate and cement paste separation. 4) All of the concrete is poured into each layer of the mold prior to vibration. 5) Particularly for molding tube testing, use three vibratory inserts at various layers. 6) Permit the vibrator to penetrate through the vibrated layer and into the layer beneath.

	7) After each layer has been vibrated, strike the exterior of the mold ten to fifteen times with a hammer or bat. 8) Surfaces are smoothed during vibration if an external vibrator (vibrating table) is used, or following vibration if an internal vibrator is used.
Maintenance	1) The outer surface of the mold must not come into direct contact with water for the first twenty-four hours after the concrete is cast, as this can alter the water content of the mixture and damage the specimen. 2) Immerse all test objects in water at a temperature of 23 ± 2^{o}C from the time they are removed from the mold until the test is conducted. 3) The storage area must be free of vibration, particularly for the first 48 hours after the specimens have been placed there. 4) Test objects can also be treated by submerging them in water containing lime or storing them in a damp room or a damp cabinet. 5) The test object must be protected from dripping or flowing water from the exterior. 6) Specifically, flexural strength test specimens must be soaked in lime-saturated water at a temperature of 23 ± 2^{o}C for a minimum of 24 hours prior to testing. Then, remove the specimens from the immersion site a sufficient amount of time prior to testing so that the surface is sufficiently dry.

Table 21. Diameter of Tamping Bar and the Number of Punctures [142]

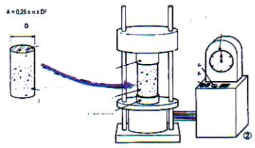
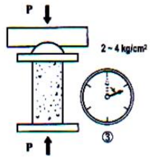
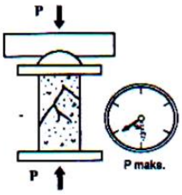
Specimen form	Height (mm)	Compacting method	Number of layers	Thickness of layers
Tube	<300	Tamping rod	3	100
	>300	Tamping rod	as required	100
	<400	Vibrator	2	200
	>400	Vibrator	3 or more	200
Cube	<200	Tamping rod	2	100
	>200	Tamping rod	3 or more	100
	<200	Vibrator	1	200
	>200	Vibrator	2 or more	200

Table 22. Diameter of Rod and the Number of Punctures [142]

Specimen form	Rod diameter	Number of compacting per layers
Tube with diameter (mm)		
50 – 150	10	25
160	16	25
200	16	50
250	16	75
Cube with area (cm^2)		
160	10	25
160 – 310	10	1x7 cm^2 of area
320	16	1x7 cm^2 of area

Test method for compressive strength of concrete

Table 23. Test method for compressive strength of concrete SNI 1974:2011 [143]

Tools	1) Measurement Universal testing machine	
Procedures	1) Position the test object in the center of the machine	
	2) Utilize a constant load addition of 2 to 4 kg/cm2 per second on the press machine.	
	3) Load the test object until it is destroyed and record the maximum load that occurs during the test object's inspection.	
Analyze	KTB = P/A KTB = concrete compressive strength (kg/cm^2); P = maximum load (kg); A = cross-sectional area of the test object (cm^2)	

3.3 Mixed Method Approach

The objectives of qualitative analysis are:

Feasibility study on environmental impact assessment:

1) To analysis feasibility of recycling disposable diaper by comparing environmental impact on different treatment on waste of disposable diaper and similar recycling products of concrete
2) To analysis mechanical properties on similar recycling products of concrete
3) To analysis source availability of the disposable diaper
4) Calculation design on environmental impact of Embodied Energy, Carbon Emission and Eco-costs by using: Bath Inventory of Carbon and Energy (ICE) [144], Industrial Design and Engineering Materials Database (Idemat) [145], Ecoinvent database [146]
5) Calculation design on mechanical properties of compressive strength and density by using secondary data on past research.
6) Calculation formula on source availability using secondary data.

Feasibility study on construction system

To propose construction method of building materials innovation by prefabrication system by following steps:

1) Literature study and preliminary design on construction system.
2) Site Survey for onsite construction by design and simulation process in detail engineering drawing for formwork and connection between materials and structure and rough Simulation on structural analysis based on site survey.
3) Building Materials and Structural Components Preparation. It designs building materials for wall and floor with panel system and structural components with steel hollow and bolt connection.
4) Construction Process, By in site molding of building materials and delivery process of structural components from manufacture to construction site.

Brief analysis of mixed method used in the study.

The problem comes up when calculating the exact waste capacity of disposable diapers that may be solved by recycling as concrete components. This part is explained the calculation by using case study of urban city in Bandung, Indonesia. The study is conducted by collecting data of disposable diapers usage in Bandung, then using calculation approach of concrete mix design to assume the replacement component capacity of concrete that filled by disposable diapers waste. The final calculation is to assume the capacity of disposable diapers concrete that benefit to use as infrastructure materials, such as building components and road pavement.

3.3.1 Parameters Approach

To assume the disposable diapers waste capacity, some parameters are used. Some literatures state that the use of disposable diapers in household depends on background of parent such as age and sex [147] [148] [149], education [17] [27] [148], marital status [147], job and income [17] [147] [148] [150] [149]. While the main parameter is background of children such as age and sex [17][[151] [152] [147] [148] [150]], breast feeding [153] [154] [155] [156] [157] and toilet training [17] [148] [153] [154] [157] [158]. These parameters have a relation to the usage of disposable diapers daily.

Table 24. Disposable diaper frequency use in household

Age of baby	Diapers Use Frequency	Source
0 - 12 months	2 - 6 times per day	[159]
0 - 4 years	11 - 15 times per week = 2 - 3 per day	[17]
0 - 3 years	2 - 10 times per day	[158]
0 - 6 months	1- 6 per day	[154]

0 - 1 month	3 - 9 times per day	[155]
0 - 1 month	3 - 8 times per day	[156]
0 – 14 month	5 – 9 times per day	[160]

In term of waste capacity of disposable diapers, the parameters that set in this study are population of children in range of 0 to 4 years old, disposable diapers use frequency per day and the weight of disposable diapers. Those parameters are derived from secondary data based on several literatures.

The population of 0 – 4 years old is based on data from the city or country. The parameter of population then market as Pb (population of age 0-4 years). Based on the Table 1, the range frequency of children from 0 – 4 years age is 1 to 10 times of changing diapers a day. In this study the frequency is assumed based on equation:

$$\text{Average} = \frac{\frac{\sum n1+n2}{2}}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{Equation 3}$$

Where n_1 and n_2 are the lowest and the highest value of the data. N is total data. Based on the equation, the average of children changing the diapers is 5 times or piece a day. This parameter then marked as F_d (frequency of diapers). The other parameter to set in this calculation is weight of disposable diapers that show in Table 25.

Table 25. Weight of disposable diapers per piece

Quantity	Weight	Source
12 pc	318.2 - 429.6 gr = 26.5 – 35.8 gr	[161] [162]
1 pc	26.5 - 27.4 gr	[160] [162]
1 pc	28.04 - 36.1 gr	[162]

Based on the equation (1), then the weight of diapers can be decided 30.06 gr per piece. This parameter then marked as m_d (mass of diapers).

After all parameters decided, then to calculate the waste capacity of diapers per day is determined by population of age 0-4 years (P_b), frequency of diapers usage daily, monthly, or annual (F_d) and mass of diapers per piece (m_d) as formulized in the equation:

$$C_d = p_b \; x \; f_d \; x \; m_d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{Equation 4}$$

C_d is marked as capacity of waste diapers.

3.3.2 Concrete Mix Design Approach

Based on several studies, the disposable diapers in concrete act as a substitute for fine aggregate. However, the replacement of fine aggregate by disposable diapers is to be considered in term of density distinction. To meet apple to apple of weight ratio, this calculation involves the formula:

$$\rho = \frac{m}{V} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{Equation 5}$$

Where:

ρ = density of material (g/cm^3)

m = mass or weight of material (g)

V = volume or three-dimensional space (cm^3)

In this scenario, the ratio of fine aggregate (fa) and disposable diaper (d) is mutual in the volumetric. So, the calculation is decided by:

$$V_{fa} : V_d = \frac{m_{fa}}{\rho_{fa}} : \frac{m_d}{\rho_d} \ldots\ldots\ldots\ldots\ldots \quad \textit{Equation 6}$$

Then the mass of disposable to replace fine aggregate in the concrete mix design is determined:

$$m_d = \%_{rep}\ x \left(\frac{\rho_d}{\rho_{fa}}\right) x\ m_{fa} \qquad \ldots\ldots\ldots \quad \textit{Equation 7}$$

Where:

ρ_d = density of disposable diaper (g/cm^3)

m_d = mass or weight disposable diaper (g)

ρ_{fa} = density of fine aggregate (g/cm^3)

m_{fa}= mass or weight fine aggregate (g)

$\%_{rep}$= replacement percentage of fine aggregate by disposable diaper (%)

For density of disposable diapers is 0.07 - 0.21 g/cm^3 [163]. Then, by incorporate *Equation 4* to *Equation 7,* the equation of diaper capacity that can be used for concrete components is obtained:

$$C_{dc} = \frac{(P_b\ x\ F_d\ x\ m_d)}{\%_{rep}\ x \left(\frac{\rho_d}{\rho_{fa}}\right) x\ m_{fa}} \qquad \ldots\ldots\ldots \quad \textit{Equation 8}$$

Then C_{dc} is marked as capacity of disposable diapers concrete that can be produced.

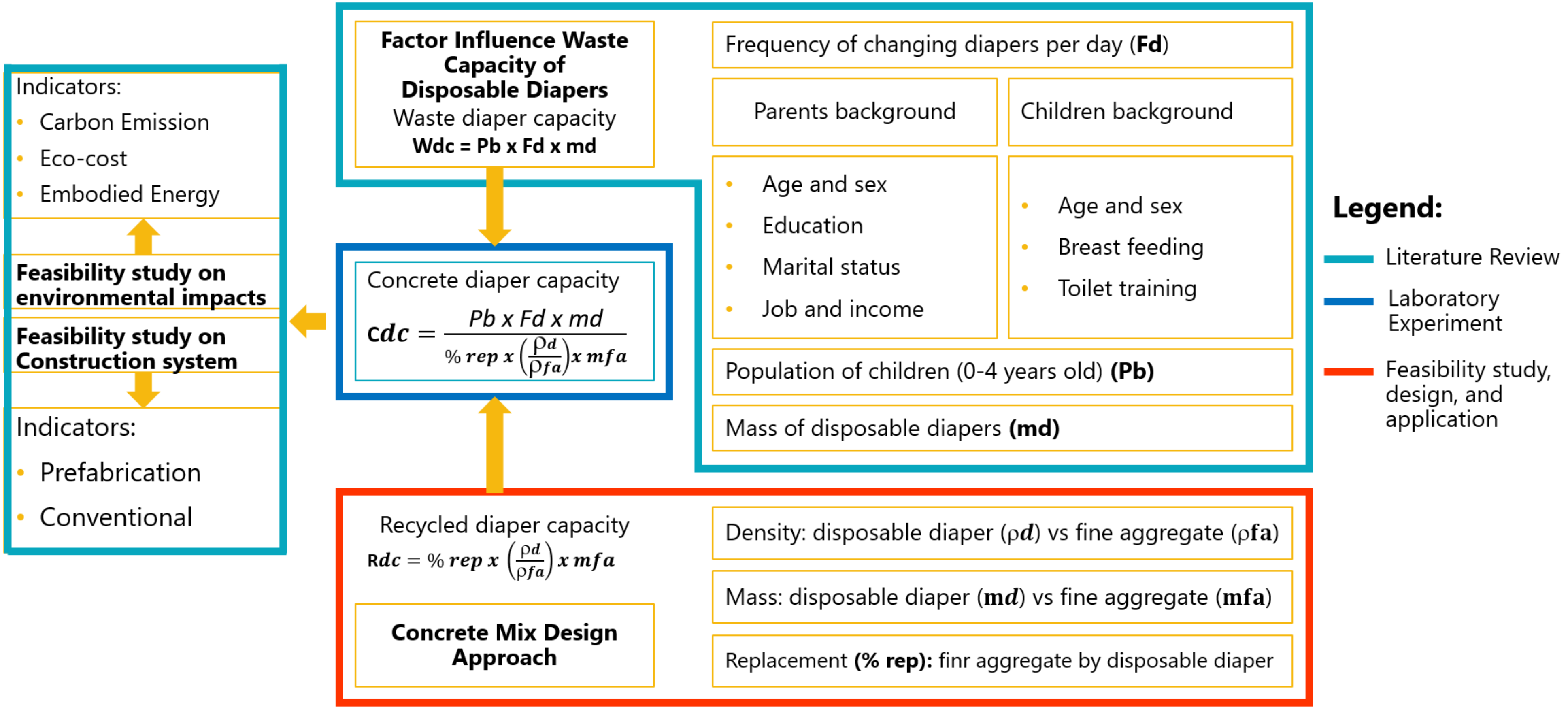


Figure 7. Connection between Methodologies

Chapter 4

Laboratory Experiment

4.1 Experimental Procedures

The mix design procedure following SNI 03-2834-2000 with assumptions:

1) This procedure is applicable to Ordinary Portland Cement (type I), Rapid Hardening Portland Cement (type II), High Early Strength Cement (type III), and Sulphate Resistant Portland Cement (type V).
2) This method differentiates between crushed aggregate (crushed stone) natural aggregate (gravel), which affects the quantity of water used.
3) Consider the gradation of fine aggregate by zone and assume that the gradation of fine aggregate will impact the concrete's workability.
4) The optimal ratio of coarse aggregate volume to concrete volume depends on the nominal maximum size of coarse aggregate and the fine aggregate grading.
5) The only factor affecting the water content of the concrete mixture is the level of workability, as measured by the slump test.
6) It is assumed that the nominal maximum size of the coarse aggregate has no effect on the mix proportions.
7) The method utilizes a concrete mixture with a water-to-cement ratio (w/c) of 0.50.

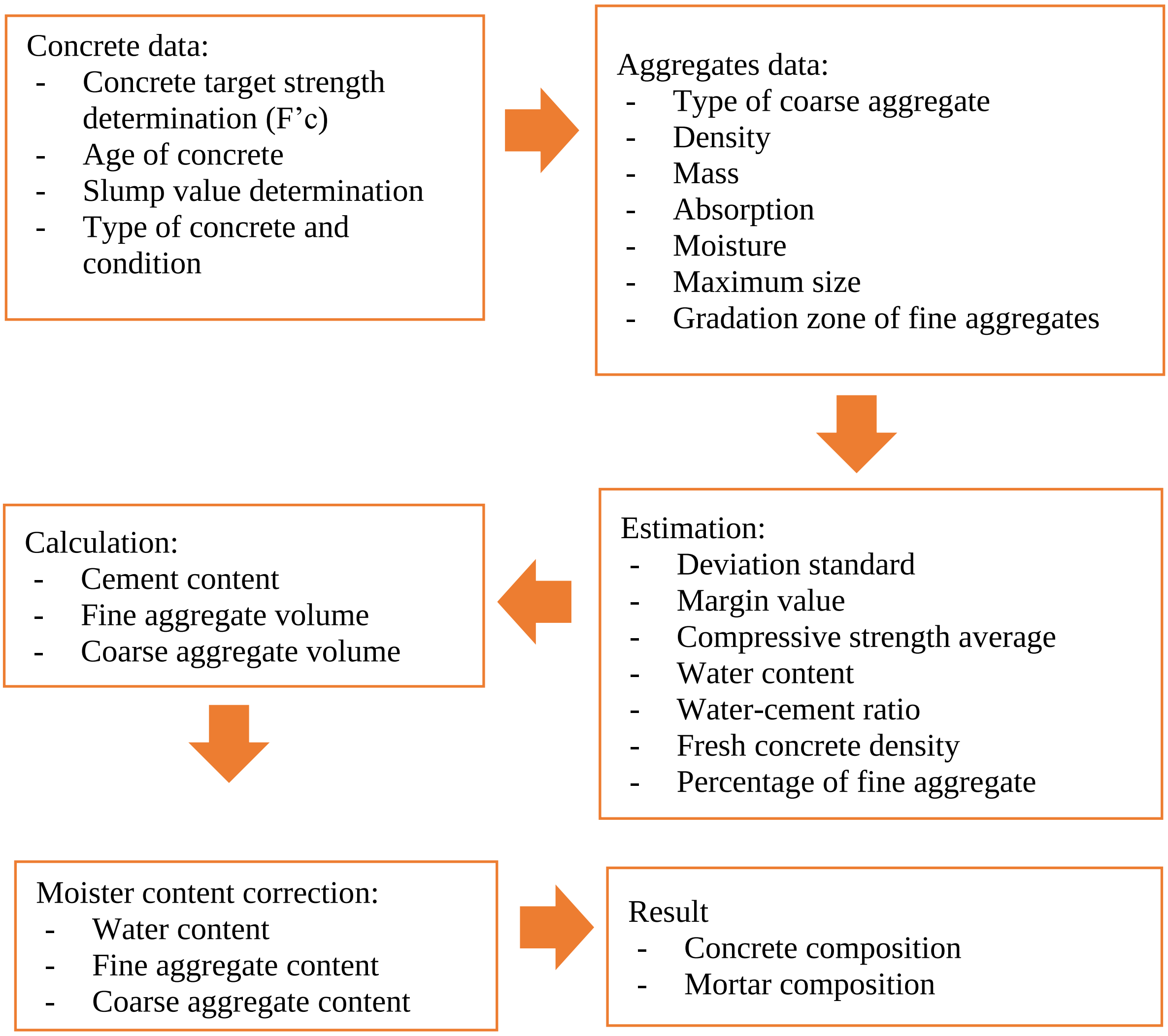


Figure 8. Procedures of concrete mix design based on SNI 03 – 2834 – 2000

Based on the laboratory result in appendix 1, the parameter of mix design is decided.

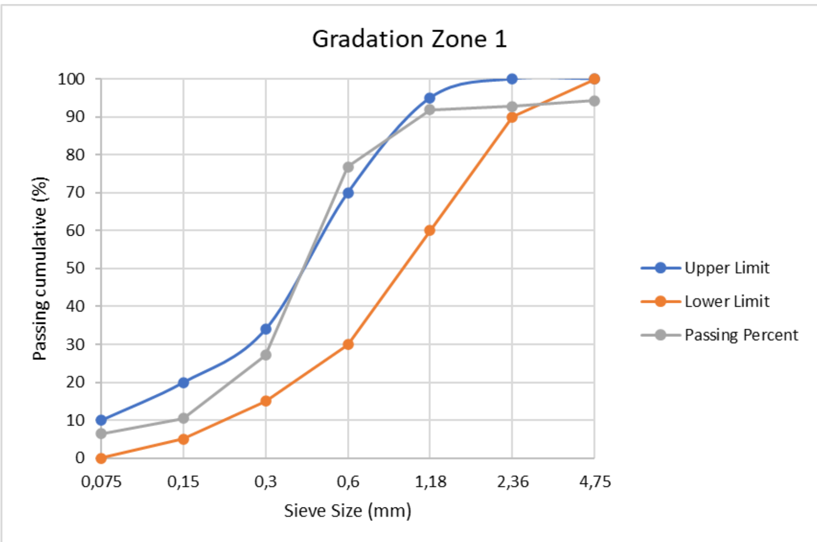


Figure 9. Fine Aggregates Gradation

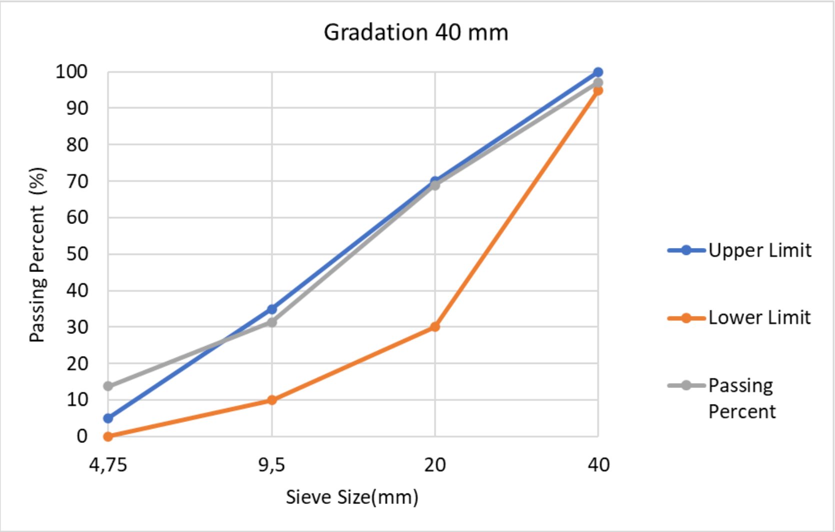


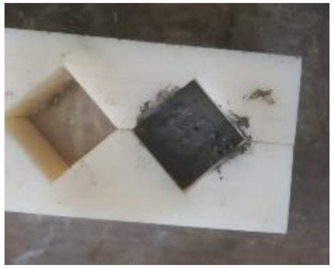
Figure 10. Coarse Aggregates Gradation

Table 26. Summary on laboratory experiment activities and figures

Experiment Activities and Results	Figures
Aggregates test	
Fine aggregates - Mud content = 4,71% - Bulk specific gravity = 2,59 - Saturated surface dry specific gravity = 2,68 - Apparent specific gravity = 2,84 - Absorption = 3,31 % - Sieve analysis = Gradation zone 1 - Fineness modulus = 2,94 *Coarse aggregates* - Bulk specific gravity = 2,23 - Saturated surface dry specific gravity = 2,37 - Apparent specific gravity = 2,6 - Absorption = 6,34 % - Sieve analysis = Gradation 40 mm Fineness modulus = 5,82	          

Experiment Activities and Results	Figures
Disposable diaper treatment	
By using manual treatment, disposable diaper was washing, drying and cutting.	
Mixing and moulding	
The mixing procedure is different with regular concrete due to the different density of disposable diaper compared to other concrete components. In the regular mixing, the materials are put all together into concrete mixer then mix the compound well. For disposable diapers, dry mixing procedure for first step then continue to wet mixing. The first step is fine and coarse aggregates and Portland cement put all together then mix them. After the compound blends well, add the disposable diaper to the first compound and mix them. Then after all the ingredients is blended well, add the water and mix it.	

Experiment Activities and Results	Figures
Curing and testing	
All the sample concrete placed into cube with dimension 15 x 15 cm and cylinder with diameter of 15 cm and height of 30 cm. After 24 hours the casting is removed and for curing time, the samples put into a water pool for 7 days and 28 days. The samples then dried for 24 hours before mechanical testing. For mechanical properties, the compressive strength is conducted. The sample put into the universal testing machine and load with the certain capacity until the sample is crash	
Similar procedures for mortar specimen	

Experiment Activities and Results	Figures
The different is in composition, mortar specimen are consist fine aggregates, Portland cement and water. The specimen then molding to cube 5x5x5 cm and tube with height 5 cm and diameter 2,5 cm.	     
Improvement: The issue came while adding water to the compound. Due to the high absorption of disposable diaper, addition of water is needed to make the compound blended well	
Superplasticizer is needed to prevent the disposable diaper absorb more water. - The rice husk superplasticizer is prepared by dissolving 400 g *Sodium hydroxide* (NaOH) into 1000 ml of water to reach the molarity of solution at 10 M. - The solution is placed to glass breaker and adding the rice husk into solution. - Boiling it for 1 hour in magnetic stove and put magnetic stirrer for mixing well.	  

Experiment Activities and Results	Figures
- After 1 hour and the solution becomes dark-brown color, turn of the magnetic stove, and wait till the solution cold. - Then filtered the solution to separate the rice husk waste.	  
Another way to to prevent the disposable diaper absorb more water is by soaking the disposable diaper in water (not in dry condition). In order to meet the required water-cement ratio.	 

4.2 Result on Application for Building Materials

4.2.1 Identifying the calculation formula for composite materials

When changing or substituting composite materials in a concrete component, the difference in material densities must be considered. For instance, the method does not directly measure weight capacity by percentage when fine aggregate is substituted with disposable diapers. The apparent similarity between 300 grams of fine aggregate and 300 grams of disposable diapers is deceiving. Because disposable diapers are lighter than fine aggregates, 300 grams of disposable diapers occupy a much larger volume. To get an apples-to-apples comparison, it is necessary to convert the weight of materials using their densities. The following formula is then used to obtain the maximum replacement capacity:

$$m_w = \left(\frac{\rho_w}{\rho_{fa}}\right) x\ m_{fa} \ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{Equation 9}$$

Where:

m_w = mass of waste material capacity (gr)

ρ_w = density of waste materials (gr/cm3)

ρ_{fa} = density of fine aggregate (gr/cm3)

m_{fa} = mass of fine aggregate (gr)

Consequently, the formula compromises as follows by adding the percentage of recyclable materials:

$$R_{wc} = \%_{rep} x \left(\frac{\rho_w}{\rho_{fa}}\right) x\ m_{fa} \ldots\ldots\ldots\ldots\ldots \quad \textit{Equation 10}$$

Where:

R_{wc} = capacity of recycled waste materials (gr)

ρ_w = density of waste materials (gr/cm^3)

ρ_{fa} = density of fine aggregate (gr/cm^3)

m_{fa} = mass of fine aggregate (gr)

$\%_{rep}$ = replacement percentage of fine aggregate by waste material (%)

In this study, waste material is repurposed into disposable diapers, and the formula is created to:

$$m_d = \left(\frac{\rho_d}{\rho_{fa}}\right) x\ m_{fa} \ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{Equation 11}$$

Where:

m_d = mass of waste disposable diaper (gr)

$ρ_d$ = density of waste disposable diaper (gr/cm^3)

$ρ_{fa}$ = density of fine aggregate (gr/cm^3)

m_{fa} = mass of fine aggregate (gr)

In consequence, the formula compromises as follows by include a percentage of recyclable disposable diapers:

$$R_{dc} = \%_{rep} x \left(\frac{ρ_d}{ρ_{fa}}\right) x\ m_{fa} \ldots\ldots\ldots\ldots \quad \textit{Equation 12}$$

Where:

R_{dc} = capacity of recycled disposable diaper (gr)

$ρ_d$ = density of waste disposable diaper (gr/cm3)

$ρ_{fa}$ = density of fine aggregate (gr/cm3)

m_{fa} = mass of fine aggregate (gr)

During the experimental investigation, disposable diapers were substituted for fine aggregates in the preparation of composite material for construction components. The first step was to prepare used disposable diapers by washing, drying, and shredding them. Figure 9, Figure 10 and Figure 11 depict the aggregates test results, which are utilized as the foundation for calculating the mix design for composite materials based on certain techniques of concrete and mortar mix design. In accordance with the aggregates test, Table 27 displays the mix of materials used to produce composite materials. It also discusses how the construction materials situation differed based on the structural and architectural components of the structure. Structural elements such as columns and beam pertain to the design of a concrete mixture including Portland cement, fine and coarse aggregates, and water. In this experiment, the concrete mix design was initially formulated to achieve a maximum compressive strength of 25,00 MPa. Refer to mortar mix design for architectural features such as walls and floors, where Portland cement, fine aggregates, and water are combined to form mortar.

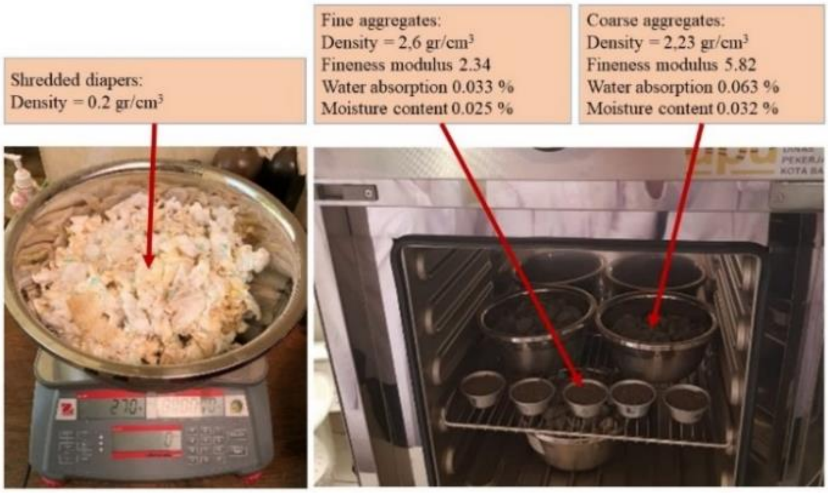


Figure 11. Physical properties of composite material

The composite material samples were then subdivided based on their intended use in construction components, such as concrete samples meant for structural components such as columns and beams (15 x 15 x 15 cm) and cylinders (dimensions: 15 x 15 x 15 cm) (height 30 cm, diameter 15 cm). While examples of mortar blocks measuring 5 x 5 x 5 cm were developed for architectural components such as walls and floors, they were shaped to resemble mortar blocks. After 28 days of curing, the compressive strength of a sample consisting of six samples was evaluated.

Table 27. Samples Composition of 1 m^3 composite materials in replacement fine aggregates by disposable diaper

Mix Design	Utilization	Portland Cement (kg)	Sand (kg)	Gravels (kg)	Disposable Diaper (kg)
N_C	Structural element: Beam, column	370	747.9	892.6	0.00
$C_{5\%}$		370	745.02	892.6	2.88
$C_{10\%}$		370	742.15	892.6	5.75
$C_{15\%}$		370	739.27	892.6	8.63
$C_{30\%}$		370	730.64	892.6	17.26
N_M	Architectural element: Wall, concrete bricks, floor	370	868.05	0.00	0.00
$M_{5\%}$		370	864.71	0.00	3.34
$M_{10\%}$		370	861.37	0.00	6.68
$M_{15\%}$		370	858.03	0.00	10.02
$M_{30\%}$		370	848.02	0.00	20.03

$M_{50\%}$	370	834.66	0.00	33.39

Note:
N_C = Normal Concrete
$C_{x\%}$ = Concrete with x% replacement of fine aggregates by disposable diaper
N_M = Normal Mortar
$M_{x\%}$ = Mortar with x% replacement of fine aggregates by disposable diaper

Table 28. Samples Proportion of 1 m^3 composite materials

Code	Portland Cement	Sand	Gravels	Disposable Diaper
N_C	18,4%	37,2%	44,4%	0,0%
$C_{5\%}$	18,4%	37,1%	44,4%	0,1%
$C_{10\%}$	18,4%	36,9%	44,4%	0,3%
$C_{15\%}$	18,4%	36,8%	44,4%	0,4%
C30%	18,4%	36,3%	44,4%	0,9%
N_M	29,9%	70,1%	0,0%	0,0%
$M_{5\%}$	29,9%	69,8%	0,0%	0,3%
$M_{10\%}$	29,9%	69,6%	0,0%	0,5%
$M_{15\%}$	29,9%	69,3%	0,0%	0,8%
$M_{30\%}$	29,9%	68,5%	0,0%	1,6%
$M_{50\%}$	29,9%	67,4%	0,0%	2,7%

Table 29. Results for the density samples of concrete and mortar

Concrete	Strength (MPa)	Mortar	Strength (MPa)
NC	24,91	NM	11,36
C5%	23,07	M5%	8,04
C10%	22,48	M10%	6,78
C15%	17,38	M15%	6,03
C30%	7,94	M30%	5,25
		M50%	1,113

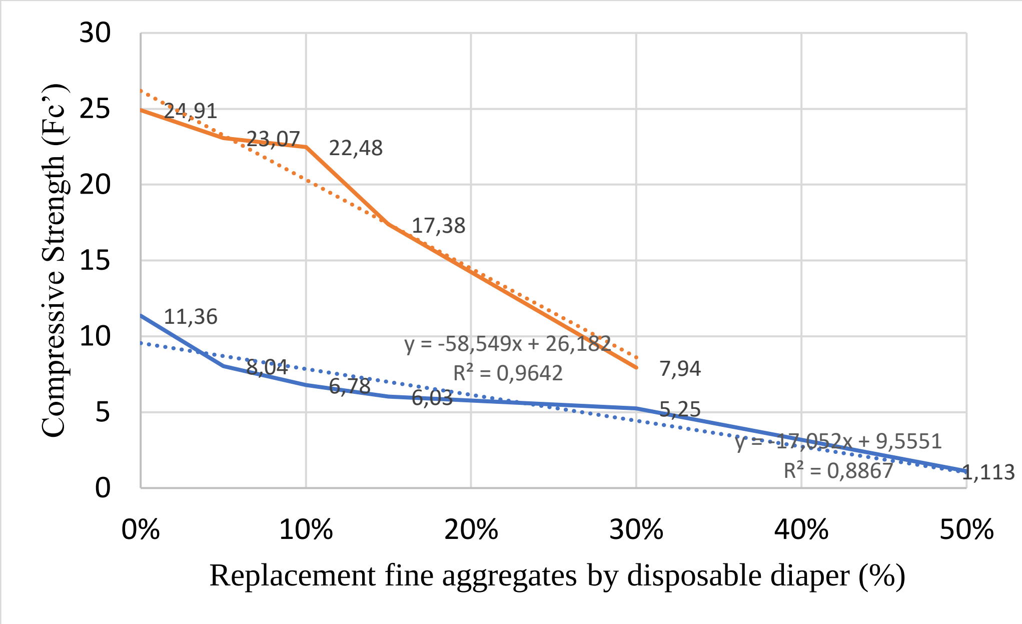


Figure 12. Compressive strength on Concrete and Mortar

Table 30. Results for the density samples of concrete and mortar

Concrete	Density (kg/m3)	Mortar	Density (kg/m3)
NC	2249,56	NM	1703,73
C5%	2147,9	M5%	1630,43
C10%	2028,4	M10%	1576,45
C15%	1913,19	M15%	1524,67
C30%	1691,25	M30%	1481,07
		M50%	1288,93

Table 31. Results for additional water and slump for samples of concrete and mortar

Concrete	Water (l)	Additional (l)	Total (l)	Total (%)	Slump (mm)
NC	185	0	0	0	120
C5%	185	50,7	235,69	23%	30
C10%	185	63,4	248,36	29%	50
C15%	185	78,2	263,17	35%	60
C30%	185	157,1	342,14	71%	65

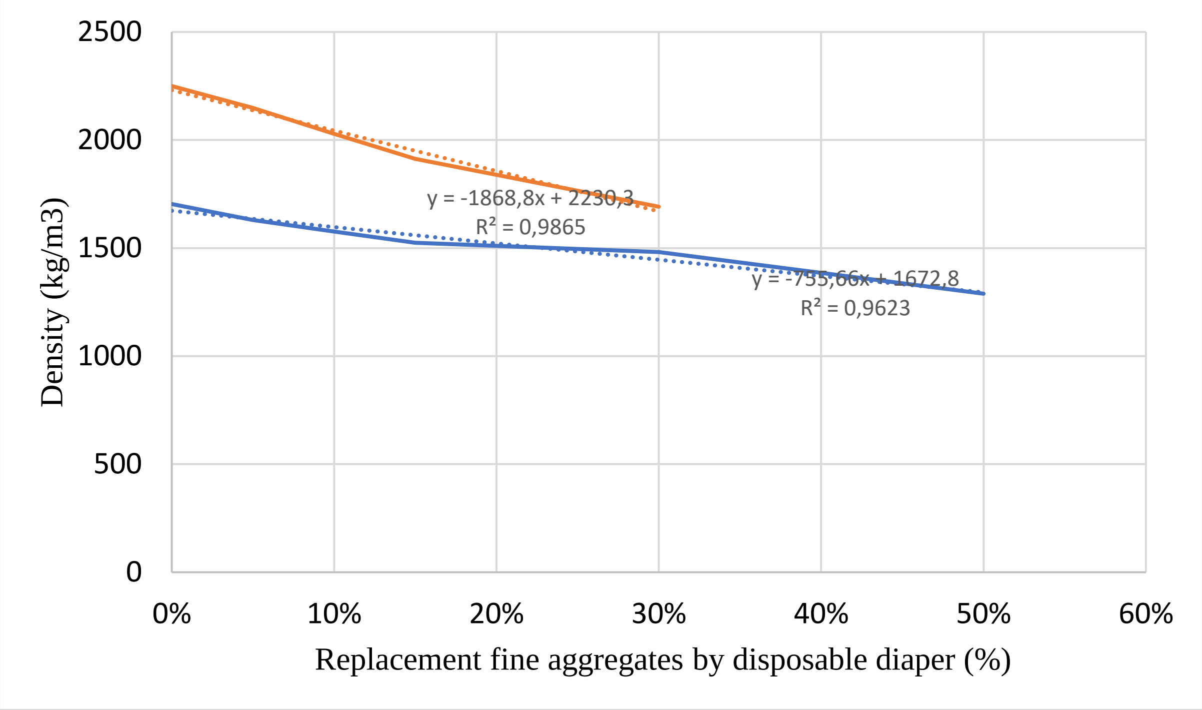


Figure 13. Density on Concrete and Mortar

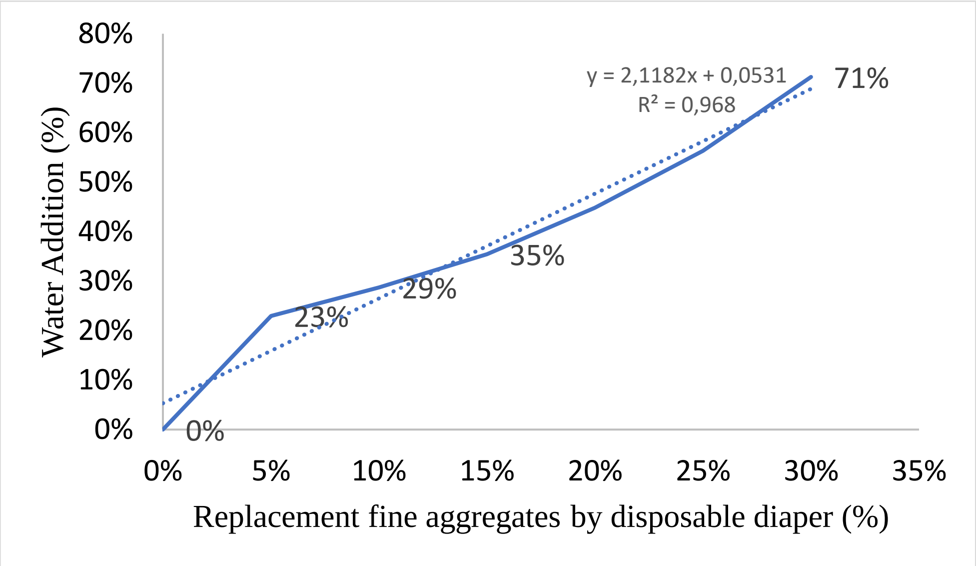


Figure 14. Additional of Water for Disposable Diaper Concrete

4.2.2 Results

Figure 15 shows the test on compressive strength of concrete and mortar specimens and the findings are displayed in Table 32. Normal concrete attains a strength of 24.91 MPa, which the value is close to the mix design's intended strength of 25 MPa. However, the substitution of fine aggregates with disposable diapers resulted in a weakening of the structure as the quantity of disposable diapers increased. Similarly, the reciprocal phenomenon happened in mortar mix design. The strength decreases as more disposable diapers are substituted for fine aggregates.

Table 32. Results for the compressive strength of samples of concrete and mortar

Concrete Type	Strength (MPa)	Mortar Type	Strength (MPa)
N_C	24.91	N_M	11.36
$C_{5\%}$	23.07	$M_{5\%}$	8.05
$C_{10\%}$	22.48	$M_{10\%}$	6.79
$C_{15\%}$	17.39	$M_{15\%}$	6.03
$C_{30\%}$	7.9	$M_{30\%}$	5.25
-	-	$M_{50\%}$	1.11

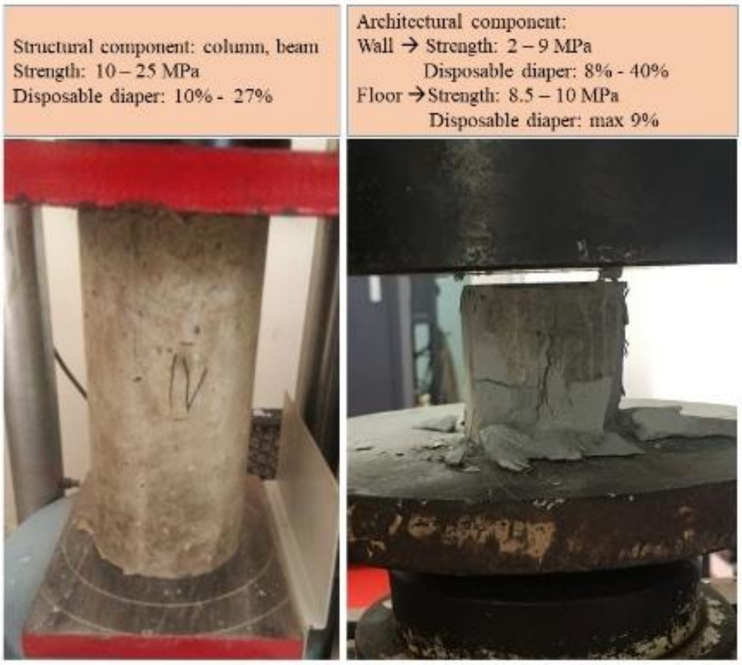


Figure 15. Tests on the Strength of Composite Materials

Consequently, the strength value is plotted to the linear regression equations by estimating the effect of disposable diaper replacement on compressive strength and considering their use as construction materials. As it is seen in Figure 16, the employment of disposable diapers in concrete as a structural component is restricted by strength. The equation shown by linear regression is:

$$y = -56.681x + 26.191 \quad \text{Equation 13}$$

where y is the compressive strength and x is the percentage substitution of fine aggregate by disposable diapers. Concrete's strength can be predicted using the equation. In addition, by referencing Table 4 of the relationship between the strength and use of concrete, Figure 16 illustrates the use of disposable diaper concrete for housing construction.

As it is shown in Figure 16, the use is restricted to structural housing with a maximum of three-story and a maximum replacement is 10%. The replacement range between 0% and 10% can achieve a strength between 20 and 25 MPa. However, for structural components the maximum replacement rate is restricted to 27%, with a maximum strength value is 10 MPa. The maximum replacement rate for non-structural components is likewise advised to be no more than 40%. In excess of this proportion, concrete cannot be utilized for construction materials.

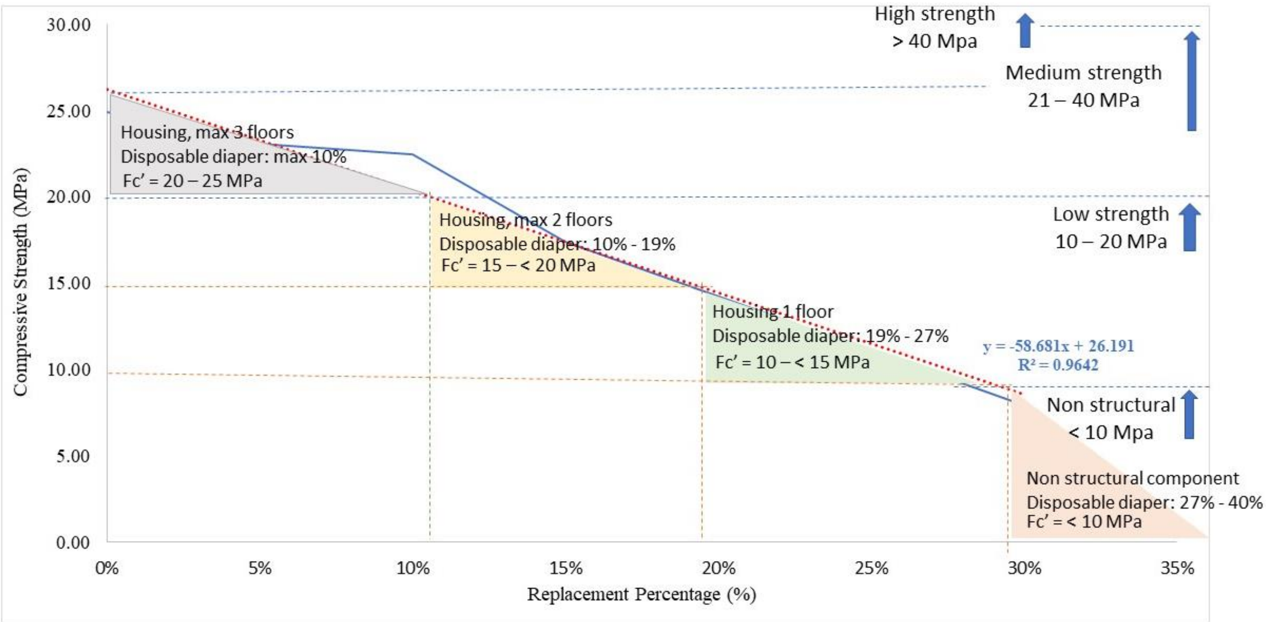


Figure 16. Utilization of Concrete with Disposable Diapers for Housing Component

The relationship between strength, percentage of replacement, and the use of mortar for architectural features is depicted in Figure 17 and Figure 18. In this study, the use is separated between concrete bricks and paver blocks based on

Table 5. Mortar Type and Utilization on Building Components

Placement	Building component	Mortar Type			
		Rec.	Fc' MPa	Alt.	Fc' MPa
Outdoor, surface level	Load bearing wall	N	5,2	S / M	12,5 - 17,2
	Wall nonstructural	O	2,4	S / M	12,5 – 17,2
	Supporting wall	N	5,2	S	12,5
Outdoor, under level	Foundation, bearing wall, tunnel, pedestrian ways	S	12,5	M	17,2
Indoor	Load bearing wall	N	5,2	S / M	12,5 - 17,2

Placement	Building component	Mortar Type			
		Rec.	Fc' MPa	Alt.	Fc' MPa
	Partition nonstructural	O	2,4	N	5,2
Indoor and outdoor	Shelter and decorative wall	O	2,4	N	5,2

Note:
Rec.: Recommended
Alt: Alternative
Fc': Compressive Strength
Mortar type composition:
M: Portland cement: burnt lime = 2: > ¼ - 1 ¼
N: Portland cement: burnt lime = 1: > ¼ - 1 ¼
S: Portland cement: burnt lime = 1.5: > ¼ - ½
O: Portland cement: burnt lime = 1: > 1 ¼ - 2 ¼

The standard relates to concrete bricks and paving blocks whose strength is categorized into four categories for architectural components. The sample in this experiment followed a solid concrete brick between two types of concrete bricks: solid and hollow. Level I is the strongest, having a minimum strength of 10 MPa, and is commonly used for structural components such bearing walls. The lowest level is level IV, which has a minimum strength of 2.5 MPa and is suitable for non-structural components such as wall partitions. The highest level for paving blocks is A, which has a minimum strength of 40 MPa and is used for public roadways. The lowest level is D, which has a minimum strength of 10 MPa and is suitable for dwelling floors or garden pavement. **Error! Not a valid bookmark self-reference.** contains more information on architectural components and their applications.

Table 6 of strength standard and application as a construction material. In addition, the linear regression provided the equation for predicting the strength and percentage replacement of fine aggregates in mortar compounds as:

$$y = -20.57\,x + 10.364 \qquad \text{Equation 14}$$

where y is the compressive strength and x is percentage substitution of fine aggregate by disposable diapers.

As it is seen in Figure 17, the strength of concrete bricks is ranked from I to IV, with I being the strongest and IV being the weakest. The maximum amount of disposable diapers that can be substituted for fine aggregates in order to achieve level I strength is 8% and for maximum replacement is 40% to achieve level IV as the lowest standard of concrete bricks. The replacement rate is restricted to 40% and additional replacement is not advised because it is out of SNI 03-0349-1989 [100]. Then, as it is seen in Figure 17, the maximum replacement of fine aggregate by a disposable diaper for a structural element such as a bearing wall under an exposed situation is 8%, whereas under a covered state, the maximum replacement is 19%. In addition, more than 19% replacement can only be applied for non-structural parts, with a maximum of 33% replacement for covered situations and exposed finishes. In addition, with a maximum of 40% replacement for plastered covered circumstances. More than 40% of disposable diapers do not meet specifications and are unsuitable for use in concrete bricks.

Then, for paving blocks depicted in Figure 18, the material is restricted to only the D level with a maximum replacement rate is 9%. This found that more than 9% substitution of fine aggregates with disposable diapers is not allowed for paving blocks due to the strength being below SNI 03-0691-1996 specifications [101]. Additionally, the use of 9% replacement is restricted for paving the floors of homes and gardens.

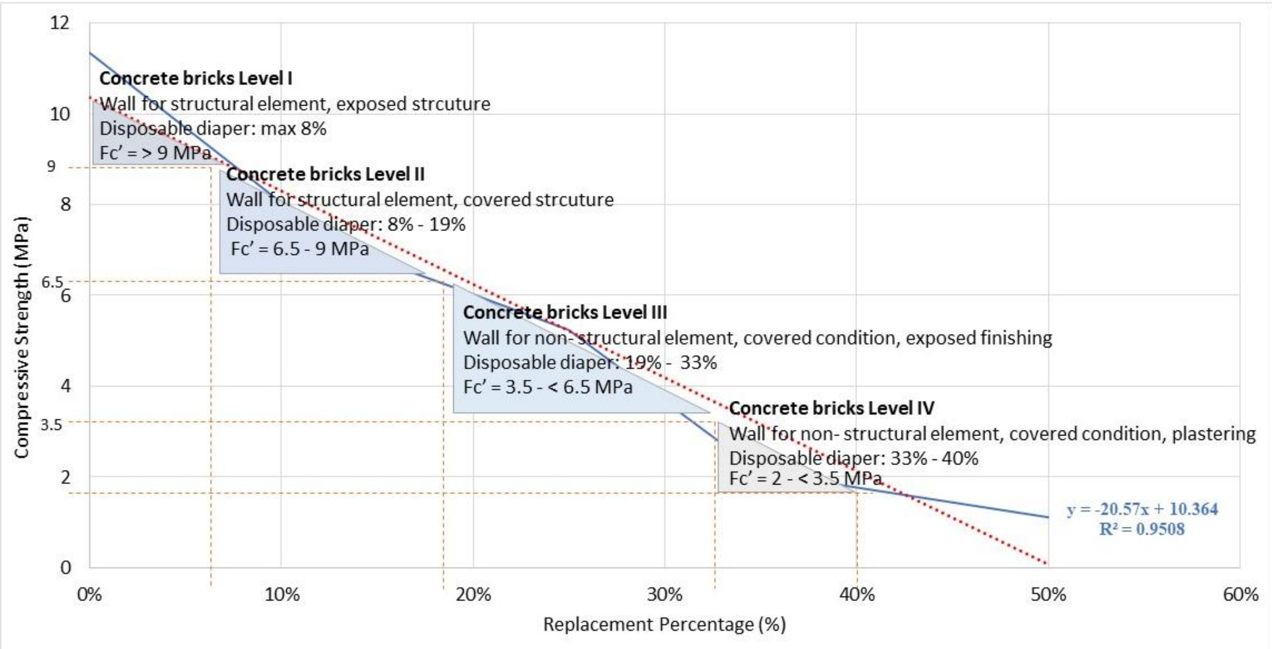


Figure 17. Utilization of mortar using disposable diapers for concrete bricks

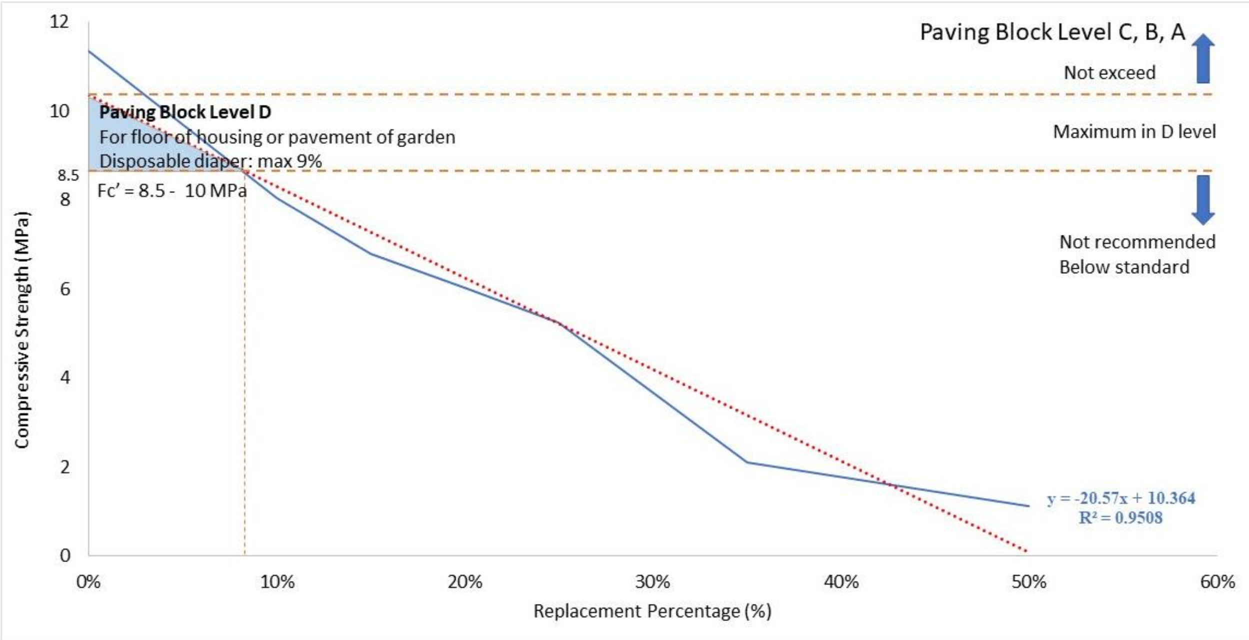


Figure 18. Utilization of mortar using disposable diapers for road pavement or paving blocks

Finally, to figure out comprehensive findings, the usage of disposable diapers on composite materials for the building materials is depicted in Figure 19 which shows the various application of materials depending on their strength and component. In general, materials for concrete as structural components, such as columns and beams, can be substituted with disposable diapers to a maximum extent of 27% and a maximum strength of 10 MPa. As well for mortar as a structural component such as bearing walls and public road pavement, the maximum replacement by a disposable diaper is between 8% and 9% with a strength of 8.5 MPa. Alternately, for maximal replacement, it can be used for non-structural components with a maximum of 40% replacement and strength of 2 MPa. This application is for non-load-bearing wall partitions and low-impact floor pavers.

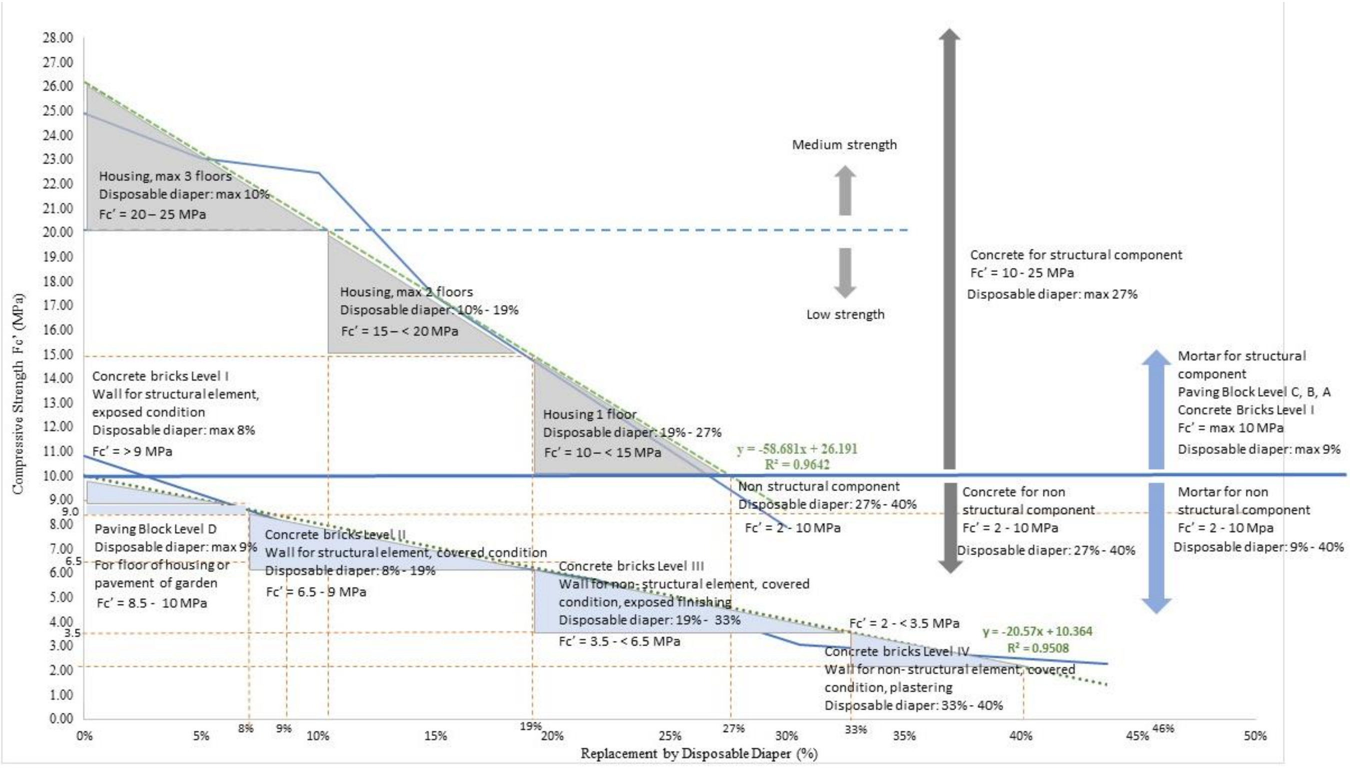


Figure 19. Summary Utilization of disposable diapers in composite materials for buildings

4.2.3 Example Application on Building Elements for Low Cost Housing

Low-cost housing is commonly understood as housing that is appropriate in quality and location while not cost a level that prevents its occupants from meeting other essential living costs or affects people fulfilment of basic human rights [164] [165] [166] [167]. In the majority of developing countries, access to appropriate and affordable housing is a present and growing issue. In some circumstances, the problem is not a shortage of housing, but an inadequate source of income [164] [165] [166]. In other circumstances, income is relatively high, but home supply and financing are limited, making housing pricey [167]. Nonetheless, widespread implementation of self-help housing programs in developing countries limited applicability. While popular processes of self-construction and bottom-up development did occur, these did not provide a long-term or massive solution to the enormous housing demands.

The high costs of two crucial inputs of land and building materials are a fundamental reason why housing is unattainable for urban poor majority. Building materials are often the single largest tangible input into the construction of housing and can account for up to 80% of the overall worth of a simple residential dwelling [168]. This is due to the fact that building materials are essential to the structural integrity of the housing. To put it another way, if the price of building materials doubles in contrast to the median price of other commodities, therefore the length of time that a household will be required to work in order to afford the price of building materials will also nearly double [169]. The latter is problematic due to the fact that many governments, both central and municipal, continue to insist on the use of conventional building materials and techniques. These are mandated by the various building rules and regulations, the majority of which are either a holdover from the days of colonialism or were imported from other nations [170]. These restrictions and standards prevent the use of building materials that are more appropriate and readily available in the local area. Additionally, these prevent the use of construction technologies that are both cost-effective and environmentally friendly.

There is a need for policies that would broaden people's access to building materials that are both appropriate and economical. In a same vein, it ought to financially support research and development efforts into cutting-edge building techniques. Construction plans and methods that are friendly to the environment, as well as technology that are energy efficient and produce less pollution, should be encouraged, and made more readily available. In this regard, a number of researchers have examined a variety of materials that can be used for low-cost housing construction that divided in to three types: natural fibers, earthen materials and industrial-building waste [171]. The most common building applications for natural fiber materials (e.g. rice husk, sisal fiber, banana leaves, etc.) are panel board, reinforced composite materials, and insulation [171] [172] [173]. Therefore, the usage of lime and mud for nonstructural construction components like bricks for walls has become increasingly common when working with earthy materials [171] [174] [175] [176] [177] [178]. Thus, the technique of making blocks out of raw mud has been developed further without including a burning step. Also recycled materials by utilization waste of material building [171] [179] such as steel and rubber will become the best choice to lessen the impact on the environment. Furthermore, there is already user-friendly technical material accessible on a variety of inventions, including compressed earth-blocks, dome construction, rammed earth, and vault construction.

Just like other developing countries, low-cost housing provision in Indonesia has been a serious concern in the last three decades as urban population has grown at a pace of 4.1% per year, and it is anticipated that 68% of Indonesians would live in urban areas by 2025 [180]. This problem has at least two main consequences for housing demand and waste management.

In terms of housing demand, Indonesia has a large gap between supply and demand, with a demand for 780,000 units of housing per year and a capability of stakeholders to deliver is

400,000 to 500,000 units per year [181] [182] [183]. There is a backlog of around 300.000 housing units every year that must be resolved to provide homes for approximately 30% of urban residents who live in non-owned housing. In accordance with government programs, the provision of housing is crucial, but building materials are limited. In Indonesia, concrete, bricks, wood, and ceramics continue to be the most used construction materials [115]. But in terms of environmental considerations, those materials create new issues, such as clay bricks and tiles have the highest embodied energy [115], carbon emissions, and eco-costs [132].

Furthermore, in terms of waste management, population growth is accompanied by an increase in waste capacity. According to statistics [184], the total waste per year in 2019 is 29,21 million tons, which rises to 32,76 million tons in 2020. Due the situation, the Indonesian government focusing more on waste capacity management and resulting to decreasing roughly 17,68 million tons of waste in 2021. Population growth also causes an increase in the use of disposable diapers for baby care. Since its introduction in the 1960s, the popularity of disposable diapers has raised due to the benefits of the circular economy within various diaper versions that have been adapted for wider applications over time [185]. In addition, there is a social benefit, especially for parents, as performances are convenient and affordable.

Since low-cost housing become a major issue in this research, the housing standard for the implemented experimental study was designed by following standards of low-cost housing [194]. In this study, the housing is designed for 4 persons with a housing area of 36 m^2 and land area of 60 m^2. The floor plan of design is shown in figure 18.

Table 33. Standard for Low costs housing in Indonesia [186]

Standard per person (m^2)	Area (m^2) for 3 persons				Area (m^2) for 4 persons			
	Housing Area	Land			Housing Area	Land		
		Minimum	Effective	Ideal		Minimum	Effective	Ideal
Minimum 7.2	21.6	60.0	72 - 90	200	28.8	60.0	72 - 90	200
(Indonesia) 9.0	27.0	60.0	72 - 90	200	36.0	60.0	72 - 90	200
(International) 12.0	36.0	60.0			48.0	60.0		

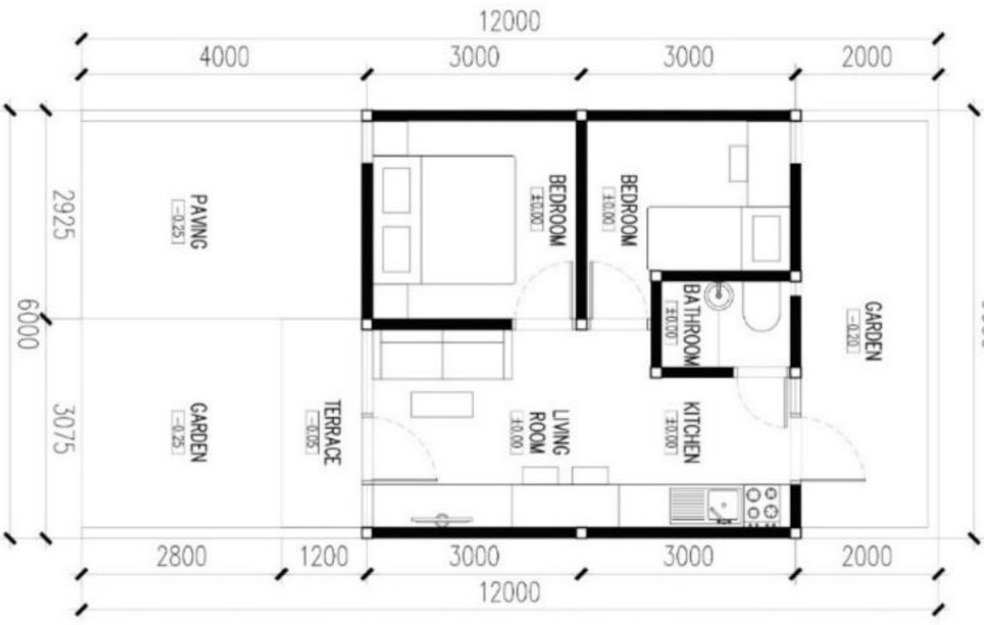


Figure 20. Floor Plan of Low-costs housing design in this study

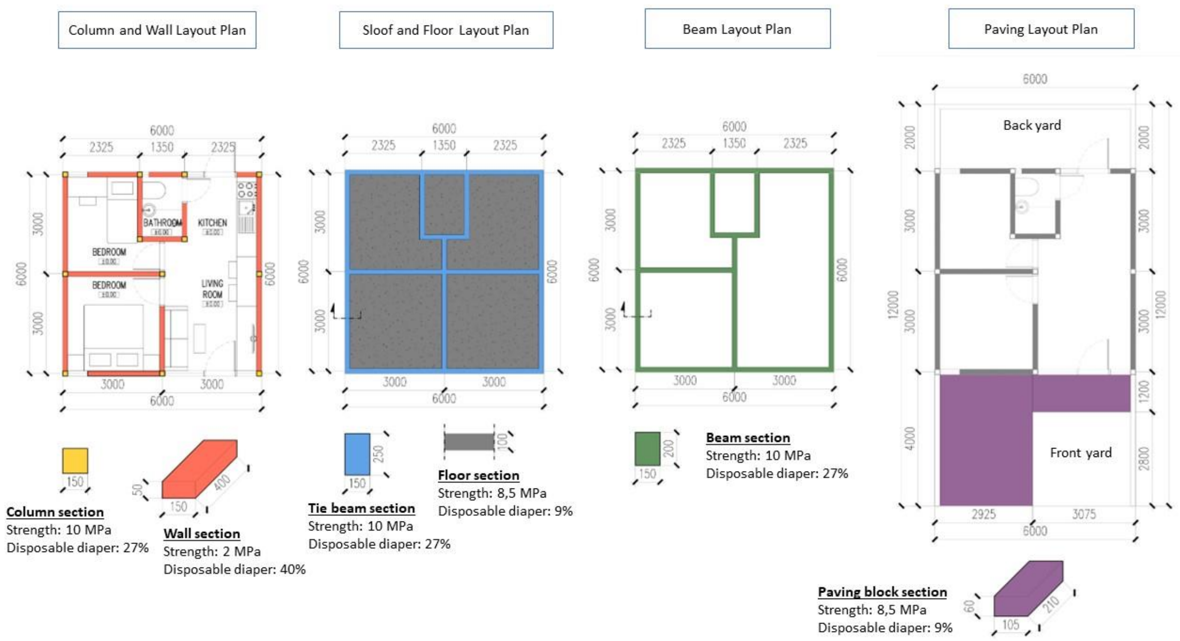


Figure 21. Layout Plan for Low-Cost Building Materials Utilizing Disposable Diapers

In addition, the result of the experimental study is applied into design requirements for low-cost housing based on Table 33 and Figure 20. The use of composite materials in the structural and architectural components of a 36 m^2 housing design is depicted in figure 8 with a maximum percentage of disposable diapers for housing components. For example, the maximum percentage of disposable diapers for column and beam structural components is 27% with the strength of 10 MPa. The maximum percentage of disposable diapers for walls and floors is 40% and 9%, respectively, with a strength of 2 MPa and 8.5 MPa.

However, the structural analysis was not calculated exhaustively for the column and beam size in this design scenario. The measurement related solely to the standard dimension of structural components for one-story housing in Indonesia. Further research and implementation of these findings must focus on more extensive structural assessments, including soil bearing capability, load capacity, and other technical tests for structural analysis. Ultimately, to quantify the amount of composite material for the housing design, the volume of each construction component is determined using the floor design and also accessible is the quantity of disposable diapers. The outcome is displayed in Table 34.

Table 34. Capacity of Building Materials to Construct Type 36 of Low-Cost Housing Prototype (36 m^2)

Components	Type material	Strength (MPa)	Sand replacement (%)	Composite material (m^3)	Disposable diaper (m^3)
Column	Concrete	10.35	27	0.81	0.02
Beam	Concrete	10.35	27	1.09	0.03
Tie beam	Concrete	10.35	27	1.44	0.04
Wall	Mortar	2.14	40	16.36	1.57
Floor	Mortar	8.51	9	2.16	0.05
Paving	Mortar	8.51	9	0.94	0.02
		Total		22.79	1.73

According to Table 34, the total amount of construction materials required to build housing type 36 is 22.79 m^3 with 1.73 m^3 of disposable diapers. This indicates that a maximum of 7.6% of disposable diapers can be used to substitute fine aggregate in construction. This finding gives insight on the effectiveness of the materials to be applied as building components on architectural design and further research. Also, by considering the environmental value of waste recycling, the material gives benefit to be developed in large scale and by involving society and other stakeholders for collecting and managing the waste of disposable diaper.

Study Implication

At the moment, the most important step in the recycling process for used diapers is to separate the plastic components from the organic fibers. This necessitates the execution of a number of complicated procedures, including the gathering, crushing, sanitizing, and sorting of the components. Due to the difficulty involved in the process, there are currently only a select few businesses that are interested in recycling used diapers such as: Knowaste Ltd. United Kingdom [6], Fater Ltd. Italy [7] [8], Diaper Recycling Technology Pte Ltd. Singapore [9], Super Faiths Inc Unicharm Ltd. Japan [10], and PHS Group United Kingdom [11]. However, the existing of the companies reveals that diaper recycling technology is currently only available in developed countries. This is primarily the result of two factors: differences in levels of expertise and access to equipment between developed and developing countries, and a lack of awareness in developing countries regarding the potentially harmful effects of diapers waste [4].

By combining the waste as a part of composite materials such concrete or mortar, it becomes easily applicable. Concrete is a widely used construction material due to the ease of processing, relatively low costs, and lack of high-tech manufacturing requirements. This research has concluded that adding used diapers to concrete does not significantly diminish its strength. This demonstrates that the use of used diapers to create composite materials is feasible, particularly in relation to the development of environmentally friendly and cost-effective materials. Further by concerning the social and economy advantages of this paper, the development of materials can be access from low to high technology. The procedures relatively easy to conduct and low-cost. It also gives wide perspective of utilizing disposable diapers waste as something valuable, since until now the waste is ended up in incineration process.

However, there are several limitations to implementing the findings broadly. To address the materials in wider applicable and in massive utilizing, it needs the involving of stakeholders for waste treatment such as collecting the waste from households and washing the diaper waste until sanitizing. The need for machines to shred the waste is also crucial to produce on a large scale, due to low technology only being able to approach small-scale of materials production. In addition, due to the existing various building rules and regulations only limited to conventional building materials, the role of government in regulating such materials needs to be opened.

At the same time, the limitations also give other benefits for future studies. The involvement of stakeholders and waste treatment mechanisms need to explore more to fill the gap. The innovation of shred machines for such materials can be challenging to be solved and invent. Moreover, to be implemented as low-cost housing, the materials need to be evaluated in terms of technical construction, cost, and housing price. This evaluation as proof to propose the materials in the financial mechanism of housing.

Conclusion

The conclusion is drawn that the use of disposable diapers on composite building materials is represented by the linear regression equation $y = -56.681x + 26.191$ for concrete and $y = -20.57x + 10.364$ for mortar. Where y is referred to compressive strength, and x is referred to percentage replacement of fine aggregate by disposable diaper. The utilization is then divided into building components such as concrete utilization covers column and beam with the maximum disposable diaper is 10% can obtain the strength of 20 MPa. This strength is appropriate for a three-story house. While a maximum utilization of 27% is recommended for a single floor of housing with a strength of 10 MPa. The greater the replacement, the lower the SNI structural standard and only recommended for non-structural components.

In addition to applying the composite mortar to wall and floor elements comprised of concrete bricks and paver blocks, respectively. The maximum replacement for a wall is 40%, resulting in 2 MPa of strength and classification as level IV concrete bricks according to SNI 03-0349-1989. Maximum replacement of 9% is required for floor paving blocks, resulting in a strength of 8.5 MPa and compliance with level D of the SNI 03-0691-1996 standard for paving blocks. This maximum quantity is suitable for partition walls with no load-bearing capacity and floor pavers with low impact capacity. Replacement more than this maximum capacity is not recommended for the utilization of building materials. Incorporating experimental study findings into the design of low-cost housing, the total waste capacity of disposable diapers that can be utilized for single-story of housing type 36 (36 m^2) is 1.73 m^3 out of a total composite material volume of 22.79 m^3.

4.2.4 Other Application on Building Elements and Infrastructure

1) **Low rise building max 3 floors**

   This scenario of housing design for low rise buildings is by estimate the amount of disposable diaper that can be utilized. Figure *22* shows the example of low-rise housing design with 3 floors of height and five units each floors. Every unit accommodate an area of 36 m^2, similar with the minimum area of single housing. By referring to the finding of application on building element, the maximum amount of disposable diaper in this scenario is different floor by floor due to the load capacity of building. In first floor, the utilization for structural element such column is maximum 10% of disposable diaper can replace the sand and for beam is up to 27%. While for second floor the amount is increase to 19% of disposable diaper for column and similar up to 27% for beam. In addition, the amount also increase for the implementation in third floor, where up to 27% of disposable diaper could be replace the sand in concrete compound for column an d beam. Thus, for walls and floors element, the sand can be replaced up to 40% and 9%, respectively and the implementation is uniform in each floors.

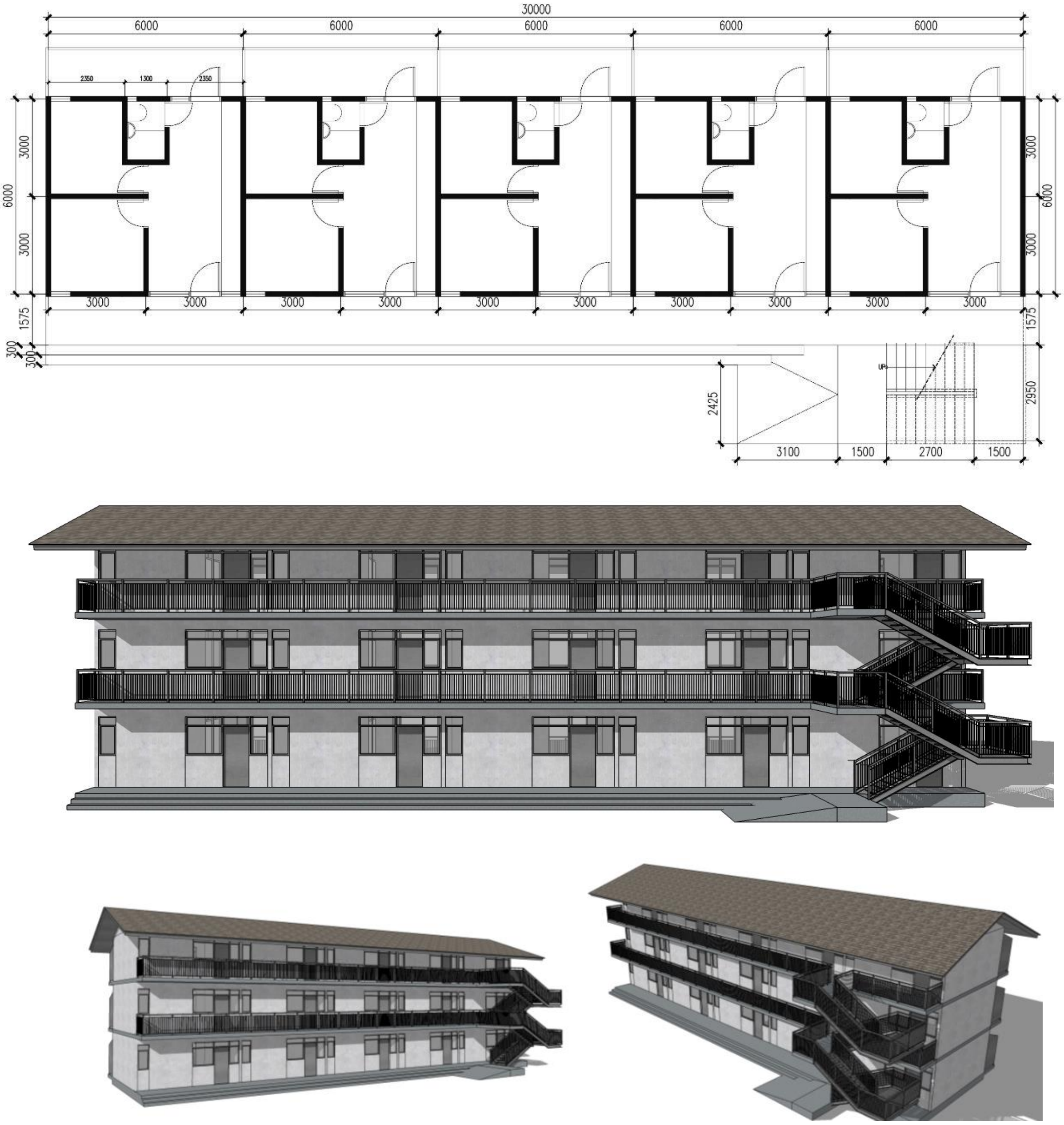
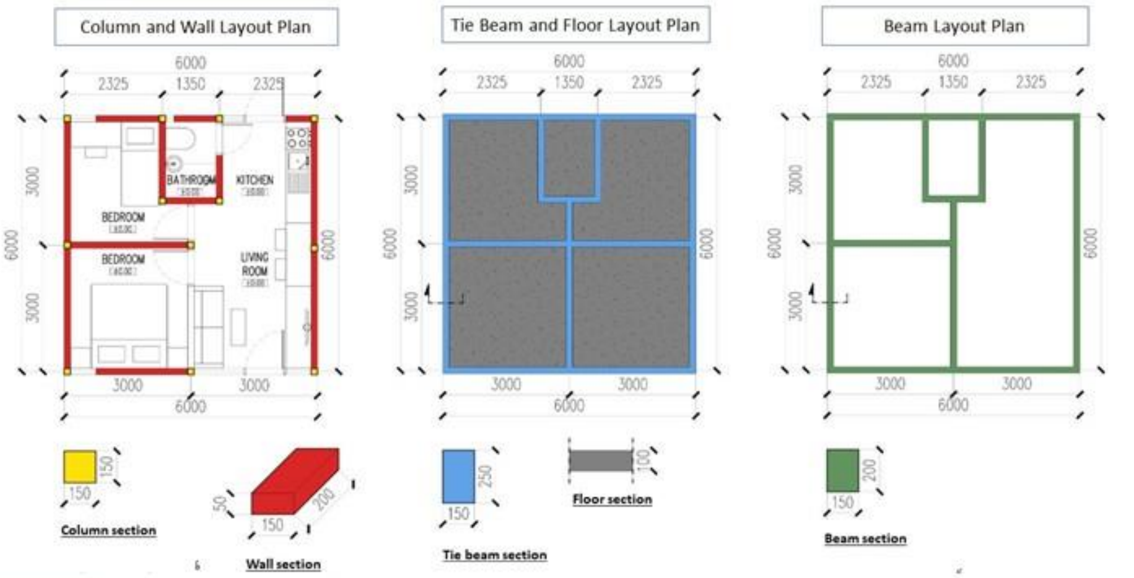


Figure 22. Example of low rise building for application the findings



1st floor	**Column:** Strength: 20 MPa Disposable diaper: 10% **Wall:** Strength: 2 MPa Disposable diaper: 40%	**Tie beam:** Strength: 10 MPa Disposable diaper: 27% **Floor:** Strength: 8,5 MPa Disposable diaper: 9%	**Beam:** Strength: 10 MPa Disposable diaper: 27%
2nd floor	**Column:** Strength: 15 MPa Disposable diaper: 19% **Wall:** Strength: 2 MPa Disposable diaper: 40%	**Beam:** Strength: 10 MPa Disposable diaper: 27% **Floor:** Strength: 8,5 MPa Disposable diaper: 9%	**Beam:** Strength: 10 MPa Disposable diaper: 27%
3rd floor	**Column:** Strength: 10 MPa Disposable diaper: 27% **Wall:** Strength: 2 MPa Disposable diaper: 40%	**Beam:** Strength: 10 MPa Disposable diaper: 27% **Floor:** Strength: 8,5 MPa Disposable diaper: 9%	

Figure 23. Estimation utilization of disposable diaper using for low rise building with maximum 3 floors

2) Mid to High rise building - limited to architectural elements

Similar with the scenario of housing design for low rise, the mid to high rise buildings is showed in Figure *24* with 5 floors of height and five units each floors. Every unit accommodate an area of 36 m^2, similar with the minimum area of single housing. By referring to the finding of application on building element, the maximum amount of disposable diaper in this scenario is only limited for walls and floors element, the sand can be replaced up to 40% and 9%, respectively and the implementation is uniform in each floors. For the structural element the regular concrete structure or other structural material is recommended to implemented due to the structural element with disposable diapers is below the standard of building structure.

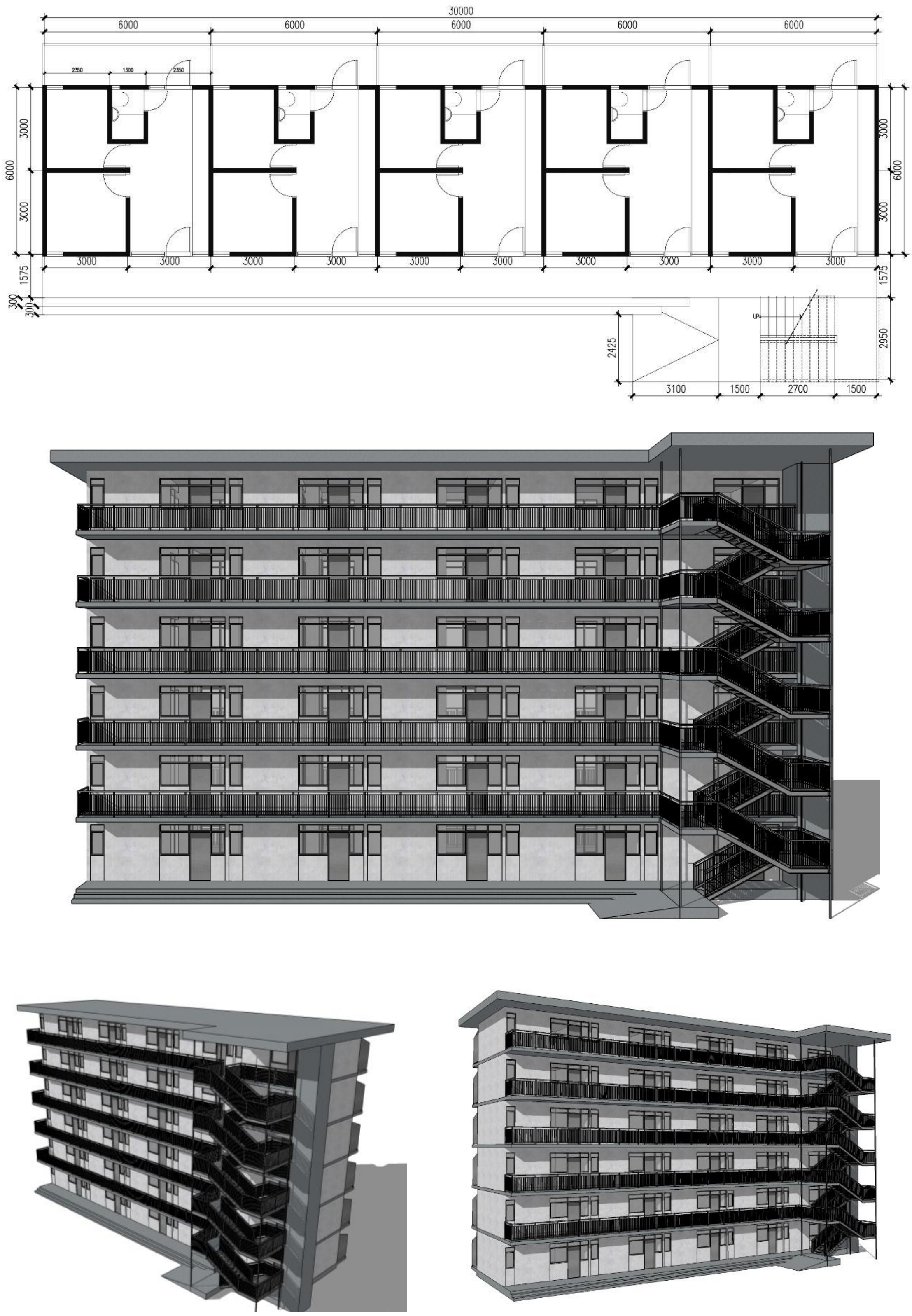


Figure 24. Example of high rise building with limited application on architectural elements

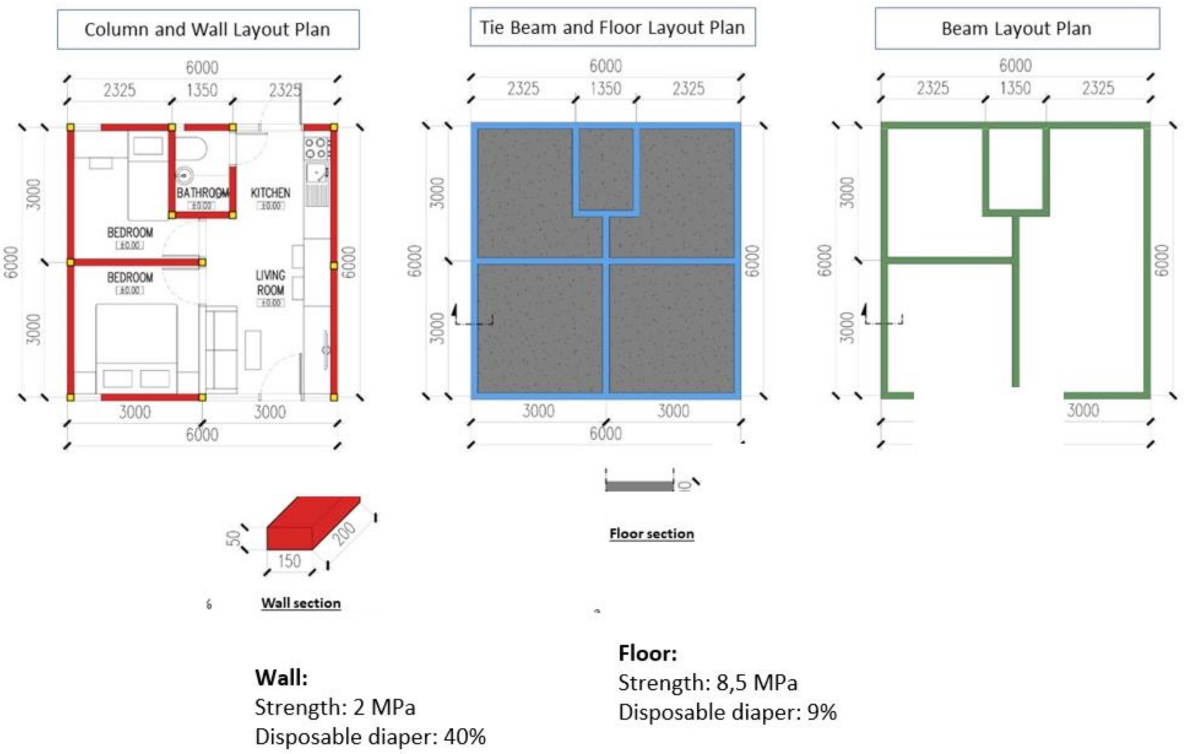


Figure 25. Estimation utilization of disposable diaper using for mid to high rise building with limited to architectural elements

3) Infrastructure (limited to pedestrian way or road with low load bearing capacity)

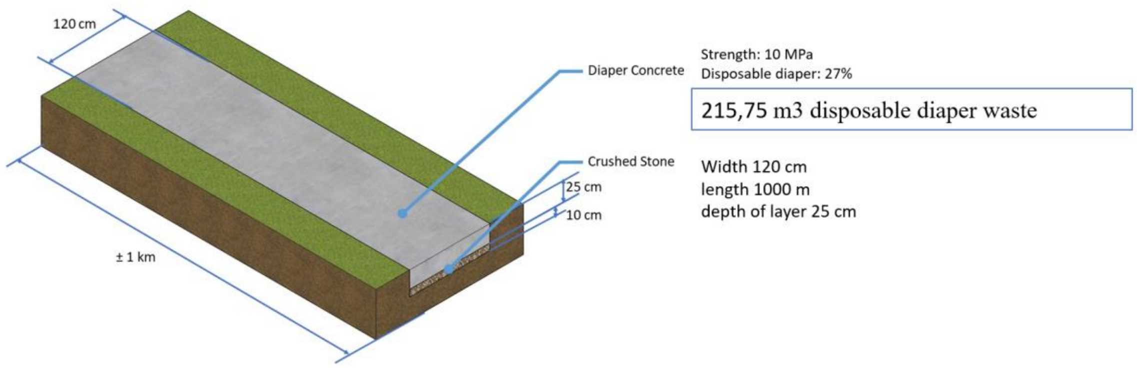


Figure 26. Estimation utilization of disposable diaper using for road infrastructure

The utilization of disposable diaper also could be implemented in infrastructure design. For example, in this scenario, to utilized the maximum capacity of diapers, pedestrian way or road with low load bearing capacity become the visible option. Up to 27% of disposable diaper could be used as replacement of sand in concrete. The capacity is depends on the width, length and depth of the layer. In this case of Figure *26*, the pedestrian ways with width 120 cm, length 1000 m and depth of layer 25 cm, could utilized up to 215,75 m^3 of disposable diaper in replace the sand.

4.3 Result on Mechanical Properties Improvement

The problem of strength remains a major issue in the development of disposable diaper concrete. Previous studies concluded that the addition of diapers to concrete is only a maximum of 1-5%. The addition more than 1-5% has decreased its strength [170] [12]. To get the optimal strength of concrete, minerals such as slag furnace slag, silica fume, fly ash and limestone filler are added [195]. Also, the use of plasticizers can increase the viscosity of the concrete which helps the material mix better [196].

In line with the use of diaper waste in concrete, other studies involving concrete plasticizers were also obtained by utilization rice husk waste. Rice husk is boiled with Sodium hydroxide solution for a certain duration. This process results novel viscous mixture that is referred to as 'mother liquor' (ML) acts as a new superplasticizer for geopolymer concrete mixtures [197]. The idea was originated from the addition of rice husk ash that can eliminate bleeding in the concrete, increasing the compressive strength to about 130 MPa after 56 days [198]. A positive influence also occurs with the addition of 15% rice husk ash that increase compressive strength of about 20% [199]. Furthermore, the most effective dose of ML super-plasticizer is 0.5% to achieve the highest compressive strength with optimal workability [197]. This superplasticizer was specifically developed for geopolymer systems due to available superplasticizer I commercial reduce the engineering properties [197].

By synchronizing these two waste utilization ideas, this study aims to see the effect of rice husk as a superplasticizer to waste disposable diaper concrete. The experiment was carried out in two stages, first to make a superplasticizer from rice husks and second to mix waste disposable diapers on the concrete with the addition of the superplasticizer.

4.3.1 Materials and Methods

Material preparation is divided into two stages. First, prepare the superplasticizers from rice husk and Sodium hydroxide (NaOH). Second, the preparation of the concrete mixture of waste disposable diapers that have been washed and cut into pieces using a machine or cutting tools.

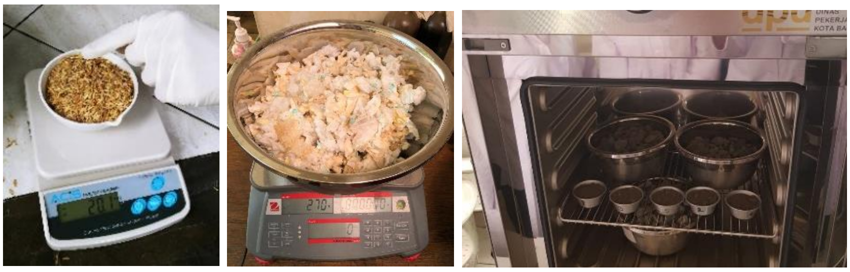


Figure 27. Materials Preparations: Rice Husk, Shredded Disposable Diapers and Aggregates

Further preparation is a concrete component consisting of cement and aggregate to include in calculation of concrete mix design. Fine and coarse aggregates test for specific gravity, density, water content and sieve analysis. The mix design calculation is aimed to reach compressive strength of K-300 (24,9 MPa). As a basis calculating for concrete mix design, Table 35 shows the result of aggregates properties testing.

Table 35. Physical properties of fine and coarse aggregates

Properties	Fine Aggregates	Coarse Aggregates
Fineness modulus	2.94	5.82
Density (kg/m3)	2600	2230
Water absorption (%)	0.033	0.063
Moisture content (%)	0.025	0.032

Superplasticizer preparation

The rice husk superplasticizer is prepared by dissolving 400 gr Sodium hydroxide (NaOH) into 1000 ml of water to reach the molarity of solution at 10 M. The solution is placed to glass breaker and adding the rice husk into solution. Boil it for 1 hour in magnetic stove and put magnetic stirrer for mixing well. After 1 hour and the solution becomes dark-brown colour, turn of the magnetic stove, and wait till the solution cold. Then filtered the solution to separate the rice husk waste.

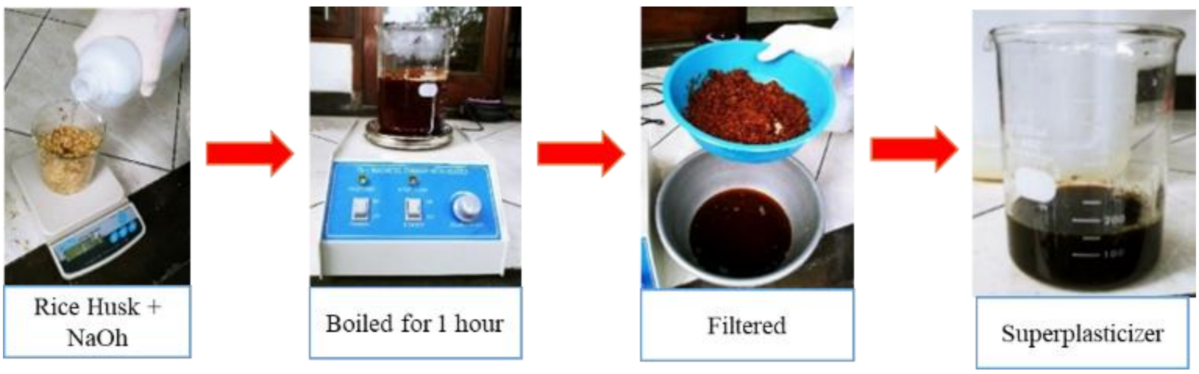


Figure 28. Rice Husk Superplasticizer Preparation

Rice husks contain organic elements, such as cellulose, hemicellulose and lignin as well as inorganic silica which accumulates on the outer surface of the rice husk [197]. Naturally, the colour change in the solution occurs due to high temperature alkaline hydrolysis of the organic elements in the rice husks and inorganic silica dissolves into the solution of the rice husks [197].

Disposable diapers concrete preparation

The results of concrete mix design calculation are shown in Table 36. In this experiment the disposable diaper act as a substitute for fine aggregate. According to several studies, the optimal addition of replacement is 5% and 10%. In calculating process, the density distinction between fine aggregate and disposable diapers must be considered to meet apple to apple of weight ratio, this calculation involves the formula in . In this scenario, the ratio of fine aggregate (FA) and disposable diaper (DD) is mutual in volumetric then the calculation is determined in *Equation 6*.

For density of disposable diapers is 0.07 - 0.21 g/cm^3 [22] and the ratio of admixture is 5% from percentage of disposable diapers [197]. Thus, the final mix design calculation of materials ratio is showed in Table 36.

Table 36. Mix design calculation of concrete components

Type of Concrete	PC (kg)	FA (kg)	CA (kg)	DD (kg)	Adm. (ml)	Water (l)
NC	370	747.9	1021	0	0	185
DDC 5	370	736.6	1021	10.1	0	185
DDC 10	370	725.2	1021	20.2	0	185
DDC 5P	370	736.6	1021	10.1	0.025	185
DDC 10P	370	725.2	1021	20.2	0.05	185

Notes	
NC	: Normal Concrete
DDC 5	: Disposable Diapers Concrete 5%
DDC 10	: Disposable Diapers Concrete 10%
DDC 5P	: Disposable Diapers Concrete 5% + Plasticizer
DDC 10P	: Disposable Diapers Concrete 10% + Plasticizer
PC	: Portland Cement
FA	: Fine aggregates
CA	: Coarse aggregates
DD	: Disposable Diapers
Adm.	: Admixture (plasticizer)

Mixing procedure and slump test

The mixing procedure is different with NC due to the different density of DD compared to other concrete components. In the NC mixing, the materials put all together into concrete mixer then mix the compound well. For DDC, dry mixing procedure for first step then continue to wet mixing. First step is FA, CA and PC put all together then mix them. After the compound blend well, add the DD to the first compound and mix them. Then after all materials is blended well, add the water and mix it.

The issue came while adding water to the compound. Due to the high absorption of DD, addition of water is needed to make the compound blended well. The addition of water also must be considered based on typical used construction of the concrete due to uniformity for different loads of concrete under field conditions [200]. To ensure this, slum test is conducted. This test is carried out using a metal cone-shaped mould made of metal or it is called the Abrams cone [201]. The cones are filled with fresh concrete which is filled in three stages of layering. Each stage of the concrete layer is tamped 25 times with metal rods. In the last stage, the top is trimmed to make it even and lifted vertically. The cone is pulled upwards until the concrete moves down. The amount of reduction is known as the slump value. If the value is greater, the fresh concrete will become thinner. To meet the workability of concrete, water addition is poured to the mixture. The water addition is counted 22,99% for 5% DDC compound and 51,73% for 10% DDC compound compared to normal concrete. Then all the sample concrete placed into cube with dimension 15 x 15 cm and cylinder with diameter of 15 cm and height of 30 cm. After 24 hours the casting is removed and for curing time, the samples put into a water pool for 7 days and 28 days. The samples then dried for 24 hours before mechanical testing.

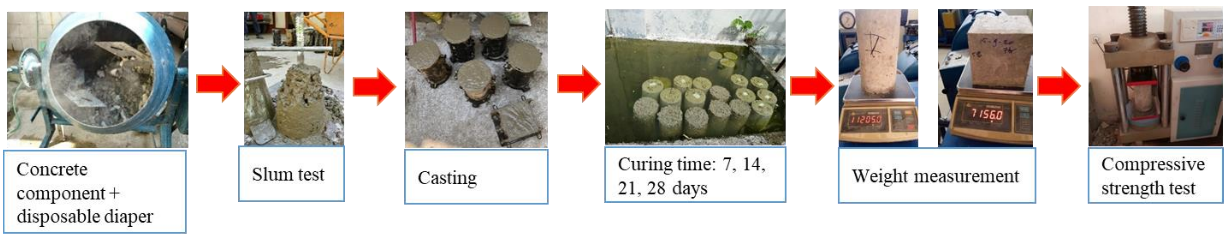


Figure 29. Disposable Diaper Concrete Processing

For mechanical properties, the compressive strength is conducted. The sample put into the universal testing machine and load with the certain capacity until the sample is crash.

The calculation of compressive strength is using equation:

$$P = \frac{F}{A} \qquad \text{.......................................} \quad \textit{Equation 15}$$

Where:

P = compressive strength

F = force or load at point of failure

A = initial cross-sectional surface area

F is determined by compressive machine and A is calculated based on sample dimension. While another mechanical test is density. Density of concrete is measure by calculating the weight and the dimension. The formula to calculate is define as equation:

$$\rho = \frac{m}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{Equation 16}$$

Where:

ρ = density of concrete

m = mass of concrete

V = volume or three-dimensional space

m is measured by weight scale and V is calculated based on sample dimension and the height.

4.3.2 Findings

This section covers slump test record and compressive strength of all test samples to analyze the effect of rice husk-based superplasticizer to concrete with disposable diaper addition.

Water absorption

To meet the workability of concrete, water addition is poured to the mixture. The water addition is counted 22,99% for 5% DDC compound and 51,73% for 10% DDC compound compared to normal concrete. As mentioned before, Diaper has superabsorbent polymer (SAP) that absorbs water up to 200-300 times from its weight. This unique property called Sodium polyacrylate has CH2–CH(CO2Na) monomers. This is a crystal-like substance that has similarity to fine sand. When the crystals exposed to water, the water is drawn inside the sodium polyacrylate. This phenomenon is called osmosis, where the crystals absorb water until their molecule is equivalent inside and outside and turn into gel-like substance. This gel will reduce the water content and turn the compound too dried and hard to meet slump value. This condition retrained optimal hydration for concrete, thus additional water content is needed. Due to this phenomenon, the calculation of water in mix design for normal concrete cannot be applied directly to disposable diaper concrete.

Density

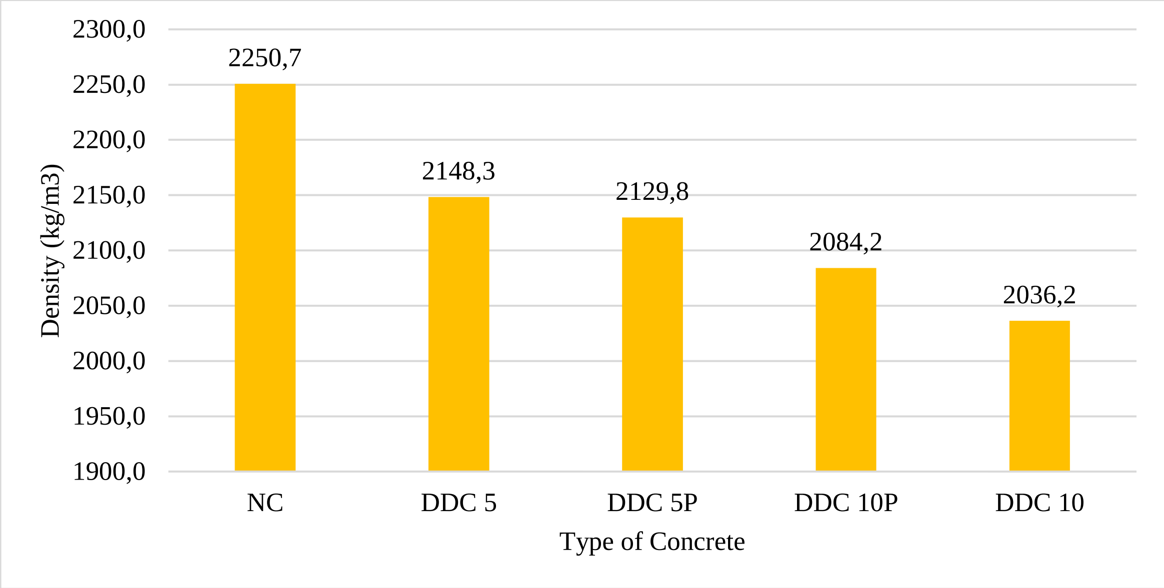


Figure 30. Density comparison of samples concrete

Figure 30 shows the density of concrete samples in 28 days. It figures out the decreasing of density by DD addition to the concrete. Normal concrete has the highest density compared to other samples. The density decreasing is due to the replacement of FA by DD, where DD has a lower density than FA that causing the replacement to reduce the density of concrete.

Furthermore, by comparing the DD concrete with and without superplasticizer, the addition of plasticizer to 5% DD concrete reduced the density. The addition of a plasticizer containing NaOH causes the water in the compound to increase and faster the hydration process. During the hydration process, water evaporates and leaves more cavities in the DD compound. This means that the porosity of the concrete is higher when the concrete reaches maximum hydration. This phenomenon causes the density to be lighter.

However, mutual phenomenon does not occur to 10% DD addition. The samples show that the addition of plasticizer to 10% DD increase the density instead. This anomaly phenomena may occur due to the hydration process for 10% DD with plasticizer has not finished in 28 days. The hydration process has not reached the maximum stage so that the water content and cement have not been bonded completely. The finding can be assumed that adding a plasticizer of more than 10% will require a curing time of more than 28 days.

Slump test

Slump test measures the amount of plasticity (viscosity) and cohesiveness of fresh concrete. This represents the concrete mixture, and the concrete slump point is obtained. The results of this test are used to control the quality of the concrete in the construction field condition.

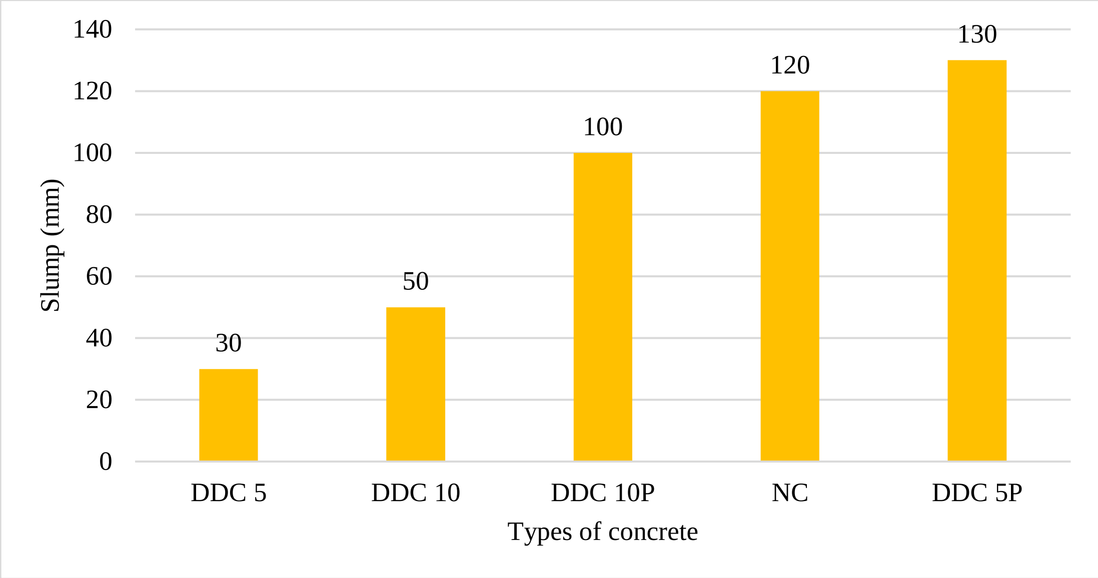


Figure 31. Slump test value of samples concrete

Figure 31 shows that normal concrete has 12 cm slump. Sample with 5% and 10% DD decrease its slump value to 3 cm and 5 cm, respectively. The decreasing slum value in DD concrete happened due to the water absorbed Sodium polyacrylate making the slurry less workable and difficult to place. The addition of plasticizer to each modified sample restores its slump value near to normal concrete, that is 13 cm and 10 cm or 2-3 times, respectively. The increase of slump value can be explained by analyzing properties of rice husk-based superplasticizer that cover the cement particles to make a repelling effect and distribute the compound uniformly [202]. This explains why workability is higher when using rice husk- based plasticizer. This phenomenon also explains that the addition of rice-husk based plasticizer improves workability of concrete.

Compressive test

Figure 32 indicate the different value of compressive strength by different curing ages. The normal specimen compressive strength value is 24,91 MPa. Addition of 5% and 10% diaper results in 23,06 and 22,47 MPa, respectively. It reduces the compressive strength compared to normal concrete as amount of 7.43% for 5% DD addition and 9.8% for 10% DD addition.

This slight decrease happened due to super-hydrophilic properties in DD absorbed water that initially intended to mix the cement and compound. This absorption phenomenon retrains hydration process of compound, thus the hydration will be imperfect and more un-hydrated Portlandite ($Ca(OH)_2$) is not optimally hydrated, causes the compressive strength to decrease [203].

Additionally, by using rice husk-superplasticizer into compounds resulting the enhancement of comprehensive strength compared to disposable diapers concrete without superplasticizer addition. The result is 24,13 MPa or 4.4% for 5% DD addition and 21,37 MPa or 6.9% for 10% DD addition. Rice husk has SiO2 that helps to accelerate the hydration process which involves CaO, SiO2, and H2O. The more SiO2 will increase the formation of Tobermory (Hydration Process and Product) by reacting with un-hydrated Portlandite [197].

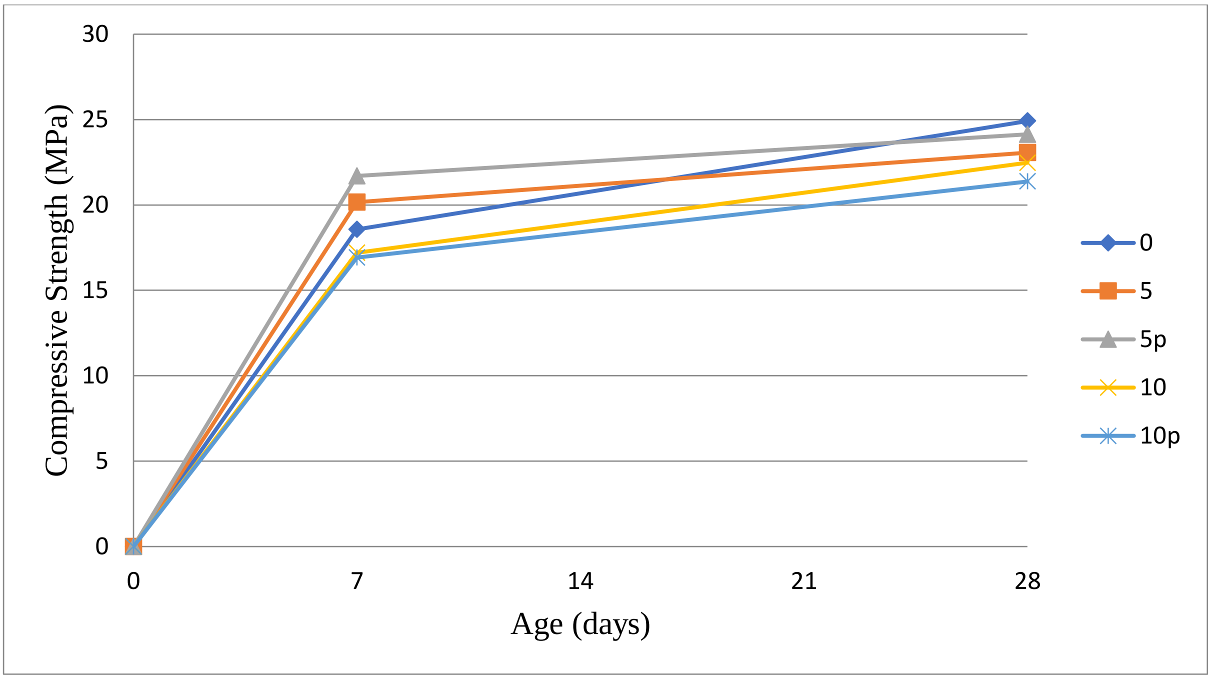


Figure 32. Compressive strength comparison of samples concrete

Example Application of concrete samples for construction field

The result of the experiment does not indicate which one is better or most useful, but each samples have their own characteristic to utilize in the construction field. For example, the slump value does not indicate the strength of the concrete but shows the workability in the construction field. Table 36 shows the slump value and the typical used for concrete.

Table 37. Typically used of concrete based on workability [197]

Slump Value (mm)	Workability	Typically used
0 - 25	Very dry	Constructing pavements or roads
10 - 40	Low workability	Foundations with light reinforcement
50 - 90	Medium workability	Normal reinforced concrete placed with vibration
> 100	High workability	Concrete reinforcing with tight spacing, and/or flow a great distance

Regarding Table 37, all samples can be utilized based on typically used in construction field. For example, DD concrete 5% and 10% addition can be used as constructing pavements or roads and foundations with light reinforcement. While DD concrete 5% and 10% addition and superplasticizer can be utilized as concrete reinforcing with tight spacing, and/or flow a great distance.

Conclusion

1) Addition of rice husk ash-based plasticizer significantly increase its slump value nearly by double for each addition of disposable diaper to concrete. Additionally, the addition of 5% disposable diaper to concrete and rice husk-based plasticizer has similar compressive strength value to normal concrete sample but the slump value is higher.
2) In the curing process of 28 days, the addition of plasticizer disposable diaper concrete enhanced compressive strength and reduce density in 5% addition, but it increased density in 10%. For more than 10 % addition it required a curing time more than 28 days.
3) The utilization of disposable diapers concrete in construction field can be used for constructing pavements to concrete reinforcing, depends on the workability and strength.

4.4 Result on Concrete Mix Design Improvement

The problem of using SAP in mortar is the super absorbent properties of the material, which can absorb water significantly up to seven times its original weight. This is a drawback of using SAP because cement needs water for hydration. If the water absorbed into the SAP, it would disrupt the hydration, or the mortar will need additional water. This promotes drawback such as cracking in hardened mortar as the result of plastic shrinkage [205], lower compressive strength as the result of porosity [206] [207]. To solve the problem, this study aimed to utilize rice husk as water reducing admixture (WRA) towards the workability and mechanical properties of SAP incorporated cement based composite mortar.

4.4.1 Materials and methods

Rice husk was collected and stored in a dry container with silica gel to ensure no excessive moisture effects on the material. 10mg of rice husk was transferred to 100°C boiled liquid consists of 50mL of NaOH and 50mL of water in heat resistant borosilicate glass. The mixture was consistently stirred using magnetic stirrer for one hour. After the color changed from transparent to dark amber, it was sieved using Erlenmeyer glass with Whitman filter paper to separate the solid rice husk and liquid solution. The liquid collected was ±80mL (Figure 33) which will be used as WRA and stored in closed container.

Figure 33. Resulting liquid derived from caustic reaction of rice husk for WRA

Rice husk was collected and stored in a dry container with silica gel to ensure no excessive moisture effects on the material. Portland Cement and sand (fine aggregate) was obtained from local construction store in Bandung, West Java, Indonesia. The sand was sieved with 30 mesh back Stainer to obtain only the fine part (silt) which will be used and removes the sandstone. SAP was prepared in dry and boiled condition. The mixture of 50mL liquid NaOH and 50mL water heated to 100°C was used to saturate SAP. The purpose of this is to fill the fine pores in SAP with water to ensure it will not absorb the water that used in cement mixing for mortar. NaOH also works to purify the residue from used diaper. Composite mortar was manufactured by mixing Portland Cement and Sand in 2:1 ratio. The water per cement (w/c) ratio was 0.46. SAP was added by 10% of cement weight. WRA was added to partially substitute 0-5% volume of water. The complete mix design in this study was presented in Table *38*.

Table 38. Mix Design of cement based composite mortar

No	Code	SAP treatment	WRA (%)
1	D0	Dry	0
2	D1	Dry	1
3	D2	Dry	2
4	D3	Dry	3
5	D4	Dry	4
6	D5	Dry	5
7	B0	Boiled	0
8	B1	Boiled	1
9	B2	Boiled	2
10	B3	Boiled	3
11	B4	Boiled	4
12	B5	Boiled	5

WRA percentage must be carefully controlled since it can cause bleeding and prolonged retardation. The liquid consists of WRA dissolved in water. The purpose was to ensure the homogeneity of admixture distribution. The dry mixture consists of Portland cement and sand were mixed first. It was followed by dissolving the dry mixture with the liquid to form slurry. It was tested its workability by filling cone mold, lifted it, and the diameter was measured (Figure 34). After that the slurry was put back into original container. Lignosulfonate and Polycarboxylate-based admixture reportedly has been used as WRA [208].

Figure 34. Measurement of slurry diameter to determine the workability of mortar.

The slurry was then poured into 50mm x 50mm x 50mm cubical silicone mold according to ASTM C109 "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)". After 24 hours, the hardened mortars were removed from mold, transferred to sealed bag container, and kept for 28 days for compressive test purposes. Specimens were weighed before testing for density measurement purposes. The mechanical properties in form of compressive strength was conducted by Iber Test Testing Machine with 2mm per second load was used for measurement. The sample was continuously given force until it breaks (Figure 35). The compressive strength (σ) was calculated by dividing Force (P) with area of mortar (A).

Figure 35. Compressive strength of cement based composite mortar

4.4.2 Findings

Workability Test Analysis

The addition of 0-5% WRA towards the workability SAP incorporated cement based composite mortar were presented in Figure 36. It shows that the workability increased proportionally to percentage of WRA. Mortar without addition of WRA has 55mm (dry) and 70mm (boiled) workability, respectively. This obviously due to extra water presented in boiled SAP. The increasing phenomenon of mortar with WRA addition is due to surfactant properties of the liquid. This means even the OH- ions from water (H_2O) is lower, it still gained extra OH- ion from NaOH. When the mortar is still in slurry state, WRA addition also tends to make mixing easier since the repellant force from ions can makes the slurry finer. By reducing the amount of water, the density of paste will increase [209].

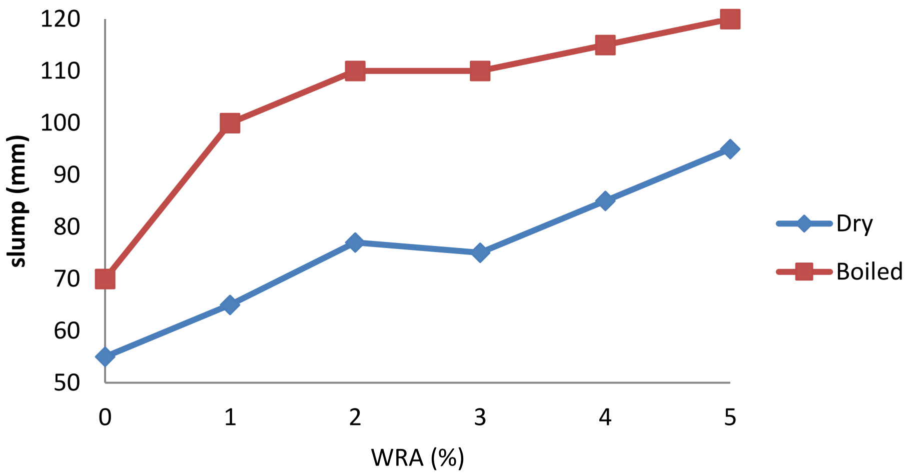


Figure 36. Workability test result of cement based composite mortar.

Density measurement test analysis

The addition of 0-5% WRA towards the density of SAP incorporated cement based composite mortar were presented in Figure 37. The density (ρ) was calculated by dividing specimen mass (kg) with volume of mortar (m^3).

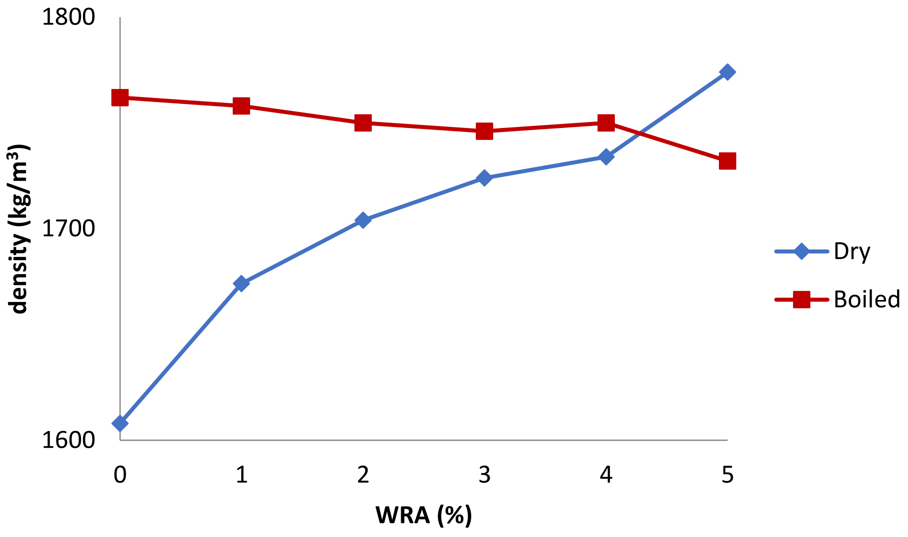


Figure 37. Hardness results from Vickers hardness testing of MOC.

The density of specimens with dry SAP were varied between 1608-1774 kg/m^3, with the highest density observed at specimen D5. This shows that dry SAP makes it not only absorb water but also the WRA, with higher percentage of WRA will fill the voids in SAP, hence makes the specimen heavier than specimen without WRA addition. Meanwhile, the density of specimens with boiled SAP were not changed significantly (1732-1762 kg/m^3) regardless of the WRA percentage. This happened because the boiled SAP has already saturated, which makes the WRA cannot penetrate their porosities further.

Compressive Test Analysis

The addition of 0-5% WRA towards the compressive strength of SAP incorporated cement based composite mortar were presented in Figure 38. It shows that the compressive strength was varied depends on the percentage of WRA.

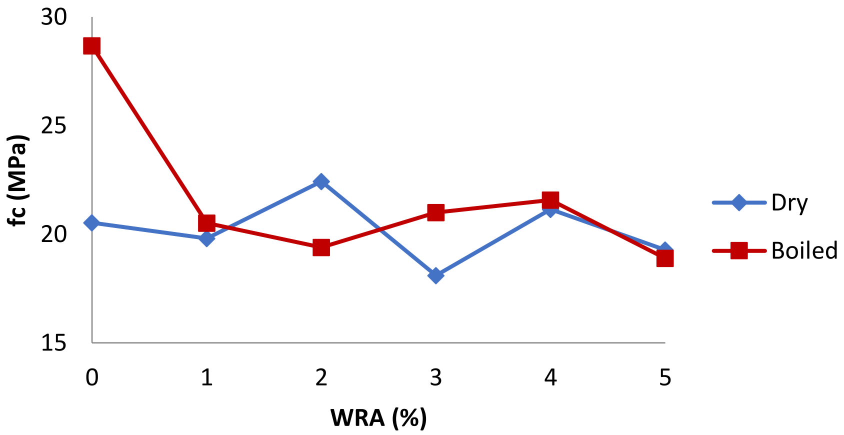


Figure 38. Workability test result of cement based composite mortar

Mortar without addition of admixture has higher compressive strength when the SAP is boiled (28.67 MPa) compared to dry SAP (20.53 MPa). This is due to when the SAP is in dry state, it absorbs the water that used for hydrating cement, results in incomplete hydration which makes resulting compressive strength is lower than typical mortar with 0.46 w/c. On the other hand, boiled SAP will saturate the fine pores contained in the material, resulting in the SAP not absorbing water from outside source. This explains the compressive strength difference of D0 and B0 coded mortar. The addition of 1-5% WRA fluctuates the compressive strength of dry SAP mortar (D1-D5). Compressive strength was increased due to Na^+ ions derived from NaOH will help the composite mortar maintains its highly basic pH due to alkalinity properties. Another reason is the WRA act as deflocculating agent, which means the Portland cement particle will be veiled by WRA. This creates the repelling force on each cement particle so it will distribute uniformly. Hence, the compressive strength is increased. The decrease in compressive strength phenomenon is due to similar repelling force created from WRA. But instead of homogenously distributed, the cement particles will have larger gap each other, which creates larger pore and weaken the capabilities of mortar to withstand external forces. Over dosage of water reducing admixture reportedly has negative effect on compressive strength of concrete [210].

The addition of 1% WRA towards the mortar with boiled SAP (B1) decreases the compressive strength compared to without WRA addition (B0). This is because the water content B0 is already stable to complete the hydration. Replacement of water using WRA will replace the H+ ions in water and replaced with Na+. This resulted in a decrease of compressive strength from 28.67 MPa to 20.51 MPa. D1-D5 has similar compressive strength ranging from 18.89 – 21.57 MPa. This means the WRA did not directly affect the compressive strength of mortar since the SAP were already boiled. Another reason was the calcium ions (Ca^{2+}) from cement is damaged due to NaOH compound is more stable. The main elements of cement are calcium (Ca), aluminum (Al), and silicon (Si), which theoretically when the Al and Si meets sodium (Na) from NaOH can form geo-polymerization. The Al and Si content in cement is not rich enough and Ca is not welcome in Geopolymer [211]. Albite or Anorthite were the typically reported compound formed in Geopolymer materials [212] [213] [214] [215] [216]. Both compounds will not form while the Tobermory as the proof of hydration product is decayed to NaOH presence. This explains the decrease in strength of mortar with WRA addition.

Conclusion

Based on the results of this study, water reducing admixture derived from cauterization of rice husk can increase the workability of both dry and boiled SAP incorporated cement-based composite to 95mm and 120mm, respectively. The dosage of admixture up to 5% does not alter the compressive strength of mortar significantly as the value fluctuates between 18-22 MPa. This makes the WRA a potential admixture to be used in areas with lack access of clean water or emergency construction which has difficulties in finding clean water source.

4.5 Result on Comparative Study on Mechanical Properties with Similar Concrete Materials

Cement is the most versatile, durable and most widely used construction material in the construction industry. Because of this, large quantities of portland cement are required and it is well known that the cement industry is considered a high emitter of carbon dioxide gas. The global production of cement has grown very rapidly in recent years, which carbon dioxide emissions is the third largest source after after fossil fuels and land-use change [210] [211] [212] [213]. The environmental problems associated with the production of portland cement are usually well known and closely monitored in terms of the amount of carbon dioxide released into the atmosphere during its production [214]. Since the current industrial growth is very high, the involvement and availability of building materials is increasing so that alternatives in industrial development are needed. In the present, research in the field of building materials and construction that is focused on designing alternative uses of cement.

Several studies even promote alternative construction materials to replace cement with 100% hydration content of non-cement, namely geopolymer as environmental friendly material [222] [223] [224] [225]. In addition to the cement problem, the next environmental problem that arises is the problem of utilizing production waste materials such from the wood industry, used drinking water bottle, and used diaper. The sawmill and plywood industry produces a lot of wood waste which possess a threat to the environmental sustainability [226] [227]. The production capacity of sawn wood in Indonesia reaches 2.6 million m^3 with a waste of 1.4 million m^3 per year. Waste is generally in the form of logs, sawdust, veneer waste and pieces of wood. Plastic water bottle usage is impacting the environment include: overflowing landfills, requiring high amounts of fossil fuel for production, and covering the ocean surface with plastic products. It has created environment threats and thus it needs to be recycled [228]. Every year the Indonesian sea is estimated to receive 70-80 percent of plastic waste used for human consumption from land. The amount is between 480 thousand-1.29 million tons of plastic waste from a total of 3.22 million tons of waste that enters the sea and coast. The global consumption rate of used diapers is increased exponentially. The global production of disposable used diapers is expected to exceed US$ 71 billion/year by 2022. Annually, about 20 billion pieces of this waste materials were dumped in landfills that require almost five century to be fully decomposed. The disposal of used diaper waste cause several environmental issues and can create problem for health [4]. The average baby wears 3-4 disposable diapers a day. In fact, every year around 4.2 to 4.8 million babies are born in Indonesia. For these reason, efforts are needed to reduce the amount of those waste material by reusing them into other materials. Therefore, this study aimed to determine the effect of sawdust, PET, and used diaper on the compressive strength of mortar.

4.5.1 Materials and methods

This part consists of materials, preparation of mortar mixtures, and compressive strength of resulting composite material.

Materials

Type IV Portland Cement was used as Binding material. Sand from Cikarang building material store prepared in Saturated Surface Dry (SSD) was used as an aggregate. The aggregates were passed through a sieve of 4.75 mm and retained on a sieve 30 µm with requirements of ASTM C-33. Sawdust was obtained from machining process of wood at construction site around Cikarang, Indonesia. Polyethylene terephthalate (PET) used drinking water bottle was collected around Cikarang, Indonesia. PET bottle was shredded manually conformed to previous study [222] [223]. Used Diaper was collected, shredded, and undergoes purification chemical solution to remove the urine and toxic substances and then dried for further application. These waste materials can be seen in Figure 39.

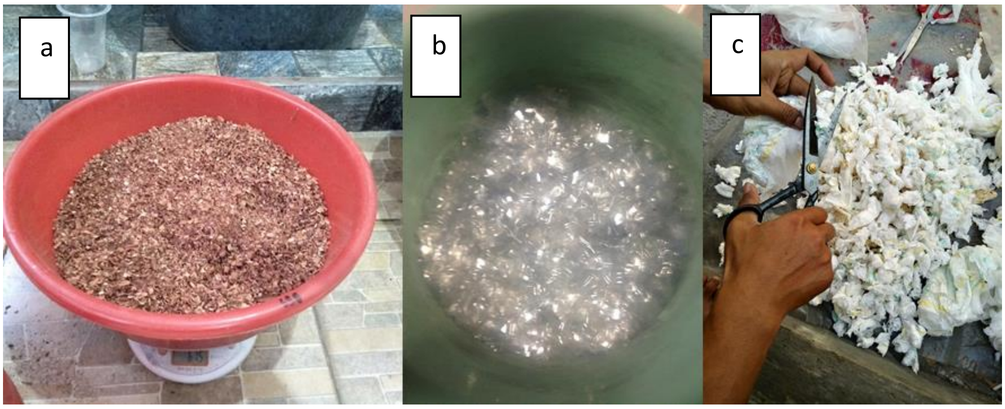


Figure 39. Waste materials used in this study (a) Sawdust (b) PET (c) Used diaper

Preparation of mortar mixtures

Thirteen mixes were prepared by adding cement with 0, 5%, 10%, 15%, and 20% replacement by mass to analyse the influence of waste replacement material to compressive strength and density of resulting composite mortar. The Replacement materials are a) Sawdust, b) PET, and c) Used diaper. The mix proportions of the studied mortars are listed in Table 39.

Table 39. Proportions of materials in mortar mixture

Mixture Labels	Binder		Waste Type
	Cement (%)	Replacement (%)	
C	100	0	-
SD-5	95	5	Sawdust
SD-10	90	10	
SD-15	85	15	
SD-20	80	20	
PET-5	95	5	PET
PET-10	90	10	
PET-15	85	15	
PET-20	80	20	
UD-5	95	5	Used diaper
UD-10	90	10	
UD-15	85	15	
UD-20	80	20	

Note: C (control) is mortar without cement replacement; SD=Sawdust; PET=Used drinking water bottle from PET material; UD=Used Diaper)

The water to cement ratio (w/c) was 0.52 by mass. The ratio of cement : agregate was 1 : 2.75 conformed to SNI 03-6825-2002. Briefly, dry mixtures were placed and mixed to ensure the component mixed homogeneously. Afterwards, the required amount of mixing water was poured into the dry mixture followed by continuous mixing. Each specimen was then cast into 20 mm x 40 mm ccylindrical molds. The specimens were left for 24 hours. Eventually, the speciment was released from the mold and cured at room temperature until compressive test.

Compressive Test

The compressive strength test of the composites were examined according to the ASTM C-39 “Compressive Strength of Concrete Cylinders” [231]. Each mixture were evaluated at the age of 3, 7, and 28 days. The compressive strength (fc) mortar was calculated by dividing the maximum compressive load received by the specimen during the test by surface area.

$$fc_{(MPa)} = \frac{max.compressive\ load\ (N)}{Surface\ area\ (mm^2)} \quad \ldots \quad \textit{Equation 17}$$

4.5.2 Findings

This section covers the resulting Density and Compressive Strength of waste material-based composites from this research.

Density Result

The Density (ρ) (*Equation 5*) of mortar was calculated by dividing the weight of hardened composite by the volume of material. The calculated density of composites are presented in Table 40 and Figure 40.

Table 40. Result on Density

Mixture Labels	Density (kg/m^3)
C	1860
SD-5	1110
SD-10	1090
SD-15	1070
SD-20	1060
PET-5	1840
PET-10	1820
PET-15	1800
PET-20	1780
UD-5	1800
UD-10	1770
UD-15	1600
UD-20	1130

Partial replacement of cement by sawdust, PET, and used diaper results in decrease of composite densities. Used diaper slightly decreased the density because diaper is made by sodium polyacrylate, this type of polymer has superabsorbent properties that absorb water heavily, and when applied to composite, it will retain some water and only makes small change in density value. Sawdust decrease the density significantly starting at 15% weight. This is because sawdust is an organic material and similar to used diaper, sawdust is also has the ability to absorb water but not as much as diaper. The PET sharply reduce the density of composites, even though used at low content as low as 5%. This material does not absorb water, which decrease the density of composites.

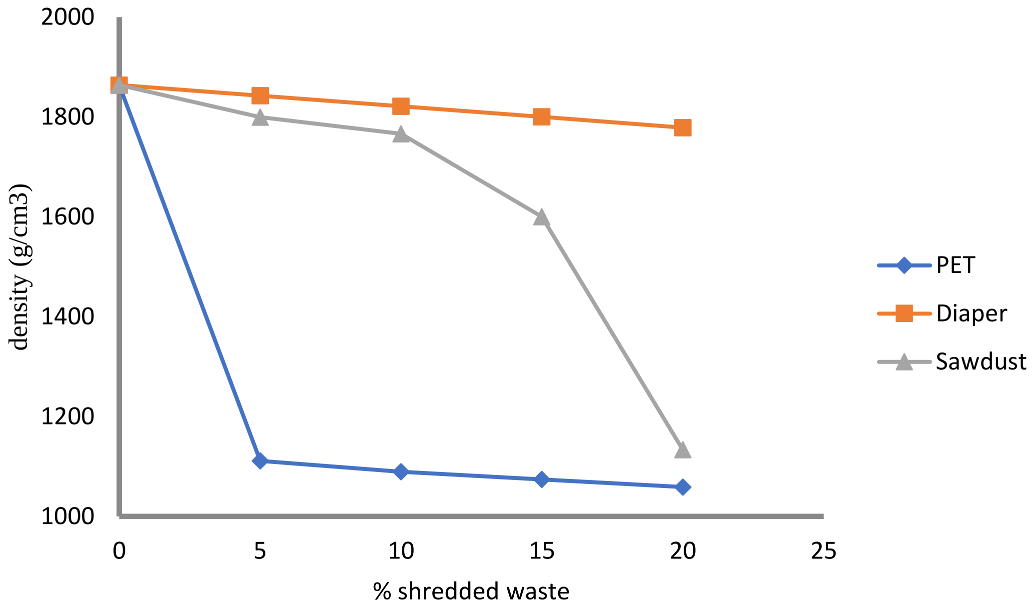


Figure 40. Density of waste material-based composites influenced by filler weight

Compressive Strength

Table 41 and Figure 41 shows the compressive strength of sawdust, PET, and used diaper based composites. Addition of Sawdust and Used diaper decrease the compressive strength of composites while 5-10% addition of PET increase the compressive strength of composites before decreased after 15% addition or more. Both sawdust and used diaper are polymeric material that absorbs water. This makes the hardened composite have excess amount of water, which explains the decrease in compressive strength of composite because there are more capillary porosities present in composite. Sawdust is an organic material that contains carbon (C) element, which delay the hydration of water and cement. If this subsequent material are activated by heating process, it can increase the early strength of cement mortars when used in low amount [232].

Table 41. Compressive strength of waste material based composites.

Mixture Labels	Compressive Strength (MPa)	
	7 days	28 days
C	15.99	24.61
SD-5	13.45	20.70
SD-10	12.74	19.59
SD-15	12.59	19.36
SD-20	6.49	9.98

Mixture Labels	Compressive Strength (MPa)	
	7 days	28 days
PET-5	31.65	33.04
PET-10	27.56	26.96
PET-15	5.23	20.89
PET-20	3.54	14.81
UD-5	11.73	18.05
UD-10	6.57	10.11
UD-15	1.40	2.16
UD-20	0.10	0.16

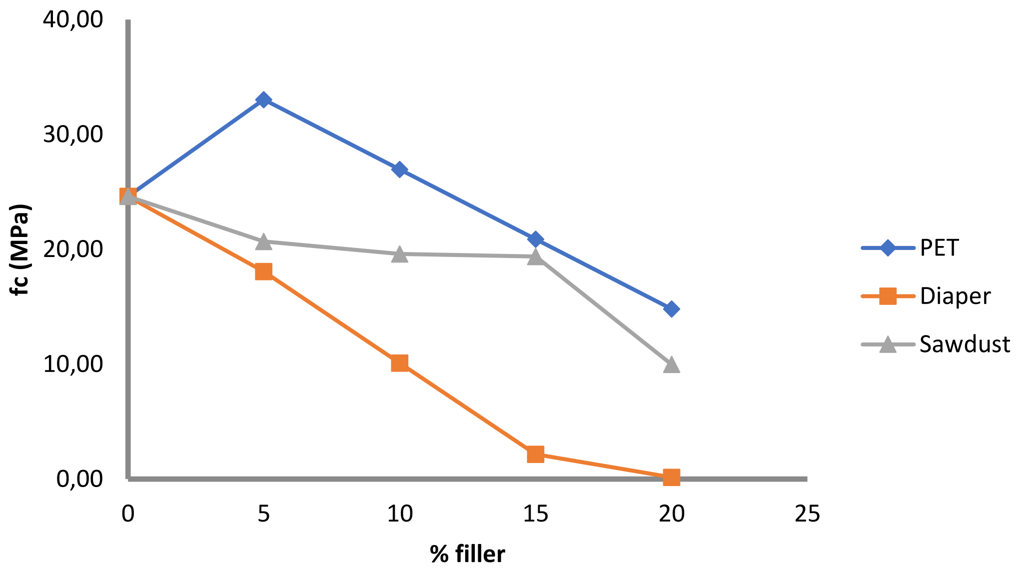


Figure 41. Compressive strength of composites influenced by filler weight

Diaper can be used as self-cure agent to improve the concrete performances when used at low amount [12]. PET when used at 5-10% weight increase the compressive strength of material, because it does not absorb water and makes the composite more compact. PET particle as cement replacement in mortar has good sulfate resistance and mechanical properties while also solves the solid waste problem generated by plastics [233]. Plastic binder when melted and mixed with granular material (aggregates) have potential structural application [234].

Composite Potential as structural lightweight concrete

To analyse the potential of waste material-based composites as structural low-density (lightweight) concrete replacement, the resulting density and 28 day compressive strength were referred to ACI 213R-14: Guide for Structural Lightweight-Aggregate Concrete. Structural lightweight concrete is made having an air-dried density of not more than 1850 kg/m^3 and compressive strength of more than 17 MPa. Table 42 represents the density and compressive strength value of composites in this study in accordance to ACI 213R-14. Columns marked by bold highlight indicates that the density and compressive strength of resulting composites are in accordance to ACI 213R-14. Sawdust and PET can be used up to 15% replacement of cement while Used diaper can be used only up to 5%. This is due to high absorbent properties of diaper will increase the water content in resulting composites, and decreasing the compressive strength even though the density is in accordance to standard.

Table 42. Density and Compressive test of composites in accordance to ACI 213R-14.

Mixture Labels	Density (kg/m^3)	Fc (MPa)	Density	fc
C	1860	24.61	No	Yes
SD-5	1800	20.70	**Yes**	**Yes**
SD-10	1770	19.59	**Yes**	**Yes**
SD-15	1600	19.36	**Yes**	**Yes**
SD-20	1130	9.98	Yes	No
PET-5	1110	33.04	**Yes**	**Yes**
PET-10	1090	26.96	**Yes**	**Yes**
PET-15	1070	20.89	**Yes**	**Yes**
PET-20	1060	14.81	Yes	No
UD-5	1840	18.05	**Yes**	**Yes**
UD-10	1820	10.11	Yes	No
UD-15	1800	2.16	Yes	No
UD-20	1780	0.16	Yes	No

Conclusion

In this study, composites based on sawdust, PET, and used diaper has developed. The raw material of the composite affects the resulting density and compressive strength. Addition of waste materials tends to decrease the density of hardened composites. The highest compressive strength of 5% sawdust, PET, and used diaper as replacement of cement are 20.70 MPa, 33.04 MPa, and 18.05 MPa, respectively. Sawdust and PET can be used up to 15% replacement of cement while used diaper can be used only up to 5% as potential structural lightweight concrete replacement.

4.6 Conclusion

1. The conclusion is drawn that the use of disposable diapers on composite building materials is represented by the linear regression equation $y = -56.681x + 26.191$ for concrete and $y = -20.57x + 10.364$ for mortar. Where y is referred to compressive strength, and x is referred to percentage replacement of fine aggregate by disposable diaper. The utilization is then divided into building components such as concrete utilization covers column and beam with the maximum disposable diaper is 10% can obtain the strength of 20 MPa. This strength is appropriate for a three-story house. While a maximum utilization of 27% is recommended for a single floor of housing with a strength of 10 MPa. The greater the replacement, the lower the SNI structural standard and only recommended for non-structural components.
2. In addition to applying the composite mortar to wall and floor elements comprised of concrete bricks and paver blocks, respectively. The maximum replacement for a wall is 40%, resulting in 2 MPa of strength and classification as level IV concrete bricks according to SNI 03-0349-1989. Maximum replacement of 9% is required for floor paving blocks, resulting in a strength of 8.5 MPa and compliance with level D of the SNI 03-0691-1996 standard for paving blocks. This maximum quantity is suitable for partition walls with no load-bearing capacity and floor pavers with low impact capacity. Replacement more than this maximum capacity is not recommended for the utilization of building materials. Incorporating experimental study findings into the design of low-cost housing, the total waste capacity of disposable diapers that can be utilized for single-story of housing type 36 (36 m^2) is 1.73 m^3 out of a total composite material volume of 22.79 m^3.
3. Addition of rice husk ash-based plasticizer significantly increase its slump value nearly by double for each addition of disposable diaper to concrete. Additionally, the addition of 5% disposable diaper to concrete and rice husk-based plasticizer has similar compressive strength value to normal concrete sample but the slump value is higher.
4. In the curing process of 28 days, the addition of plasticizer disposable diaper concrete enhanced compressive strength and reduce density in 5% addition, but it increased density in 10%. For 20 % addition it required a curing time more than 28 days.

5. The utilization of disposable diapers concrete in construction field can be used for constructing pavements to concrete reinforcing, depends on the workability and strength.
6. Water reducing admixture derived from cauterization of rice husk can increase the workability of both of dry and boiled SAP incorporated cement-based composite to 95mm and 120mm, respectively. The dosage of admixture up to 5% does not alter the compressive strength of mortar significantly as the value fluctuates between 18-22 MPa. This makes the WRA is a potential admixture to be used in area with lack access of clean water or emergency construction which has difficulties in finding clean water source.
7. In this study, composites based on sawdust, PET, and used diaper has developed in paste mix design. The raw material of the composite affects the result of density and compressive strength. Addition of waste materials tends to decrease the density of hardened composites. The highest compressive strength of 5% sawdust, PET, and used diaper as replacement of cement are 20.70 MPa, 33.04 MPa, and 18.05 MPa, respectively. Sawdust and PET can be used up to 15% replacement of cement while used diaper can be used only up to 5% as potential structural lightweight concrete replacement.

Chapter 5

Feasibility Study on Environmental Impact Assessment

5.1 Environmental Impact Indicators

Life Cycle Assessment (LCA) based on ISO 14040 is one of the environmental management techniques for risk assessment, environmental performance evaluation, environmental audit, and analysis of environmental impacts [235]. LCA is usually not used to assess social or economic aspects, but its approach and methodology can be applied to other aspects. In several LCA-based studies, several indicators regarding environmental impact were measured by embodied energy and carbon emissions [236] [237] [238] [115] [239] [240] [241] [242] [243] [244] [245] [132]. Some even measure the high environmental costs that must be incurred due to these emissions, known as eco-cost [246] [247] [248] [136] [249] [250] [251]. Embodied energy (EE), carbon emission (CE) and eco-cost (EC) are used as indicators of environmental impact assessment. In this study several databases were used as basic data to calculate EE, CE, and EC, such as Inventory of Carbon and Energy (ICE) of Bath - United Kingdom [144], IDEMAT [145] and Eco-Invent [146] that is already compiled in the database of Eco-costs [145].

In calculating EE, CE and Eco-costs several databases could be used as main data such as ICE Bath, IDEMAT and Eco-Invent. Those databases basically are derived from the European standard that may the calculation for this case study is uncertainty. Calculation is quite ease but the limitation of its calculation should be considered as a part of the calculation scenario. The limitation is for example in transportation, fuel extraction and disposal process. Although the method includes uncertainty, this is useful when case-specific data is unavailable, such as in countries where the data inventory is not available [238] [115]. Assessing embodied energy and carbon emissions in buildings is still difficult to do because of the complexity in data analysis, therefore it is necessary to apply relevant approaches [239]. The lack of material inventory data for EE requires another method to fulfill EE by combining case-specific data with statistical data, can be directly applied to case buildings to identify design improvements and material options, and to evaluate after construction is complete [238].

5.1.1 Embodied Energy (EE) Calculation

The understanding of embodied energy is often difficult to distinguish from energy in use. Even though both have very different definitions. The definition of these two terms more clearly, energy use is the energy required by residents of an existing or planned building, especially for space heating, water heating and lighting and needs to be reduced [236] [240] [241] [242]. Decreasing energy demand through more efficient buildings brings benefits to the global environment as well as lower costs and improves quality of life for residents.

Energy is needed not only for building operations but also to create building products and to construct them. In simple terms, embodied energy is the energy needed to convert products from raw materials into ready-to-use materials [243]. Building embodied energy is defined as the total energy required to build, obtain raw materials, process, and production, as well as transport and construct materials [236]. A similar definition is also expressed that embodied energy is the energy consumed by all processes associated with the production of a building, from the acquisition of natural resources to product delivery, including mining, manufacturing of materials and equipment functions, transport, and administration [244] [245].

In some literature, EE is resumed as the total energy required to produce building materials starting from the procurement of raw materials, fuel for the procurement of raw materials, the manufacturing process of building materials and the type of transportation for moving these raw materials. It can also be said to be a form of 'cradle to gate' which is calculated from the initial process to the product manufacturing, transportation to the site, installation or construction, maintenance, and demolition or recycling [235] [236] [238].

In terms of EE calculation for building component that is applied in Indonesia, this study had been conducted in building component such as bricks, wood, stone, ceramic and clay tiles [115] [132]. It showed that clay tile has a high EE for the building components, especially for low costs housing in Indonesia. It is due to the process of making clay tile which need energy for combustion and the larger volume compared to other materials. Another research on low-energy housing concluded that embodied energy can explain as much as 40-60% of the total energy use [242] [245].

5.1.2 Eco-Cost (EC) Calculation

Eco-cost is a measure to express the amount of burden borne by the environment where the measurement is used as a basis for consideration of preventing further burdens. Eco-cost is costs that should be considered to reduce environmental pollution and reduce material at a level that is in line with the load capacity that can be borne from nature.

The basic idea is to link the 'value chain' to the ecological 'product chain'. In the value chain, added value (in terms of money) and additional costs are determined for each step of the product during the life cycle [240]. Likewise, the ecological impact of each step in the product chain is expressed in terms of money, which is called eco-cost. Modeling of eco-cost is based on the sum of the marginal prevention costs over the product's life cycle for the prevention of toxic emissions, material depletion, energy consumption and land conversion, and includes labor and depreciation associated with the production and use of the product [239].

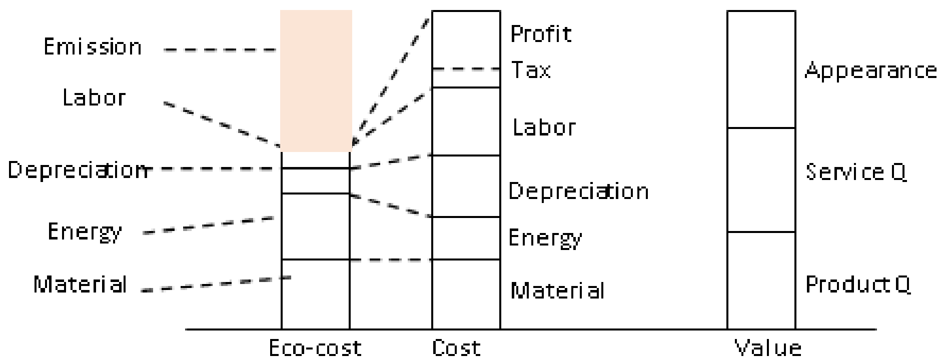


Figure 42. Eco-Cost Concept [239]

5.1.3 Carbon Emission (CE) Calculation

In terms of CO_2, the carbon footprint is expressed as a sum of fossil emissions that is calculated with the help of IPPC weighting factors (for 100 years). The increasing environmental awareness has paid much attention to the greenhouse emissions, especially the carbon dioxide (CO_2) emissions. Building industry is one of environmental recovery target due to its large energy consumption for about 40% and for about 30% is related to greenhouse gas emissions [252] [253] [254] [255]. Several researches conclude that reinforced concrete construction has the highest CO2 and the highest CE is in the building operation phase, followed by the construction work [255] [256]. In the city level, the highest CE is in building operation phase, followed by the construction material preparation phase as the second highest contribution, also the behavior factor was the main driver of the energy consumption [253] [257].

Furthermore, in terms of building materials for low-costs housing in Indonesia, the study had been conducted and it was concluded that stone has the highest CE due to the large amount that is used [115] [132].

5.2 Result on Environmental Impacts of Waste Treatments

This part explored further about the advantages of waste diaper treatment as a concrete component in terms of environmental impact. Indicators of carbon emissions and eco costs is be used as a quantitative analysis. Furthermore, to strengthen the discussion, other types of waste treatment such as co firing and incineration also be used as a comparison. This part also compares the disposable diapers treatment using electricity co-firing and electricity incineration. Those treatments are claimed as environmentally friendly waste treatments. Cofiring is the use of fuel from biomass and waste which is converted into the form of garbage pellets, wood pellets and wood chips which are used for power generation. the practice is converting biomass to electricity by using biofuels as a partial substitute energy feedstock in high-efficiency coal boilers [258]. Due to relatively minor modification, coal is widely used as coal-fired electricity plants by using biomass in existing fuel storage [258]. Co-firing shows socioeconomic and environmental advantages, especially for CO_2 and SO_2 emissions reduction [259]. Biomass cofiring has the advantage of reducing carbon emissions because it can reduce coal use by 20% - 50% [260]. Compared to a power plant that burns 100% biomass, co-firing offers several advantages including lower capital costs, higher efficiency, better economies of scale and lower electricity costs [260]. In addition, coal-biomass co-firing could make the power generation efficiency reach more than 70% [261] and in economic, it may boost rural economy and cut back the production of coal mining sector [262].

Municipal Solid Waste (MSW) incinerations is the waste treatment that include some hierarchy such as indiscriminate dumpling, controlled dumpling, landfilling, sanitary landfilling and mechanical treatment. For now, there's additional environmental control that introduced at each level. MSW incineration significantly reduce the volume of waste to be landfilled approximately 90% [263]. The MSW incineration is usually authorities by relevant stakeholders based on local condition, political and financial situation, and also it is important to review possible waste treatment and disposal facilities. In term of energy efficiency, it shows in Table 43.

Table 43. Examples of Energy Efficiency for Incineration [264]

Outputs	Efficiency	Use
Heat Only	Up to 80% – 90% thermal efficiency	Local district heating for buildings (residential, commercial) and or for industrial processes
Electricity	14% - 27%*	Can be supplied to national grid for sale and distribution
Heat and Power	Dependent on specific demand for heat and power	Combination of above

* The lower efficiency performance is more typical of older facilities and it is possible that in the future the efficiency of electricity generation using incineration will increase

5.2.1 Methods

The methods used in this study are described as follows:

1. Define the scope and boundary of product, in this case the product is define as disposable diaper product that derived from its single components. The boundary is transportation and energy to create the product are excluded.
2. Determine the data inventory that include materials, specification of materials, unit, coefficient of eco-costs and carbon emission (Table 44)
3. Calculate the eco-costs and carbon emission (Table 45). In this study, databases were used as basic data to calculate are IDEMAT 2014 dan Eco-invent, Delft University of Technology, Netherland.
4. Interpretation of the data.

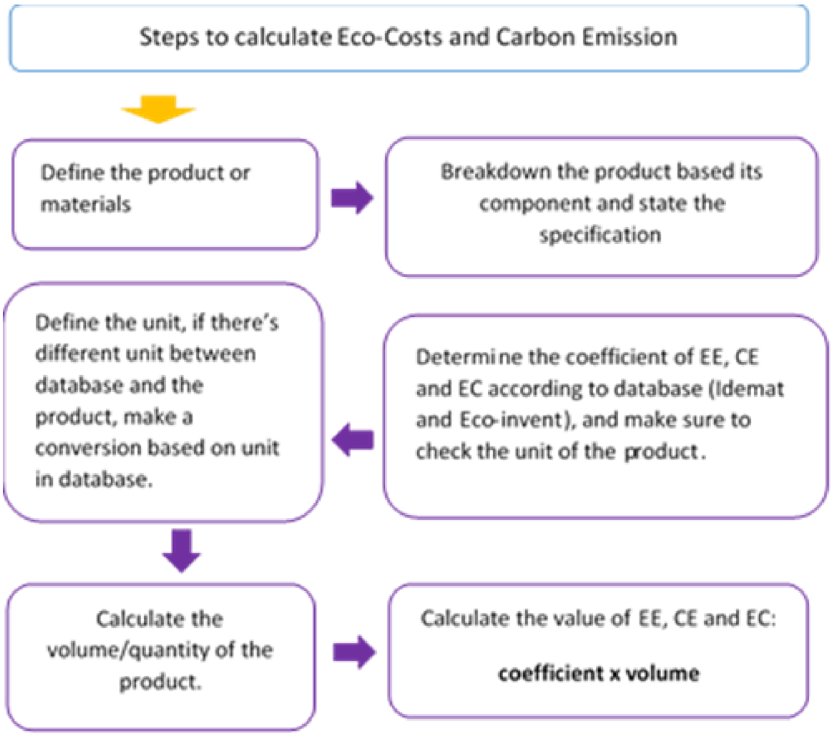


Figure 43. Methodology Flowchart on Environmental Impact Assessment

5.2.2 Findings

In this study, the environmental indicators that used as consideration are carbon emission (CE) and eco-costs (EC). In short terms, eco-costs is environmental tax that should be considered to reduce environmental pollution at a level that is in line with the load capacity that can be borne by nature **[246]**. The cost should be added to the product or process that release emission to the environment. Thus, the increasing of environmental awareness has been paid much attention to the greenhouse emissions, especially the carbon dioxide (CO_2) emissions.

The following Figure 44 and Figure 45 show the result of CE and EC regarding disposable diaper waste treatments. The product is calculated by its weight of 1 kg. In Figure 44, recycling the product takes the lowest CE. Even the result is in negative value, which means the recycling process gives more benefits in reducing the CE by amount of 2.93 $kgCO_2$. Followed by cofiring as another alternative treatment that environmentally friendly. The cofiring also gives negative value which also means, the process does not add the CE to environment, instead it reduces the CE as amount of 0.24 $kgCO_2$. Although MSW incineration is claimed as environmentally friendly waste treatment, but it still gives 0.58 $kgCO_2$ that released to the environment. But it is better than the product thrown away without any treatment. It gives more negative impact as amount of 4.64 $kgCO_2$.

Table 44. Data Inventory of Disposable Diaper Components

Materials	Carbon Emission Value (CO_2/kg)				Eco-Costs (Euro/kg)			
	Recycling	Not recycling	Co-firing	MSW incineration	Recycling	Not recycling	Co-firing	MSW incineration
Superabsorbent Polymers (SAP)	-5.54	7.20	0.50	1.25	-1.592	1.95	0.09	0.24
Polypropylene (PP)	-0.766	2.10	0.26	1.54	-0.814	1.09	0.05	0.29
Pulp	-2.577	4.60	-1.20	-0.66	-0.471	0.87	-0.23	-0.12
Polyethylene (PE)	-0.993	2.20	0.27	1.55	-0.869	1.14	0.05	0.29
Polystyrene (PS)	-2.113	3.60	0.73	1.91	-1.113	1.40	0.14	0.36

Table 45. Calculation of Carbon Emission and Eco-Costs of 1 kg Disposable Diaper Waste Treatments

Materials		Carbon Emission (Kg CO_2)				Eco-Costs (Euro)			
	Compositions	Rec.	Not rec.	Co.	MSW inc.	Rec.	Not rec.	Co-firing	MSW inc.
Superabsorbent Polymers (SAP)	27.90%	-1.54	2.01	0.14	0.35	-0.44	0.54	0.03	0.07
Polypropylene (PP)	18.70%	-0.14	0.39	0.05	0.29	-0.15	0.20	0.01	0.05
Pulp	40.90%	-1.05	1.88	-0.49	-0.27	-0.19	0.36	-0.09	-0.05
Polyethylene (PE)	6.20%	-0.06	0.14	0.02	0.10	-0.05	0.07	0.00	0.02
Polystyrene (PS)	6.20%	-0.13	0.22	0.05	0.12	-0.07	0.09	0.01	0.02
Total		**-2.93**	**4.64**	**-0.24**	**-0.58**	**-0.91**	**1.26**	**-0.05**	**0.11**

The next Figure 45 shows EC of 1 kg disposable diaper waste treatments. In a general knowledge, the CE and EC have direct correlation, when CE increased the EC will increase too. As it predicted, the recycling process has the most reliable treatment for disposable diaper due to it could reduce the environmental tax as amount of 0.91 Euro. Followed by cofiring as well, could reduce 0.01 Euro for the tax. Furthermore, MSW incineration still give tax addition for the environment as amount of 0.11 Euro. But still, when the product is landfilling or degrade by the biological process, it’s more added to environmental tax as amount 1.26 Euro

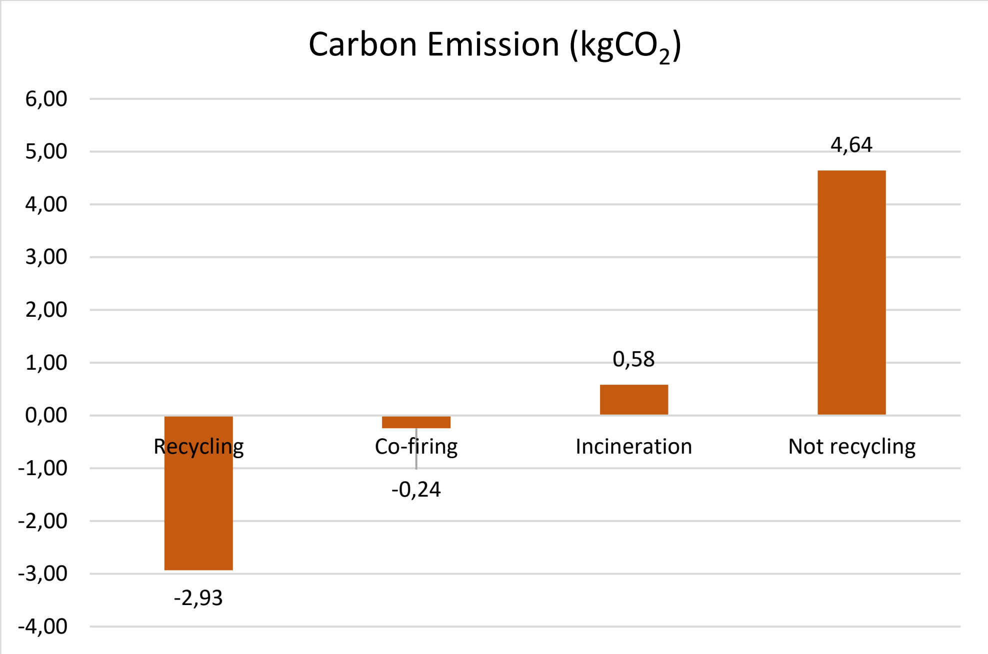


Figure 44. Carbon emission of 1 kg disposable diaper treatments

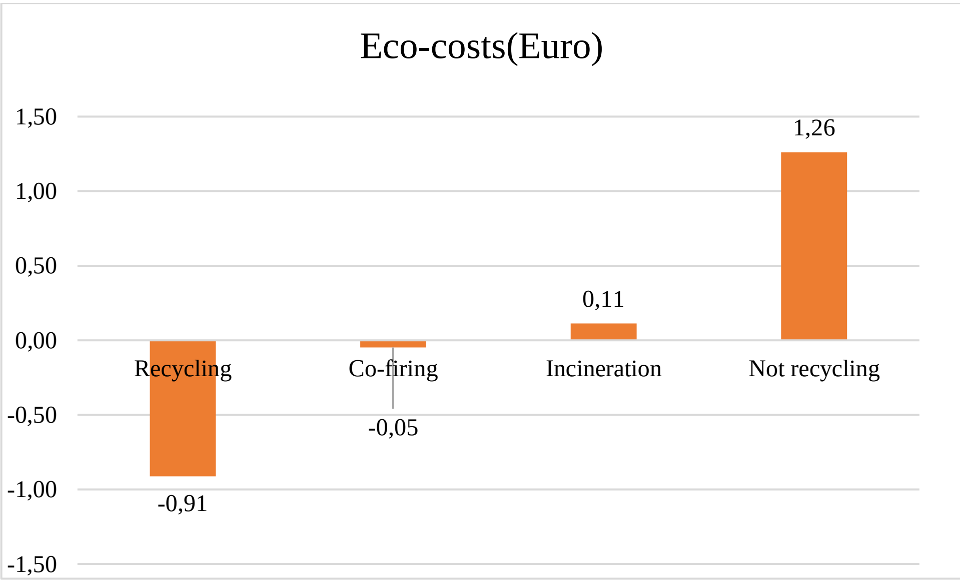


Figure 45. Eco-costs of 1 kg disposable diaper treatments

Regarding the environmental benefit result for disposable diaper waste treatments, the recycling product is the most visible treatment to reduce environmental burden by emission. In the term of material innovation, disposable diaper recycling is become happening this recent time. Although, the research is still very limited, but it is very applicable. One of example is the disposable diaper recycling as a concrete composite material. For example the additional of 1-10% used baby diapers to the concrete mixture [170]. The results of these studies indicate the findings that concrete cubes with the addition of 1% of polymer baby diapers have optimal results. The hydration for internal curing improves and gives positive results and has the highest strength and good staying power. In addition, the shrinkage test and compressive strength and drying shrinkage with the results of the compressive strength of concrete containing 5% polymer baby diapers showing the highest strength at 28 days compared to other percentages [1].

Conclusions

Based on the result, the considering of recycling waste disposable diaper to concrete components, give more beneficial environmental impact such as:

1) Compare to other waste treatments, recycling is the best choice to decline environmental impact cause by waste disposable diaper.
2) Recycling process reduce 2.93 kgCO2 and reduce 0.91 Euro per kg waste disposable diaper for environmental tax.
3) In the term of concrete component, the use of waste disposable diaper in certain amount is not significantly reduce the physical and mechanical properties of the concrete, so it's visible to apply for the material.

5.3 Result on Comparative Study with Similar Concrete Materials

Disposable diaper and *Polyethylene terephthalate* (PET) waste become an environmental problem that has not been found the right solution to handle it [265] [266] [267] [268] [170] [12] The common principles to reduce environmental problems due to waste are reduce, recycle and reuse [247]. In the infrastructure field, these activities are major concerns as a contribution in reducing waste problems such as reuse the construction waste itself, reduce the use of material with effectiveness of design and construction and recycle the waste materials into new products [266] [267] [170] [12] [269].

In terms of recycle, most of the recycled waste makes it as composite material as filler of concrete. Some studies on recycling plastic waste are creating it as mixture of concrete [265] [266] [267] [268]. Some studies concluded that plastic waste was not suitable to replace fine aggregates, this was used to replace coarse aggregates. In this case, the type of plastic must be considered. The result also indicates that the density of plastic cement produced was different depending on the percentage of plastic waste in the concrete mix design. Plastic waste can be effectively reused without significantly affecting mechanical properties (5-10%), because the specific gravity of plastic waste is smaller than fine aggregate, so the weight of the concrete itself decreases, thereby reducing the overall structural weight/structural components. Another study of wasted plastic composite was application to panel for building component [230].

Another study on waste material composite is recycling wood waste into composite panels [270] [271]. The usage for these types of products include insulating acoustical board; carpet board: wall, ceiling and floor acoustical insulation panels; nail baseboard; and floor and roof insulation boards and describe the potential for producing selected composites from waste wood, paper, plastics, fly ash, gypsum, and other forms of waste biomass [272]. For cement-wood composite in terms of building materials, the study conclude that the wall panels meet the requirement of Indonesian National Standard (SNI) 03-0349-1989 with concrete steel-brick level IV as a non-structural brick [181].

The recent studies also develop disposable diaper as concrete component, but only a few studies apply this waste recycling process. 1-10% waste baby diapers had been added to the concrete mixture [170]. The result of these studies indicated the findings that concrete cubes with the addition of 1% polymer baby diapers have optimal results. The hydration for internal curing improves and gives positive results and has the highest strength and good staying power. In addition, the shrinkage test and compressive strength and drying shrinkage were carried out with the results of the compressive strength of concrete containing 5% polymer baby diapers showing the highest strength at 28 days compared to other percentages [12]. The results of previous researches are still lacked in terms of methods and the percentage of used baby diapers that were not very significant in reducing environmental waste.

Beside cement composite material waste provides a solution to environmental problems caused by waste, on the other hand the use of cement itself has a negative impact to the environment. There are many studies that describe the negative effects of cement production, such as CO_2 emissions released during the cement production process [273] [274] [275] [276]. The other problems also related to the use of recycled material that its basic material has negative impact to the environment for example, disposable diapers and *Polyethylene terephthalate* (PET) that contribute as the hardest degradable material. Regarding this, new problems come up from the production of cement-based composite material, that is the extent of the impact of waste on the environment starting from the supply of raw materials to the demolition of the material itself. In addition, the economic value of the material is another consideration that needs to be studied. In respond to the issue, this study will try to analyze the potential environmental impacts of recycled waste usage in cement composite material. Four types of concrete products such as normal concrete (NC), PET concrete (PET), disposable diaper concrete (DDC) and shredded wood concrete (SWC) were analyzed. Embodied energy (EE), carbon emission (CE) and eco-cost (EC) are used as indicators of environmental impact assessment.

5.3.1 Methods

Materials

Three types of recycled waste composite materials were studied: plastic concrete, shredded wood concrete and disposable diapers concrete. The component of materials is shown intable 1. The composition is based on Indonesian National Standard (SNI) 7394:2008 The Procedure for Calculating the Unit Price of Concrete Work for Building and Housing Construction. This standard contains the calculation of materials and labor composition that is required in concrete work. In this study, the concrete was designed in high strength of K-300 that usually is used in building construction in Indonesia.

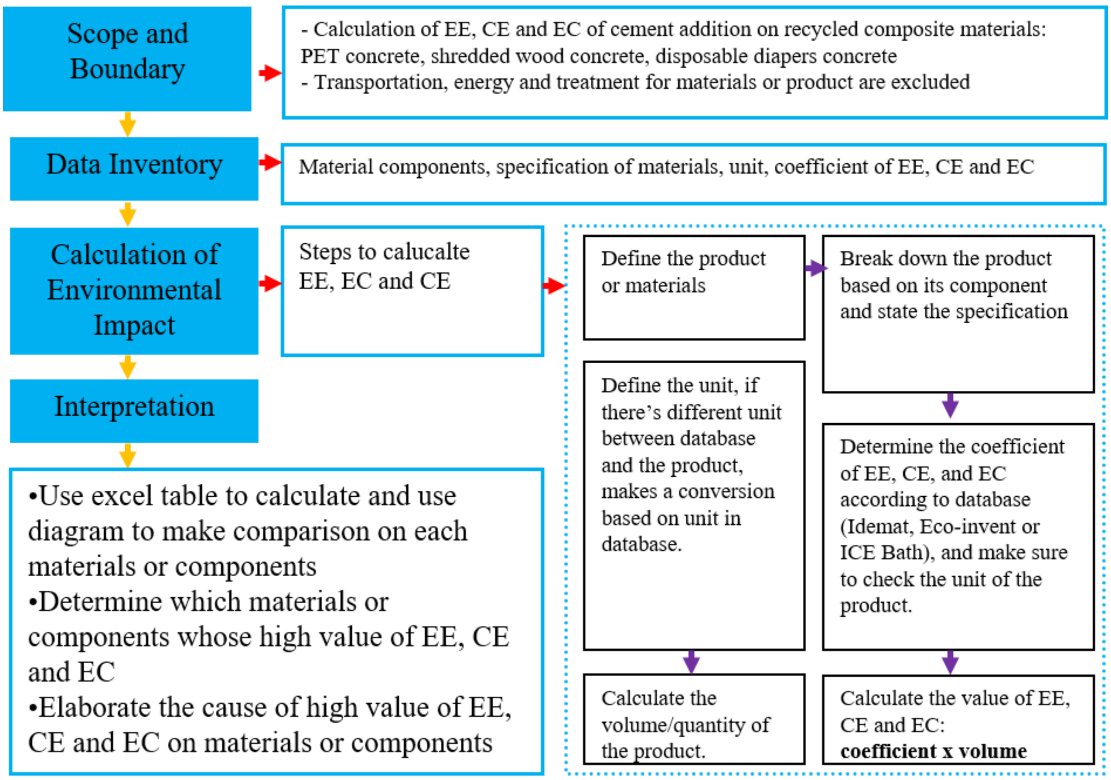


Figure 46. Research Methodology Flow Chart

Table 46. Materials Composition for 1 m^3 Concrete Works

Type of Concrete	Compositions				
	Portland Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (litre)	Wasted Materials (kg)
Normal Concrete (NC)	413	681	1021	215	0
PET Concrete (PC)	413	672.49	1021	215	9.28
Shredded Wood Concrete (SWC)	413	633.33	1021	215	47.67
Disposable Diapers Concrete (DDC)	413	670.62	1021	215	10.36

In this case, the wasted materials are used to replace fine aggregate with the percentage of 5% replacement for the most effective composition [265] [266] [267] [268] [170]. The important procedure to calculate the wasted material composition is to know its density because fine aggregate and waste materials have different density. So, conversion of material unit should be well calculated.

Methods

In general, the methods used in this study are described as follows:

1. Define the scope and boundary of product, in this case the product is defined as concrete materials and waste materials as replacement of fine aggregate. The waste materials that were used are PET, disposable diapers and shredded wood (Table 46). The boundary of the product is transportation, energy and treatment for materials are excluded in calculation.
2. Determine the data inventory that include materials, specification of materials, unit, coefficient of EE, CE and EC.
3. Calculate EE, CE, and EC of each material.
4. Interpretation.

Table 47 shows the EE, CE and EC values for 1 kg of materials that is used in the study.

Table 47. EE, CE and EC of 1 kg Materials

No	Materials (kg)	Abrv.	EE value (MJ/kg)	CE value (CO2/kg)	EC value (IDR/kg)
1	Cement	PC	4.6	0.917	Rp 2,550
2	Fine Aggregate	Fag	0.1	0.007	Rp 51
3	Coarse Aggregate	Cag	0.1	0.016	Rp 111
4	Water	W	0	0	Rp -
5	PET	PET	90.45	0.10	Rp (15,333)
6	Shredded Wood	Sh Wood	8.5	0	Rp -
7	Disposable Diapers				
-	Superabsorbent Polymers (SAP) (27.9%)	SAP	131	0.10	Rp (27,064)
-	Polypropylene (18.7%)	PP	93.97	-0.766	Rp (13,838)
-	Pulp (40.9%)	Pulp	31.58	-2.577	Rp (8,007)
-	Polyethylene (6.2%)	PE	89.72	-0.993	Rp (14,773)
-	Polystyrene (6.2%)	PS	103.83	-2.113	Rp (18,921)

5.3.2 Findings

The following Figure 47, Figure 48, and Figure 49 are to elaborate the comparison of EE, CE and EC value of 1 kg material components in this study. For more detailed information about the calculation process of the concrete product, please refer to Table 48.

Figure 47 shows the EE value for concrete materials. SAP as the main components of disposable diaper has the highest EE value as amount 131 MJ/kg. Followed by the other components of disposable diaper such as PS 103,83 MJ/kg, PP 93,97 MJ/kg, PE 89,72 MJ/kg and pulp 31,58 MJ/kg. The total EE value for disposable diaper is around 450,1 MJ/kg, the fantastic EE value compares to other components such as PET 90.45 MJ/kg, even for the PC which has 4.6 MJ/kg. The natural components such as fine and coarse aggregate are excepted, which only 0.1 MJ/kg and for water and wood are 0 MJ/kg. For the natural components, there is no production process so the energy that is used is lower than manufacturing components.

In Figure 48, the CE value for disposable diaper components decreases to minus value, which means, in the life cycle process the components give credit to lower the CE instead. For disposable diaper recycling, the credit of CE gives as amount of 11,98 kgCO2 to reduce CE that may release during its process to the environment. The same principle is conducted to PET which is the recycling credits given as amount of 1.85 kgCO2. In this case study, the recycling credit do not give to PC and aggregates, due to the product still use its origin components, the CE value is in its own form. The PC is 0.917 kgCO2 and the fine and coarse aggregates are 0.005 kgCO2. But still, for materials that are derived from nature, the CE is still much lower.

While for shredded wood, the EE is quite higher compared to other natural materials. This is due to shredded process that may include energy for tools such as electricity and transportation.

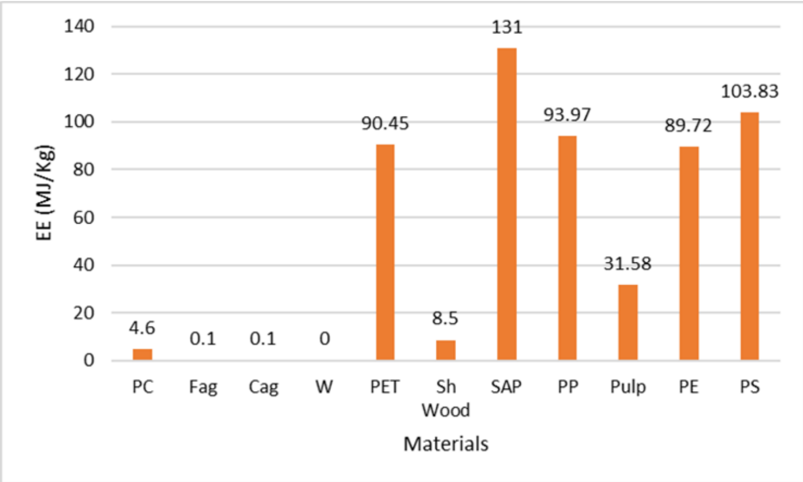


Figure 47. EE Value of Concrete Materials (MJ/kg)

In Figure 49, SAP as main components of disposable diapers gives credit to reduce the environmental tax as amount of Rp. 27.064/kg and Rp. 15.333/kg for PET. While the different principle is occurred to PC and the aggregates, the amount of Rp. 2.550/kg must to pay for environment tax for PC, Rp. 51/kg for fine aggregate and Rp. 111/kg for coarse aggregate.

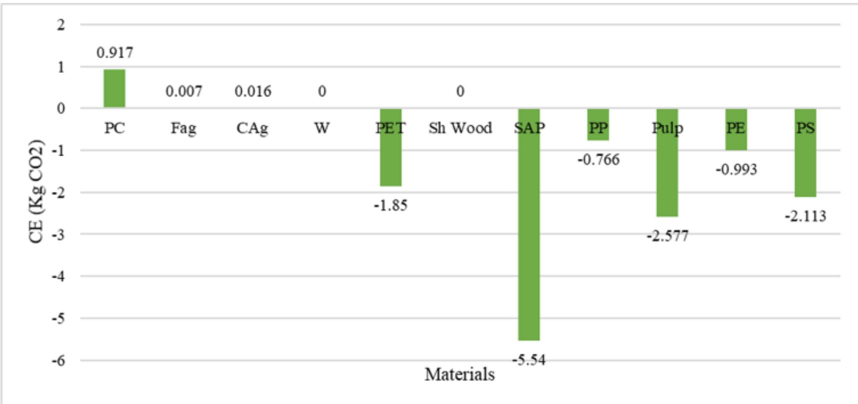


Figure 48. CE Value of Concrete Materials (kgCO2)

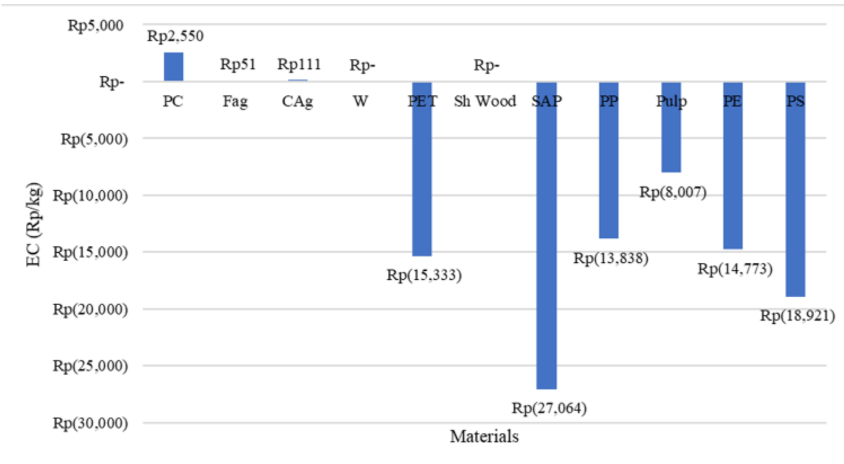


Figure 49. EC Value of Concrete Materials (Rp/kg)

The next following Figure 50, Figure 51, and Figure 52 describe the comparison of EE, CE and EC value of 1 m^3 concrete works in this study. Figure 50, for 1 m^3 works of NC, it needs 2070 MJ energy, 2887.79 MJ for DDC, 2908,53 MJ for PETC and 2470.43 MJ for SWC. The anomaly happened to SWC, the SWC is conduct as a half replacement for fine aggregate. Although the filled concrete using natural materials, the EE is still higher than NC, this is due to the embodied energy of shredded wood is higher than fine aggregates.

Figure 51 shows the calculation by recycled disposable diaper and PET as concrete components, it could give benefits to reduce CO2 as amount of 370,06 kgCO2 for PET and 356,78 kgCO2 for DDC. While for NC and SWC have slightly similar amount as 386,99 kgCO2 and 387,23 kgCO2 respectively.

The environmental tax of the concrete products is shown in Figure 52. Normal concrete has the highest fee to pay for the tax, as amount of Rp. 6.087.190 per m^3. It should be added to the price of concrete product. For example, if the production cost of normal concrete is Rp. 2.000.000 per m^3, so the EC should be added and the total cost is calculated as:

Total cost = production cost + eco-cost

= Rp. 2.000.000 + 6.087.190

= 8.087.190 per m^3.

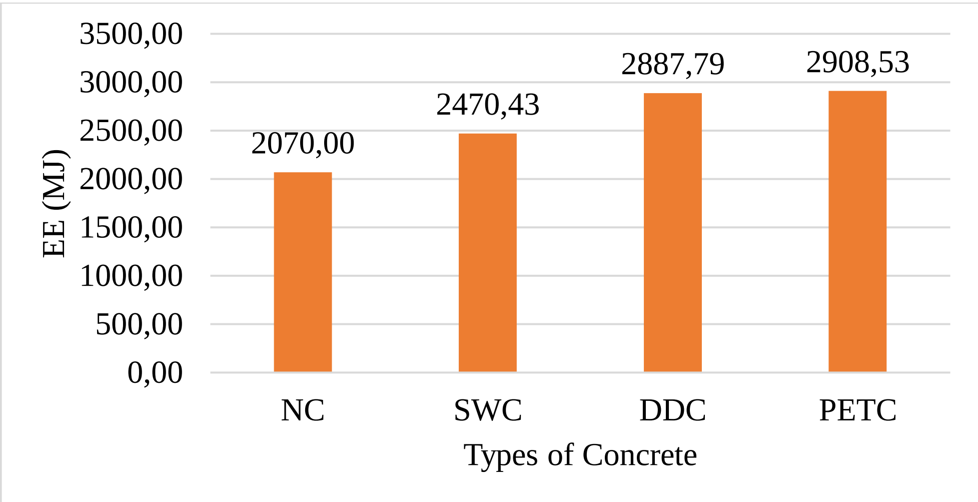


Figure 50. Comparison of EE Value for 1 m^3 Concrete

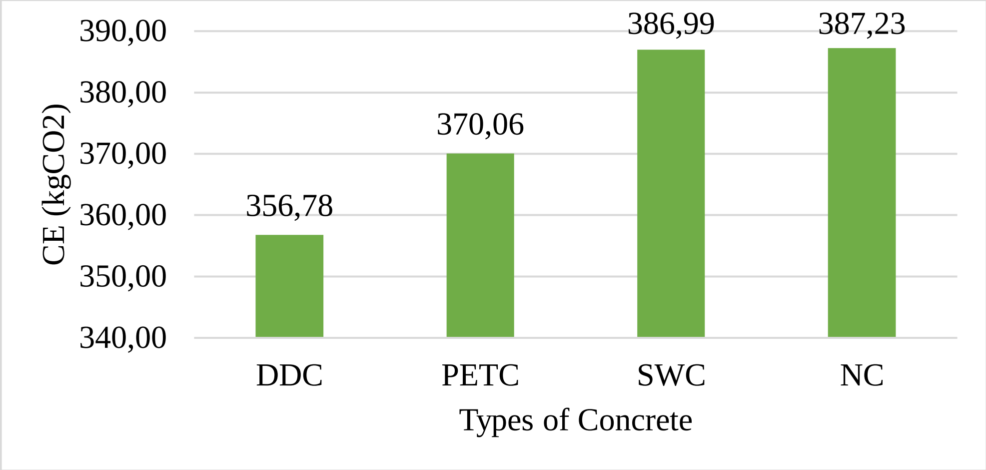


Figure 51. Comparison of CE Value for 1 m^3 Concrete

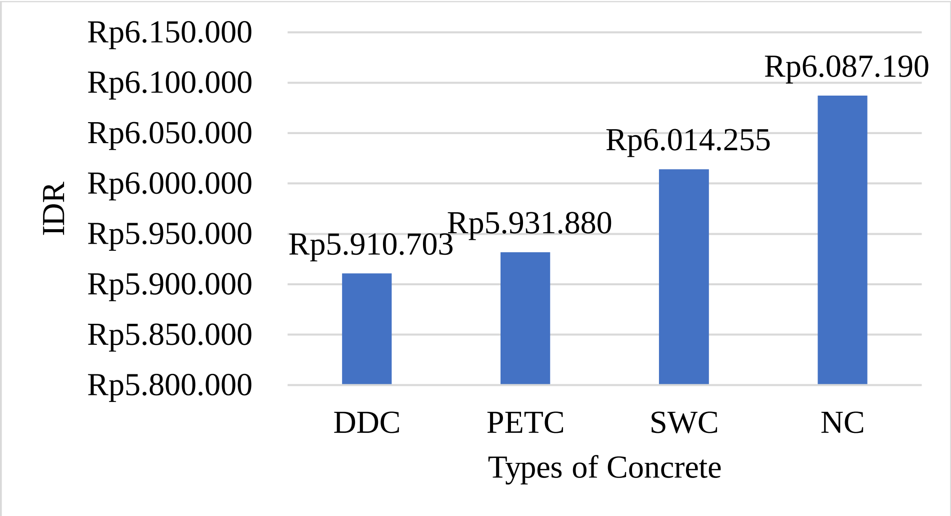


Figure 52. Comparison of EC Value for 1 m^3 Concrete
in Indonesian Rupiah

Table 48. Calculation Details in Determining EE, CE and EC of 1 m^3 Waste Concrete Works

No	Materials (kg)	Specification	Volume	Unit	EE value (MJ/kg)	CE value (CO2/kg)	EC value (Euro/kg)	SUM EE (MJ)	SUM CE (kgCO2)	SUM EC (Euro)
A	Normal Concrete (NC)									
1	Cement	Portland Cement	413,00	kg	4,60	0,92	0,15	1899,80	378,72	61,95
2	Fine Aggregate	General, exclude transportation	681,00	kg	0,10	0,01	0,09	68,10	3,41	61,29
3	Coarse Aggregate	General, exclude transportation	1021,00	kg	0,10	0,01	0,23	102,10	5,11	234,83
4	Water	Water supply only, e.g. excludes water treatment, considering the water ends up in the product.	215,00	kg	0,00	0,00	0,00	0,00	0,00	-
							Total	2070,00	387,23	358,07
B	PET Concrete (PC)									
1	Cement	Portland Cement	413,00	kg	4,60	0,92	0,15	1899,80	378,72	61,95
2	Fine Aggregate	General, exclude transportation	672,49	kg	0,10	0,01	0,09	67,25	3,36	60,52
3	Coarse Aggregate	General, exclude transportation	1021,00	kg	0,10	0,01	0,23	102,10	5,11	234,83
4	Water	Water supply only, e.g. excludes water treatment, considering the water ends up in the product.	215,00	kg	0,00	0,00	0,00	0,00	0,00	-
5	PET	Bottle grade, recycling credit	9,28	kg	90,45	-1,85	-0,902	839,38	-17,13	(8,37)
							Total	2908,53	370,06	348,93
C	Shredded Wood Concrete (SWC)									
1	Cement	Portland Cement	413,00	kg	4,60	0,92	0,15	1899,80	378,72	61,95
2	Fine Aggregate	General, exclude transportation	633,33	kg	0,10	0,01	0,09	63,33	3,17	57,00

No	Materials (kg)	Specification	Volume	Unit	EE value (MJ/kg)	CE value (CO2/kg)	EC value (Euro/kg)	SUM EE (MJ)	SUM CE (kgCO2)	SUM EC (Euro)
3	Coarse Aggregate	General, exclude transportation	1021,00	kg	0,10	0,01	0,23	102,10	5,11	234,83
4	Water	Water supply only, e.g. excludes water treatment, considering the water ends up in the product.	215,00	kg	0,00	0,00	0,00	0,00	0,00	-
6	Shredded Wood	General, Recycling wood	47,67	kg	8,50	0,00	0,00	405,20	0,00	-
	TOTAL							2470,43	386,99	353,78
D	Disposable Diapers Concrete (DDC)									
1	Cement	Portland Cement	413,00	kg	4,60	0,92	0,15	1899,80	378,72	61,95
2	Fine Aggregate	General, exclude transportation	670,62	kg	0,10	0,01	0,09	67,06	3,35	60,36
3	Coarse Aggregate	General, exclude transportation	1021,00	kg	0,10	0,01	0,23	102,10	5,11	234,83
4	Water	Water supply only, e.g. excludes water treatment, considering the water ends up in the product.	215,00	kg	0,00	0,00	0,00	0,00	0,00	-
7	Disposable Diapers :									-
-	Superabsorbent Polymers (SAP)	Sodium polyacrylate --> PMMA (Acrilylic Polymethyl methacrylate), recycling credit	2,89	kg	131,00	-5,54	-1,59	378,65	-16,00	(4,60)
-	Polypropylene	recycling credit	1,94	kg	93,97	-0,77	-0,81	182,05	-1,48	(1,58)
-	Pulp	Cellulose polymers (CP), recycling credit	4,24	kg	31,58	-2,58	-0,47	133,81	-10,92	(2,00)
-	Polyethylene	recycling credit	0,64	kg	89,72	-0,99	-0,87	57,63	-0,64	(0,56)
-	Polystyrene	recycling credit	0,64	kg	103,83	-2,11	-1,11	66,69	-1,36	(0,71)
							Total	2887,79	356,78	347,69

Discussion

In general knowledge, when EE increases, the CE will also increase [240]. Nevertheless, the thing does not happen when the materials get recycled. Although the EE of disposable diaper is the highest, when the materials conduct as recycled components, the recycling credits is given as a value to reduce carbon emission [246].

In general, the fundamental concept of EC is to convert the CE into currency unit that must to pay as the consideration of emission released during the creating process/product [246] [248]. This amount of EC became an environmental tax that embed into the process/product. In some countries, the implementation of EC is used to recover the environment such as for planting more trees. Although the aggregates derive from nature, but the replacement from its habitat will change the ecosystem cycle, so the emission will release during the process, and the environmental tax may be added as the consequence. For the water as long the process excluded transportation, energy or treatment, the emission and EC set zero [246] [247]. Likewise, for the shredded wood, the recycling process give zero value for both emission and environmental tax. In Figure 50, Figure 51, and Figure 52 describe the comparison of EE, CE and EC value of 1 m^3 concrete works in this study. As it is predicted from the EE value of the material components from disposable diaper and PET, the EE for the materials are the highest too, as can be seen in Figure 50. When the disposable diaper added as a concrete component, the energy is embedded during its life. From Figure 50, we can see that normal concrete is still much lower EE compared to other concrete that is filled by recycled materials. This happens due to EE from filled material still embedded during its life cycle. For the manufacture product, there is no other way to reduce EE from the product that had been created, because the energy of the process is already merged. The EE should be considered in the planning phase. When the product is already created, the best way is to reduce its effect when the product degraded to environment.

Figure 51 shows the opposite. Although compared to normal concrete, the EE of recycled material concretes are higher, but in terms of CE, the concrete product could cut more emission. The recycling credits are given to the DDC and PETC. While for the SWC the EC and CE are similar to the NC product. The shredded wood does not give significant value in terms of CE and EC, because it is a natural product, the environment could degrade the product by itself, without being recycled. But the other value may add as economic value. The recycling process could give economic value for natural products.

The similar calculation conducts for other concrete product in this study. According to Figure 52, the EC of recycled material concretes are lower than the normal one. The principle is similar with the explanation in previous paragraph, regarding recycling credit that reduces the emission and makes the value of EC becomes minus.

Furthermore, what we could find out is the volume has a significant role in raising the environmental indicator value. For example, the coarse aggregate has a similar value of EE, CE and EC to fine aggregate, but the volume of material is higher. When the calculation is summed, the result comes with higher EE, CE, and EC value for coarse aggregate.

Conclusions

The main objective of this study is to reveal the benefits of the environmental aspect by recycling waste material as concrete components. Based on the analyses that employs several environmental impact indicators, it reveals that:

1) Although for LCA method, this case study is uncertainty due to the unavailable inventory data, but the calculation approach is applicable for such condition.
2) In the term of EE indicator, SAP as disposable diapers components has the highest EE value with 131 MJ/kg. However, when the materials are compounded as concrete components, PET is slightly higher than disposable diapers. It contributed to 2908.53 MJ/m^3 concrete work, while disposable diaper is only 2887.79 MJ/m^3. The result is due to the volume of PET compared to SAP is larger. For the lowest EE is the normal concrete (without adding waste material).
3) In terms of CE indicator, waste concrete materials are lower than normal concrete. Especially for DDC and PETC, the recycling credit is given to reduce emission. DDC contributes to low CE as amount 370,06 kgCO2 and PETC decrease as much 356,78 kgCO2.
4) In terms of EC, wasted concrete materials also give lower environmental tax compared to normal concrete. DDC is the lowest, followed by PETC as the second lowest.
5) SWC does not give significant value in terms of CE and EC, because it's a natural product, the environment could degrade the product by itself, without being recycled, so there's no recycling credit for natural material.
6) Due to the recycling credit that gives to materials, although the materials have high EE in the creating process, when the material get recycled, it will reduce the EC and CE. But still, the EE of materials should be considered in terms of processing phase. Processing phase also could create emission and environmental tax.

5.4 Result on Availability of the Source

Due to the population growth become the main issue of waste production, this case study involved metropolitan city in Indonesia. The other criteria in determining case study is population age of 0-4 years old, because the waste production for disposable diapers derived from this population. Another one is waste management in the case study, how the government or local communities deal with the waste production. These criteria for selected city are compiled from secondary data based on Indonesian Municipal Central Bureau of Statistics (BPS). Based on the criteria, Bandung is appropriate to be the selected city due to the available information that provide in Table 49.

Table 49. Selection Criteria for Waste Capacity of Disposable Diaper

No.	Metropolitan Cities	Population	Population Age 0-4	Waste Production	Waste Treatment	Source
1	East Jakarta	3 037 100	238 497	not available	not available	[270]
2	Bekasi	3 003 900	not available	not available	not available	[271]
3	Surabaya	2 896 000	183 975	not available	not available	[272]
4	Bandung	2 507 900	182 116	66 472 340	Categorized	[273]
5	West Jakarta	2 434 500	184 826	67 461 490	Not Identify	[274]

Table 50. Waste Type Separation in Bandung City [273]

Garbage Type	(m^3/Day)	Percentage %
Food waste and leaves	772,69	44,51%
Woods and twigs	69,09	3,98%
Paper	227,76	13,12%
Plastic	324,28	18,68%
Metal	15,62	0,90%
Cloths	82,46	4,75%
Rubber and leather	41,32	2,38%
Hazardous waste	131,42	7,57%
Others	71,35	4,11%
Total	1 735,99	100,00%

Based on population criteria, Bandung is fourth rank the most populous city in Indonesia. Compared to other populous cities, the information waste management in Bandung also available. Table 50 shows the garbage type that currently separated in municipal solid waste of

Bandung. For disposable diapers waste, there is still categories to other type of garbage. Unlike other categories such as plastic, cloth or metal which have value to be recycled, disposable diaper is still unvaluable. The waste will be ended up in the incineration system. The recycling idea for disposable diapers will be triggered the government or society to separate the waste and turn it into new valuable items.

To calculate the volume of diaper waste that can be recycled into building components, a concrete mix design calculation approach is based on Indonesian National Standard (SNI) 7394:2008 The Procedure for Calculating the Unit Price of Concrete Work for Building and Housing Construction [169]. It should be noted that the use of concrete mix design in this case study is only for simplifying calculations. For more valid mix design results, it is necessary to carry out further laboratory tests, such as tests for aggregates and other mixed materials for concrete.

For example, in this part, the concrete was designed in high strength of K-300 with the composition for 1 m3 concrete is 413 kg coarse aggregate, 1021 kg fine aggregate and 681 kg Portland cement. The disposable diapers is replacement for fine aggregate. The optimal percentage of replacement is 5% to 10% addition to reach the optimal compressive strength [170] [171] [12].

According to *Equation 4* and *Equation 7*, the capacity of waste disposable diapers in case study is determined:

ρ_d= 182116 people (pc)

F_d= 5 pc/day

m_d = 30.06 gr/pc

ρ_d= 1400 kg/m^3 (middle range)

ρ_{fa}= 2082 kg/m^3

m_{fa}= 681 kg

$\%_{rep}$= 7.5% (middle range)

Then the capacity of waste disposable diaper in Bandung can be determined based on *Equation 4* as:

ρ_d= 182116 people (pc)

C_d= 27372 kg/day = 19.56 m3/day

Source Availability

Parameters on Waste of Disposable Diapers Capacity

Frequency of using diapers (Fd)

Parents Background
- ✓ Age and sex
- ✓ Education
- ✓ Marital status
- ✓ Job and income

Children Background
- ✓ Age and sex
- ✓ breast feeding
- ✓ toilet training

Population of children in range of 0 to 4 years old (Pb)

Weight or mass of disposable diapers (md)

Average: F*d*=*5* pc/day

Age of baby	Diapers Use Frequency	Source
0 - 12 months	2 - 6 times per day	[159]
0 - 4 years	11 - 15 times per week = 2 - 3 per day	[17]
0 - 3 years	2 - 10 times per day	[158]
0 - 6 months	1- 6 per day	[154]
0 - 1 month	3 - 9 times per day	[155]
0 - 1 month	3 - 8 times per day	[156]
0 – 14 month	5 – 9 times per day	[160]

Pb = 182116 people (pc)

No.	Metropolitan Cities	Population	Population Age 0-4	Waste Production	Waste Treatment	Source
1	East Jakarta	3 037 100	238 497	not available	not available	[270]
2	Bekasi	3 003 900	not available	not available	not available	[271]
3	Surabaya	2 896 000	183 975	not available	not available	[272]
4	Bandung	2 507 900	**182 116**	66 472 340	Categorized	[273]
5	West Jakarta	2 434 500	184 826	67 461 490	Not Identify	[274]

Average : md = 30.06 g/pc

Quantity	Weight	Source
12 pc	318.2 - 429.6 g = 26.5 – 35.8 g	[161] [162]
1 pc	26.5 - 27.4 g	[160] [162]
1 pc	28.04 - 36.1 g	[162]

Amount of diapers:

Cd = Pb x Fd x md

Example: The capacity of waste disposable diaper in Bandung

Cd = Pb x Fd x md

Cd = 27372 kg/day

= **19.56 m^3/day**

Figure 53. Source availability of disposable diaper waste

Then the capacity of recycled disposable diapers for 1 m^3 concrete component is based on *Equation 7*:

m_d = 34.35 kg= 0.025 m^3

Then, capacity of disposable diapers concrete that can be produced in Bandung is determined by *Equation 8* is 796.99 m^3.

Next the author tries to simulate the calculation of this diaper concrete production with a design proposal for a type 36 housing with the standard structure shown in the following Table 51. The table shows the capacity of diaper concrete that can be used to build a housing of type 36, which is 48.15 m^3. By considering the daily production of diaper concrete, which is 796.99 m^3, approximately 16 units of type 36 houses can be obtained. In addition, the author tries to simulate the disposable diapers concrete as road pavement. The calculation by designing a 4 m wide pavement with a thickness of 20 cm and the result is 0.997 km of road pavement can be constructed. However, it is noted that this calculation is for daily diaper waste production, if it is calculated in monthly or yearly terms, there will be even more amount of diaper waste that must be added recycled into building components or road pavements.

Table 51. Estimation on design simulation of housing type 36

Building component	Dimension (m)	Unit	*DDC (m^3)
Colom	0.3 x 0.3 x 3	9	2.43
Beam	0.3 x 0.4 x 3	12	4.32
Wall Panel	3 x 3 x 0.05	12	5.4
Floor	6 x 6	1	36
Total DDC per housing unit of type 36			48.15

*DDC = disposable diapers concrete

Based on those simple simulation and calculation approach, this paper is recommended for recycling the disposable diapers as concrete component, it would be more effective as road pavement that housing component.

5.5 Conclusion

Based on the result, the considering of recycling waste disposable diaper to concrete components, give more beneficial environmental impact such as:

1. Compare to other waste treatments, recycling is the best choice to decline environmental impact cause by waste disposable diaper.
2. Recycling process reduce 2.93 kgCO2 and reduce 0.91 Euro per kg waste disposable

diaper for environmental tax.

3. In the term of concrete component, the use of waste disposable diaper in certain amount is not significantly reduce the physical and mechanical properties of the concrete, so it’s visible to apply for the material.
4. Although for LCA method, this case study is uncertainty due to the unavailable inventory data, but the calculation approach is applicable for such condition.
5. In the term of EE indicator, SAP as disposable diapers components has the highest EE value with 131 MJ/kg. However, when the materials are compounded as concrete components, PET is slightly higher than disposable diapers. It contributed to 2908.53 MJ/m^3 concrete work, while disposable diaper is only 2887.79 MJ/m^3. The result is due to the volume of PET compared to SAP is larger. For the lowest EE is the normal concrete (without adding waste material).
6. In terms of CE indicator, waste concrete materials are lower than normal concrete. Especially for DDC and PETC, the recycling credit is given to reduce emission. DDC contributes to low CE as amount 370,06 kgCO2 and PETC decrease as much 356,78 kgCO2.
7. In terms of EC, waste concrete materials also give lower environmental tax compared to normal concrete. DDC is the lowest, followed by PETC as the second lowest.
8. SWC does not give significant value in terms of CE and EC, because it’s a natural product, the environment could degrade the product by itself, without being recycled, so there’s no recycling credit for natural material.
9. Due to the recycling credit that gives to materials, although the materials have high EE in the creating process, when the material get recycled, it will reduce the EC and CE. But still, the EE of materials should be considered in terms of processing phase. The processing phase also could create emission and environmental tax.
10. Parameters to calculate waste capacity for disposable diapers is age population of 0-4 years, frequency of changing diaper and mass of diaper.
11. The amount or capacity of diapers is depending on the case study or area of population. The higher the population of babies the higher amount of waste can be produced. By determining 182116 population of babies, the amount of disposable diapers produce is 19.56 m^3/day

Chapter 6

Feasibility Study on Construction System

6.1 Development of Construction Technology for Housing in Indonesia

Since 2015, reducing the housing backlog and providing affordable housing has become a policy priority for the Indonesian government. The government has developed a policy objective to meet the demand for new households and address the housing deficit through a program of *Satu Juta Rumah* (One Million Housing/OMH) which was officially launched on April 30, 2015 [277]. This program is launched for 5 years with the aim of producing an average of one million housing each year. This target set by the government is providing the need for affordable housing for new households and reducing the existing housing deficit.

Simultaneously, housing construction has been developed massively and to support the construction program, building materials procurement become one issue to be solved. Based on the data [278], in 2012 national cement sales amounted to 55.0 million tons, after rising rapidly from 48.0 million tons in 2011 and 40.8 million tons in 2010, followed by ceramic products. Beside cement industry, steelworks are set to be among the main beneficiaries of rising construction activity, while aluminum is becoming an increasingly popular building material. Readily available deposits of clays, feldspar and silica sand support the industry, while low per-capita consumption leaves space for expansion [278].

In line with government programs, the fulfilment of housing provision is important, but there are several limitations in the provision of building materials. Until now in Indonesia, the use of building materials is still dominated by concrete, bricks, woods, and ceramics [115]. In term of environmental consideration, the conventional building materials causes new problems, as an example clay bricks and tile contribute the highest embodied energy [115], carbon emission and eco-costs [132].

By considering the limitations, many researchers have studied and have developed alternative building material that may become more affordable and low-costs, as well have good performance. Thus, this paper is trying to elaborate more comprehensive on alternatives building materials for low-cost housing in Indonesia by describing the existing low-cost housing from policy to innovation in order to give recommendations and new insight for housing planners or architects.

To elaborate implementation low cost-housing, at least there are three factor influences: policy, building materials and low-cost housing construction [279]. In order to fulfill the objective of this study, literature review by compiling information using search engine is conducted. The data collection is done by elaborate scientific papers in appropriate journal publisher using searching keywords such as 'low-cost housing', 'building materials', 'low-cost building material,' 'Indonesian housing policy', '*program sejuta rumah'*. Moreover, the analysis of data is conducted by comparing and compiling the information provided. The analysis then divided in to three discussions: first, development of housing policy by describe history of housing policy in Indonesia. The brief history is explained in four governmental period: the Pre-Independence period, Old Order, New Order and Reformation Era. Next development of building materials is described from the using of natural material for housing until using industrial material. As well the material standards also become a part of elaboration. For the final discussion is elaboration existing material for low-cost housing and its alternatives. The alternative is derived from the latest researches of building materials for low-cost housing that have been implemented in some countries and proposed to be implemented.

The development of the National Housing Policy through formal institutions has started since the Pre-Independence period. During the Dutch colonial period, housing policy was regulated in *Burgerlijke Woningsregeling* 1934, which was implemented using *Algemene Voorwaarden voor de uitvoering bij aanneming van Openbare Werken in Indie* 1941 and *Indische Comptabiliteits Wet* [280]. The implementation of these provisions is carried out by the *Van*

Verkeer en Waterstaat Department which handles public housing (*Volkshuisvesting*) and state/government buildings/houses (*Landsgebouwen*) as well as *Pest Bestrijding* to handle urban disease outbreaks [279]. Meanwhile, during the Japanese colonial period, housing policy was handled by *Doboku*, which was a substitute agency for the *Van Verkeer en Waterstaat Department* [279]. For further information of housing policy history in Indonesia, is showed in Table 52.

In 2015, within the OMH program, the central and local governments carried out housing developments throughout the country. The initiative primarily targets low-income households or *Masyarakat Berpenghasilan Rendah* (MBR), other income groups are also eligible for government subsidies. OMH spans the following [281]:

1) Regulations relating to taxation, financing schemes, and land use to facilitate housing development;
2) Provision of housing for low-income households. These include simple rental flats (Rusunawa), special purpose houses (Rusus), and home improvement subsidies (Bantuan Stimulan Perumahan Swadaya, BSPS); and
3) Access to housing finance through credit-linked programs. The main programs (and hence the focus of this chapter) are mortgage-linked subsidies, also known as KPR (*Kredit Perumahan Rakyat*).

Then Figure 54 shows the achievement of OMH program from 2015 to 2020, that has reached more than 5,3 million units in total. In the first year, the program couldn’t meet the target expected. It was only reach 0,6 million units. But then, with the rapid coordination of the stakeholders: government, financial institutions, the private sector and the community, the program are consistently increasing every year. However, it experienced a great contract in 2020 related to the Covid-19 pandemic and changes that occur in the world.

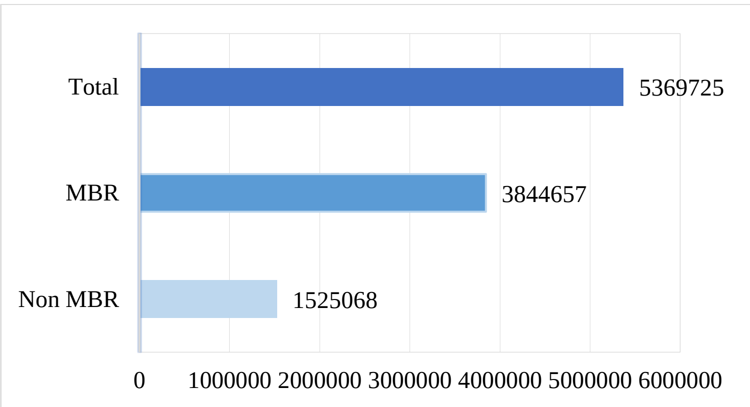


Figure 54. Number of Houses Built in OMH Program 2015 – 2020 [282]

Table 52. Development of housing policy in Indonesia

Period	Housing Development Description
Dutch Government 1924 - 1932	The policy targets still limited to civil servants, rental houses, and environmental improvement in the context of health and was intended to support Dutch Government for example *Kampung Improvement Program* (KIP) in Surabaya; Construction of Loji, a large house belonging to a Dutch official;
Orde Lama (Old Order) 1950 - 1969	The government began to focus on developing housing for the people by establishing a public housing agency and also formulating minimum housing standards and technical regulations related to housing structure and sanitation. This development focus was also supported by the Implementation of Land and Building Tax (PBB), MPRS Decree no. 2 / 1960, Basic Housing Law no. 2, 1962 concerning Housing Policy for the underprivileged. Previously the *Yayasan Karya Pembangunan* (YKP) targeted 12,000 houses by developing Public Housing (PERUM) of Tenggilis and Jemur Handayani in Surabaya, and Unmer in Malang which was later the form of housing adapted in Law no. 1 of 1964 (Perpu 1962). Then the KIP program held in Jakarta.
Orde Baru (New Order) 1972 - 2000	The government established official bodies to support public housing programs such as the National Housing Coordinating Board (BKPN) and National Public Housing (Perumnas). In addition, there were also community organizations in housing matters such as Real Estate Indonesia. This policy encourages the development of new residential areas such as in Jakarta and Medan and KIP became a national program. In terms of financial support for housing, there were PT. Papan Sejahtera (Bank Papan) and Group-based Housing Development (P2BPK) and support by housing loans (KPR) that was provided by private banks.
Reformation Era 2000 - now	Construction of *Rusunawa/Rusunami*; Self-help Housing by financial supporting.

6.1.1 Building Materials Standards and Regulations

Before building material's industry have developed, in Indonesia, building material was dominated by natural material, such as wood, bamboo and stone. For instance, in West Java, there are several traditional dwellings called *Kampong Adat.* Figure 55 shows traditional housing in several *Kampung Adat* in West Java where the government inaugurated to secure its authentic. The *Kampong Adat* has been built for hundreds of years without any change in structure or building material and using local material that is derived from its neighborhood [283] [249].

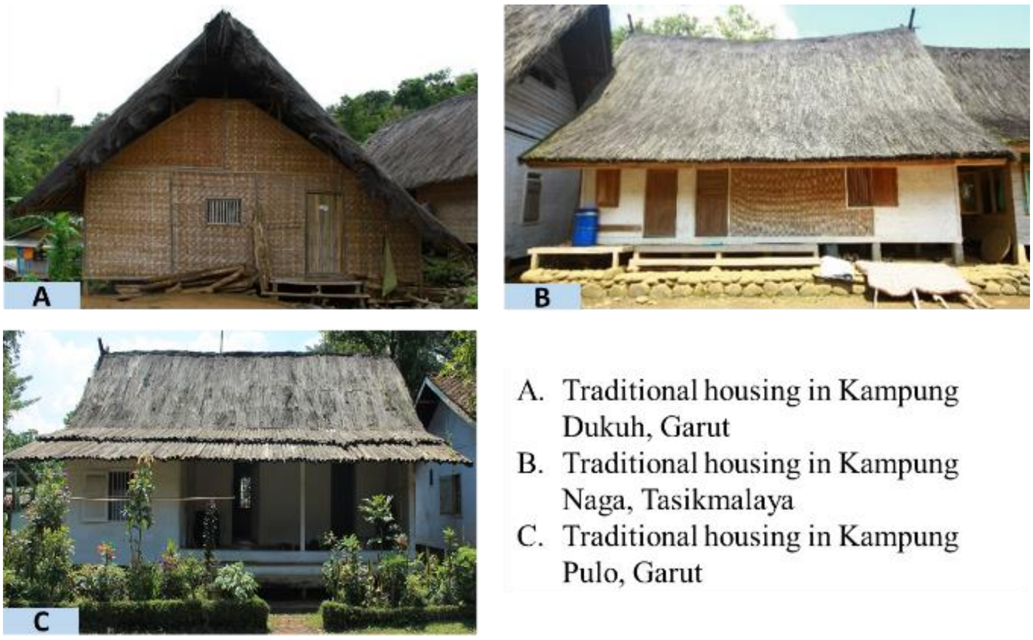


Figure 55. Traditional Housing in West Java, Indonesia [249]

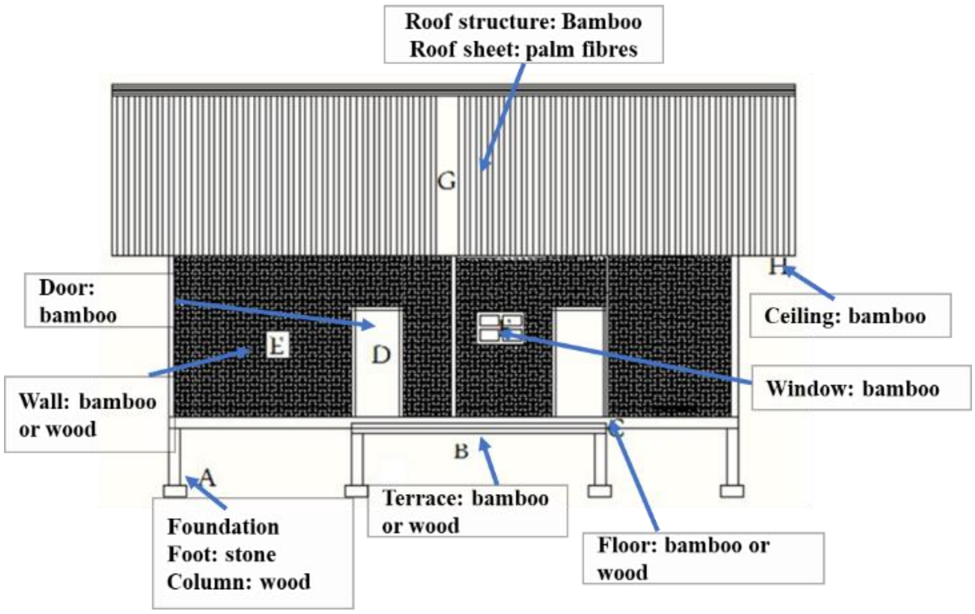


Figure 56. Identification Of Building Materials for traditional housings in West Java, Indonesia [249]

Based on previous study conducted in Kampung Dukuh, Kampung Pulo and Kampung Naga, the materials for building components can be seen in Figure 56. In line with the development of science and technology and also globalization, the usage of material for building in Indonesia have been evolving. The building material is not limited to natural material but also change to material composite such as burnt clay, concrete and steel. For natural materials also have been transforming became more durable by adding preservative or by using laminating technology. To accommodate the building materials technology, the Indonesian government then enforce the standards for building materials through official board called *Badan Standarisasi Nasional* (national standardization agency). Thus, the standard is entitled *Standar Nasional Indonesia* (SNI). By referring to SNI, the building materials in Indonesia currently is showed in Table 53.

Table 53. Current building materials and its standard in Indonesia

Materials for Building	Standard
Aggregate	SNI 03-2461- 1991
Bondek (Lightweight steel plat)	SNI 03-1729- 2002
Bricks	NI-3; NI- 1O
Cement	SNI 15-0129-2004; SNI 15-0302-2004; SNI 15-2049-2004; SNI 15-2049-2004; SNI 15-3758-2004; SNI 15-7064-2004
Ceramic	SNI 03-1331- 19
Clay	SNI -2835- 2008
Concrete bricks	SNI 03-2784- 02
Concrete roster	SNI 03 - 2847 - 2002
Fly ash	SNI 03-0349- 89
Gravel	SNI 03-2847- 2002
Gypsum	SNI 03-6821- 2002; SNI 13-3496- 1994
Iron/ferro	SNI DT-91- 0014-2007
Lightweight bricks	SNI 03-1726- 2012
Lightweight concrete	SNI 03-2461- 2002;
Lightweight steel	SNI 07-0358- 1989
Lime	ASTM C-926- 90; SNI 02-0482- 1998; SNI 03-6825-2002
Marble	SNI 19- 6728.4-2002
Multiplex	SK SNI T-15- 1991-03
Paving Blok	SNI 03-0691- 1996; SK SNI T-04- 1990-F
Porcelain	SNI 7275:2008
Roof Tile	SNI 03-2095-1991; SNI 03-0096- 1999

Materials for Building	Standard
Sand	SNI No: 1737- 1989-F; SNI-03-2847- 2002; SK SNI S-04-1989-F:28; SNI.15-2094- 1991; SNI 01-3140- 2001; SNI 01-3922- 1995
Sandstone	SNI:1732- 1989-F
Steel	SNI 03-1729-2001
Steel reinforcement	SNI 03-3435-2002
Stone	SNI 01-3839-1995
Stone ash	SNI 03-0349- 89
Tras Bricks	SNI 01-6128 –2008
Water	SK-SNI-S04-989-F; ASTM C 109
Wood	SK SNI 03- 5007.2-2000
Zinc	SNI 07-0311- 1989

6.1.2 Technology on Housing Construction

Previous study was conducted to elaborate building materials for low-cost housing by collecting information from housing advertisement and by interviewing housing developers. The results showed that generally the developer decide to use building materials based on consideration of building materials availability in housing area. In addition, the price of building materials is another factor for determining construction costs. On table 4, the result of previous study describes that for low-cost housing, the use of building materials is dominated by concrete, bricks, and other industrial materials.

Based on Table 54, the use of low-cost housing materials in Indonesia is not much different from the use of housing materials in general. This causes housing prices to remain high. In order to lower the price, Indonesian government within its financial supporting, provides subsidies for housing construction. In fact, using lower-priced materials can reduce the cost of housing construction.

Table 54. Building materials for low-cost housing in Indonesia [115]

Building Components	Developer 1	Developer 2	Developer n
Foundation	Stone	Stone	Stone
Floor	Ceramic	Ceramic	Ceramic
Column	Concrete	Concrete	Concrete
Wall	Brick	Brick	Brick

Window	Wood	Aluminium	Wood
Door	Wood Panel	Wood Panel	Wood Panel
Roof	Wood frame	Steel frame	Wood frame
Roof Cover	Aluminium	Clay Tile	Clay Tile

Figure 57. Vertical and Landed Housing for Low-income in Indonesia *[371]*

Therefore, to tackle pricing issue, in term of housing construction, Ministry of Public Work and Housing of Indonesia (PUPR) developed *Rumah Instan Sehat Sederhana* (RISHA/Simple Healthy Instant Home). RISHA is a technology precast which by the with reference to technical requirements referring to Ministry Decree No. 403/KPTS/M/2002 that released on December 20, 2004 [284]. RISHA is intended for housing construction of low-cost housing, self-help housing, refugee and emergency housing. This invention is to accelerate housing development and reduce construction costs through prefabrication methods. The components of the house are assembled in the field using a knock-down or permanent system. Knockdown systems can be built with partition walls made of panels fixed with bolts and permanent systems, made of red brick, light brick, con-block, and others. Time required to assemble a type 28.8 m2 is 1 day.

The RISHA technology was then further developed to *Rumah Unggul Sistem Panel Instan* (RUSPIN/Instant Panel System Housing) in 2013 [285]. Similar to RISHA, RUSPIN was developed with a modular system that divides building components into small parts (modules) with efficient sizes so that they can be assembled into a large number of different products [286].

Figure 58. RISHA and RUSPIN: prefabricated concrete components for Low-cost Housing in Indonesia *[284] [285] [286]*

Another innovation developed by PUPR to address housing needs, particularly those related to disasters, is *Rumah Instan Kayu* (RIKa/Wood Instant House). RIKA's innovation is able to improve the quality of low-quality wood into better quality through laminated veneer lumber (LVL) technology [287]. This technology increases the strength of class 3 wood to class 2 wood. However, this technology can only be developed in some areas of Indonesia that have abundant wood production to reduce construction costs. Therefore, fast-growing wood was chosen to

Figure 59. RIKa: Low-quality Wood Innovation for Low-cost Housing in Indonesia [372]

increase production massively, quickly, cheaply, and to increase production forest regeneration.

For alternatives building materials, some researcher also studied several alternatives materials that may use for housing construction which is claimed as low-cost. The materials can be divided in to three: earthen materials, natural fiber and industrial-building waste materials [288].

Table 55. Natural fiber and its applications in building [288]

Item	Application in building material
Rice husk	Fuel, building materials and products
Banana leaves/stalk	building boards, fire resistance fibre board
Coconut husk	building boards, roofing sheets, insulation boards, building panels, as a lightweight aggregate, coir fibre reinforced composite board
Groundnut shell	buildings panels, building blocks, for making chip boards, roofing sheets, particle boards
Jute fiber	chip boards, roofing sheets, door shutte
Rice/wheat straw	roofing units and walls panels/boards
Sawmill waste	cement bonded wood chips, blocks, boards, particle boards, insulation boards, briquettes
Sisal fibers	For plastering of walls and for making roofing sheets, composite board with rice husk, cement roofing sheet, roofing tiles,paper and pulp
Cotton stalk	Fiber boards, panel, door shutters, roofing sheets, autoclaved cement composite, paper, plastering of walls

In term of natural fiber material, the utilization for building is generally applied for panel board, reinforced composite materials and insulation. Thus, for earthen material, the use of lime and mud for non- structural building component such as bricks for wall become more popular. For raw soil is also elaborated more in term of block-forming technology without burning process. While recycled materials by utilization waste of material construction such as steel and rubber will become the best choice to reduce environmental impact.

Table 56. Currently earthen materials and industrial building waste for low-cost housing in several countries

Innovation Materials and Utilization	Source
Lime based-materials: Magnesium lime, Lime kiln rejects, Lime sludges, Activated lime pozzolana mixtures (ALPM)	[289]
Recycled material:	[289] [290] [291] [292]

Innovation Materials and Utilization	Source
Throw-aways/waste/garbage; blocks constructed of recycled building rubble; Recycled steel, concrete diapers	[293] [294]
Slab component: EPS (Expanded polystyrene); Foundry sand	[295]
Insulation materials: Polyurethane foam	[292]
Reinforced materials: Glass fiber reinforced Gypsum technology (GFRG); Glass fiber reinforced composites	[292] [296]
Plastics based- materials: PET bottles, plastics	[297] [183]
Mud based -bricks: Earth (mud), rammed earth, Alumina red mud, non erodable mud plaster; earthbag walls- burnt brick walls; Reinforced mud bricks; Mud concrete block, Soil-stabilized bricks,	[292] [296] [298] [179] [289] [185] [299]
Fly ash -Bricks: Fly –ash sand lime bricks, Fly ash hollow bricks	[289] [179] [300] [295] [294]
Concrete: Dense concrete blocks, hollow clay blocks, Compressed earth block, Solid concrete and stone blocks, Sandcrete; Autoclaved aerated concrete	[179] [287]
Block-soil based: Cement concrete hollow bocks, Cement-stabilised clay blockwall, cement stabilized earth blocks (CSEB), soil cement blocks	[179] [301] [302]
Cover/sheet component: Corrugated roofing sheets; Precast concrete flooring/roofing units; RCC solid plank flooring/roofing; Prefabricated brick panel roofing/flooring	[303]

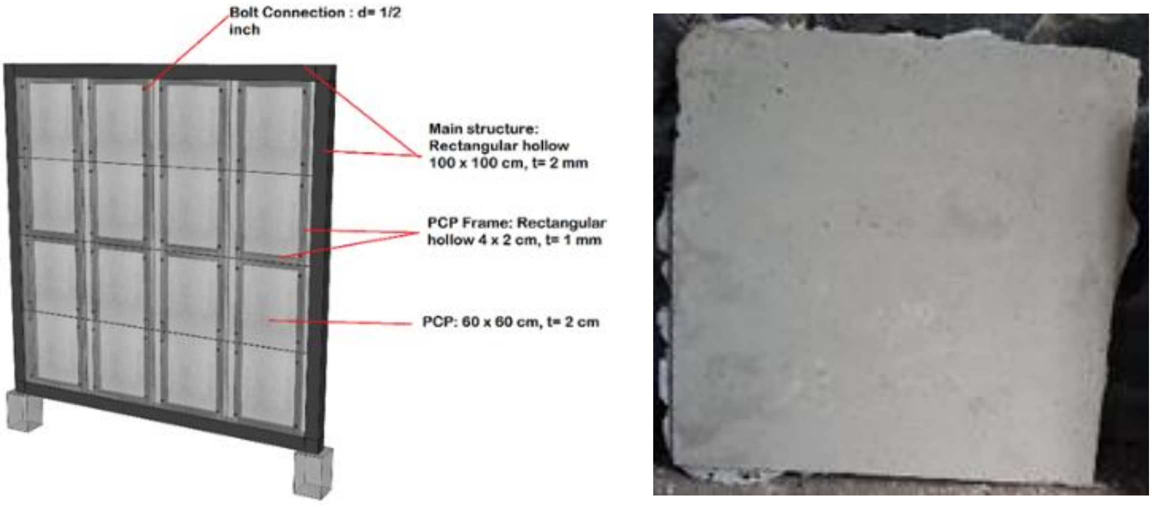


Figure 60. Alternative housing construction from galvanized steel and waste recycling for wall panel [304]

In addition, recycling of plastic- based waste in recent time have become increasing in researches. For housing construction, previous research showed the utilization of steel galvanized as an alternative for housing structure by combining composite material for wall panel. This panel was developed from recycling of plastic waste [304] and wood waste [269].

6.2 Preliminary Design and Construction for Disposable Diapers based Materials

Construction technology is essential to increase the speed of construction and reduce costs. For example, by comparing the construction methods for walls using clay bricks and lightweight concrete panels, the cost of conventional construction on clay bricks is higher than prefabrication method on lightweight concrete panel [304]. The prefabrication method is considered to accelerate construction speed [305] and also effective to reduce construction waste [306], and environmental impact [307] [308].

By linkage, the phenomenon of alternative building material and construction, this paper tries to elaborate on the utilization of undegradable waste for building materials by proposing disposable diaper waste as composite materials for building components. An experimental study conducted by several researchers reveal that the application of disposable diaper waste for building materials give a positive result in terms of environmental impact [309] [310], good durability and strength with a maximum mixture of the diaper is 1-5% [170] [1] and no effect in term of healthiness compared to clean diapers [3] [5]. Nevertheless, the previous studies are only limited to the mechanical and physical properties of materials, and the application of materials for building needs to explore more.

Thus, to overcome the limitation, this paper proposes construction techniques for building materials by using a prefabrication system with modular housing elements. Disposable diaper waste in this study is utilized as panel composite materials for wall and flooring and be applicable for low-cost housing concept. The prototype housing design is illustrated with an area of 36 m^2 based on housing minimum standards in Indonesia and applied prefabrication system with hollow steel as structural components and composite panel with dimensions of 60 x 60 cm as architectural components. Then the final is to calculate the construction cost of the housing.

6.2.1 Methods

The method of study is divided into:

1) An experimental study for building materials was investigated by testing the mortar samples consist disposable diaper waste that are used for housing components such as walls and flooring. The application is designed to meet requirements for building materials based on Indonesian Standard (SNI).
2) Housing design and prototyping by applying the materials requirements on experimental study. The housing design also consider minimum housing area based on Indonesian Standard and simulating prefabrication method for housing construction.

6.2.2 Findings

Determine Public Housing Standard in Indonesia

To solve the housing backlog, Indonesian government improve policy to accommodate housing demands. The policy employs two approaches that are: supply-side approach, which was undertaken through larger supply of housing stocks by government and demand-side approach, through housing financing scheme [277]. The government also controls the maximum price for subsidized housing as shown in table 1 and the minimum size requirement is shown in Table 57.

Table 57. Maximum Subsidized Housing Price for Landed Housing in 2016 – 2018 (In million Indonesian Rupiah) [311]

No	Region	2016	2017	2018
1	Java Island (except Jakarta, Bogor, Depok, Tangerang, Bekasi)	116.5	123	130
2	Sumatera Island (Except, Riau Islands and Bangka Belitung)	116.5	123	130
3	Kalimantan	128	135	142
4	Sulawesi	122.5	129	136
5	Maluku and North Maluku	133.5	141	148.5
6	Bali and Nusa Tenggara	133.5	141	148.5
7	Papua and West Papua	183.5	193.5	205
8	Kep Riau and Bangka Belitung	122.5	129	136
9	Jakarta, Bogor, Depok, Tangerang, Bekasi	133.5	141	148.5

Table 58. Standard for Subsidized Housing in Indonesia [312]

Standard per person (m^2)	Housing Area for 3 persons (m^2)	Housing Area for 4 persons (m^2)
Minimum 7.2	21.6	28.8
(Indonesia) 9.0	27.0	36.0
(International) 12.0	36.0	48.0

Based on the minimum housing subsidized requirements in Table 58, this study illustrate housing prototype design with housing area of 36 m^2 and land area of 60 m^2.

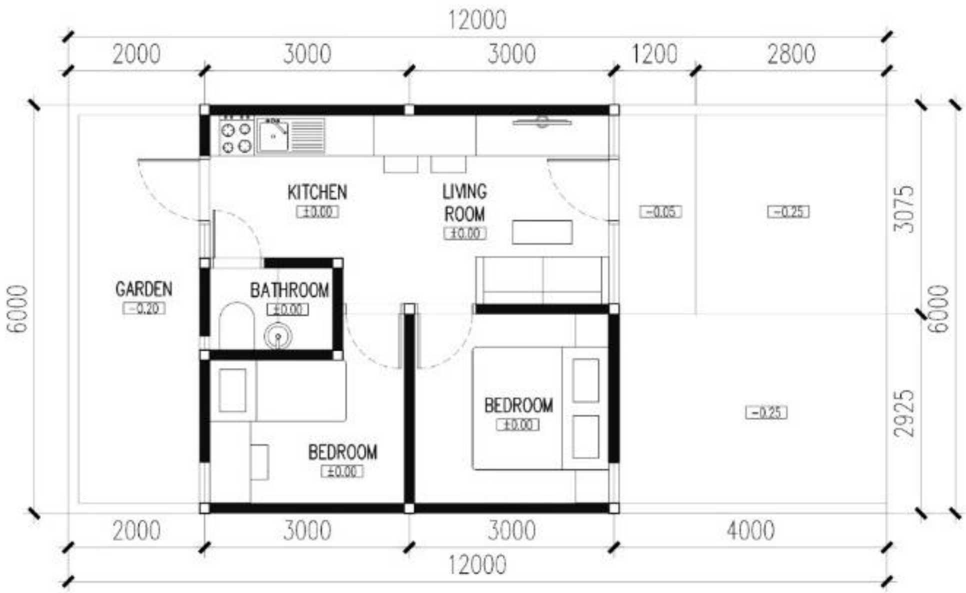


Figure 61. Floor Plan of Housing Prototype of 36 m^2

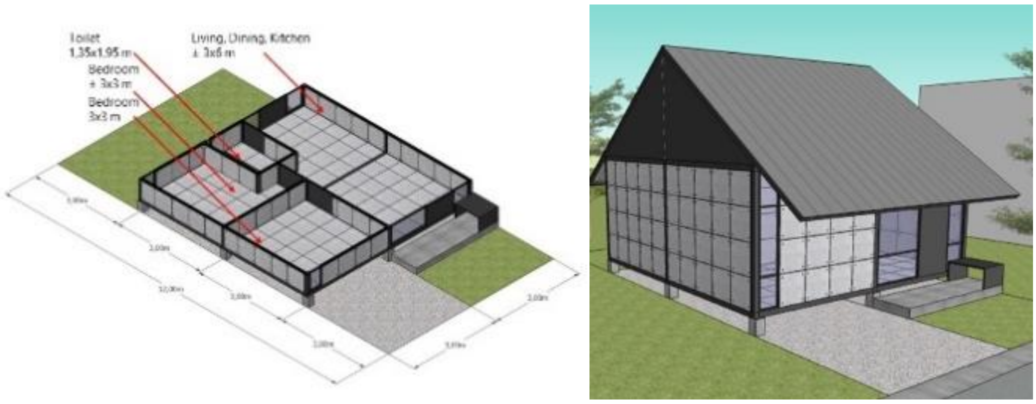


Figure 62. Isometric 3D Plan and Perspective View of Prefabricated Low-Cost Housing Prototype Design

Determine the Formula of Disposable Diaper Waste Utilization for Building Materials

Two ways approach can be used in utilizing disposable diapers as composite materials for concrete, first as filler or addition and second as replacement of fine aggregates in the concrete compounds. However, to decrease the weight of materials the second way is recommended. Thus, by replacing fine aggregates with disposable diapers, the formula is involved in *Equation 12*.

Following the formula, the experimental study had been conducted to measure the compressive strength of mortar which consist of water, fine aggregate, and Portland cement. The mortar standard of building is based on SNI 03-6882-2002 Mortar Specification for Building Materials, which the specification of mortar type is shown in
Table 5.

As a result, the experimental study revealed that the maximum replacement of mortar for utilizing as building materials based on SNI is 30% replacement of fine aggregates to disposable diaper and resulting compressive strength of 5.25 MPa. This maximum replacement is utilized for nonstructural component of building, such as partition and decorative wall. For maximum compressive strength, the replacement is limited to 5% and resulting 8.05 MPa and the utilization for building is also limited to structural wall or supporting wall in surface level and indoor. For more information, table 4 shows the results of experimental study.

Figure 63. Experimental Study of Mortar compounds and Comprehensive Strength Test

Table 59. Experimental Result on Compressive Strength of Mortars and the Utilization

Samples	Strength (MPa)	Utilization
Normal Mortar	11.36	Load bearing wall
MDD 5%	8.05	Structural wall or supporting, surface level, indoor
MDD 10%	6.79	Nonstructural wall or supporting, surface level, indoor
MDD 15%	6.03	Nonstructural wall or supporting, surface level, indoor
MDD 30%	5.25	Nonstructural wall, partition or decorative, indoor and outdoor
MDD 50%	1.11	Not recommended for building components
Note: MDD : Mortar with disposable diaper waste		

Based on the experimental study, the building components for housing is designed with using a maximum replacement of 30% and fits for nonstructural wall or partition for housing. While for flooring, it used 5% replacement with the highest compressive strengths and fits for structural elements.

Prefabrication System on Housing Components

As a principle, the prefabrication system has been known in developing countries for using local materials based on low technology processes and developed by small industries. It has been developed by simple modules, processes, and efficiency in servicing and delivery that supported the construction company to being more responsive and adaptable to the uncertain market housing on a low scale [313]. In Amerika and Canada, prefabricated housing is known as manufactured house that is supported by steel structure in following mobile home or caravan as dynamic housing that become the ancestor in almost four hundred years. It involves several procedures in manufacturing such as assembly the housing components off site construction location before the component installed in the site construction [314].

Previous study that conducted by the authors [304], had proposed the utilization of plastic waste for wall panel and prefabrication method for construction with varies installation concepts. The studied estimate construction costs for propose prefabricated system by comparing three alternative designs that are construction by hollow steel as a frame, double C channel and in site construction. The study revealed that hollow steel frame with bolt connection is recommended due to more applicable and low cost compared to other designs.

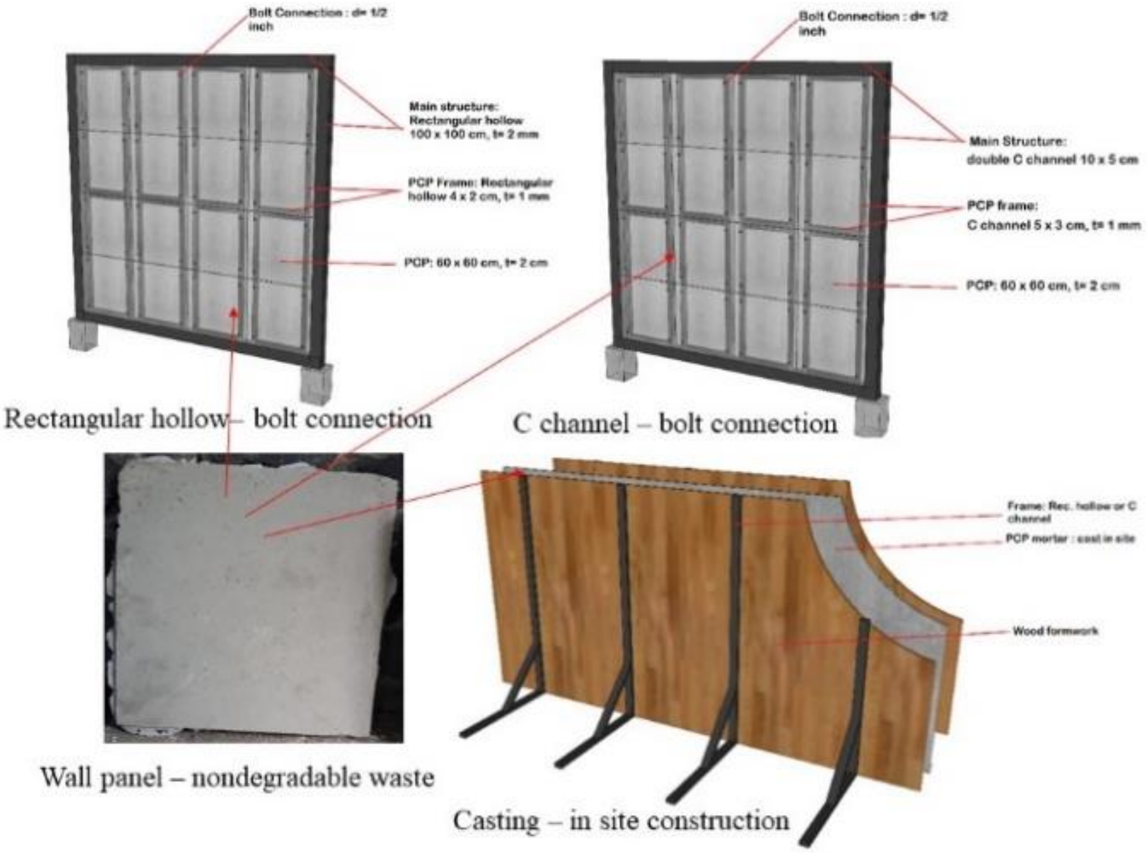


Figure 64. Comparative study of Installation and Connection Design of Prefabricated Wall Panel [304]

By applying the same concepts, this study tries to elaborate disposable diaper waste for building material in form of panel with dimension of 60 x 60 and proposed to be utilized as wall and floor component of housing. The prototype housing design is illustrated as low-cost housing with housing area 36 m^2 and land area 60 m^2. The structure is developed by using rectangular hollow steel frame with the dimensions of column and beam of 10x10 cm and for panel frame dimension of 2x4 cm. Other buildings components such as roof structure is constructed with rectangular hollow steel frame with dimensions of 4x8 cm and roof sheet is covered with metal roof. The connection between all elements is using bolt connector.

However, the housing prototype design in this study does not include structural analysis comprehensively. Brief structural analysis conducted to estimate the safety of proposed structure and conclude that the structure has the largest deflection of 7.8 mm and is smaller than the maximum required deflection of 12.9167 mm.

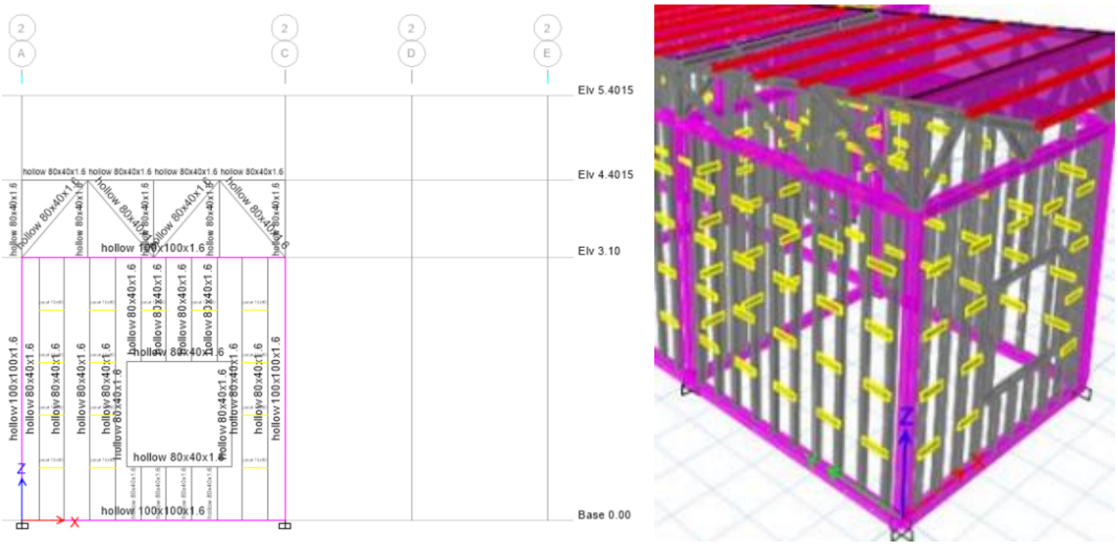


Figure 65. Schematic Diagram of Structural Analysis of Prototype Housing Elements

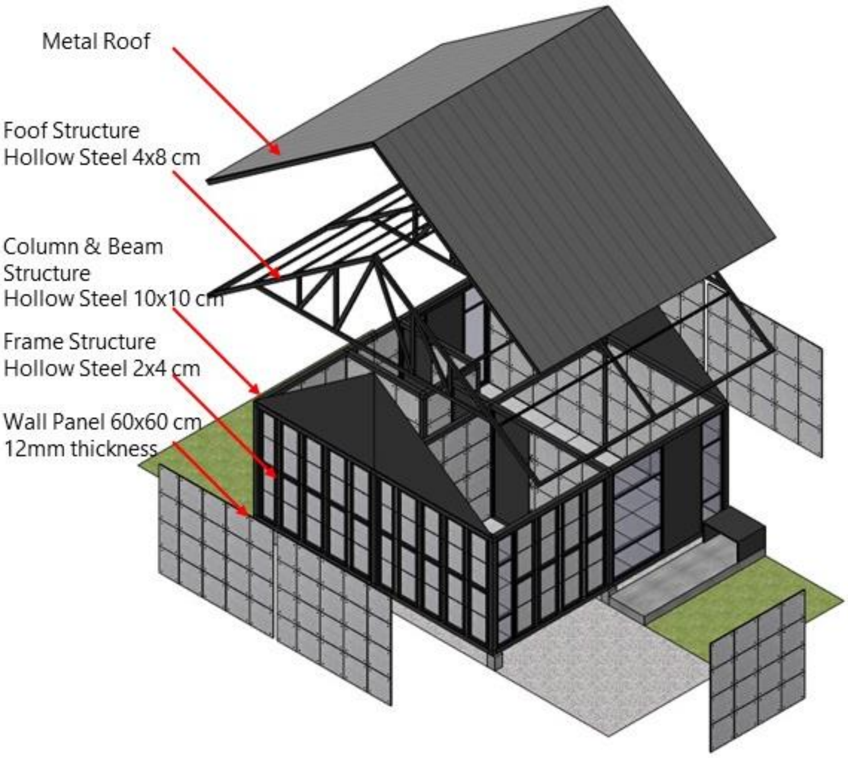


Figure 66. Exploded Axonometry of Prefabricated Low-Cost Housing Prototype Design

Construction Cost of Housing Prototype Design

In estimating construction cost of the design, there are some limitations that be considered due to the different technical aspects that involved several phases from clearing the site, construction stages to finishing stage such as coating and installation. In this study, the phases are not identified comprehensively but are limited to the assembly of upper housing components. The understructure of housing such as the foundation is outside of the calculation due to it is needed to elaborate more in terms of soil bearing capacity to determine foundation type and dimension. To interpret the findings and avoid bias, the scenario of construction cost is clearly stated in Table 60.

Table 60. Limitation Scenario for Construction cost of prefabricated low-cost housing prototype

No	Construction Phases	Scenario
1	Site work and foundation	Site clearing, trimming, site measurement, soil works, foundation and other works related to site works and under structure are with lumpsum/common cost estimation
2	Rough framing	Column, beam, wall, roof, and other upper structures and building elements are included in the detail calculation
3	Exterior construction	The stage involves installing the windows, doors, siding, plaster work and painting are with lumpsum/common cost estimation
4	Mechanical, Electrical, Plumbing (MEP)	Lumpsum/ common cost estimation
5	Interior construction	Outside the calculation
6	Hardscape and Landscape construction	Paving and planting for outdoor aesthetic are outside the calculation

Table 60 describe construction cost scenario in this study is only limited to site work and foundation, rough framing, exterior construction and MEP installation. Further for unit price analysis is only limited to rough framing due to this scenario is involved whole prefabrication process. While for other works is only estimated by lumpsum scenario. In addition, the price analysis for housing construction is adjusted to Indonesian standards regarding unit price analysis, i.e.:

1) SNI 2837:2008: The procedure for calculating the price of the plastering unit for the construction of buildings and housing [315]
2) SNI 7394:2008: The procedure for calculating the unit price of concrete works for the construction of buildings and housing [169]
3) SNI 7393-2008 - procedures for calculating the unit price of steel and aluminum work for the construction of buildings and housing [316]
4) Regulation of The Minister of Public Works and Housing, Republic of Indonesia, Number 28/PRT/M/2016: Guidelines for Unit Price Analysis on Public Work [317]

The region for housing prices is also limited to Java Island, with a case of study in Bandung as an urban city in Java. This case of study is important to be decided because housing construction cost, price of materials and fee of labor is different by region. As a result, construction cost in this study is elaborated for prefabricated housing components with include wall panel and frame construction (Figure 67), floor panel and frame construction (Figure 68). Thus, the result of the construction cost for each component can be figured out in Table 61. Moreover, to capture comprehensive construction cost estimation, Table 62 shows the total cost of construction.

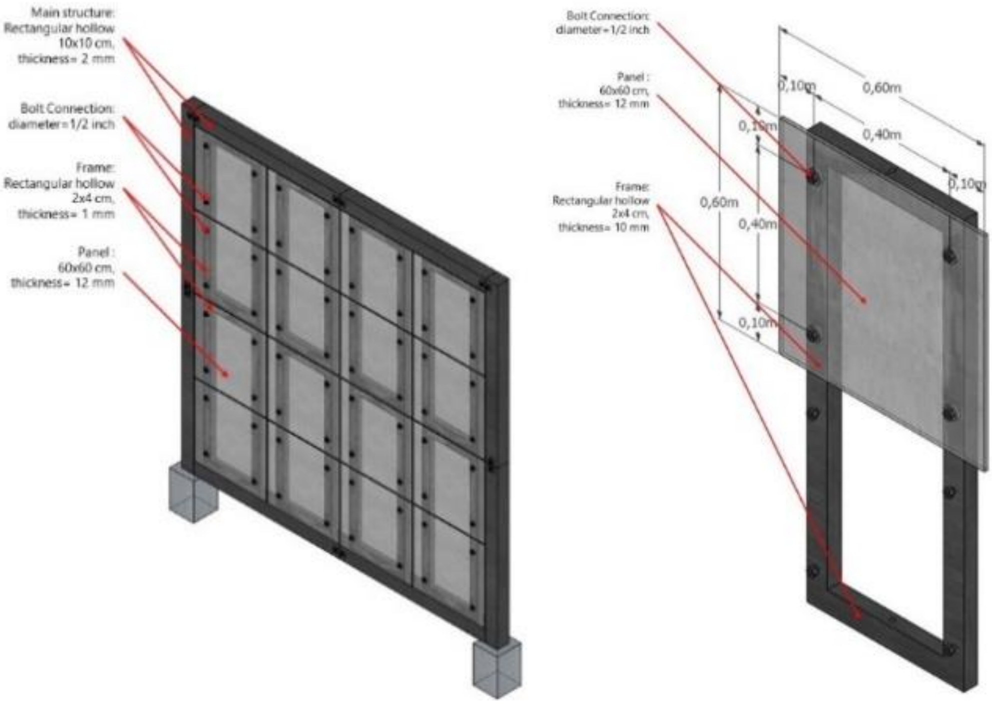


Figure 67. Isometric Wall Panel and Frame Construction

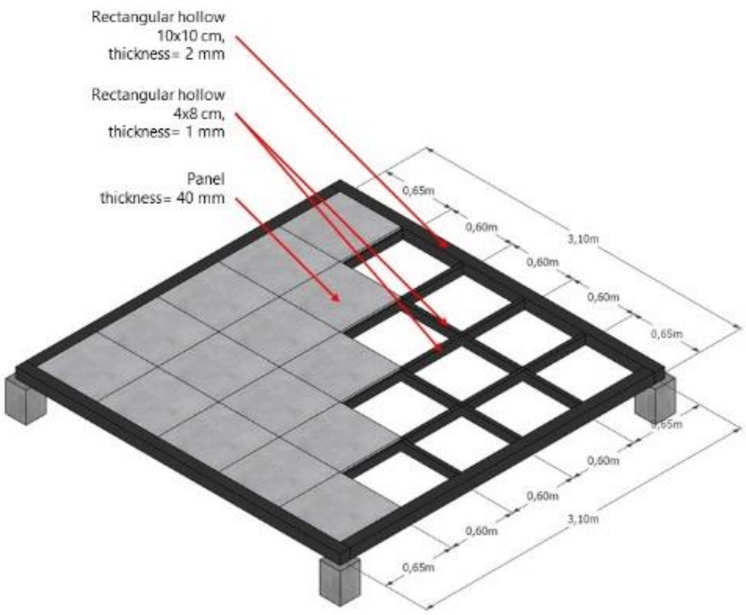


Figure 68. Isometric Floor Panel and Frame Construction

Table 61. Construction Cost of Prefabricated Low-Cost Housing Components per m^2

Components	Unit	Unit Price
1. Wall panel - Hollow Steel frame - Bolt connection:		
- Panel, t = 1.2 cm	m^2	148,566.34
- Formwork	m^2	81,286.10
- Hollow steel 2/4 - Bolt connection	m^2	235,033.16
	Total Unit Price	464,885.59
2. Floor panel - Hollow Steel frame - Bolt connection:		
- Panel, t = 4 cm	m^2	151,198.84
- Formwork	m^2	81,286.10
- Hollow steel 4/8 - Bolt connection	m^2	284,383.16
	Total Unit Price	516,868.09
3. Roof structure - Hollow Steel frame - Bolt connection:		
- Hollow steel 4/8- Bolt connection n	m^2	284,383.16
- Metal cover	m^2	62,768.10
	Total Unit Price	347,151.26
4. Column and Beam - Hollow Steel frame - Bolt connection		
- Hollow steel 10/10 - Bolt connection	m	200,628.34
	Total Unit Price	200,628.34

Table 62 shows the total construction cost of housing prototype is IDR 120,047,728, which by related to housing price standard in table 1, the housing prototype is affordable.

Table 62. Construction Cost of Prefabricated Low-Cost Housing Prototype with Area of 36 m^2

Housing components	Vol.	Unit	Unit Price (IDR)	Total Price (IDR)
1. Rough framing:				
- Walls	28.5	m^2	464,886	13,249,239
- Floors	36	m^2	516,868	18,607,251
- Roof structure and cover	62	m^2	347,151	21,523,378
- Columns	36	m	200,628	7,222,620
- Beams	72	m	200,628	14,445,240
2. Site work and foundation	1	ls	20,000,000	20,000,000
3. Exterior construction	1	ls	20,000,000	15,000,000
4. Mechanical, Electrical, Plumbing	1	ls	10,000,000	10,000,000
			Total Construction Cost	120,047,728

6.3 Onsite Prototype Housing Construction

6.3.1 Construction Principles

In principle, the pre-fabrication method is used to solve construction speed problems. In the pre-fabrication method, several fundamental construction techniques are known, one of which is modular construction. The modular system is in a prefabricated position which is seen based on its grid. Following are the fundamental technical found and often used in pre-fabricated construction methods:

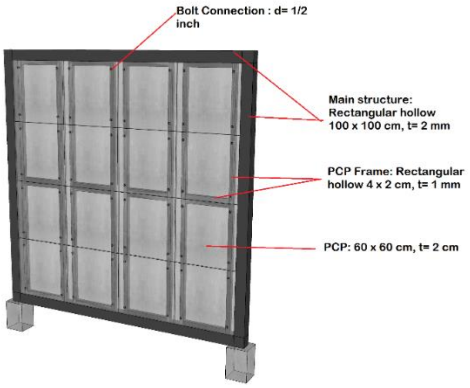
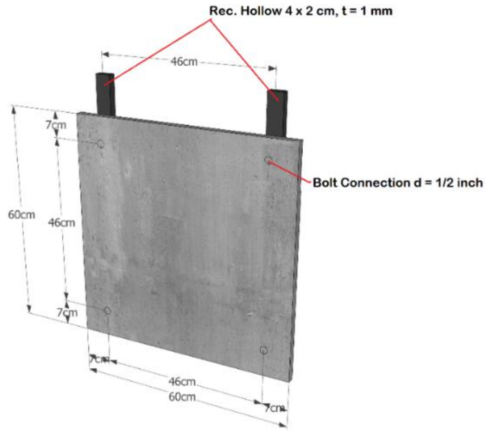
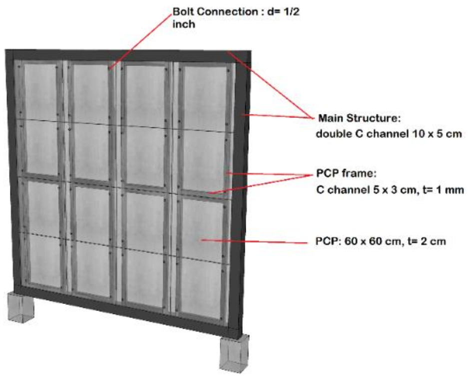
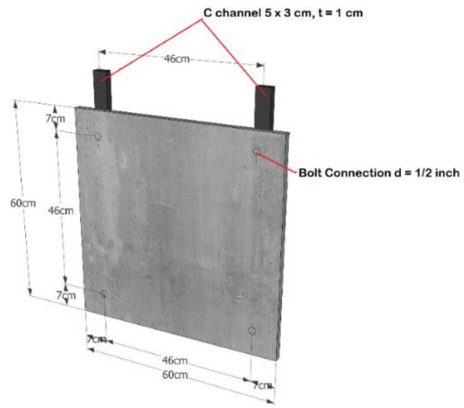
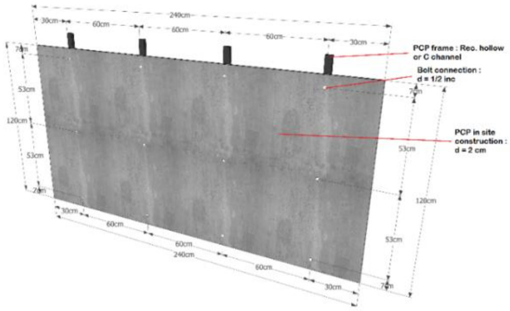
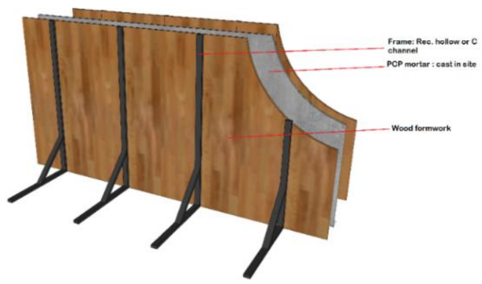
Table 63. Fundamental Construction Techniques in Pre-Fabrication Methods [318]

Prefabricated fundamental construction types based on:	Explanations
Building System	Structural, facad, mechanical and electrical, space frame (wall, plafond, floor)
Material	Wood, steel, concrete, composite
Method	Manufacture, Prefabricated
Product	Made to stock, Assembled to Order, Made to Order, Engineered to Order

Prefabricated fundamental construction types based on:	Explanations
Class	Open system, closed system
Grid	Axial, modular

Modular system in principle is a construction system that works with modules or components and parts of a standardized system with the same dimensions and shapes and precision as a building component or part of a building. Concrete, brick can be called the smallest module, even a caravan is also a large module. The idea of modulation in the context and the proper and promising application of this term is that it can be applied not only as a building component but also in the design and application process [319]. Exploratory design method is used to explore the possibility construction and connection of the walls and floors that may apply as simple as to be. Three alternative designs are proposed. First alternative is using hollow steel as a frame, the second one is using double C channel and the last is using in site construction. In site construction still must be considered because this conventional method still very popular in Indonesia. After the design was made, the quantitative method by calculating budget estimation for construction will be a comparative study for the designs. For further information of research framework is showed in the fig. 7. In addition, to estimate construction budget is used Indonesian National Standard (SNI): The procedure for calculating the unit price of work for the construction of building and housing. This standard is very specific in calculating building components, for example they have different calculation for plastering, concrete, wall etc., while for the panels itself, it requires an adjustment in the calculation. This adjustment is conducted by finding the calculation prices of similar building component. In this case, the calculation closed to plastering standard analysis. Connection between materials and hollow steel is used bolt connection with diameter of ½ inch. It is applied on each corner of panels, 4 pieces of bolt for a module.

Table 64. Alternatives Design Construction

<table>
<tr><th>Alternative</th><th>Construction design</th><th>Section</th></tr>
<tr><td>Rectangular hollow – bolt structure</td><td>
</td><td>
</td></tr>
<tr><td>C channel – bolt structure</td><td>
</td><td>
</td></tr>
<tr><td>On site construction</td><td>
</td><td>
</td></tr>
</table>

Afterwards for second alternative with using C channel steel with dimension C 5 x 3 cm for frame and using double C channel with dimension C 10 x 5 cm, and for connector is bolt diameter ½ inch. The construction is mutual with hollow construction, the differences is only at its frame material. While the last one by using in site conventional construction such as concrete casting work which uses formwork. for this method the module is made wider with a size of 2.4 x 1.2 m. Frames are placed every 60 cm. The construction is carried out like concrete casting in general, that is, the formwork is placed as a casting with a thickness of 2 cm (according to the thickness of the panel). After that the panel mortar is inserted into the formwork until it hardens or reaches the setting time. After hardening, tighten the bolts in each frame. This conventional method more flexible, frame can be used from rectangular hollow, c channel, concrete or even wood. For the formwork also can be used wood formwork, aluminum formwork or PVC formwork, but wood formwork is still more familiar in Indonesia.

Cost Estimation of Alternatives Construction Design

As explained earlier, the price analysis for construction is adjusted to Indonesian standards regarding unit price analysis, i.e.:

1) SNI 2837:2008: The procedure for calculating the price of the plastering unit for the construction of buildings and housing [315]
2) SNI 7394:2008: The procedure for calculating the unit price of concrete works for the construction of buildings and housing [169]
3) SNI 7393-2008 - procedures for calculating the unit price of steel and aluminum work for the construction of buildings and housing. [316]

Based on Table 65, it showed the comparison of unit price construction with several alternatives. The analysis was included labors fee based on Jakarta rate fee for labors. In Indonesia, there is a difference rate fee for labors that it's depended on regulation of local city government. As shown in Table 65, the main structure is excluded from calculation and the highest rate is Cast in site construction - Hollow steel frame. This happened due to wood formwork that used in site construction need more material. While the lowest rate is C Channel Steel frame- Bolt Construction. In this case, while the main structure calculation is included, the price will rise due to C channel for main structure is using double frame (double C channel) and the price will be the highest. C channel also has an issue of its easy to build due to the inertia of the section. This study also compares construction with conventional clay bricks. Compared to prefabricated construction, the conventional one is still pricey.

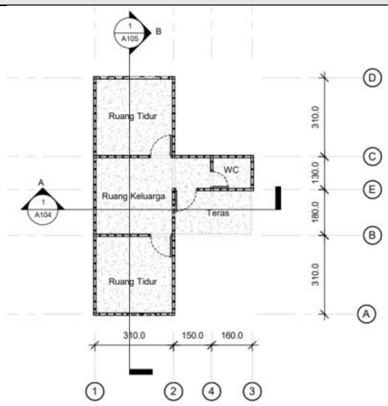
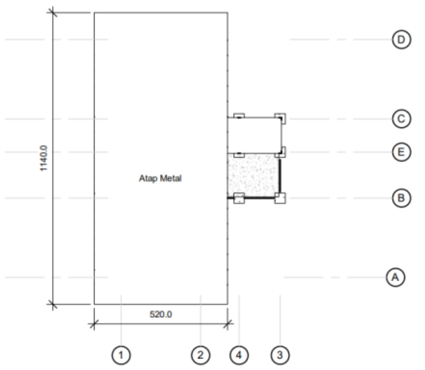
Table 65. Comparison of Unit Price Analysis Construction Design

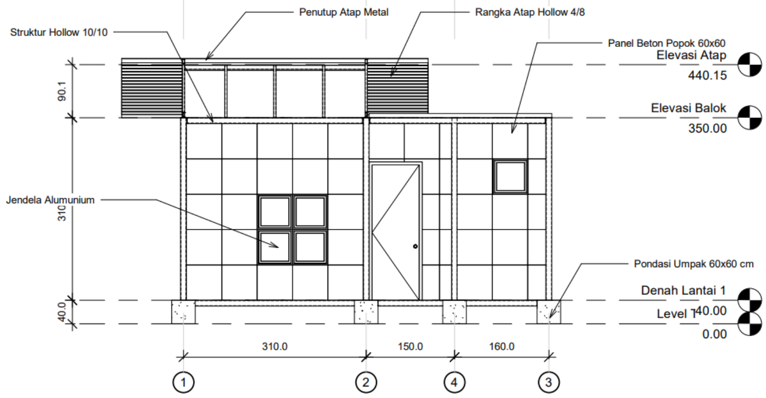
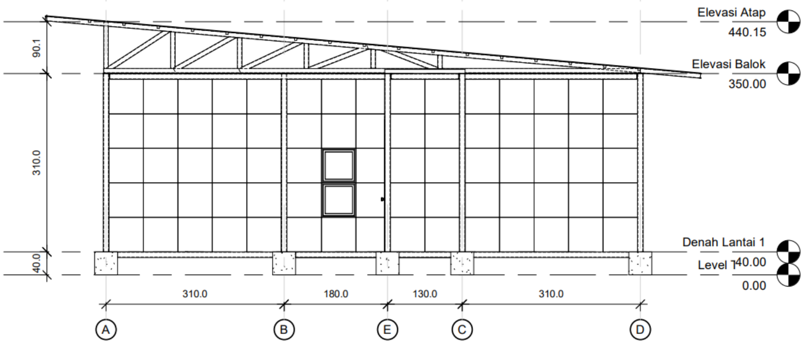
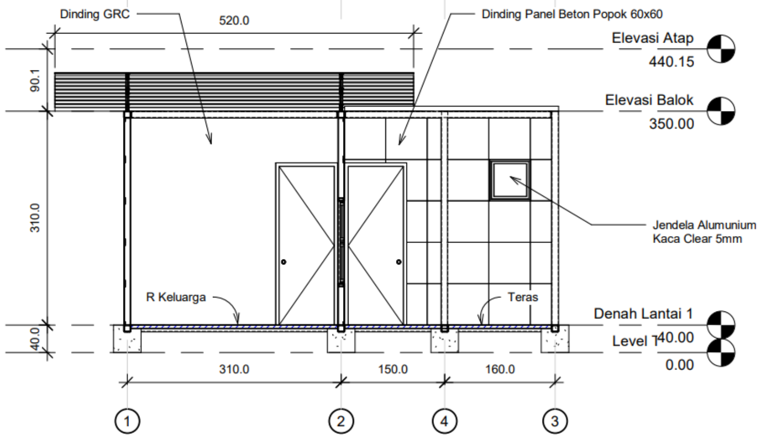
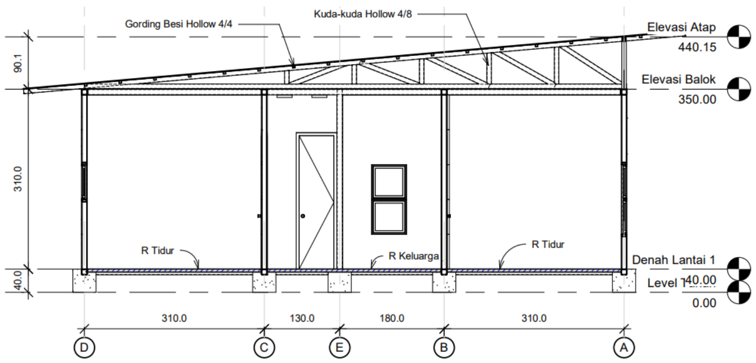
No	Construction Design	Components	Unit Price (IDR)
1	Hollow Steel frame - Bolt Construction	1 m2 PCP, t = 2 mm	148,566.34
		1 m2 Wood Formwork	81,286.10
		1 m2 Hollow steel - Bolt Construction	235,033.16
		Total Price	**464,885.59**
2	C Channel Steel frame- Bolt Construction	1 m2 PCP, t = 2 mm	148,566.34
		1 m2 Wood Formwork	81,286.10

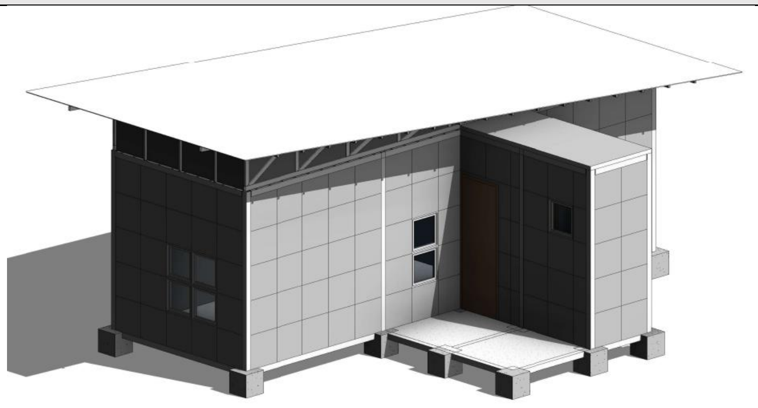
No	Construction Design	Components	Unit Price (IDR)
		1 m2 C channel steel - Bolt Construction	190,583.16
		Total Price	**420,435.59**
3	Cast in site construction - Hollow steel frame	1 m2 PCP, t = 2 mm	148,566.34
		1 m2 Wood Formwork	81,286.10
		1 m2 Hollow steel - Bolt Construction	210,108.60
		Total Price	**593,708.09**
4	Cast in site construction – C channel steel frame	1 m2 PCP, t = 2 mm	148,566.34
		1 m2 Wood Formwork	81,286.10
		1 m2 C channel steel - Bolt Construction	190,583.16
		Total Price	**549,258.09**
5	Conventional Clay Bricks Construction	1 m2 Clay Bricks	183,445.00
		1 m2 Sand-cement -Plastering – two side	214,553. 36
		1 m2 Cement -Plastering- two side	114,226.28
		Total Price	**512,266.28**

6.3.2 Preliminary Design

Table 66. Preliminary Design on site prototype housing construction [320]

Design	Figures
Floor plan and roof plan	 Floor plan  Roof plan

<table>
<tr><th>Design</th><th>Figures</th></tr>
<tr><td>Front elevation</td><td>
</td></tr>
<tr><td>Right side elevation</td><td>
</td></tr>
<tr><td>A Section</td><td>
</td></tr>
<tr><td>B Section</td><td>
</td></tr>
</table>

Design	Figures
3D view	

6.3.3 Rough Simulation on Structural Analysis

Basic Structure Planning

The planning of a structural building is carried out using certain principles and assumptions that have been determined and explained in regulations and literature references which are continuously refined to date. This section will explain the assumptions and rules that will be used in this planning.

Standard Guideline

1. SNI 2847:2019 Structural Concrete Requirements for Buildings [321]
2. SNI 1729:2015 Specifications for Structural Steel Buildings [322]
3. SNI 1726:2019 Earthquake Resistance Planning Procedures for Building and Non-Building Structures [323]
4. SNI 1727:2013 Minimum Load for the Design of Buildings and Other Structures [324]
5. SNI 8460:2017 Geotechnical Design Requirements [325]
6. 2017 Earthquake Hazard Source Map [326]

Structure overview

The building being built is a 1-storey building. The structural system of this building uses a special moment-bearing frame structure. The supporting elements of the main structure, namely beams and columns, are made of reinforced concrete as well as secondary structures such as slabs made of reinforced concrete.

Dead Load

Dead load is the weight of all building construction materials installed, including walls, floors, roofs, ceilings, stairs, fixed partition walls, finishing, building cladding and architectural components and other structures and other equipment installed including the weight of the crane.

Table 67. Self-weight of building materials and building components [324]

Building Material		
Steel	7850	kg/m^3
Concrete	2200	kg/m^3
Reinforced Concrete	2400	kg/m^3
Building Components		
Mixture, per cm thick		
- From cement	21	kg/m^2
- From lime, red cement or tras	17	kg/m^2
Asphalt, including mineral additives, per cm thick	14	kg/m^2
Red masonry walls:		
- One stone	450	kg/m^2
- Half stone	250	kg/m^2
Concrete brick walls:		
Hollow		
- wall thickness 20 cm (HB 20)	200	kg/m^2
- wall thickness 10 cm (HB 10)	120	kg/m^2
Solid		
- wall thickness 15 cm	300	kg/m^2
- wall thickness 10 cm	200	kg/m^2
Ceilings and walls (including ribs, without hangers or stiffeners), consisting of:		
- asbestos cement (plasterboard and other similar materials), with thickness maximum 4mm	11	kg/m^2
- glass, 3-4 mm thick	10	kg/m^2
Ceiling hanger (of wood), with maximum span 5 m and a minimum distance of 0.80 m	7	kg/m^2
Tiled roof covering with battens and rafters, per m^2 roof area	50	kg/m^2
Corrugated zinc roof covering (BWG 24) without ridge	10	kg/m^2
Floor covering of portland cement tiles, terrazzo, and concrete without mix, per cm thick	24	kg/m^2
Wave asbestos cement (5 mm thick)	11	kg/m^2

Live Load

Live loads are loads caused by users and occupants of buildings or other structures that are not included in construction loads and environmental loads, such as wind loads, rain loads, earthquake loads, flood loads or dead loads.

Table 68. Minimum evenly distributed live load [324]

Building Category and Utilization	Uniform (kN/m^2)	Centralized (kN)
Apartment (see house)		
Dining room and restaurant	4.79	
Residential (see house)		

Hospital		
Operation room, laboratory	2.87	4.45
Patient room	1.92	4.45
The corridor above the first floor	3.83	4.45
Hotel (see house)		
Factory		
Light	6.00	8.90
Heavy	11.97	13.4
Office Building		
File rooms and computers must be designed for a moderate load heavier based on estimated occupancy		
First floor lobby and corridors	4.79	8.90
Office	2.40	8.90
The corridor above the first floor	3.83	8.90
House		
One family and two-family house		
An uninhabitable attic without a shed	0.48	
Uninhabitable attic with shed	0.96	
A livable loft and sleeping area	1.44	
All spaces except stairs and balcony	1.92	
All other dwelling houses		
Private rooms and corridors serving them	1.92	
Public spaces and corridors serving them	4.79	
School		
Classroom	1.92	4.5
The corridor above the first floor	3.83	4.5
First floor corridor	4.79	4.5
Stairs and exit	4.79	
Warehouse above the ceiling	0.96	
Warehouse for storing goods before distribution to retailers (if anticipated to be a storage shed, shall be designed for heavier loads)		
Light	6.00	
Heavy	11.97	
Shop		
Retail		
First floor	4.79	4.45
Floor above	3.59	4.45
Wholesale, on all floors	6.00	4.45

Each section of a roof is designed to be capable of withstanding the load of all collected rainwater when the primary drainage system for that section is closed plus the uniform load caused by rising water over the inlet of the secondary drainage system in the design flow.

$$R = 0.0098(d_s + d_h) \quad \text{(SNI 1727 Psl. 8.3) [324]}$$

Which

R = rainwater load on non-deflected roof (kN/m^2)

d_S = depth of water on the non-deflected roof increases to the inlet of the secondary drainage system when the primary drainage system is closed (mm)

d_h = additional water depth on non-deflected roof above inlet of secondary drainage system at design water flow (mm)

Earthquake Load - Spectra Response Analysis

Earthquake load is the load acting on a structure because of ground movement caused by an earthquake (be it a tectonic or volcanic earthquake) that affects the structure. The earthquake resulted in a load on the structure due to the interaction of the soil with the structure and the response characteristics of the structure.

Spectral response is a spectrum that is presented in the form of graphs/plots between the period of vibration of the structure (T), versus the maximum responses based on certain damping and earthquake ratios. Maximum responses can be the maximum displacement (spectral displacement, SD), maximum velocity (spectral velocity, SV), or maximum acceleration (spectral acceleration, SA) of the structural mass with a single degree of freedom (SDOF).

Loading Combination

Structures, structural members and foundation elements shall be designed so that their design strength equals or exceeds the effect of factored loads in the following combinations:

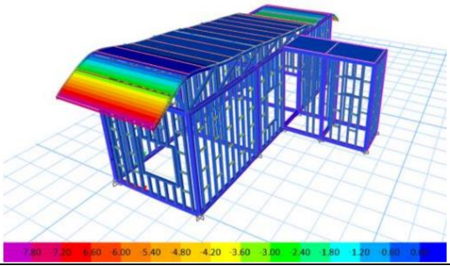
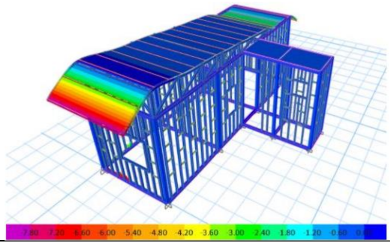
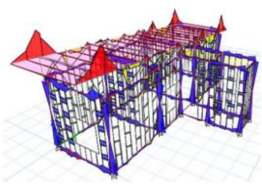
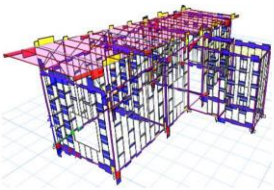
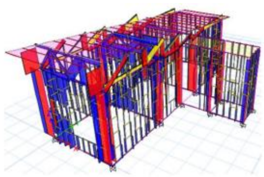
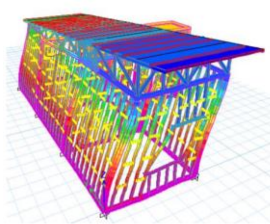
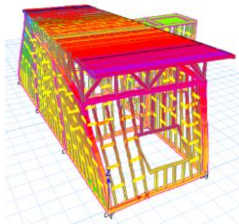
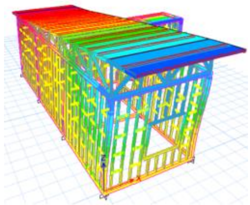
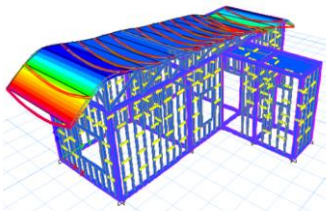
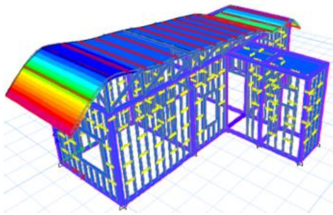
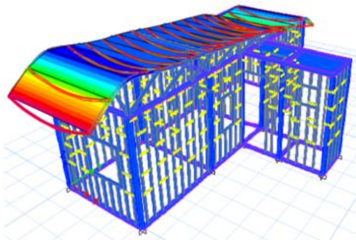
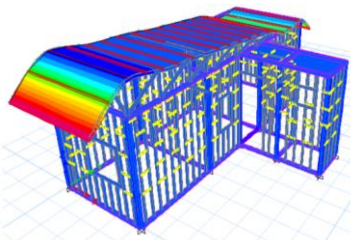
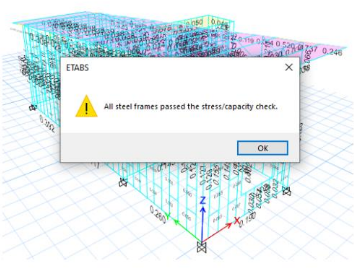
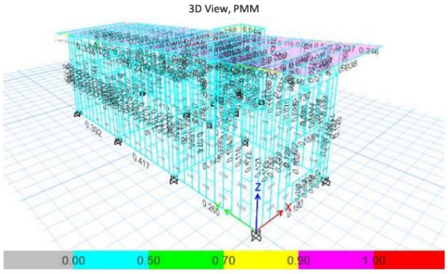
1. $1.4D$
2. $1.2D + 1.6\text{L} + 0.5(L_r \text{ or } R)$
3. $1.2D + 1.6(L_r \text{ or } R) + (L \text{ or } 0.5W)$
4. $1.2D + 1.0W + L + 0.5(L_r \text{ or } R)$
5. $1.2D + 1.0E + L$
6. $0.9D + 1.0W$
7. $0.9D + 1.0E$

Which

D = Effect of dead load
L = Effect of live load
L_r = Effect of roof live load
R = Effect of rainwater load
W = Effect of wind loads
E = Effect of earthquake loads

Table 69. Summary Rough Structural Analysis on site prototype housing construction [320]

Structural Analysis	Figures

Permit Deflection = L / 240 L= 3,1 m, 3100⁄240 = 12.9167 mm Simulation = 7,8 mm (passed)	 
Forces in structure as a reference in the steel/metal design process.	   3D View, Moment 3D View, Shear 3D View, Axial
Mode shape Movement of structures due to earthquake	  
The influence of live loads and dead loads	Regular units   Dead loads Live loads Combination units   Dead loads Live loads
Check failure (Stress/Capacity) The structure passes the check design and has a PMM Ratio in the range of 0.00 to 0.50.	 3D View, PMM 

6.3.4 Documentation of Prototype Housing Construction

Table 70. Construction process on site prototype housing construction [320]

Construction Steps and Process	Figures
Preconstruction	
Laboratory simulation for construction system	
The prototype building structure system uses a knock down system with a nut and bolt connection and a frame made of hollow iron. This knock down system is very suitable because it can save construction time in the field. In procuring the structural frame, the researcher collaborated with a third party who has experience in building construction work.	

Construction Steps and Process	Figures
The architectural elements are designed by panel form with dimension 60x60 cm, thickness 1 cm and 5 cm. This panel is used for walls and floors.	
On Site construction	

Construction Steps and Process	Figures
Site survey and treatment - Looking for suitable land for prototype development - Provides an overview of land conditions and the variables involved in making structural and architectural designs based on real conditions in the field.	    
on site building material components manufacturing by low technology	  

Construction Steps and Process	Figures
	 
On site panel components casting	  
Final products of panels	  

Construction Steps and Process	Figures
Frame and structural connection	  
Constructing panel components and structural frames	     

Construction Steps and Process	Figures
Final products: on site prefabricated housing prototype	 

6.4 Conclusion

The alternatives construction design of the prototype housing can be constructed to all possibility proposed design. In order to achieve the efficiency and effectiveness of construction process, prefabrication - Hollow Steel frame - Bolt Construction is recommended. This recommendation does not only consider construction price, but also construction speed and easy to build. For further study the structural analysis on frame structure and connection, needs to conduct to give the best alternative solution based on design and structural analysis.

This chapter also proposed alternative building materials for housing components by utilizing disposable diaper waste as a composite panel for walls and flooring. The experimental study reveals positive results in terms of compressive strength where the panel composite meets the required standard of building materials. Then by proposing the construction system of the panels, the study figures out a housing design prototype to be constructed in the prefabrication method. The structure of construction by utilization of rectangular hollow steel also gives benefits in terms of structural analysis where the deflection does not exceed the maximum and in terms of construction cost, the system is also more affordable compared to housing price standard. Based on the findings, the proposed housing prototype design becomes more applicable and can be implemented by constructing the prototype on the site by prefabrication system.

Chapter 7

Evaluation

7.1 Evaluation on Laboratory Experiment

The findings of compressive strength in concrete indicated that for high strength, the optimum replacement of sand by disposable diaper is 10% (20 MPa) in utilizing for structural element of building such as beam and column or infrastructure such as road for low load bearing capacity. For the maximum replacement is 27% (10 MPa) disposable diaper is reaching the lowest standard in application on building materials, but still applicable for structural element to bear the low load bearing capacity of single housing. However, more that 27% is not recommended for structural element of building but still applicable for non-structural element such as walls. This application also has limited to maximum 40% of disposable diaper, where exceed this number, the application is no longer meet requirements of building materials standards. In the findings of mortar, the highest compressive strength is in optimum replacement of sand by 9% disposable diaper (8.5 MPa) and the lowest strength is 40% of disposable diaper (2 MPa). The application is applicable to all levels of walls element (Level 1 to IV) and only level D (the lowest level) of floors element, respectively.

Based on the result and finding of this study, in terms of compressive strength is confirmed that the more disposable diapers take a part in replacing the sand, the more compressive strength is decreasing. Similar with the others findings that the SAP inside the compound increases the number of macroscopic pores in the matrix, resulting in a decrease in the mechanical properties of cement-based materials [54] [55]. Water intake increases the number of capillary pores, leave a significant number of voids in the cementitious matrix after it has hardened caused reduce the mechanical properties [47]. However, to enhance the mechanical properties, some studies suggest for the addition of fibers or additives [69].

Furthermore, other findings on properties are density of concrete increase as the amount of disposable diapers increase. Also, the replacement of sand by disposable diaper in amount of from 25,8% is considered as lightweight concrete. This finding is expected that the materials can be proposed as earthquake resistant for buildings. Similar to the water absorption of the compound in concrete as well increasing simultaneously by the increasing of disposable diaper in compound. It found that 1% of replacement sand by disposable diaper boost the demand of 7% additional of water. In line with other studies, the water demand has become a major concern in using SAP to concrete because it decreases water-cement ratio [52] which will influence to decrease slump value and workability. To prevent the more demand of water the study conducted improvement on mechanical properties of concrete by adding super plasticizer made from rice husk and it found that the addition of superplastisizer can improve slum value and workability of concrete with no effect to compressive strength. Other improvement also by boiled or presoak the disposable diaper (in SSD condition) to prevent the water absorption. The result indicates that presoak can stabilize the density of mortar and prevent more water absorption. The finding also confirms previous studies that found that presoak Pre-soaked SAP could improve the static stability and passing ability and prevent the addition of water to compound and increase the slump of concrete [39] [34].

Thus, in summary the findings on properties of material can be addressed in Table 71. However, although the findings in this study confirm similar findings to others, there are some different cases in terms of SAP. Most of the study incorporate with SAP, are only use SAP not a whole disposable diaper. Despite, this study case is not only using SAP, but also whole disposable diaper that consist of pulp, polypropylenes and polyethylene as a part of disposable diaper may have influence on the mechanical and physical properties of composite materials. For instance, the study [327] conducted pulp as shredded wastepaper (SWP) in concrete compound revealed that the slump and splitting tensile strength of the concrete increase up to 10% addition due to it has higher cellulose, average fiber length, proportion of medium and long fiber contents. However, it decreased gradually at higher than 10% addition of SWP and concluded that generally, 5% to 10% addition of SWP is the most suitable mix proportion [327]. In addition, other study that incorporates polypropylenes (PP) to mortar conclude the fibers are commonly used to restrict early shrinkage and control micro-crack propagation in mortars but increased porosity along with reduction in mechanical properties [69]. The study also explored application of SAP and PP of 20% improvement in compressive strength, increases the resistance of mortar to water penetration by up to 60% [69]. Furthermore, polyethylene (PE) also takes an important part in properties of materials in this study that doesn't explore more. However, previous study conducted the addition of PE fibers to the concrete mix conclude that although it had a slight increase in the compressive strength and 22% reduction in the porosity, the tensile strength is one of the main advantages and demonstrated an excellent capacity for controlling cracks in concrete [328].

Table 71. Summary on properties of concrete and mortar with disposable diapers

Properties	% replacement of sand	Findings	Evaluation	Application
Compressive strength	Decrease as the diapers increase			
• Concrete	10%	20 MPa	Medium strength	Beam and column for maximum 3 floors of housing
	Up to 27%	10 MPa	Low strength	Beam and column for single story housing
	More than 27%	below 10 MPa	Not recommended	Non-structural element
• Mortar	9%	8,5 MPa	Low strength	Paving block lowest level (D level) – road with low load bearing capacity
	Up to 40%	2 MPa	Non-structural	All level of walls (I to IV level) with no load bearing capacity
Density	Decrease as the diapers increase			
• Concrete	From 25,8%	1748,15 kg/m3	lightweight concrete	Expected to earthquake resistant
Water absorption	Increase as the diapers increase			
• Concrete	1%	7% additional water	✓ Decrease slump value. ✓ Decrease workability.	Depends on the utilization in construction field, it may be applicable for

Properties	% replacement of sand	Findings	Evaluation	Application
			✓ Not good for area with water shortage ✓ Need water reducer additive	construction which need lower slump value

7.2 Evaluation on Environmental Impact Assessment

Environmental impact on comparative study between waste treatment of disposable diapers concludes that carbon emissions of disposable diapers in recycling treatment is the lowest compared to others waste treatments. By comparing to common waste treatment, the recycling of 1 kg disposable diapers is estimated to be less than 0,86 kgCO_2 to co-firing, 1,02 kgCO_2 to incineration and 2,17 kgCO_2 to non-recycling/landfilling. As it showed in Table 72, the eco-costs in recycling treatment also have the lowest compared to other waste treatments. In 1 kg of recycling disposable diaper can reduce environmental burden to less than 2,69 Euro to co-firing, 3,52 Euro to incineration and 7,56 Euro to non-recycling/landfilling. The result of this findings also confirms the argument of recycling the organic material that is contained in used diapers offers an appealing alternative for the management of both waste and resources [27].

Moreover, Table 73 shows the comparison of environmental impact between concrete with disposable diaper, regular concrete, concrete wit PET and concrete with sawdust. The results reveal that in term of carbon emission and eco-costs, concrete with disposable diaper has the lowest compared to others. Carbon emission in 1 m^3 concrete consisting of disposable diaper is less than 13,27 kgCO_2 to concrete with PET, 30,21 kgCO_2 to concrete with sawdust and 30,45 kgCO_2 to normal concrete. This result is in line with the eco-costs where in 1 m^3 concrete consist of disposable diaper can reduce environmental burden less than 1,32 Euro to concrete with PET, 6,47 Euro to concrete with sawdust and 11,03 Euro to normal concrete. Based on the database used, recycling credit for non-degradable materials has become a value that makes disposable diaper has a lower impact on carbon emissions and eco-costs. The harder materials being degradable by nature the bigger recycling credit given. Compared to sawdust, recycling credit is lower than PET and disposable diapers due to sawdust can be easily degradable by nature without needing to be recycled.

However, in embodied energy calculation, compared to normal concrete and concrete with sawdust, concrete with disposable diaper has higher embodied energy up to 817,79 MJ and

417,36 MJ, respectively. This phenomenon happened due to the energy of production process of disposable diaper that already embedded to the product, and it can't be reduced after processing. There is no other way to reduce embodied energy from a manufactured product, as the energy of the process has already been incorporated into the product. The embodied energy should be considered during the planning phase. When a product has already been manufactured, the best course of action is to minimize its environmental impact upon degradation. Instead, concrete with PET has the highest embodied energy among others which is means that in the production process, PET demand highest energy and leads to highest embodied energy during life cycle.

Table 72. Environmental impact of recycling disposable diaper compared to common waste treatment of disposable diaper

Environmental Impact	Co-firing	Incineration	Non-recycling/landfilling
Carbon Emission (kgCO_2)	> 0,86	> 1,62	> 2,17
Eco-costs (Euro)	> 2,69	> 3,52	> 7,56

Table 73. Environmental impact of concrete with disposable diaper compared to similar materials

Environmental Impact	Regular concrete	Concrete with PET	Concrete with sawdust
Embodied Energy (MJ)	< 817,79	> 20,73	< 417,36
Carbon Emission (kgCO_2)	> 30,40	> 13,27	< 30,21
Eco-costs (Euro)	> 11,03	> 1,32	> 6,47

However, in the process of calculating the environmental impact there are some limitations that did not include such as:

- the separation process of waste disposable diaper to others household waste that may require time and labor.
- the washing process of waste disposable diaper that requires water and other sanitizing additives to remove dirties may require additional costs.
- the drying and shredding process need machine or tools and labors and may require the energy to operate the machine and costs for labors
- the standard and database using European Standard may different with other countries in term of database.

In previous study, those limitations also argued by [4] that in recycling process there are some limitations such as the requirement for additional costs, health concerns for workers who are constantly exposed to waste and feces. By considering the limitation, the calculation of environmental impacts may not be too significantly lower compared to others waste treatment. Further study in elaborating the detail process and indicators should be addressed more to prove the environmental benefits of recycling disposable diapers. Due to the limitations, this study could give suggestion for waste treatment to maximize waste treatment on disposable diaper such shows in Figure 69.

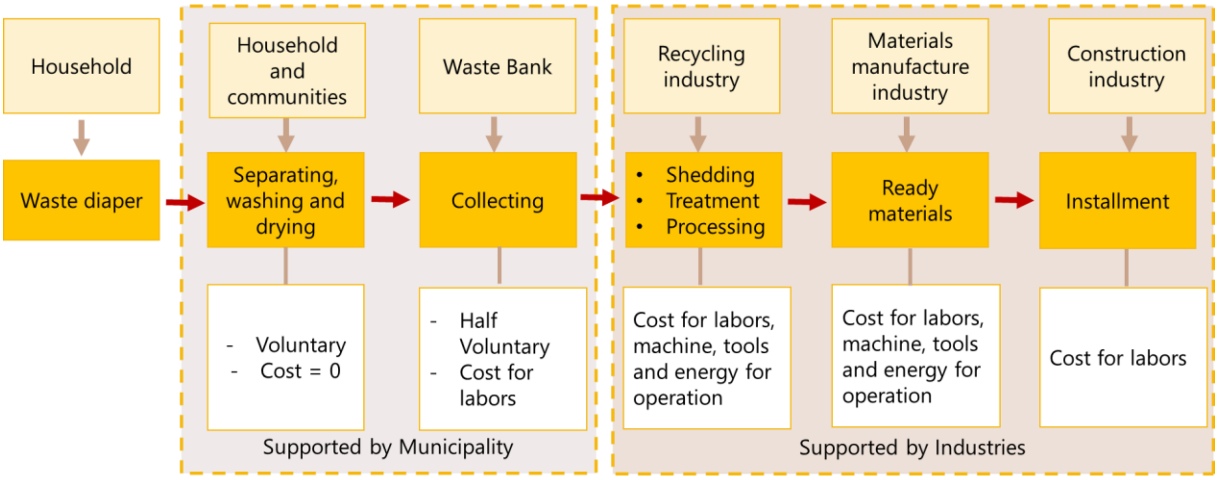


Figure 69. Suggested waste treatment scheme for disposable diaper

7.3 Evaluation on Construction System

The optimum application depends on the design of the building element. In this study the design scenario was determined by designing unit area of housing for minimum capacity. In Table 74 it summarized evaluation of the applications in housing where optimum application on all housing element of single floor with area of 36 m^2 can utilized 1,73 m^3 of disposable diaper. In addition, maximum application for low-rise building (3 floors) with unit area of 36 m^2 in total 15 unit can utilize 4,23 m^3 of disposable diaper. However, for mid to high-rise buildings, it is only limited to application for walls and floors where for 36 m^2 area of housing can utilize 1,62 m^3 of disposable diaper. Thus, in utilization for infrastructure, the ooptimum application is for pedestrian road pavement and road with low load bearing capacity. The amount depends on width and length of road and depth of layer. In this study the sample of design was determined: road with 120 cm width, length 1000 m and depth of layer 25 cm (total 2500 m^3), with optimum replacement 27%, it can reduce 215,75 m^3 of the waste.

In rough evaluation, to optimize the utilization of disposable diaper as part of composite materials, the application for infrastructure is more promising than for housing. This evaluation due to some reasons. First in term of capacity, road application can accommodate optimum capacity due to the demand for road is higher than for housing. Second in terms of hygiene of materials, the materials in this study need to elaborate more. Due to the dirties that embedded in the waste may influence to indoor quality of housing. In contrast with roads or pedestrian where it is placed outdoors, the hygiene may not give too significant an impact for people. And last, in term of workability in construction, materials for building is harder to placed due to different design or

Table 74. Evaluation on application on building and infrastructure

Application on building/infrastructure	Element of building/infrastructure	Scenario design/area	Estimated amount of waste
Building			
Single house	Beam, column, wall, and floors	36 m^2	1,73 m^3
Low-rise building	Beam, column, wall, and floors	36 m^2 per unit of 15 units, maximum 3 floors	4,23 m^3 of 3 units vertically
Mid-rise building	wall, and floors	36 m^2 per unit	1,62 m^3
High-rise	wall, and floors	36 m^2 per unit	1,62 m^3
Infrastructures			
Road pavement	Pedestrian/road with low load bearing capacity	- Width = 120 cm - Length =1000 m - depth of layer = 25 cm - total 2500 m^3	215,75 m^3
Others	Others infrastructure element with low load bearing capacity	Depends on utilization with optimum strength of 20 MPa	Optimum 10% up to 27% to replace the sand

As a result, the findings on application were then elaborated in a real construction system. In this study the construction system is proposed prefabrication method. The primary difference between prefabricated and conventional construction is the way in how building components are assembled. Traditional construction only assembles and constructs the building on-site using building components. On the construction site, foundations, walls, and roofs are constructed, among other components. In prefabricated construction, building components (also known as "modules") are assembled in a factory under strict quality and safety controls before being transported to the construction site. Interior and exterior finishes can be constructed using modules. The components are then transported to the construction site, secured to the existing foundation, and assembled on schedule. It is well known that modular construction is a more environmentally friendly construction method than conventional construction. Using sustainable modules, prefabricated construction reduces a building's carbon footprint. Compared to conventional construction, modules utilize materials more efficiently, are more cost-effective, and produce less waste.

Table 75. Observation on construction time and costs by prefabrication method

Construction time and costs by prefabrication method	Observation
1 module of frame (3 x 3 m)	7 days
Total modules of frame for 36 m^2	30 days
1 panel until ready to install	24 hours in dry weather, 48 hours in wet weather
Installment all elements (36 m^2)	28 days (8 working hours)
Labors	3 people
Estimation construction time for 36 m^2	2 months
Limitation of construction cost	- The cost is limited to ready materials, not including the processing. - The cost of diapers treatment such as collecting, washing, and shredding is also not included

As it observed in Table 75, the housing prototype in this study can be constructed in 2 months from the preparation of materials until finishing. Also, for construction cost, the price of housing can accommodate price for low-costs housing which means the housing prototype is affordable for low-income households. However, it should be noted that the cost is limited to ready materials, not including the processing of diapers treatment such as collecting, washing, and shredding. It means that the cost could be similar or higher depending on the cost of diapers treatments. In this study the treatment of waste is cost zero due to all the process is conducted individually by author and research teams.

In addition, by comparing the construction method in Table 76, proposing prefabrication method is promising in term of to cut the price of construction, time and labours. Also the construction process is completed off-site in a controlled indoor environment to avoid outdoor risks. In contrast with conventional methods where various building components, labor time, labor shortages, weather conditions, and other unknown variables can lead to rising costs and the quality of materials hard to determine, depending on labors experience. By design the walls and floors in panel system, it is also confirming previous studies that precast sandwich panel system faster than conventional method of construction [329]. However, it also offers some limitation such as there are design restrictions associated with modules and high initial cost for machine and tools. Which means that prefabrication method may offers high or low cost, it argued that in some cases the cost of prefabricated construction projects is greater than that of conventional construction projects, primarily as a result of stricter code requirements for prefabricated construction projects, which result in a higher input level of resources, higher consumption, and a greater cost of construction materials and precast concrete components [330].

Table 76. Evaluation on construction method by conventional and prefabrication method

Construction Method	Conventional	Conventional with diapers materials	Prefabrication	Prefabrication with diapers materials
Housing Area	36 m^2	36 m^2	36 m^2	36 m^2
Average Price (IDR)*	130,000,000	143,000,000**	120,047,728	132,052,500**
Time (months)	4	5	2	3
Labors (people)	4	5	3	4
Advantage	- Adaptable to custom design because on-site construction is utilized. - No need initial cost for advanced machine and tools	- Similar to conventional method - The additional of environmental value on recycling disposable diaper	- 90% of the construction process is completed off-site in a controlled indoor environment to avoid outdoor risks. - reduce construction time and labors	- Similar with prefabrication method - The additional of environmental value on recycling disposable diaper
Limitations	- The quality of materials hard to determine, depends on labors experience. - Various building components, labor time, labor shortages, weather conditions, and other unknown variables can lead to rising costs.	- Similar to conventional method - The additional limitation is cost, time and labors on processing the materials	- There are design restrictions associated with modules. - High initial cost for machine and tools	- Similar with conventional method The additional limitation is cost, time and labors on processing the materials

Notes:
- *Average price for low-cost housing in Bandung in 2018, others area may different
- *Price in Indonesian Rupiahs (IDR)
- ** Additional cost on processing the disposable diaper is estimated to 10% from the cost of construction

Chapter 8

Conclusion and Recommendation

8.1 Conclusion of the Study

1. In analyzing the mechanical properties of concrete and mortar consist of disposable diapers, it concluded that:
   1) In terms of mechanical properties, the utilization of disposable diaper as part of concrete and mortar is visible for certain proportion. By replacing the sand, the disposable diaper can be used for concrete component up to 10% for structural elements of building for highest compressive strength and no more than 27% for the lowest compressive strength. For mortar as structural element is up to 9% replacement sand and no more than 40% for non-structural element. The replacement of sand both for concrete and mortar shall be no more that 40% for non-structural element. More than 40% is not recommended in using for building materials.
   2) The density of materials for both concrete and mortar consist of disposable diaper is lower than the normal material. For concrete from 25,8% replacement sand, can be considered as lightweight concrete.
   3) To enhance the workability of concrete, water addition is needed in mix design. By replacing sand with disposable diaper, 1% replacement demand for 7% additional of water.

It also means that, in slum test, concrete with disposable diaper has lower value of slum with similar water-cement ratio.

4) To prevent the demand of water in mix design, addition of rice husk ash-based plasticizer significantly increase its slump value nearly by double for each addition of disposable diaper to concrete without significantly reduce compressive strength. In addition, by boiling or soaking the diapers, it also can prevent the addition water in mix design.

2. In analyzing the environment impact by comparing to common waste treatment and similar materials, it concluded that:
   1) In terms of waste treatment, recycling disposable diapers has the lowest carbon emission and eco-costs compared to land filling, co-firing and incineration.
   2) In terms of similar materials, concrete with disposable diapers has the lowest carbon emission and eco-costs compared to regular concrete, concrete with PET and concrete with sawdust. However, concrete with diapers has higher embodied energy compared to regular concrete and concrete with sawdust, but lower than concrete with PET.
   3) In calculating embodied energy, carbon emission and eco-costs, several databases could be used as main data such as ICE Bath, IDEMAT and Eco-Invent. Those databases basically are derived from the European standard that may the calculation for this case study is uncertainty. The limitation in calculating environmental impact should be considered as a part of the calculation scenario. The limitation is for example in transportation, fuel extraction and disposal process. Although the method includes uncertainty, this is useful when case-specific data is unavailable, such as in countries where the data inventory is not available.
3. In analyzing the influence factors on source of disposable diapers, it concluded that:
   1) Parameters to calculate waste capacity for disposable diapers is age population of 0-4 years, frequency of changing diaper and mass of diaper.
   2) Parameters to be considered for replacement of concrete component by waste materials, especially disposable diapers is density of materials, mass of materials and percentage of replacement.
4. In estimating the utilization of materials for construction industry, it concludes that:
   1) The application of the results in this study can be implemented as building materials and infrastructure. For building materials, the single housing can accommodate all the applications such as for beam, column, walls, and floors. For low-rise buildings up to 3 floors, the materials can be implemented to beam, column, walls and floors depending on

the structural analysis in each floor. Thus, for mid to high-rise is only applicable for architectural and non-structural element such as walls and floors. For infrastructure materials, it can be implemented for pedestrians or roads with low load bearing capacity.

2) The proposed construction system by prefabrication reveals that the method is promising in terms of time and cost compared to conventional method. Also, the price of housing construction is similar to low-cost housing which means it is affordable for low-income people to adopt. However, the limitation on initial cost in providing machines and tools to produce the materials is excluded in the calculation.

8.2 Recommendation for Future Studies

1. The mixing process of concrete using diapers is important to make the compound well distributed. The recommendation to mix is sand, gravels and Portland cement put all together then mix them. After the compound blends well, add the disposable diaper to the first compound and mix them. Then after all the ingredients are blended well, add the water, and mix it. Additional of water for the compound need to consider at the mixing design to ensure the water-cement ratio.
2. The particle size of disposable diaper was not uniform distributed due to the shredding/cutting process using manual, so it's hard to cut in similar size. It may influence the distribution of materials in concrete components. The need for machines to shred the waste is also crucial to produce on a large scale, due to low technology only being able to approach small-scale of materials production. The innovation of shred machines for such materials can be challenging to solve and invent.
3. Waste treatment for disposable diapers is important in terms of hygiene and the healthy factor of materials. Future study needs to address this limitation to ensure that the materials are visible to produce in large scale.
4. Due to the existing various building rules and regulations only limited to conventional building materials, the role of government in regulating such materials needs to be opened. The involvement of stakeholders and waste treatment mechanisms need to be explored more to fill the gap.
5. The materials need to be evaluated in more detail in terms of technical construction, cost, and housing price. This evaluation is proof to propose the materials in the financial mechanism of housing.
6. In calculating environmental impacts, regional or local database is better to use to ensure the significant result.

References

[1] S. Beddu, D. Mohamad, F. M. Nazri, S. N. Sadon and M. . G. Elshawesh, "Properties of Self-curing High Strength Concrete by using Baby Polymer Diapers," *MATEC Web of Conferences,* vol. 203, p. 06022, 2018.

[2] H. Karimi, Q. L. Yu and H. J. Brouwers, "Valorization of waste baby diapers in concrete," *Resources, Conservation and Recycling*, vol. 153, p. 104548, 2020.

[3] H. Karimi, Q. Yu and H. Brouwers, "Valorization of waste baby diapers in concrete," *Resources, Conservation and Recycling,* vol. 153, p. 104548, 2020.

[4] S. C. Khoo, X. Y. Phang, C. M. Ng, K. L. Lim, S. S. Lam and N. L. Ma, "Recent technologies for treatment recycling of used disposable baby diapers," *Process Safety and Environmental Protection,* vol. 123, p. 116–129, 2019.

[5] D. Mohamad, S. Beddu, N. M. Zahari, M. . H. Zawawi, A. Syamsir, N. Radzuan and W. K. M. Sapuan, "The Performance of Diapers Polymer In Concrete As Self-Curing Agent In Term Of Chemical Properties," *AIP Conference Proceedings,* p. 020186, 2018.

[6] Knowaste, "http://www.knowaste.com/," Knowaste Ltd, 2023. [Online]. Available: http://www.knowaste.com/the-knowaste-recycling-process.html. [Accessed 23 2 2023].

[7] Fater, "fatergroup.com," Fater Group, 2017. [Online]. Available: https://fatergroup.com/uk/sustainability/recycling-of-used-products. [Accessed 1 10 2020].

[8] Fater, "fatergroup.com," Fater Group, 2017. [Online]. Available: https://fatergroup.com/ww/news/press-releases/recycling-project. [Accessed 1 10 2020].

[9] D. Recycling, "https://diaperrecycling.technology/," Diaper Recycling Technology Pte Ltd., 2017. [Online]. Available: http://diaperrecycling.technology/factory-waste/#menu-diaper-factorywaste-solutions. [Accessed 20 2 2023].

[10] Unicharm, "https://www.unicharm.co.jp/en/home.html," Super Faiths Unicharm Ltd., 2023. [Online]. Available: https://www.unicharm.co.jp/en/csr-eco/education/note-04.html. [Accessed 23 2 2023].

[11] T. Olivio, "https://www.nonwovens-industry.com/," Nonwoven Industry, 13 4 2017. [Online]. Available: https://www.nonwovens-industry.com/contents/view_online-exclusives/2017-04-13/phs-group-turns-dirty-diapers-into-energy/. [Accessed 25 2 2023].

[12] S. Beddu, D. Mohamad, F. M. Nazri, S. N. Sadon and M. G. Elshawesh, "Properties of Self-curing High Strength Concrete by using Baby Polymer Diapers," in *MATEC Web of Conferences 203*, 2018.

[13] EDANA, "Edana The Voice of Nonwoven," EDANA, [Online]. Available: https://www.edana.org/nw-related-industry/nonwovens-in-daily-life/absorbent-hygiene-products/baby-diapers. [Accessed 23 05 2023].

[14] J. Spurrier and A. Wofford, "GearLab Baby," 2 September 2019. [Online]. Available: https://www.babygearlab.com/parenting-advice/cloth-diapers-vs-disposables-how-and-what-to-choose. [Accessed 23 05 2023].

[15] M. Jesca and M. Junior, "Practices Regarding Disposal of Soiled Diapers among Women of Child Bearing Age in Poor Resource Urban Setting," *Journal of Nursing and Health Science,* vol. 4, no. 4, pp. 63-67, 2015.

[16] J. Spurrier, "GearLab Baby," Baby GearLab, 24 5 2018. [Online]. Available: https://www.babygearlab.com/expert-advice/what-is-inside-those-disposable-diapers. [Accessed 23 5 2023].

[17] K. . E. Wambui, M. Joseph and S. Makindi, "Soiled Diapers Disposal Practices among Caregivers in Poor and Middle Income Urban Settings," *International Journal of Scientific and Research Publications,* vol. 5, no. 10, pp. 1-10, 2015.

[18] T. Laylin, "FIX," 8 12 2015. [Online]. Available: https://www.fix.com/blog/green-diaper-guide/. [Accessed 23 5 2023].

[19] D. Moya, C. Aldas, G. Lopez and P. Kaparaju, "Municipal solid waste as a valuable renewable energy resource: a worldwide opportunity of energy recovery by using Waste-To-Energy Technologies," *Energy Procedia,* vol. 134, pp. 286-295, 2017.

[20] A. Kumar and S. Samadder, "A review on technological options of waste to energy for effective management of municipal solid waste," *Waste Management,* vol. 69, pp. 407-422, 2017.

[21] F. Lino and K. Ismail, "Incineration and recycling for MSW treatment: Case study of Campinas, Brazil," *Sustainable Cities and Society,* vol. 35, pp. 752-757, 2017.

[22] X. Sun, J. Li, X. Zhao, B. Zhu and G. Zhang, "A Review on the Management of Municipal Solid Waste Fly Ash in American," *Procedia Environmental Sciences,* vol. 31, pp. 535-540, 2016.

[23] V. M. Pathak and Navneet, "Review on the current status of polymer degradation: a microbial approach," *Bioresources and Bioprocessing,* vol. 4, p. 15, 2017.

[24] R. M. Espinosa-Valdemar , S. Turpin-Marion , I. Delfín-Alcalá and A. Vázquez-Morillas , "Disposable diapers biodegradation by the fungus Pleurotus ostreatus," *Waste Management,* vol. 31, no. 8, pp. 1683-1688, 2011.

[25] T. Lewis, "Live Science," 5 9 2014. [Online]. Available: https://www.livescience.com/47693-growing-mushrooms-on-diapers.html. [Accessed 23 5 2023].

[26] R. M. Espinosa-Valdemar, A. Vázquez-Morillas, S. Ojeda-Benítez , G. Arango-Escorcia , S. Cabrera-Elizalde, X. Quecholac-Piña , M. Velasco-Pérez and P. X. Sotelo-Navarro , "Assessment of Gardening Wastes as a Co-Substrate for Diapers Degradation by the Fungus Pleurotus ostreatus," *Sustainability,* vol. 7, no. 5, pp. 6033-6045, 2015.

[27] R. M. Espinosa-Valdemar, P. X. Sotelo-Navarro, X. Quecholac-Piña , M. A. García-Rivera, M. Beltrán-Villavicencio, S. Ojeda-Benítez and A. Vázquez-Morillas, "Biological recycling of used baby diapers in a small-scale composting system," *Resources, Conservation and Recycling,* vol. 87, pp. 153-157, 2014.

[28] S. S. Lam, R. K. Liew, A. Jusoh, C. T. Chong, F. N. Ani and . H. A. Chase, "Progress in waste oil to sustainable energy, with emphasis on pyrolysis techniques," *Renewable and Sustainable Energy Reviews,* vol. 53, pp. 741-753, 2016.

[29] S. S. Lam, . R. K. Liew, X. Y. Lim, F. N. Ani and A. Jusoh, "Fruit waste as feedstock for recovery by pyrolysis technique," *International Biodeterioration & Biodegradation,* vol. 113, pp. 325-333, 2016.

[30] S. S. Lam, R. K. Liew, C. K. Cheng and H. A. Chase , "Catalytic microwave pyrolysis of waste engine oil using metallic pyrolysis char," *Applied Catalysis B: Environmental,* Vols. 176-177, pp. 601-617, 2015.

[31] S. S. Lam, R. K. Liew, Y. M. Wong, E. Azwar, A. Jusoh and R. Wahi , "Activated Carbon for Catalyst Support from Microwave Pyrolysis of Orange Peel," *Waste and Biomass Valorization,* vol. 8, pp. 2109-2119, 2017.

[32] L. Liang, R. Sun, J. Fei, S. Wu, X. Liu, K. Dai and N. Yao, "Experimental study on effects of moisture content on combustion characteristics of simulated municipal solid wastes in a fixed bed," *Bioresource Technology,* vol. 99, no. 15, pp. 7238-7246, 2008.

[33] F. Wang, Y. Zhou, B. Peng, Z. Liu and S. Hu, "Autogenous shrinkage of concrete with super-absorbent polymer," *ACI Materials Journal,* vol. 106, no. 2, pp. 123-127, 2009.

[34] X.-m. Kong, Z.-l. Zhang and Z.-c. Lu , "Effect of pre-soaked superabsorbent polymer on shrinkage of high-strength concrete," *Materials and Structures,* vol. 48, pp. 2741-2758, 2015.

[35] T. L. Ávalos-Rendón and C. J. Mendoza, "Study on the Expansion of a Cement-Based System Containing Sap Polymer and Supplementary Cementing Materials," *Materials Sciences and Applications,* vol. 8, no. 2, 2017.

[36] X. Kong and Z. Zhang, "Effect of super-absorbent polymer on pore structure of hardened cement paste in high-strength concrete," *Journal of the Chinese Ceramic Society,* vol. 41, no. 11, pp. 1474-1480, 2013.

[37] X. Kong and Q. Li, "Influence of super absorbent polymer on dimension shrinkage and mechanical properties of cement mortar," *Journal of the Chinese Ceramic Society,* vol. 37, no. 5, pp. 855-861, 2009.

[38] X. Kong and Z. Zhang, "Investigation on the shrinkage-reducing effect of super-absorbent polymer in high-strength concrete and its mechanism," *Journal of Building Materials,* vol. 17, no. 4, pp. 559-571, 2014.

[39] H. AzariJafari, A. Kazemian, M. Rahimi and A. Yahia, "Effects of pre-soaked super absorbent polymers on fresh and hardened properties of self-consolidating lightweight concrete," *Construction and Building Materials*, vol. 113, pp. 215-220, 2016.

[40] S. Gupta, "Effect of presoaked superabsorbent polymer on strength and permeability of cement mortar," *Magazine of Concrete Research*, vol. 70, no. 9, pp. 473-486, 2018.

[41] S.-H. Kang, . S.-G. Hong and J. Moon, "Absorption kinetics of superabsorbent polymers (SAP) in various cement-based solutions," *Cement and Concrete Research*, vol. 97, pp. 73-83, 2017.

[42] M. Wyrzykowski, G. Terrasi and P. Lura, "Expansive high-performance concrete for chemical-prestress applications," *Cement and Concrete Research,* vol. 107, pp. 275-283, 2018.

[43] X. Ma, J. Liu, Z. Wu and C. Shi, "Effects of SAP on the properties and pore structure of high performance cement-based materials," *Construction and Building Materials*, vol. 131, pp. 476-484, 2017.

[44] D. Snoeck, O. Jensen and N. D. Belie, "The influence of superabsorbent polymers on the autogenous shrinkage properties of cement pastes with supplementary cementitious materials," *Cement and Concrete Research,* vol. 74, pp. 59-67, 2015.

[45] D. Snoeck, J. Dewanckele, V. Cnudde and N. D. Belie, "X-ray computed microtomography to study autogenous healing of cementitious materials promoted by superabsorbent polymers," *Cement and Concrete Composites*, vol. 65, pp. 83-93, 2016.

[46] A. Assmann and H. Reinhardt, "Tensile creep and shrinkage of SAP modified concrete," *Cement and Concrete Research*, vol. 58, pp. 179-185, 2014.

[47] Z. He, A. Shen, G. Yinchuan, Z. Lyu, D. Li, X. Qin, M. Zhao and Z. Wang, "Cement-based materials modified with superabsorbent polymers:A review," *Construction and Building Materials,* vol. 225, pp. 569-590, 2019.

[48] S. Mönnig, "Superabsorbing additions in concrete : applications, modelling and comparison of different internal water sources," Publication Server of the University of Stuttgart, Stuttgart, 2009.

[49] S.-H. Kang, S.-G. Hong and J. Moon, "Importance of drying to control internal curing effects on field casting ultra-high performance concrete," *Cement and Concrete Research,* vol. 108, pp. 20-30, 2018.

[50] C. Schroefl, V. Mechtcherine, P. Vontobel, J. Hovind and E. Lehmann, "Sorption kinetics of superabsorbent polymers (SAPs) in fresh Portland cement-based pastes visualized and quantified by neutron radiography and correlated to the progress of cement hydration," *Cement and Concrete Research*, vol. 75, pp. 1-13, 2015.

[51] F. C. Almeida and A. J. Klemm, "Efficiency of internal curing by superabsorbent polymers (SAP) in PC-GGBS mortars," *Cement and Concrete Composites,* vol. 88, pp. 41-51, 2018.

[52] D. Snoeck, D. Schaubroeck, . P. Dubruel and N. D. Belie, "Effect of high amounts of superabsorbent polymers and additional water on the workability, microstructure and strength of mortars with a water-to-cement ratio of 0.50," *Construction and Building Materials,* vol. 72, pp. 148-157, 2014.

[53] K. Farzanian, K. P. Teixeira, I. P. Rocha, L. D. S. Carneiro and A. Ghahremaninezhad, "The mechanical strength, degree of hydration, and electrical resistivity of cement pastes modified with superabsorbent polymers," *Construction and Building Materials,* vol. 109, pp. 156-165, 2016.

[54] V. Mechtcherine, D. Snoeck, C. Schröfl, N. De Belie, A. Klemm, K. Ichimiya, J. Moon, M. Wyrzykowski, P. Lura, N. Toropovs, A. Assmann and S.-i. Igarashi, "Testing superabsorbent polymer (SAP) sorption properties prior to implementation in concrete: results of a RILEM Round-Robin Test," *Materials and Structures,* vol. 51, no. 1, p. 28, 2018.

[55] M. Li, Y.-j. Wang , W.-b. Wang, Q. Tian and J.-p. Liu, "Quantitative characterisation of absorption capacity and dosage of SAP in cement paste," *Advances in Cement Research,* vol. 28, no. 8, pp. 518-528, 2016.

[56] X. Ma, J. Zhang and J. Liu, "Review on superabsorbent polymer as internal curing agent of high performance cement-based material," *Journal of the Chinese Ceramic Society,* vol. 43, no. 8, pp. 1099-1110, 2015.

[57] C.-H. Zhu, X.-T. Li, B.-J. Wang and Y.-J. Xie, *Journal of Building Materials,* vol. 16, no. 2, pp. 221-225, 2013.

[58] L. Senff , R. Modolo, G. Ascensão, D. Hotza, V. Ferreira and J. Labrincha , "Development of mortars containing superabsorbent polymer," *Construction and Building Materials,* vol. 95, pp. 575-584, 2015.

[59] E. Secrieru, V. Mechtcherine, C. Schröfl and D. Borin, "Rheological characterisation and prediction of pumpability of strain-hardening cement-based-composites (SHCC) with and without addition of superabsorbent polymers (SAP) at various temperatures," *Construction and Building Materials,* pp. 581-594, 2016.

[60] L. Senff, R. Modolo, G. Ascensão, D. Hotza, V. Ferreira and J. Labrincha, "Development of mortars containing superabsorbent polymer," *Construction and Building Materials,* vol. 95, pp. 575-584, 2015.

[61] J. Dang , J. Zhao and Z. Du, "Effect of Superabsorbent Polymer on the Properties of Concrete," *Polymers,* vol. 9, no. 12, p. 672, 2017.

[62] B. Craeye, M. Geirnaert and G. D. Schutter , "Super absorbing polymers as an internal curing agent for mitigation of early-age cracking of high-performance concrete bridge decks," *Construction and Building Materials,* vol. 25, no. 1, pp. 1-13, 2011.

[63] L. P. Esteves, P. Cachim and V. M. Ferreira , "Mechanical properties of cement mortars with superabsorbent polymers," *Advances in Construction Materials 2007,* pp. 451-462, 2007.

[64] H. Beushausen, M. Gillmer and M. Alexander, "The influence of superabsorbent polymers on strength and durability properties of blended cement mortars," *Cement and Concrete Composites,* vol. 52, pp. 73-80, 2014.

[65] H. Beushausen and M. Gillmer, "The use of superabsorbent polymers to reduce cracking of bonded mortar overlays," *Cement and Concrete Composites,* vol. 52, pp. 1-8, 2014.

[66] L. P. Esteves, P. Cachim and V. M. Ferreira , "Mechanical properties of cement mortars with superabsorbent polymers," *Advances in Construction Materials,* pp. 451-462, 2007.

[67] P. Lawrence, M. Cyr and E. Ringot, "Mineral admixtures in mortars: Effect of inert materials on short-term hydration," *Cement and Concrete Research,* vol. 33, no. 12, pp. 1939-1947, 2003.

[68] A. Mignon, M. Vagenende, J. Martins, . P. Dubruel, S. V. Vlierberghe and N. D. Belie, "Development of amine-based pH-responsive superabsorbent polymers for mortar applications," *Construction and Building Materials,* vol. 132, pp. 556-564, 2017.

[69] S. Gupta, H. W. Kua and S. D. Pang, "Combination of polypropylene fibre and superabsorbent polymer to improve physical properties of cement mortar," *Magazine of Concrete Research,* vol. 70, no. 7, pp. 350-364, 2018.

[70] L. P. Esteves, I. Lukošiūtė and J. Čėsnienė , "Hydration of cement with superabsorbent polymers," *Journal of Thermal Analysis and Calorimetry,* vol. 118, p. 1385–1393, 2014.

[71] P. Savva and M. F. Petrou, "Highly absorptive normal weight aggregates for internal curing of concrete," *Construction and Building Materials,* vol. 179, pp. 80-88, 2018.

[72] P. Yan, C. Yu, Q. Wang and B. Zhang, "Shrinkage-reducing measurement of high strength self-compacting concrete," *Journal of the Chinese Ceramic Society,* vol. 43, no. 4, pp. 363-367, 2015.

[73] D. Shen, X. Wang, D. Cheng and J. Zhang, "Effect of internal curing with super absorbent polymers on autogenous shrinkage of concrete at early age," *Construction and Building Materials,* vol. 106, pp. 512-522, 2016.

[74] K. Wang, D. C. Jansen, S. P. Shah and A. F. Karr, "Permeability study of cracked concrete," *Cement and Concrete Research,* vol. 27, no. 3, pp. 381-393, 1997.

[75] N. Heide, "Crack Healing in Hydrating Concrete," Delft Technology University, Delft, 2005.

[76] H. X. D. Lee, H. S. Wong and N. R. Buenfeld, "Potential of superabsorbent polymer for self-sealing cracks in concrete," *Advances in Applied Ceramics,* vol. 109, no. 5, pp. 296-302, 2013.

[77] D. Snoeck, K. Van Tittelboom, S. Steuperaert, D. Peter and D. B. Nele, "Self-healing cementitious materials by the combination of microfibres and superabsorbent polymers," *Journal of Intelligent Material Systems and Structures,* vol. 25, no. 1, pp. 13-24, 2014.

[78] A. Mignon, . G.-J. Graulus, D. Snoeck, J. Martins, N. D. Belie, . P. Dubruel and . S. Van Vlierberghe , "pH-sensitive superabsorbent polymers: a potential candidate material for self-healing concrete," *Journal of Materials Science,* vol. 50, pp. 970-979, 2015.

[79] A. Mignon, D. Snoeck, D. Schaubroeck, N. Luickx, P. Dubruel, S. Van Vlierberghe and N. D. Belie, "pH-responsive superabsorbent polymers: A pathway to self-healing of mortar," *Reactive and Functional Polymers,* vol. 93, pp. 68-76, 2015.

[80] K. Van Tittelboom, J. Wang , M. Araújo, D. Snoeck, E. Gruyaert, B. Debbaut, H. Derluyn, V. Cnudde, E. Tsangouri, D. Van Hemelrijck and N. D. Belie , "Comparison of different approaches for self-healing concrete in a large-scale lab test," *Construction and Building Materials,* vol. 107, pp. 125-137, 2016.

[81] H. Lee, H. Wong and N. Buenfeld, "Self-sealing of cracks in concrete using superabsorbent polymers," *Cement and Concrete Research,* vol. 79, pp. 194-208, 2016.

[82] D. Snoeck, . S. Steuperaert, K. Van Tittelboom , P. Dubruel and . N. D. Belie, "Visualization of water penetration in cementitious materials with superabsorbent polymers by means of neutron radiography," *Cement and Concrete Research,* pp. 1113-1121, 2012.

[83] M. T. Hasholt and O. M. Jensen, "Chloride migration in concrete with superabsorbent polymers," *Cement and Concrete Composites,* pp. 290-297, 2015.

[84] J. Dang, J. Zhao and Z. Du , "Effect of Superabsorbent Polymer on the Properties of Concrete," *Polymers,* vol. 9, no. 12, p. 672, 2017.

[85] H. Paiva, L. Esteves, P. Cachim and V. Ferreira, "Rheology and hardened properties of single-coat render mortars with different types of water retaining agents," *Construction and Building Materials,* vol. 23, no. 2, pp. 1141-1146, 2009.

[86] S. Laustsen, M. T. Hasholt and O. M. Jensen , "Void structure of concrete with superabsorbent polymers and its relation to frost resistance of concrete," *Materials and Structures,* vol. 48, pp. 357-368, 2015.

[87] X. Ma, J. Liu, Z. Wu and C. Shi, "Effects of SAP on the properties and pore structure of high performance cement-based materials," *Construction and Building Materials,* vol. 131, pp. 476-484, 2017.

[88] A. Mignon, D. Snoeck, P. Dubruel, S. Van Vlierberghe and N. D. Belie, "Crack Mitigation in Concrete: Superabsorbent Polymers as Key to Success?," *Materials,* vol. 10, no. 3, p. 237, 2017.

[89] D. Bentz and O. Jensen, "Mitigation strategies for autogenous shrinkage cracking," *Cement and Concrete Composites,* vol. 26, no. 6, pp. 677-685, 2004.

[90] S. Monnig and P. Lura, "Superabsorbent polymers - an additive to increase the freeze-thaw resistance of high strength concrete," *Advances in Construction Materials,* 2007.

[91] V. Mechtcherine, "Use of superabsorbent polymers (SAP) as concrete additive," *RILEM technical letters,* vol. 1, pp. 81-87, 2016.

[92] V. Mechtcherine, C. Schröfl, M. Wyrzykowski, M. Gorges, P. Lura, D. Cusson, J. Margeson, N. De Belie, D. Snoeck, K. Ichimiya, S.-I. Igarashi and V. Falikman, "Effect of superabsorbent polymers (SAP) on the freeze–thaw resistance of concrete: results of a RILEM interlaboratory study," *Materials and Structures,* vol. 50, no. 1, p. 14, 2017.

[93] W. A. Jones and W. J. Weiss, "Freeze Thaw Durability of Internally Cured Concrete Made Using Superabsorbent Polymers," in *4th International Conference on the Durability of Concrete Structures*, West Lafayette, IN, USA, 2014.

[94] V. Mechtcherine, "Use of superabsorbent polymers (SAP) as concrete additive," *RILEM technical letters,* vol. 1, pp. 81-87, 2016.

[95] A.-E. Brudern and V. Mechtcherine, "Multifunctional use of SAP in Strain-hardening cement-based composites," in *International RILEM conference on Use of Superabsorbent Polymers and Other New Additives in Concrete*, Lyngby, Denmark, 2010.

[96] A. Assmann, "Physical properties of concrete modified with superabsorbent polymers," University Stuttgart, Stuttgart, 2013.

[97] A. Mignon, D. Snoeck, P. Dubruel, S. Van Vlierberghe and N. De Belie, "Crack Mitigation in Concrete: Superabsorbent Polymers as Key to Success?," *Materials,* vol. 10, no. 3, p. 237, 2017.

[98] H. Beushausen, M. Gillmer and M. Alexander, "The influence of superabsorbent polymers on strength and durability properties of blended cement mortars," *Cement and Concrete Composites,* vol. 52, pp. 73-80, 2014.

[99] I. M. o. P. W. a. Housing, Spesifikasi Umum 2018 Untuk Pekerjaan Konstruksi Jalan dan Jembatan, Seksi 7 Beton dan Beton Kinerja Tinggi, Jakarta: Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2018.

[100] SNI, "Standar Nasional Indonesia No. 03-6882-2002 Spesifikasi Mortar untuk Material Bangunan," 2002.

[101] SNI, "Standar Nasional Indonesia No. 03-0349-1989 Bata Beton," 1989.

[102] SNI, "Standar Nasional Indonesia No. 03-0691-1996 Paving Block / Concrete Block," 1996.

[103] I. Z. Bribián, . A. V. Capilla and A. A. Usón, "Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential," *Building and Environment,* vol. 46, no. 5, pp. 1133-1140, 2011.

[104] I. Z. Bribián, A. A. Usón and S. Scarpellini, "Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification," *Building and Environment,* vol. 44, no. 12, pp. 2510-2520, 2009.

[105] I. 14040, "Environmental Management — Life Cycle Assessment — Principles And Framework," 2006.

[106] J. Monahan and . J. Powell , "An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework," *Energy and Buildings,* vol. 43, no. 1, pp. 179-188, 2011.

[107] M. Pellegrino, B. Thakur, H. Guha and M. Simonetti, "Energy Efficient Choice of Brick Façade in Kolkata, India," *Procedia Engineering,* vol. 21, pp. 737-744, 2011.

[108] D. Yeo and . R. D. Gabbai , "Sustainable design of reinforced concrete structures through embodied energy optimization," *Energy and Buildings,* vol. 43, no. 8, pp. 2028-2033, 2011.

[109] A. Shukla, G. Tiwari and M. Sodha, "Embodied energy analysis of adobe house," *Renewable Energy,* vol. 34, no. 3, pp. 755-761, 2009.

[110] N. A. Utama, B. C. Mclellan, S. H. Gheewala and K. N. Ishihara, "Embodied impacts of traditional clay versus modern concrete houses in a tropical regime," *Building and Environment,* vol. 57, pp. 362-369, 2012.

[111] N. Crishna, . P. Banfill and . S. Goodsir , "Embodied energy and CO2 in UK dimension stone," *Resources, Conservation and Recycling,* vol. 55, no. 12, pp. 1265-1273, 2011.

[112] D. D. Tingley and B. Davison, "Developing an LCA methodology to account for the environmental benefits of design for deconstruction," *Building and Environment,* vol. 57, pp. 387-395, 2012.

[113] J. Goggins, T. Keane and A. Kelly, "The assessment of embodied energy in typical reinforced concrete building structures in Ireland," *Energy and Buildings,* vol. 42, no. 5, pp. 735-744, 2010.

[114] J. Vogtländer, P. van der Lugt and H. Brezet, "The sustainability of bamboo products for local and Western European applications. LCAs and land-use," *Journal of Cleaner Production,* vol. 18, no. 13, pp. 1260-1269, 2010.

[115] Y. S. Wahyuni, Pengembangan Strategi Mitigasi Dampak Lingkungan Melalui Pertimbangan Nilai Embodied Energy Material pada Pembangunan Rumah Sederhana, Bandung: Institut Teknologi Bandung, 2017.

[116] J. Monahan and J. Powell, "A comparison of the energy and carbon implications of new systems of energy provision in new build housing in the UK," *Energy Policy,* vol. 39, no. 1, pp. 290-298, 2011.

[117] T. Hong, C. Ji and H. Park, "Integrated model for assessing the cost and CO2 emission (IMACC) for sustainable structural design in ready-mix concrete," *Journal of Environmental Management,* vol. 103, pp. 1-8, 2012.

[118] O. Salmi and M. Wierink, "Effects of waste recovery on carbon footprint: a case study of the Gulf of Bothnia steel and zinc industries," *Journal of Cleaner Production,* vol. 19, no. 16, pp. 1857-1864, 2011.

[119] Y.-S. Jeong, S.-E. Lee and J.-H. Huh, "Estimation of CO2 emission of apartment buildings due to major construction materials in the Republic of Korea," *Energy and Buildings,* vol. 49, pp. 437-442, 2012.

[120] J. Park, S. Tae and T. Kim, "Life cycle CO2 assessment of concrete by compressive strength on construction site in Korea," *Renewable and Sustainable Energy Reviews,* vol. 16, no. 5, pp. 2940-2946, 2012.

[121] A. Hasanbeigi, W. Morrow, J. Sathaye, E. Masanet and T. Xu, "A bottom-up model to estimate the energy efficiency improvement and CO2 emission reduction potentials in the Chinese iron and steel industry," *Energy,* vol. 50, pp. 315-325, 2013.

[122] T. Yihui , Q. Zhu and G. Yong, "An analysis of energy-related greenhouse gas emissions in the Chinese iron and steel industry," *Energy Policy,* vol. 56, pp. 352-361, 2013.

[123] K. Tanaka, "A comparison study of EU and Japan methods to assess CO2 emission reduction and energy saving in the iron and steel industry," *Energy Policy,* vol. 51, pp. 578-585, 2012.

[124] L. Ren and W. Wang, "Analysis of Existing Problems and Carbon Emission Reduction in Shandong's Iron and Steel Industry," *Energy Procedia,* vol. 5, pp. 1636-1641, 2011.

[125] L. K. Turner and F. G. Collins, "Carbon dioxide equivalent (CO2-e) emissions: A comparison between geopolymer and OPC cement concrete," *Construction and Building Materials,* vol. 43, pp. 125-130, 2013.

[126] J. Nässén, F. Hedenus, S. Karlsson and J. Holmberg, "Concrete vs. wood in buildings – An energy system approach," *Building and Environment,* vol. 51, pp. 361-369, 2012.

[127] N. Maoduš, B. Agarski, T. K. Mišulić, I. Budak and M. Radeka, "Life cycle and energy performance assessment of three wall types in south-eastern Europe region," *Energy and Buildings,* vol. 133, pp. 605-614, 2016.

[128] B. V. Reddy and K. Jagadish, "Embodied energy of common and alternative building materials and technologies," *Energy and Buildings,* vol. 35, no. 2, pp. 129-137, 2003.

[129] N. Huberman, D. Pearlmutter, E. Gal and I. Meir, "Optimizing structural roof form for life-cycle energy efficiency," *Energy and Buildings,* vol. 104, pp. 336-349, 2015.

[130] A. Chel and G. Kaushik , "Renewable energy technologies for sustainable development of energy efficient building," *Alexandria Engineering Journal*, vol. 57, no. 2, pp. 655-669, 2018.

[131] N. Kisku, P. Rajhans, S. Panda, S. Nayak and V. Pandey, "Development of durable concrete from C&D waste by adopting identical mortar volume method in conjunction with two-stage mixing procedure," *Construction and Building Materials*, vol. 256, p. 119361, 2020.

[132] S. Zuraida, Y. S. Wahyuni and D. Larasati, "Life Cycle Assessment of Low Costs Housing in Indonesia," in *The 2nd International Conference on Green Civil and Environmental Engineering* , Malang, 2019.

[133] B. Palacios-Munoz, . L. Gracia-Villa, . I. Zabalza-Bribián and B. López-Mesa, "Simplified structural design and LCA of reinforced concrete beams strengthening techniques," *Engineering Structures*, vol. 174, pp. 418-432, 2018.

[134] J. Vogtländer, P. Van der Lugt and H. Brezet, "The Sustainability of bambu products for local and Western European ppplications: LCAs and Land-Use," *Journal of Cleaner Production*, vol. 18, no. 13, pp. 126-1269, 2010.

[135] P. van der Lugt, A. van den Dobbelsteen and J. Janssen, "An environmental, economic and practical assessment of bamboo as a building material for supporting structures," *Construction and Building Materials*, vol. 20, no. 9, pp. 648-656, 2006.

[136] S. Zuraida and D. Larasati, "The Assessment of Marginal Prevention Costs on Bamboo Preservation Method," *Procedia Environmental Sciences*, vol. 28, pp. 789-798, 2015.

[137] SNI, "Standar Nasional Indonesia No. 2847:2019 Persyaratan Beton Struktural untuk Bangunan Gedung," 2019.

[138] SNI, "Standar Nasional Indonesia No. 7656:2012 Tata Cara Pelaksanan Campuran untuk Beton Normal, Beton Berat dan Beton Masa," 2012.

[139] SNI, "Standar Nasional Indonesia No. 03-2834-2000 Tata Cara Campuran untuk Beton Normal," 2000.

[140] Pusdiklat Perumah. Permukim. Pengemnb. Infr. Wil, Modul 3: Rancangan Campuran Beton, Bandung: Pusdiklat Jalan, Perumahan, Permukiman, dan Pengembangan Infrastruktur Wilayah, 2017.

[141] SNI 1972:2008, "Procedures of Slump Testing," Badan Standarisasi Nasional, Jakarta, 2008.

[142] SNI 2493:2011, "Procedures for the manufacture and maintenance of concrete specimens in the laboratory," Badan Standarisasi Nasional, Jakarta, 2011.

[143] SNI 1974:2011, "Test method for compressive strength of concrete," Badan Standarisasi Nasional, Jakarta, 2011.

[144] G. Hammond and C. Jones, The Inventory of Carbon and Energy (ICE), F. Lowrie and P. Tse, Eds., Bath: University of Bath - BSRIA, 2011.

[145] IDEMAT, "Industrial Design & Engineering MATerials database," Delft University of Technology, Delft, 2014.

[146] Ecoinvent, "Ecoinvent database," Ecoinvent, Zurich.

[147] A. Shanon, W. Feldman, W. James and C. Dulberg, "Diapers: What do parents choose and why?," *Can Fam Physician,* vol. 36, pp. 1705-1708, 1990.

[148] N. Lita, "Gambaran pemakaian diapers sekali pakai pada anak usia prasekolah," *Photon Jurnal Sain dan Kesehatan,* vol. 7, no. 2, pp. 47-52, 2017.

[149] Ullya, Widyawati and D. Armalina, "Hubungan antara pengetahuan dan perilaku ibu dalam pemakaian disposable diapers pada batita dengan kejadian ruam popok," *Jurnal Kedokteran Diponegoro,* vol. 7, no. 2, 2018.

[150] P. Warner and P. Kelly, Mengajari anak pergi ke toilet, Jakarta: Arcan, 2006.

[151] R. J. O'Connor, V. Sanchez, Y. Wang, R. Gibb, D. L. Nofziger, M. Bailey and A. N. Carr, "Evaluation of the Impact of 2 Disposable Diapers in the "Natural" Diaper Category on Diapered Skin Condition," *Clinical Pediatrics,* vol. 58, no. 7, pp. 806-815, 2019.

[152] S. H. Rahat, A. T. Sarkar, S. A. A. Rafie and S. Hossain, "Prospects of diaper disposal and its environmental impacts on populated urban area like dhaka city," in *2ndInternational Conference on Advances in Civil Engineering*, Bangladesh, 2014.

[153] L. A. Nommsen-Rivers, M. J. Heinig, R. J. Cohen and K. G. Dewey, "Newborn wet and soiled diaper counts and timing of onset of lactation as indicators of breastfeeding inadequacy," *Journal of Human Lactation,* vol. 24, no. 1, pp. 27-33, 2008.

[154] T. P. Health, "Protocol #3 Signs of Effective Breastfeeding," Toronto Public Health, Toronto, 2013.

[155] A. W. Breastfeeding, "Breastfed Baby Diaper Count," Arkansas WIC Breastfeeding , Arkansas.

[156] N. M. H. L. Consultants, "Breastfeeding Lo," Northwestern Memorial Hospital, 2022.

[157] S. Ratih and A. F. Dwi, "Analysis of factors related to the continuity flow of breast milk in normal postpartum mother," in *Seminar Nasional Hasil Penelitian dan Pengabdian Pada Masyarakat IV Tahun 2019*, Purwokerto, 2019.

[158] N. Fitrianingsih, "Pengaruh pola asuh orang tua dan intensitas penggunaan diapers terhadap tingkat kesiapan toilet training pada anak usia toddler di little care stikes surya global Yogyakarta," Universitas Sebelas Maret, Surakarta, 2013.

[159] A. D. Moelyaningrum, "Persepsi ibu terhadap sampah popok bayi sekali pakaidan manajemen pengelolaanya," in *rosiding Seminar Nasional Kependudukan, "Peran*

Keilmuan Kesehatan Masyarakat dalam Pembangunan Kependudukan Pasca MDGs 2015, Jember, 2013.

[160] Pampers, "Diaper Size and Weight Chart Guide," Pampers, 10 2021. [Online]. Available: https://www.pampers.com/en-us/baby/diapering/article/diaper-size-and-weight-chart. [Accessed 10 10 2022].

[161] M. V. Bohnen, "Weighing Wet Diapers A New Approach to Measuring Infant Output," University of Utah, Utah, 1971.

[162] "From conception to birth," 11 5 2021. [Online]. Available: https://bloga8.com/baby/how-much-does-a-dry-diaper-weigh.html.

[163] Y. Bachra, A. Grouli, F. Damiri, A. Bennamara and M. Berrada, "A new approach for assessing the absorption of disposable baby diapers and superabsorbent polymers: A comparative study," *Results in Materials,* vol. 8, p. 100156, 2020.

[164] U. N. H. S. P. (UN-HABITAT), Affordable Land and Housing in Asia, Nairobi: UNON, Publishing Services Section, 2011.

[165] U. N. H. S. P. (UN-HABITAT), Affordable Land and Housing in Africa, Nairobi: UNON, Publishing Services Section, 2011.

[166] U. N. H. S. P. (UN-HABITAT), Affordable Land and Housing in Latin America and The Carribean, Nairobi: UNON, Publishing Services Section, 2011.

[167] U. N. H. S. P. (UN-HABITAT), Affordable Land and Housing in Europe and North America, Nairobi: UNON, Publishing Services Section, 2011.

[168] M. M and A. M, Livelihoods among the Roofing Construction Subsector In Nakuru, Kenya, Warwickshire: Intermediate Technology Development Group, 2001.

[169] U. N. C. f. H. S. (UNCHS), "Building materials for housing: Report of the Executive Director, United Nations Commission on Human Settlements," *Habitat International,* vol. 17, no. 2, pp. 1-20, 1993.

[170] U. N. H. S. P. (UN-HABITAT), Enabling Shelter Strategies: Review of Experience from Two Decades of Implementation, Nairobi: UN-HABITAT, 2006.

[171] M. Srivastava and V. Kumar, "The methods of using low cost housing techniques in India," *Journal of Building Engineering,* vol. 15, pp. 102-108, 2018.

[172] E. Q. Bolanos, M. G. Oviedo, J. M. Bello, L. . S. Vitola, U. Berardi and C. B. Lecompte, "Potential use of coconut fibre modified mortars to enhance thermal comfort in low-income housing," *Journal of Environmental Management,* vol. 277, p. 111503, 2021.

[173] S. Zuraida and S. Pratiwi, "Panel Komposit Limbah Serbuk Kayu sebagai Alternatif Komponen Bangunan Ramah Lingkungan," *Journal of Applied Science (JAPPS),* vol. 2, no. 1, pp. 61-66, 2021.

[174] Y. Kulshreshtha, N. J. A. Mota, K. S. Jagadish, J. Bredenoord, P. . J. Vardon, M. C. M. van Loosdrechtf and H. M. Jonkers, "The potential and current status of earthen material for low-cost housing in rural India," *Construction and Building Materials,* vol. 247, p. 118615, 2020.

[175] K. . V. Gough, "Self-help Housing in Urban Colombia: Alternatives for the Production and Distribution of Building Materials," *Habitat International*, vol. 20, no. 4, pp. 635-651, 1996.

[176] C. Udawattha and R. Halwatura, "Life cycle cost of different Walling material used for affordable housing in tropics," *Case Studies in Construction Materials,* vol. 7, pp. 15-29, 2017.

[177] I. B. Ugochukwua and I. B. Chioma, "Local building materials: affordable strategy for housing the Urban poor in Nigeria," *Procedia Engineering,* vol. 118, pp. 42-49, 2015.

[178] R. Wesonga, H. Kasedde, N. Kibwami and M. Manga, "A Comparative Analysis of Thermal Performance, Annual Energy Use, and Life Cycle Costs of Low-cost Houses Made with Mud Bricks and Earthbag Wall Systems in Sub-Saharan Africa," *Energy and Built Environment,*, vol. 4, no. 1, pp. 13-24, 2023.

[179] V. M. Gohnert, I. Bulovic and R. Bradley, "A Low-cost Housing Solution: Earth Block Catenary," *Structures,* pp. 270-278, 2018.

[180] W. Bank, "Project Information Document (PID) Concept Stage," 2011.

[181] W. Bank, "Indonesia Public Expenditure Review: Spending Better Results," 2020.

[182] I. Statistic, "Statistik Perumahan dan Permukiman 2019," Badan Pusat Statistik, Jakarta, 2020.

[183] I. M. o. Finance, "Peranan APBN Dalam Mengatasi Backlog Perumahan Bagi Masyarakat Berpenghasilan Rendah (MBR)," Direktorat Jenderal Anggaran Kementerian Keuangan, Jakarta, 2015.

[184] I. M. o. E. a. Forestry, 2022.

[185] EDANA, "Sustainability Report 2007-2008: Absorbent Hygiene Products," European Disposable and Nonwovens Association , Brussels, 2008.

[186] I. M. o. P. W. a. Housing, "Keputusan Menteri Permukiman dan Prasarana Wilayah No. 403/KPTS/M/2002, tentang Pedoman Teknis Pembangunan Rumah Sederhana Sehat (Rs SEHAT)," 2002.

[187] D. Mohamad, S. Beddu, S. N. Sadon, N. . L. M. Kamal, Z. Itam, K. Mohamad and W. M. Sapuan, "Self-curing Concrete using Baby Diapers Polymer.," *Indian Journal of Science and Technology,* vol. 10, no. 4, 2017.

[188] B. Lagerblad, "Mechanism of carbonation," in *18th International Baustofftagung Ibausil*, Weimar, 2011.

[189] W. Nocun-Wczelik and G. Lój, "Effect of finely dispersed limestones additives of different origin on cement hydration kineticks and cement hardening," in *International Congress on the Chemistry of Cement*, Madrir, 2011.

[190] R. K. Chouhan, M. Mudga, . A. Bisarya and A. K. Srivastava, "Rice-husk-based superplasticizer to increase performance of fly ash geopolymer concrete," *Emerging Materials Research,* vol. 7, no. 3, pp. 169-177, 2018.

[191] H. T. Le and H.-M. Ludwig, "Effect of rice husk ash and other mineral admixtures on properties of self-compacting high performance concrete," *Materials & Design,* vol. 89, pp. 156-166, 2016.

[192] S. A. Zareei, F. Ameri, F. Dorostkar and M. Ahmadi, "Rice husk ash as a partial replacement of cement in high strength concrete containing micro silica: Evaluating durability and mechanical properties," *Case Studies in Construction Materials,* vol. 7, pp. 73-81, 2017.

[193] B. M. L. Gambhir, Tata McGraw-Hill, 2004, pp. 127-128.

[194] W. Mckay and . J. Mckay, Building Construction Vol. II (Fourth Edition), Orient Longman Private Limited, 1971, p. 32.

[195] A. Harmaji, A. M. Imran and B. Sunendar, "The Effect of Pulp Industrial Waste as Chemical Admixture to Compressive Strength of Fly Ash Based Alkali Activated Materials," in *MATEC Web of Conferences*, 2017.

[196] E. Koenders, M. Pepe and E. Martinelli, "Compressive strength and hydration processes of concrete with recycled aggregates," *Cement and Concrete Research,* vol. 56, pp. 203-212, 2014.

[197] L. Arthur, Materials for architects and builders, Butterworth: Butterworth-Heinemann, 2007.

[198] F. Sayahi, M. Emborg and H. Hedlund, "Effect of Water-Cement Ratio on Plastic Shrinkage Cracking in Self-Compacting Concrete," in *23th Symposium on Nordic Concrete Research & Developement*, Aalborg, Denmark, 2017.

[199] S. Zheng , T. Liu, G. Jiang, C. Fang, B. Qu , P. Gao , L. Li and Y. Feng , "Effects of Water-to-Cement Ratio on Pore Structure Evolution and Strength Development of Cement Slurry Based on HYMOSTRUC3D and Micro-CT," *Applied Sciences,* vol. 11, no. 7, p. 3063, 2021.

[200] Y.-Y. Kim, K.-M. Lee, J.-W. Bang and S.-J. Kwon, "Effect of W/C Ratio on Durability and Porosity in Cement Mortar with Constant Cement Amount," *Advances in Materials Science and Engineering,* vol. 2014, p. 11, 2014.

[201] P. R. d. Matos, R. D. Sakata, M. Foiato, W. L. Repette and P. J. P. Gleize, "Workability maintenance of water-reducing admixtures in high-performance pastes produced with different types of Portland cement," *Matéria*, 2021.

[202] A. M. Mansor, R. P. Borg, A. M. M. Hamed, M. M. Gadeem and M. M. Saeed, "The effects of water-cement ratio and chemical admixtures on the workability of concrete," in *FIB Conference: Sustainable Concrete: Materials and Structures*, 2018.

[203] D. Leonard and M. Ishak, "The Effect of Over Dosage of Water Reducing and Retarding Admixture to Concrete Strength," 2017.

[204] J. Li, L. Yang, F. Rao, W. Liu, H. Ma, X. Chi and S. Zhong, "Influence of Ca on the mechanical properties and microstructures of slag-fly ash geopolymers," *Minerals and Mineral Materials,* vol. 1, no. 2, 2022.

[205] A. Harmaji and B. Sunendar, "Utilization of Fly Ash, Red Mud, and Electric Arc Furnace Dust Slag for Geopolymer," *Materials Science Forum,* vol. 841, pp. 157-161, 2016.

[206] A. Harmaji, A. M. Imran, B. Sunendar, M. S. Lazuardi, I. Khairunnasari and A. Sobandi, "Effect of air-cooled slag and granulated blast furnace slag addition as substitutor on fly ash based geopolymer," in *Green Construction and Engineering Education (GCEE) Conference*, Malang, 2017.

[207] Y. Faza, A. Harmaji, V. Takarini, Z. Hasratiningsih and A. Cahyanto, "Synthesis of Porous Metakaolin Geopolymer as Bone Substitute Materials," *Key Engineering Materials,* vol. 829, pp. 182-187, 2019.

[208] A. Harmaji, C. Claudia, L. Asri, B. Sunendar and A. Nuruddin , "Pengaruh Waktu Curing Terhadap Kuat Tekan Geopolimer Berbasis Fly Ash," *ENSAINS Journal,* vol. 2, no. 1, p. 50, 2019.

[209] A. Harmaji, "Seawater as Alkali Activator in Fly Ash Based Geopolymer," *Engineering, Mathematics And Computer Science (Emacs) Journal,* vol. 4, no. 2, 2019.

[210] M. Á. Sanjuán , C. Andrade , P. Mora and A. Zaragoza, "Carbon Dioxide Uptake by Cement-Based Materials: A Spanish Case Study," *Applied Sciences,* vol. 10, no. 1, p. 339, 2019.

[211] M. M. H. Khan, J. Havukainen and M. Horttanainen, "Impact of utilizing solid recovered fuel on the global warming potential of cement production and waste management system: A life cycle assessment approach," *Waste Management & Research: The Journal for a Sustainable Circular Economy,* vol. 39, no. 4, p. 561–572, 2020.

[212] R. M. Andrew, "Global CO2 emissions from cement production," *Earth System Science Data,* vol. 10, no. 1, p. 195–217, 2018.

[213] G. U. Fayomi, S. E. Mini, O. S. I. Fayomi and . A. A. Ayoola, "Perspectives on environmental CO2 emission and energy factor in Cement Industry," in *International Conference on Energy and Sustainable Environment,* Nigeria, 2019.

[214] A. V. Lăzărescu, H. Szilagyi, C. Baeră and A. Ioani, "The Effect of Alkaline Activator Ratio on the Compressive Strength of Fly Ash-Based Geopolymer Paste," in *International Conference on Innovative Research - ICIR Euroinvent*, Iasi, Romania, 2017.

[215] L. Tian , D. He , J. Zhao and H. Wang , "Durability of geopolymers and geopolymer concretes: A review," *Reviews On Advanced Materials Science,* vol. 60, no. 1, pp. 1-14, 2021.

[216] N. Singh and B. Middendorf , "Geopolymers as an alternative to Portland cement: An overview," *Construction and Building Materials,* vol. 237, p. 117455, 2020.

[217] T. Luukkonen, Z. Abdollahnejad, J. Yliniemi, P. Kinnunen and M. Illikainen, "One-part alkali-activated materials: A review," *Cement and Concrete Research,* vol. 103, pp. 21-34, 2018.

[218] Z. Tang, W. Li, Y. Hu , J. L. Zhou and V. W. Tam, "Review on designs and properties of multifunctional alkali-activated materials (AAMs)," *Construction and Building Materials,* vol. 200, pp. 474-489, 2019.

[219] L. N. Sambe, B. Origbo, S. Gbande and P. U. Ande, "Assessment of wood waste generation and utilization in Makurdi metropolis: Implication for sustainable management of forest resources," *Journal of Research in Forestry, Wildlife and Environment,* vol. 13, no. 1, p. 188–196, 2021.

[220] S. Adhikari and B. Ozarska , "Minimizing environmental impacts of timber products through the production process "From Sawmill to Final Products," *Environmental Systems Research,* vol. 7, no. 1, pp. 1-15, 2018.

[221] K. Choudhary, K. S. Sangwan and D. Goyal, "Environment and economic impacts assessment of PET waste recycling with conventional and renewable sources of energy," *Procedia CIRP,* vol. 80, pp. 422-427, 2019.

[222] S. Zuraida, A. Primasetra, R. B. Margono and A. Harmaji, "The Application of Plastic Composite Panel for Prefabricated Low Costs Housing: A Green Design Proposal," *Journal of Asian Institute of Low Carbon Design,* pp. 605-610, 2020.

[223] A. Harmaji and S. Zuraida, "Green construction material: Polyethylene waste reinforce concrete for panel application," *International Journal of Built Environment,* vol. 3, no. 1, pp. 1-6, 2019.

[224] A. I. C39/C39M-03, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," West Conshohocken, PA, USA, 2003.

[225] S. Na, S. Lee and S. Youn , "Experiment on Activated Carbon Manufactured from Waste Coffee Grounds on the Compressive Strength of Cement Mortars," *Symmetry,* vol. 13, no. 4, p. 619, 2021.

[226] A. S. Benosman, H. Taïbi, Y. Senhadji, M. Mouli, M. Belbachir and M. Bahlouli, "Plastic Waste Particles in Mortar Composites: Sulfate Resistance and Thermal Coefficients," *Progress in Rubber, Plastics and Recycling Technology,* vol. 33, no. 3, p. 171–202, 2017.

[227] M. Thiam, M. Fall and . M. Diarra, "Mechanical properties of a mortar with melted plastic waste as the only binder: Influence of material composition and curing regime, and application in Bamako," *Case Studies in Construction Materials,* vol. 15, p. e00634, 2021.

[228] ISO 14040, Environmental Management —life cycle assessment–principles and framework, International Organization for Standardization, 2006 .

[229] E. G. Dascalaki, P. Argiropoulou, C. A. Balaras, K. G. Droutsa and S. Kontoyiannidis, "Analysis of the embodied energy of construction materials in the life cycle assessment of Hellenic residential buildings," *Energy and Buildings,* vol. 232, no. 1, p. 110651, 2021.

[230] X. Chen, C. Shuai, Y. Wu and Y. Zhang, "Analysis on the carbon emission peaks of China's industrial, building, transport, and agricultural sectors," *Science of The Total Environment,* vol. 709, p. 135768, 2020.

[231] E. Resch, C. Lausselet, H. Brattebø and I. Andresen, "An analytical method for evaluating and visualizing embodied carbon emissions of buildings," *Building and Environment,* vol. 168, p. 106476, 2020.

[232] X. Zhang and X. Zhang, "A subproject-based quota approach for life cycle carbon assessment at the building design and construction stage in China," *Building and Environment,* vol. 185, p. 107258, 2020.

[233] L. F. Cabeza, L. Boquera, M. Chàfer and D. Vérez, "Embodied energy and embodied carbon of structural building materials: Worldwide progress and barriers through literature map analysis," *Energy and Buildings,* vol. 231, p. 110612, 2021.

[234] H. Zheng, A. Li , F. Meng and G. Liu , "Energy flows embodied in China's interregional trade: Case study of Hebei Province," *Ecological Modelling,* vol. 428, p. 109061, 2020.

[235] B. Liu, W. Dedong, X. Youquan, C. Liu and M. Luther , "Embodied energy consumption of the construction industry and its international trade using multi-regional input–output analysis," *Energy and Buildings,* vol. 173, pp. 489-501, 2018.

[236] A. E. Fenner, C. J. Kibert, J. Li , M. A. Razkenari, H. Hakim, X. Lu, M. Kouhirostami and M. Sam, "Embodied, operation, and commuting emissions: A case study comparing the carbon hotspots of an educational building," *Journal of Cleaner Production,* vol. 268, p. 122081, 2020.

[237] M. Robati, D. Daly and G. Kokogiannakis, "A method of uncertainty analysis for whole-life embodied carbon emissions (CO2-e) of building materials of a net-zero energy building in Australia," *Journal of Cleaner Production,* vol. 225, pp. 541-553, 2019.

[238] Y. Cang, L. Yang, Z. Luo and N. Zhang , "Prediction of embodied carbon emissions from residential buildings with different structural forms," *Sustainable Cities and Society,* vol. 54, p. 101946, 2020.

[239] J. G. Vogtlander, A Quick Reference Guide to LCA Data And Eco-Based Materials Selection, Delft, Netherland: Delft Academic Press, 2015.

[240] J. G. Vogtlander, LCA: A Practical Guideline for Students, Designers and Business Managers, Delft, Netherland: Delft Academic Press, 2017.

[241] J. Carreras, D. Boer, L. F. Cabeza, L. Jiménez and G. Guillén-Gosálbez, "Eco-costs evaluation for the optimal design of buildings with lower environmental impact," *Energy and Buildings,* vol. 119, pp. 189-199, 2016.

[242] S. Zuraida and D. Larasati, "Eco-Costs Life Cycle Assessment of Traditional Housing in Indonesia: The Case of West Java," in *International Symposium of Architectural Interchanges in Asia*, Sendai, Japan, 2016.

[243] S. Zuraida and D. Larasati, " Economic Analysis of Bamboo Preservation Method in Indonesia," in *ASEAN Bamboo Symposium,* Kuala Lumpur, Malaysia, 2016.

[244] S. Zuraida and D. Larasati, " Environmental Impacts of Bamboo Preservation Methods as an Assessment of Sustainable Material," in *International Seminar On Partnership For Sustainable Housing and Urban,* Surabaya, Indonesia, 2015.

[245] Z. Ding, S. Liu, L. Luo and L. Liao, "A building information modeling-based carbon emission measurement system for prefabricated residential buildings during the materialization phase," *Journal of Cleaner Production,* vol. 264, p. 121728, 2020.

[246] X. Zhang, K. Liu and Z. Zhang, "Life cycle carbon emissions of two residential buildings in China: Comparison and uncertainty analysis of different assessment methods," *Journal of Cleaner Production,* vol. 266, p. 122037, 2020.

[247] M. Lu and J. Lai, "Review on carbon emissions of commercial buildings," *Renewable and Sustainable Energy Reviews,* vol. 119, p. 109545, 2020.

[248] J. Lee , S. Tae and R. Kim, "A Study on the Analysis of CO2 Emissions of Apartment Housing in the Construction Process," *Sustainability,* vol. 10, no. 2, p. 365, 2018.

[249] L. Luo and Y. Chen, "Carbon emission energy management analysis of LCA-Based fabricated building construction," *Sustainable Computing: Informatics and Systems,* vol. 27, p. 100405, 2020.

[250] Y. Gong and D. Song, "Life Cycle Building Carbon Emissions Assessment and Driving Factors Decomposition Analysis Based on LMDI—A Case Study of Wuhan City in China," *Sustainability,* vol. 7, no. 12, pp. 16670-16686, 2015.

[251] M. E. Goerndt, F. X. Aguilar and K. Skog, "Drivers of biomass co-firing in U.S. coal-fired power plants," *Biomass and Bioenergy,* vol. 58, pp. 158-167, 2019.

[252] A. Valero, "Co-firing of low rank coal and biomass: a chance for biomass penetration in the renewables," *RE&PQJ*, vol. 1, no. 1, 2003.

[253] ETSAP and IRENA, "Biomass Co-firing in Coal Power Plants," IEA- ETSAP and IRENA Technology-Policy Brief E21, 1 2013. [Online]. Available: www.etsap.org; www.irena.org. [Accessed 4 1 2020].

[254] Y. Xu, J. Zhou, K. Yang and G. Zhao, "Biomass co-firing power generation technology: current status, challenges and policy implications," *Sustainability,* vol. 12, p. 3629, 2020.

[255] M.-K. Kim, B. Paudel and D. L. Snyder, "Benefit Cost For Biomass Co-Firing In Electricity Generation: Case Of Utah U.S.," *International Journal of Food and Agricultural Economic,* vol. 3, no. 3, pp. 15-30, 2015.

[256] Wold Bank, "Municipal Solid Waste Incineration: Requirement for Successful Project," The World Bank, The World Bank, 2000.

[257] DEFRA, "Examples of Energy Efficiency for Incineration: Incineration of Municipal Solid Waste," Department for Environment, Food & Rural Affairs (DEFRA), 2013.

[258] M. Aldahdooh, A. Jamrah, A. Alnuaimi, M. Martini, M. Ahmed and A. Ahmed, "Influence of various plastics-waste aggregates on properties of normal concrete," *Journal of Building Engineering,* vol. 17, pp. 13-22, 2018.

[259] Y. Ghernouti, B. Rabehi, B. Safi and R. Chaid, "Use of recycled plastic bag waste in the concrete," *Materials, Methods & Technologies,* vol. 8, pp. 480-487, 2014.

[260] M. Záleská, M. Pavlíková, J. Pokorný, O. Jankovský, Z. Pavlík and R. Černý, "Structural, mechanical and hygrothermal properties of lightweight concrete based on the application of waste plastics," *Construction and Building Materials,* vol. 180, pp. 1-11, 2018.

[261] C. Aciu, D.-A. Ilutiu-Varvara , D.-L. Manea, Y.-A. Orban and F. Babota , "Recycling of plastic waste materials in the composition of ecological mortars," *Procedia Manufacturing,* vol. 22, pp. 274-279, 2018.

[262] S. Zuraida and S. Pratiwi, "Analisis Fisik dan Mekanik pada Pengembangan Panel Komposit Limbah Serbuk Kayu," *Journal of Applied Science,* vol. 2, no. 1, pp. 61-66, 2020.

[263] R. H. Setiyawan, "Karakteristik komposit serat enceng gondok dengan fraksi volume 15%, 20%, 25% terhadap uji bending, uji tarik dan daya serap bunyi untuk dinding peredam suara," Universitas Muhammadiyah Surakarta, Surakarta, 2016.

[264] B. Coppola, L. Courard, F. Michel , L. Incarnato, P. Scarfato and L. D. Maio, "Hygro-thermal and durability properties of a lightweight mortar made with foamed plastic waste aggregates," *Construction and Building Materials,* vol. 170, pp. 200-206, 2018.

[265] A. Kharazipour and U. Kües, "Recycling of Wood Composites and Solid Wood Products," in *Wood Composite and Wood Recycling*, 2007, pp. 509-533.

[266] International Energy Agency (IEA), "Energy Technology Perspectives 2016: Towards Sustainable Urban Energy systems," International Energy Agency (IEA), 2016.

[267] Intergovernmental Panel on Climate Change (IPCC), "Introduction BT - IPCC Guidelines for National," Intergovernmental Panel on Climate Change (IPCC), 2006.

[268] R. M. Andrew, "Global CO2 emissions from cement production 1928–2018," *Earth System Science Data,* vol. 11, no. 4, p. 1675–1710, 2019.

[269] C. Peng, "Calculation of a building's life cycle carbon emissions based on Ecotect and building information modeling," *Journal of Cleaner Production,* vol. 112, no. 1, pp. 453-465, 2016.

[270] BPS-Statistic of Jakarta Timur Municipality, Jakarta Timur Municipality in Figures 2021, Jakarta Timur Municipality, 2021.

[271] BPS-Statistic of Bekasi Municipality, Bekasi Municipality in Figures 2021, Bekasi: Bekasi Municipality, 2021.

[272] BPS-Statistic of Surabaya Municipality , Surabaya Municipality in Figures 2021, Surabaya: Surabaya Municipality, 2021.

[273] BPS-Statistic of Bandung Municipality, Bandung Municipality in Figures 2021, Bandung: BPS-Statistic of Bandung Municipality, 2021.

[274] BPS-Statistic of Jakarta Barat Municipality, Jakarta Barat Municipality in Figures 2021, Jakarta: Jakarta Barat Municipality , 2021.

[275] SNI 7394:2008, "The procedure for calculating the unit price of concrete works for the construction of buildings and housing," Badan Standarisasi Nasional, 2008.

[276] D. Mohamad, S. Beddu, N. M. Zahari, M. H. Zawawi, A. Syamsir, N. Radzuan and W. K. M. Sapuan, "The Performance of Diapers Polymer In Concrete As Self-Curing Agent In Term Of Chemical Properties," in *AIP Conference Proceedings,* 2018.

[277] W. Bank, "Project Information Document (PID) Concept Stage. National Affordable Housing Program (P154948)," World Bank, 2017.

[278] G. Indonesia, "Global Business Guide Indonesia," 2014. [Online]. Available: http://www.gbgindonesia.com/en/property/article/2014/indonesia_s_buildingandamp_construction_materials_sector.php. [Accessed 1 2 2020].

[279] T. Ringsholt, "Development of Building Materials and," United Nations Industrial Development Organization (UNIDO).

[280] Suparwoko, Peningkatan Kapasitas Perumahan Swadaya di Indonesia, Jogjakarta: Total Media, 2013.

[281] Ministry of Finance Republic Indonesia, "Indonesia Public Expenditure Review: Spending for Better Result," Ministry of Finance Republic Indonesia, Jakarta, 2020.

[282] F. Aulia, "The One Million Housing Program," 15 12 2020. [Online]. Available: https://irij-jakarta.com/indonesia-one-million-houses-program-in-2020/. [Accessed 10 1 2022].

[283] S. Zuraida and D. Larasati, " Eco-Costs Life Cycle Assessment Of Bamboo Preservation As Local Indigenous Method," in *Conference for Civil Engineering Research Networks (Concern)*, Bandung, 2014.

[284] Kementerian Pekerjaan Umum dan Perumahan Rakyat, Sistem Pracetak untuk Rumah Sederhana, Jakarta: Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2016.

[285] Pusat Penelitian Pengembangan Perumahan Pemukiman, Rumah Sehat Instan Sederhana (RISHA), Bandung: usat Penelitian Pengembangan Perumahan dan Pemukiman, 2015.

[286] Pusat Penelitian Peng. Kebijakan Penerapan Tek., Forum Bisnis Teknologi Litbang PUPR, Jakarta: Pusat Penelitian dan Pengembangan Kebijakan dan Penerapan Teknologi.

[287] E. A. Wicaksono, J. Thiodore and G. G. Amunisianto, "Kajian Evaluasi Rumah Rakit Berkonstruksi Kayu sebagai Hunian Sementara," in *Seminar Nasional Desain Sosial*, 2021.

[288] M. Srivastava and V. Kumar, "The methods of using low cost housing techniques in India," *Journal of Building Engineering,* vol. 15, pp. 102-108, 2018.

[289] Y. Kulshreshtha, N. Mota, K. S. Jagadish, J. Bredenoord, P. J. Vardon, M. C. van Loosdrecht and H. M. Jonkers, "The potential and current status of earthen material for low-cost housing in rural India," *The potential and current status of earthen material for low-cost housing in rural India,* vol. 247, p. 118615, 2020.

[290] M. Gohnert, I. Bulovic and R. Bradley, "A Low-cost Housing Solution: Earth Block Catenary Vaults," *Structures,* vol. 15, pp. 270-278, 2018.

[291] K. V. Gough, "Self-help Housing in Urban Colombia; Alternatives for the Production and Distribution of Building Materials," *Habitat International,* vol. 20, no. 4, pp. 635-651, 1996.

[292] Venkata Ramana M., Rao G.V., Shankar Rao B. and Shiva Prasad B. , "Design & development of durable low cost housing from glass fiber composites," *Materials Today: Proceedings,* vol. 38, no. 5, pp. 3205-3212, 2021.

[293] M. S. Gupta, U. K. Roy and M. Roy, "Expediting Faster Housing Supply in India Using Straw Bale as Prefab Building Material," *Encyclopedia of Renewable Sustainable Materials,* vol. 4, pp. 92-101, 2020.

[294] Varun Raj P, Surya Teja P, Sai Siddhartha K and Kalyana Rama J.S., "Housing with low-cost materials and techniques for a sustainable construction in India-A review," *Materials Today: Proceedings,* vol. 43, no. 2, pp. 1850-1855, 2021.

[295] M. Arun, K. Baskar, B.S. Geethapriya , M. Jayabarathi and R. Angayarkkani, "Affordable housing: Cost effective construction materials for economically weaker section," *Materials Today: Proceedings,* vol. 45, no. 9, pp. 7838-7844, 2021.

[296] C. Udawattha and R. Halwatura, "Life cycle cost of different Walling material used for affordable housing in tropics," *Case Studies in Construction Materials,* vol. 7, pp. 15-29, 2021.

[297] D. J. Pati and S. P. Dash, "Strategy for promoting utilization of non-biodegradable wastes in affordable housing in India," *Materials Today: Proceedings,* vol. 60, no. 1, pp. 26-32, 2022.

[298] E. Quiñones-Bolaños, M. Gómez-Oviedo, J. Mouthon-Bello, L. Sierra-Vitola, U. Berardi and C. Bustillo-Lecompte, "Potential use of coconut fibre modified mortars to enhance thermal comfort in low-income housing," *Potential use of coconut fibre modified mortars to enhance thermal comfort in low-income housing,* vol. 277, p. 111503, 2021.

[299] R. Wesonga, H. Kasedde, N. Kibwami and M. Manga, "A Comparative Analysis of Thermal Performance, Annual Energy Use, and Life Cycle Costs of Low-cost Houses Made with Mud Bricks and Earthbag Wall Systems in Sub-Saharan Africa," *Energy and Built Environment,* vol. x, no. x, p. x, 2021.

[300] M. . S. Gupta, U. . K. Roy and M. Roy, "Expediting Faster Housing Supply in India Using Straw Bale as Prefab Building Material," *Encyclopedia of Renewable and Sustainable Materials,* vol. 4, pp. 92-101, 2020.

[301] A. Olotuah, "Recourse to earthfor low-cost housing in Nigeria," *Building and Environment,* vol. 37, pp. 123-129, 2002.

[302] M. Gohnert, I. Bulovic and R. Bradley, "A Low-cost Housing Solution: Earth Block Catenary Vaults," *Structures,* vol. 15, pp. 270-278, 2018.

[303] M. Rai and N. G. Dave, "Building Materials for Low-cost housing," *Building and Environment,* vol. 26, no. 3, pp. 295-300, 1991.

[304] S. Zuraida, A. Primasetra, R. . B. Margono and A. Harmaji, "The Application of Plastic Composite Panel for Prefabricated Low Costs Housing in Indonesia: A Green Construction Design Proposal," *Journal of Asian Institute of Low Carbon Design (JAILCD),* 2020.

[305] M.-. Hill, "Prefabrication and Modularization, Increasing Productivity in Construction industry," McGraw- Hill Construction, 2011.

[306] W. Lu, W. M. Lee, F. Xue and J. Xu, "Revisiting the effects of prefabrication on construction waste minimization: A quantitative study using bigger data," *Resources, Conservation and Recycling,* vol. 170, p. 105579, 2021.

[307] O. Pons and G. Wadel, "Environmental impacts of prefabricated school buildings in Catalonia.," *Habitat International,* vol. 35, pp. 553-563, 2011.

[308] Y. Teng, K. Li, W. Pan and T. Ng, "Reducing building life cycle carbon emissions through prefabrication: Evidence from and gaps in empirical studies," *Building and Environment,* vol. 132, pp. 125-136, 2018.

[309] S. Zuraida, H. Armijaya, A. Harmaji, R. B. Margono and B. J. Dewancker, "A Calculation Approach of Embodied Energy, Carbon Emission and Eco-Costs on Waste Recycled Composite Materials," *Journal of Applied Science and Engineering,* vol. 25, pp. 109-118, 2021.

[310] S. Zuraida, B. J. Dewancker and R. B. Margono, "An Environmental Consideration of Disposable Diaper Waste Treatment as Concrete Component," *Journal of Asian Institute of Low Carbon Design,* pp. 153-158, 2021.

[311] KEMENPUPR, "Batasan Penghasilan Kelompok Sasaran KPR bersubsidi, Batasan Harga jual Rumah sejahtera Tapak dan Satuan Rumah sejahtera Susun, Serta Besaran subsidi bantuan uang muka perumahan," Kementerian pekerjaan umum dan perumahan rakyat, Jakarta, 2016.

[312] KEMENPERPRAWIL, "Pedoman Teknis Pembangunan Rumah Sederhana Sehat (Rs SEHAT)," Kementerian Permukiman dan Prasarana Wilayah, Jakarta, 2002.

[313] C. Davidson, "Myths And Realities Of Prefabrication For Postdisaster," *Journal I Rec Building resilience*, 2008.

[314] C. Goodier and A. G. F. Gibb, "Future opportunities for offsite in the UK," *Construction Management and Economics*, vol. 25, no. 6, pp. 585-597, 2007.

[315] SNI 2837:2008, "The procedure for calculating the price of the plastering unit for the construction of buildings and housing," Badan Standarisasi Nasional, 2008.

[316] SNI 7393-2008, "Procedures for calculating the unit price of steel and aluminum work for the unit price of steel and aluminum work for the," Badan Standarisasi Nasional, 2008.

[317] The Minister of Public Works and Housing, "Guidelines for Unit Price Analysis on Public Work 28/PRT/M/2016," The Minister of Public Works and Housing, 2016.

[318] McGraw Hill Construction, "Prefabrication and modularization, increasing productivity in costruction industry," Smart Market Report, 2011.

[319] C. Davidson, G. Lizarralde and C. Johnson, "Myths and reakities of prefabrication for postdisaster reconstruction," in *i-Rec 2008*, 2008.

[320] M. A. Irfan, S. Zuraida, A. Primasetra, A. Harmaji, F. F. A. Risnandar and Ilham, "Pengembangan Rumah Pra-pabrikasi Berbahan Dasar Popok Bekas sebagai Hunian," Self publishing, Bandung, 2021.

[321] SNI 2847:2019, "Structural Concrete Requirements for Buildings," Badan Standarisasi Nasional, 2019.

[322] SNI 1729:2015, "Specifications for Structural Steel Buildings," Badan Standarisasi Nasional, 2015.

[323] SNI 1726:2019, "Earthquake Resistance Planning Procedures for Building and Non-Building Structures," Badan Standarisasi Nasional, 2019.

[324] SNI 1727:2013, "Minimum Load for the Design of Buildings and Other Structures," Badan Standarisasi Nasional, 2013.

[325] SNI 8460:2017, "Geotechnical Design Requirements," Badan Standarisasi Nasional, 2017.

[326] Disaster Board of Indonesia, "Earthquake Hazard Source Map," Badan Penanggulangan Bencana, 2017.

[327] B. Solahuddin and F. Yahaya, "Properties of concrete containing shredded waste paper as an additive," *Materials Today: Proceedings,* vol. 51, no. 2, pp. 1350-1354, 2022.

[328] J. A. Sainz-Aja, M. Sanchez, L. Gonzalez, P. Tamayo, G. G. del Angel, A. Aghajanian, S. Diego and C. Thomas, "Recycled Polyethylene Fibres for Structural Concrete," *Applied Sciences,* vol. 12, no. 6, p. 2867, 2022.

[329] P. Pawar, P. Minde and M. Kulkarni, "Analysis of challenges and opportunities of prefabricated sandwich panel system: A solution for affordable housing in India," *Materials Today: Proceedings,* vol. 65, no. 2, pp. 1946-1955, 2022.

[330] S. Wang, H. Zhang, C. Wang and Y. Wu, "Cost Analysis Between Prefabricated Buildings and Traditional Buildings," 2019.

[331] A. Ebekozien, A. R. A. Aziz and M. Jaafar, "Housing finance inaccessibility for low-income earners in Malaysia: Factors," *Habitat International,* vol. 87, pp. 27-35, 2019.

[332] O. Dosumu and C. Aigbavboa, "Drivers and Effects of Sustainable Construction in The South African Construction Industry," *Acta Structilia,* vol. 28, no. 2, pp. 78-107, 2021.

[333] V. R. M, R. . G. V, S. R. B and S. P. B, "Design & development of durable low cost housing from glass fiber composites," *Materials today: Proceeding,* vol. 28, no. 5, pp. 3205-3212, 2021.

[334] V. R. P, S. T. P, S. S. K and K. R. J. S, "Housing with low-cost materials and techniques for a sustainable construction in India- A review," *Materials today: Proceeding,* vol. 43, no. 2, pp. 1850-1855, 2021.

[335] Y. Kulshreshtha, N. J. Mota, . K. . S. Jagadish, J. Bredenoord, P. . J. Vardon, M. . C. van Loosdrecht and H. M. Jonkers, "The potential and current status of earthen material for low-cost housing in rural India," *Construction and Building Materials,* vol. 247, p. 118615, 2020.

[336] M. Arun, K. Baskar, B. Geethapriya, M. Jayabarathi and R. Angayarkkani, "Affordable housing: Cost effective construction materials for economically weaker section,," *Materials Today: Proceedings,* vol. 45, no. 9, pp. 7838-7844, 2021.

[337] D. . J. Pati and S. . P. Dash, "Strategy for promoting utilization of non-biodegradable wastes in affordable housing in India," *Materials Today: Proceedings,* vol. 60, no. 1, pp. 26-32, 2021.

[338] C. Turco, A. C. P. Junior, E. R. Teixeira and R. Mateus, "Optimisation of Compressed Earth Blocks (CEBs) using natural origin materials: A systematic literature review," *Construction and Building Materials,* vol. 309, p. 125140, 2021.

[339] N. Jannat, A. Hussien, B. Abdullah and A. Cotgrave, "Application of agro and non-agro waste materials for unfired earth blocks construction: A review," *Construction and Building Materials,* vol. 254, p. 119346, 2020.

[340] G. Ruiz, X. Zhang, W. F. Edris, I. Cañas and L. Garijo, "A comprehensive study of mechanical properties of compressed earth blocks," *Construction and Building Materials,* vol. 176, pp. 566-572, 2018.

[341] E. S. R. Abdullah, A. K. Mirasa, H. Asrah and C. H. Lim, "Review on interlocking compressed earth," *IOP Conference Series: Earth and Environmental Science,* vol. 476, p. 012029, 2020.

[342] G. Lan, T. Wang, Y. Wang and K. Zhang, "Seismic performance of interlocking compressed-earth block composite walls," *Composite Structures,* vol. 308, p. 116704, 2023.

[343] J. . C. Salcido , . A. . A. Raheem and S. Ravi, "Comparison of embodied energy and environmental impact of alternative materials used in reticulated dome construction," *Building and Environment,* vol. 96, pp. 22-34, 2016.

[344] A. K. Faghih and M. N. Bahadori, "Solar radiation on domed roofs," *Energy and Buildings,* vol. 41, pp. 1238-1245, 2009.

[345] A. Chel, "Performance of skylight illuminance inside a dome shaped adobe house under composite climate at New Delhi (India): A typical zero energy passive house," *Alexandria Engineering Journal,* vol. 53, no. 2, pp. 385-397, 2014.

[346] V. Strazzeri and A. Karrech, "Qualitative and quantitative study to assess the use of rammed earth construction technology in Perth and the south-west of Western Australia," *Cleaner Materials,* vol. 7, p. 100169, 2023.

[347] D. Thompson, . C. Augarde and . J. P. Osorio, "A review of current construction guidelines to inform the design of rammed earth houses in seismically active zones," *Journal of Building Engineering,* vol. 54, p. 104666, 2022.

[348] F. Ávila, E. Puertas and . R. Gallego, "Characterization of the mechanical and physical properties of stabilized rammed earth: A review," *Construction and Building Materials,* vol. 325, p. 126693, 2022.

[349] F. L. Almansa, . V. Sarrablo, . J. Barros, . P. Roca , F. da Porto and C. Modena, "Reinforced brick masonry light vaults: Semi-prefabrication, construction, testing and numerical modeling," *Construction and Building Materials,* vol. 24, no. 10, pp. 1799-1814, 2010.

[350] G. Castori, . A. Borri and M. Corradi , "Behavior of thin masonry arches repaired using composite materials," *Composites Part B: Engineering,* vol. 87, pp. 311-321, 2016.

[351] M. Rossi, . C. C. Barentin, T. V. Mele and P. Block, "Experimental study on the behaviour of masonry pavilion vaults on spreading supports," *Structures,* vol. 11, pp. 110-120, 2017.

[352] A. Ebekozien and C. Aigbavboa, "COVID-19 recovery for the Nigerian construction sites: The role of the fourth industrial revolution technologies," *Sustainable Cities and Society,* vol. 69, p. 102803, 2021.

[353] A. Ebekozien, M. S. Samsurijan, C. Aigbavboa, R. B. R. Firdaus, N. A. N. Azazi and G. C. Amadi, "Infrastructure development in higher institutions: the role of private organisations via unexplored expanded corporatesocial responsibility (ECSR)," *Property Management,* vol. 41, no. 1, pp. 149-168, 2023.

[354] U. N. H. S. Programme, "Addressing Urban Poverty, Inequality, and Vulnerability in a Warming World," UN Habitat and UNDP, 2013.

[355] S. Zuraida, H. Armijaya, R. B. Margono, A. Harmaji and B. J. Dewancker, "A Calculation Approach of Embodied Energy, Carbon Emission and Eco-Costs on Waste Recycled Composite Materials," *Journal of Applied Science and Engineering,* vol. 25, no. 1, pp. 109-118, 2021.

[356] S. Zuraida, B. J. Dewancker and R. B. Margono, "An Environmental Consideration of Disposable Diaper Waste Treatment as Concrete Component," in *Journal Asian Institute of Low Carbon Design*, Kitakyushu, 2021.

[357] D. Mohamad, S. Beddu, S. N. Sadon, N. L. M. Kamal, Z. Itam, K. Mohamad and W. M. Sapuan, "Self-curing Concrete using Baby Diapers Polymer," *Indian Journal of Science and Technology,* vol. 10, no. 4, 2017.

[358] E. Browne, "Benefits of urbanisation in Asia," GSDRC, University of Birmingham, Birmingham, UK:, 2014.

[359] UN-HABITAT, "Addressing Urban Poverty, Inequality, and Vulnerability in a Warming World," UN-HABITAT and UNDP, 2013.

[360] S. H. Fransiska Ninditya, "Government eyes reducing housing backlog to five million in 2024," ANTARA, 9 2 2021. [Online]. Available: https://en.antaranews.com/news/167660/government-eyes-reducing-housing-backlog-to-five-million-in-2024. [Accessed 3 1 2022].

[361] K. P. U. d. P. Rakyat, "Tingkatkan Kepemilikan Hunian Layak, Realisasi Program Sejuta Rumah Hingga Akhir Oktober 2020 Capai 601.637 Unit," Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2020. [Online]. Available: https://www.pu.go.id/berita/view/18970/tingkatkan-kepemilikan-hunian-layak-realisasi-program-sejuta-rumah-hingga-akhir-oktober-2020-capai-601-637-unit. [Accessed 4 5 2021].

[362] M. A. Adabre, A. P. Chan, A. Darko, R. O. Kyei, R. Adiboye and T. A. Kumi, "Critical barriers to sustainability attainment in affordable housing: International construction professionals' perspective," *Journal of Cleaner Production,* vol. 253, p. 119995, 2020.

[363] A. P. Chan and M. A. Adabre, "Bridging the gap between sustainable housing and affordable housing: The required critical success criteria (CSC)," *Building and Environment,* vol. 151, pp. 112-125, 2019.

[364] M. Srivastava and V. Kumar, "The methods of using low cost housing techniques in India," *Journal of Building Engineering,* vol. 15, pp. 102-108, 2018.

[365] V. W. Y. Tam, "Cost effectiveness of using low cost housing technology in construction," *Procedia engineering,* vol. 14, pp. 156-160, 2011.

[366] Y. Kulshreshtha, N. J. Mota, K. S. Jagadish, J. Bredenoord, P. . J. Vardon, M. . C. van Loosdrechtf and H. M. Jonkers, "The potential and current status of earthen material for low-cost housing in rural India," *Construction and building materials,* vol. 247, p. 118615, 2020.

[367] V. Puria, P. Chakraborttya, S. Ananda and S. Majumdarb, "Bamboo reinforced prefabricated wall panels for low cost housing," *Journal of Building Engineering,* vol. 9, pp. 52-59, 2017.

[368] D. Larasati, A. Primasetra and Suhendri, "Accelerating Low-Cost Housing Construction in Indonesia: Lesson Learned From Kampong Naga.," *DIMENSI − Journal of Architecture and Built Environment,,* vol. 44, no. 1, pp. 79-86, 2017.

[369] E. . Q. Bolanos, M. . G. Oviedo, J. M. Bello, L. . S. Vitola, U. Berardi and C. B. Lecompte, "Potential use of coconut fibre modified mortars to enhance thermal comfort in low-income housing," *Journal of Environmental Management,* vol. 277, p. 111503, 2021.

[370] J. T. Heia, M. M. Islam and A. Islam, "An Investigation towards the Effects of Using Fiber Reinforced Polymers in the Enhancement of Shear Strength of Reinforced Concrete Beams," in *International Exchange and Innovation Conference on Engineering & Sciences (IEICES),* Fukuoka, 2021.

[371] R. Chakraborty, T. Paul and A. B. S. Ornob, "A Review on Tensile Behavior of Different Kinds of Fiber Reinforced Concrete," in *International Exchange and Innovation Conference on Engineering & Sciences (IEICES)* , Fukuoka, 2020.

[372] D. Pimentel, P. Huang, M. Pimentel and A. Codova, "Impact of a Growing Population on Natural Resources: The Challenge for Environmental Management," *Frontiers: The Interdisciplinary Journal of Study Abroad,* vol. 3, no. 1, pp. 105-131, 1997.

[373] EDANA, "Sustainability Report 2007-2008: Absorbent Hygiene Products," EDANA, Brussel, Belgium, 2008.

[374] S. Zuraida, . B. J. Dewancker and R. B. Margono, "Calculation formula in determining recycling of disposable diapers waste as concrete composite materials," in *The 3rd International Conference on Green Civil and Environmental Engineering*, Malang, 2021.

[375] Direktorat Jenderal Penyediaan Perumahan, Perjalanan Lima Tahun Program Sejuta Rumah, Jakarta: Yayasan Penerbit Pekerjaan Umum, 2019.

[376] Badan Penelitian dan Pengembangan, "Teknologi Rika (Rumah Instan Kayu) Dengan Teknologi Laminated Veneer Lumber," Badan Penelitian dan Pengembangan, Kementerian Pekerjaan Umum dan Perumahan Rakyat, [Online]. Available: http://elearning.litbang.pu.go.id/teknologi/teknologi-rika-rumah-instan-kayu-dengan-teknologi-laminated-veneer-lumber. [Accessed 10 1 2022].

APPENDIX

List of Appendix Tables

List of Appendix Graphs

List of Appendix Figures

Appendix Table 1. Mud content test for fine aggregates

Indonesian Concrete Standar 1971 (PBI NI-2-1971).			
Mud Content Test for Fine Aggregates			
Identifcation	Sample		
	1	2	
Cup weight	10,21	10,15	g
Sand before washing (oven dried) (A)	100	100	g
Sand before washing (oven dried)(B)	95,81	94,78	g
Mud content $\frac{A-B}{A} x100\%$	4,19	5,22	%
Average Mud content	4,71		%
Conclusion	Passed (mud content < 5 %)		

Appendix Table 2. Specific gravity and water absorption for fine aggregates

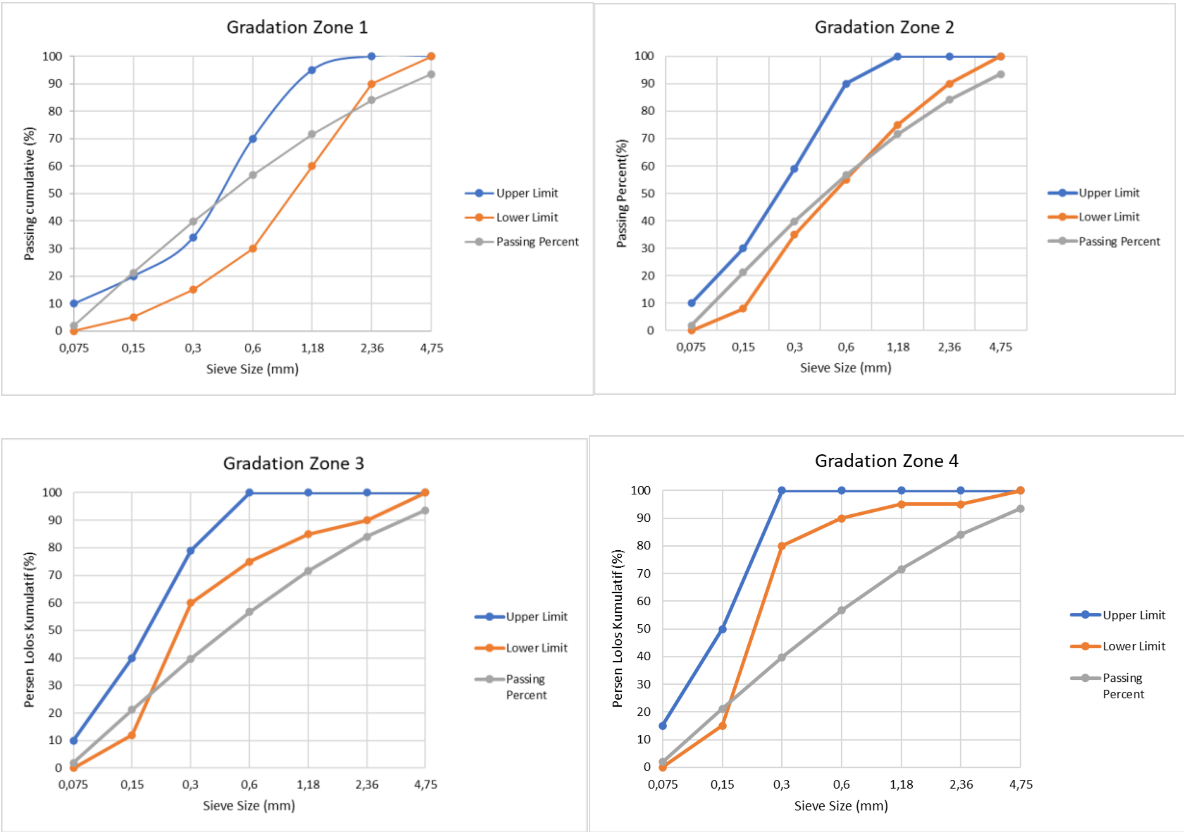
SNI 03-1970-1990			
Specific Gravity and Water Absorption Testing of Fine Aggregate			
Identifcation	Specimen		
	1	2	
Weight of saturated surface dry (SSD)	500	500	g
Weight of oven dry test (Bk)	486,14	481,84	g
Weight of pycnometer filled with water 25°C (B)	681,00	670,60	g
Weight of pycnometer + specimen in SSD + Water 25°C	995,28	982,86	g
Bulk specific gravity $\frac{Bk}{(B+500-Bt)}$	2,62	2,57	
Saturated surface dry specific gravity $\frac{500}{(B+500-Bt)}$	2,69	2,66	
Apparent specific gravity $\frac{Bk}{(B+Bk-Bt)}$	2,83	2,84	
Absorption $\frac{500-Bk}{(Bk)} x\ 100\ \%$	2,85	3,77	%
Average	**3,31**	%	

Appendix Table 3. Specific gravity and water absorption for coarse aggregates

SNI 03-1970-1990			
Specific Gravity and Water Absorption Testing of Coarse Aggregate			
Identification	Specimen		
	1	2	
Weight of saturated surface dry (Bj)	5270	4970	g
Weight of oven dry test (Bk)	4960	4670	g
Weight of specimen in the water (Ba)	3060	2860	g
Bulk specific gravity $\frac{Bk}{Bj-Ba}$	2,24	2,21	
Saturated surface dry specific gravity $\frac{Bj}{Bj-Ba}$	2,38	2,36	
Apparent specific gravity $\frac{Bk}{Bk-Ba}$	2,61	2,58	
Absorption $\frac{Bj-Bk}{Bk}100\%$	6,25	6,42	%
Average	**6,34**	%	

Appendix Table 4. Sieve analysis for fine aggregates Sample 1

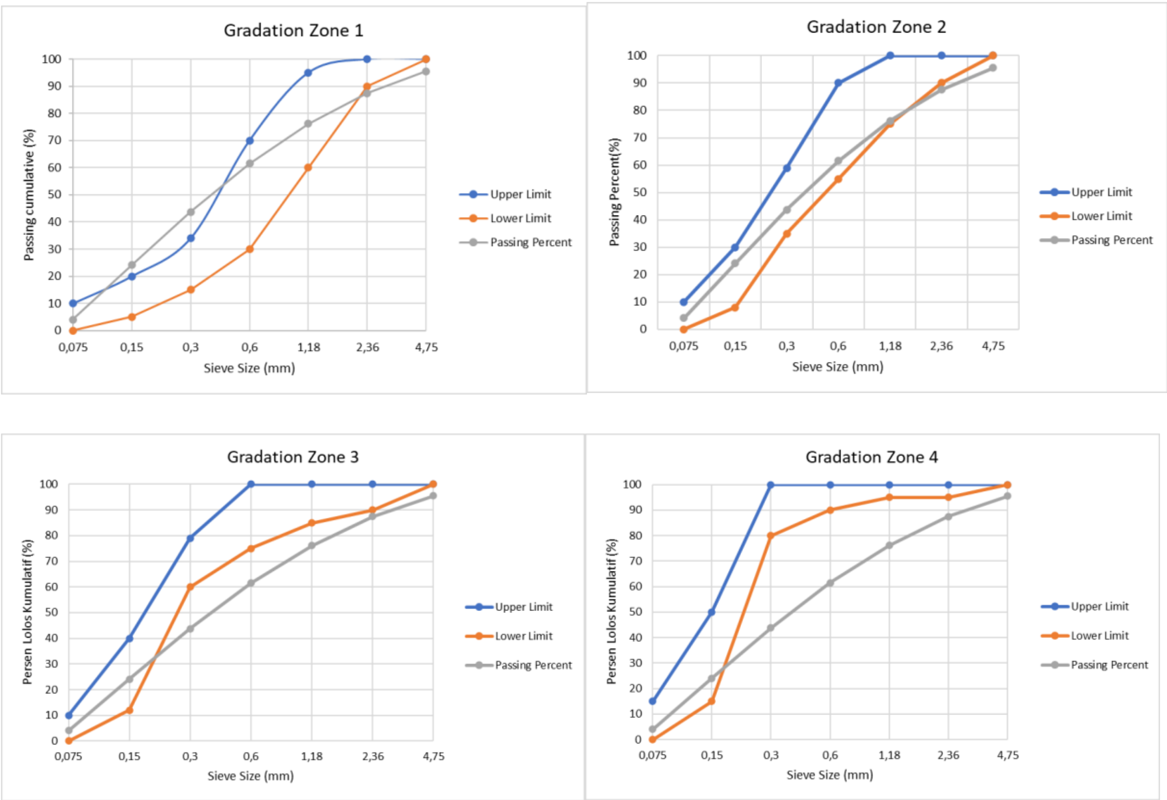
Sieve Analysis of Fine Aggregate Sample 1					
No	Sieve Size (mm)	Weight retained (gr)	Weight retained (%)	Weight retained cumulative(gr)	Passing cumulative (%)
1	12,5	0	0	0	100
2	9,5	69,86	1,37	1,37	98,63
3	4,75	258,39	5,06	6,42	93,58
4	2,36	484,12	9,47	15,90	84,10
5	1,18	636,62	12,46	28,36	71,64
6	0,6	762,68	14,93	43,28	56,72
7	0,3	865,71	16,94	60,22	39,78
8	0,15	951,08	18,61	78,84	21,16
9	0,075	983,12	19,24	98,08	1,92
	Pan	426,48	8,35	106,42	0,00
Total		5109,81		324,68	
Finess Modulus				3,25	



Appendix Graph 1. Gradation zones for fine aggregates Sample 1

Appendix Table 5. Sieve analysis for fine aggregates Sample 2

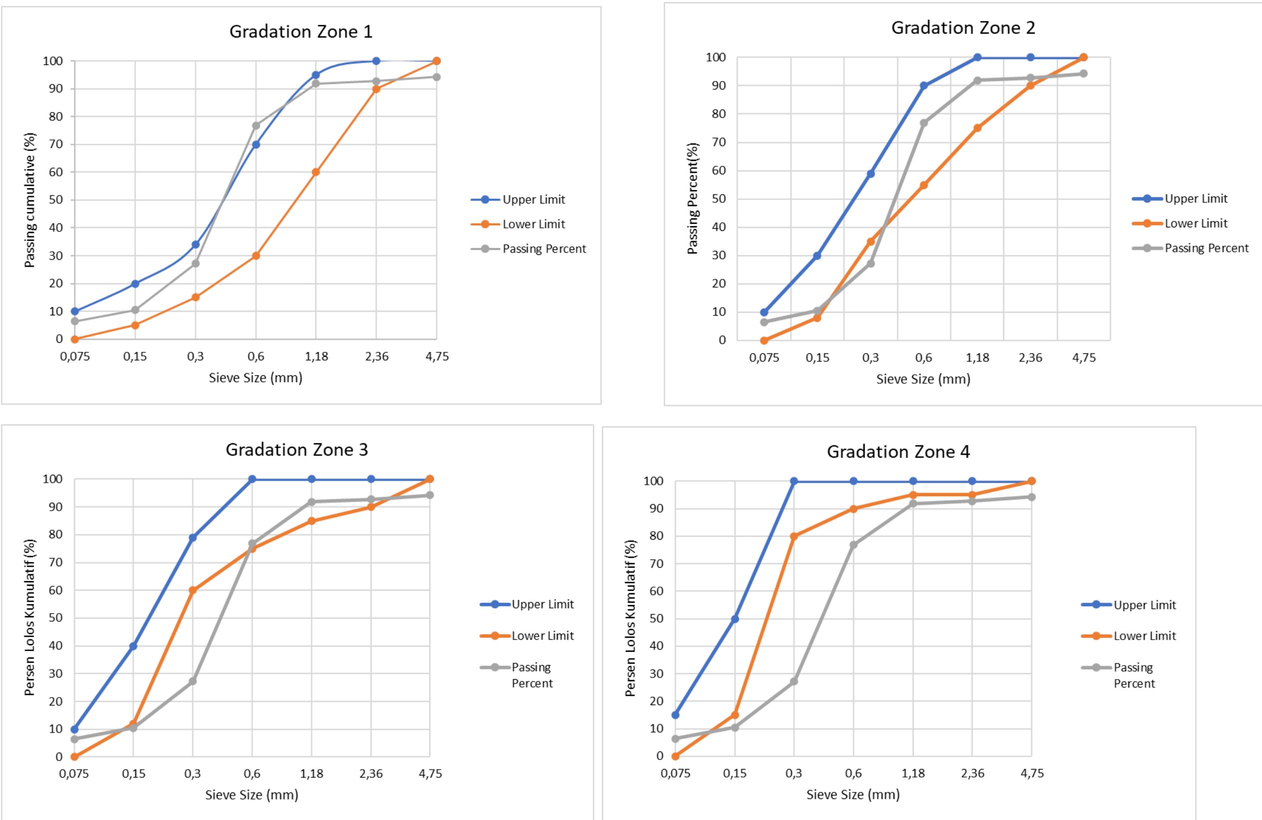
Sieve Analysis of Fine Aggregate Sample 2					
No	Sieve Sieze (mm)	Weight retained (gr)	Weight retained (%)	Weight retained cumulative(gr)	Passing cumulative (%)
1	12,5	0	0,00	0	100,00
2	9,5	40,02	0,80	0,80	99,20
3	4,75	183,1	3,67	4,47	95,53
4	2,36	400,14	8,02	12,49	87,51
5	1,18	566,24	11,35	23,83	76,17
6	0,6	730,33	14,63	38,47	61,53
7	0,3	889,55	17,82	56,29	43,71
8	0,15	980,67	19,65	75,94	24,06
9	0,075	997,62	19,99	95,93	4,07
	Pan	426,48	8,54		
Total		4991,03		302,94	
Finess Modulus				3,03	



Appendix Graph 2. Gradation zones for fine aggregates Sample 2

Appendix Table 6. Sieve analysis for fine aggregates Sample 3

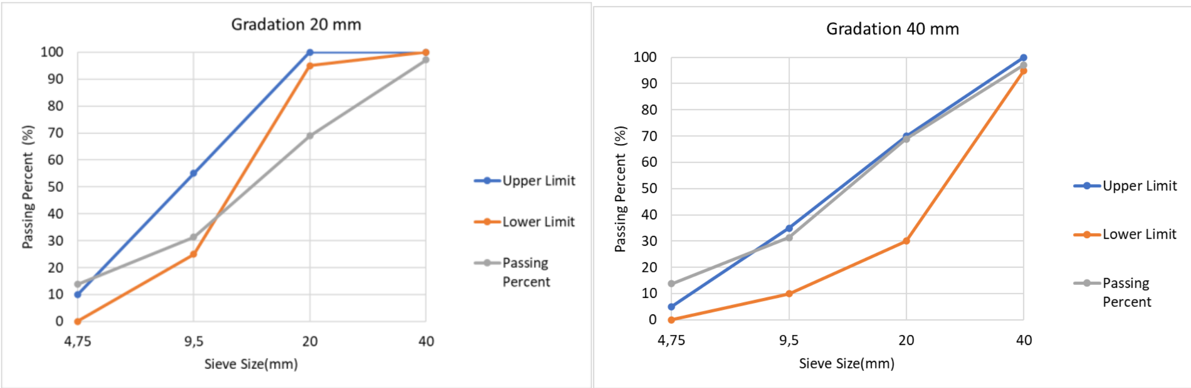
Sieve Analysis of Fine Aggregate Sample 3					
No	Sieve Size (mm)	Weight retained (gr)	Weight retained (%)	Weight retained cumulative(gr)	Passing cumulative (%)
1	12,5	0	0	0	100
2	9,5	190,86	5,46	5,46	94,54
3	4,75	10,39	0,30	5,76	94,24
4	2,36	50,66	1,45	7,21	92,79
5	1,18	30,52	0,87	8,08	91,92
6	0,6	525,24	15,03	23,11	76,89
7	0,3	1736,56	49,69	72,80	27,20
8	0,15	585,23	16,74	89,54	10,46
9	0,075	140,31	4,01	93,56	6,44
	Pan	426,48	12,20	105,76	0,00
Total		3495		294,29	
Finess Modulus				2,94	



Appendix Graph 3. Gradation zones for fine aggregates Sample 3

Appendix Table 7. Sieve analysis for coarse aggregates Sample 1

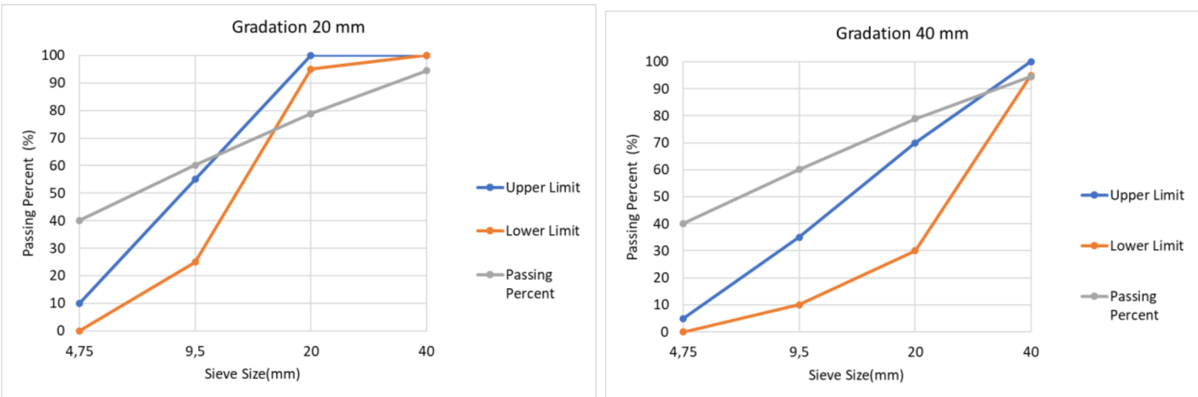
Sieve Analysis of Coarse Aggregate Sample 1					
No	Sieve Size (mm)	Weight retained (gr)	Weight retained (%)	Weight retained cumulative(gr)	Passing cumulative (%)
1	40	152,85	2,86	2,86	97,14
2	20	1512,15	28,26	31,12	68,88
3	9,5	2005,65	37,49	68,61	31,39
4	4,75	938,87	17,55	86,16	13,84
5	2,36	395,48	7,39	93,55	6,45
6	1,18	337,97	6,32	99,87	0,13
7	0,6	0,00	0,00	99,87	0,13
8	0,3	0,00	0,00	99,87	0,13
	Pan	7,03	0,13	100,00	0,00
	Total	5350		581,91	
			Finess Modulus	5,82	



Appendix Graph 4. Gradation zones for fine aggregates Sample 1

Appendix Table 8. Sieve analysis for coarse aggregates Sample 2

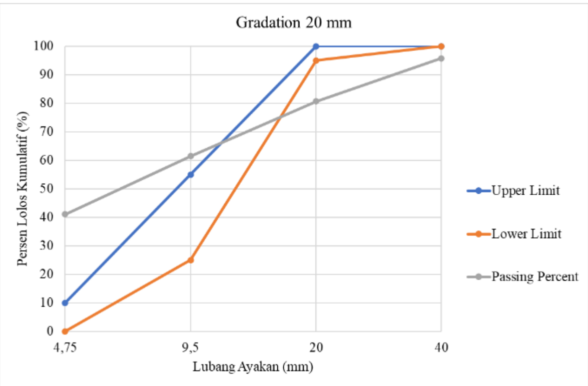
Sieve Analysis of Coarse Aggregate Sample 2					
No	Sieve Size (mm)	Weight retained (gr)	Weight retained (%)	Weight retained cumulative(gr)	Passing cumulative (%)
1	19,1	298,93	5,52	5,52	94,48
2	12,5	846,97	15,65	21,17	78,83
3	9,5	1012,66	18,71	39,89	60,11
4	4,75	1080,69	19,97	59,86	40,14
5	2,36	1082,64	20,01	79,86	20,14
6	1,18	1082,86	20,01	99,87	0,13
7	0,6	0,00	0,00	99,87	0,13
8	0,3	0,00	0,00	99,87	0,13
	Pan	7,03	0,13	100,00	0,00
	Total	5411,78		505,91	
			Finess Modulus	5,06	

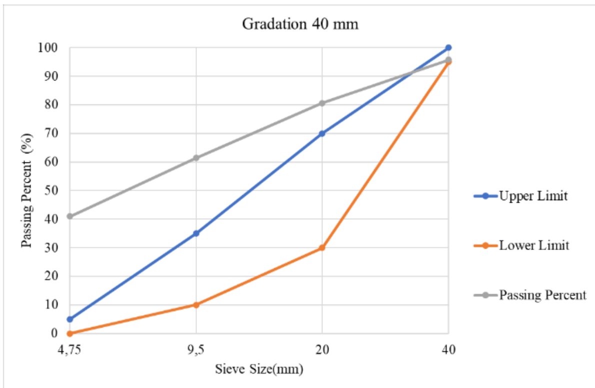


Appendix Graph 5. Gradation zones for fine aggregates Sample 2

Appendix Table 9. Sieve analysis for coarse aggregates Sample 3

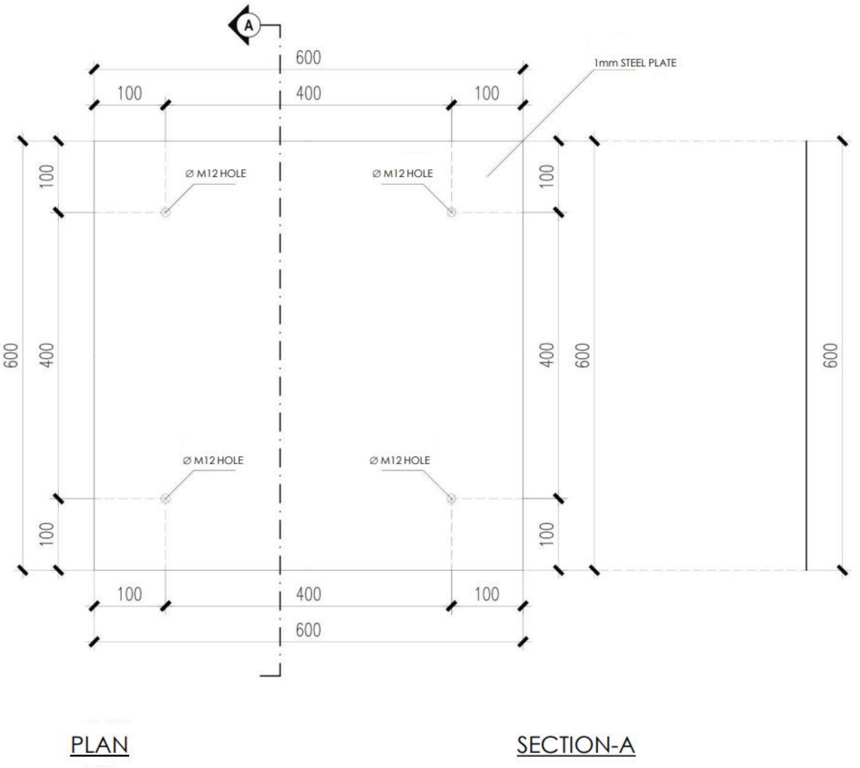
Sieve Analysis of Coarse Aggregate Sample 3					
No	Sieve Size (mm)	Weight retained (gr)	Weight retained (%)	Weight retained cumulative(gr)	Passing cumulative (%)
1	19,1	211,25	4,27	4,27	95,73
2	12,5	748,78	15,14	19,41	80,59
3	9,5	949,83	19,21	38,62	61,38
4	4,75	1008,00	20,38	59,00	41,00
5	2,36	1010,07	20,42	79,43	20,57
6	1,18	1010,33	20,43	99,86	0,14
7	0,6	0,00	0,00	99,86	0,14
8	0,3	0,00	0,00	99,86	0,14
	Pan	7,03	0,14	100,00	0,00
	Total	4945,29		500,31	
			Finess Modulus	5,00	



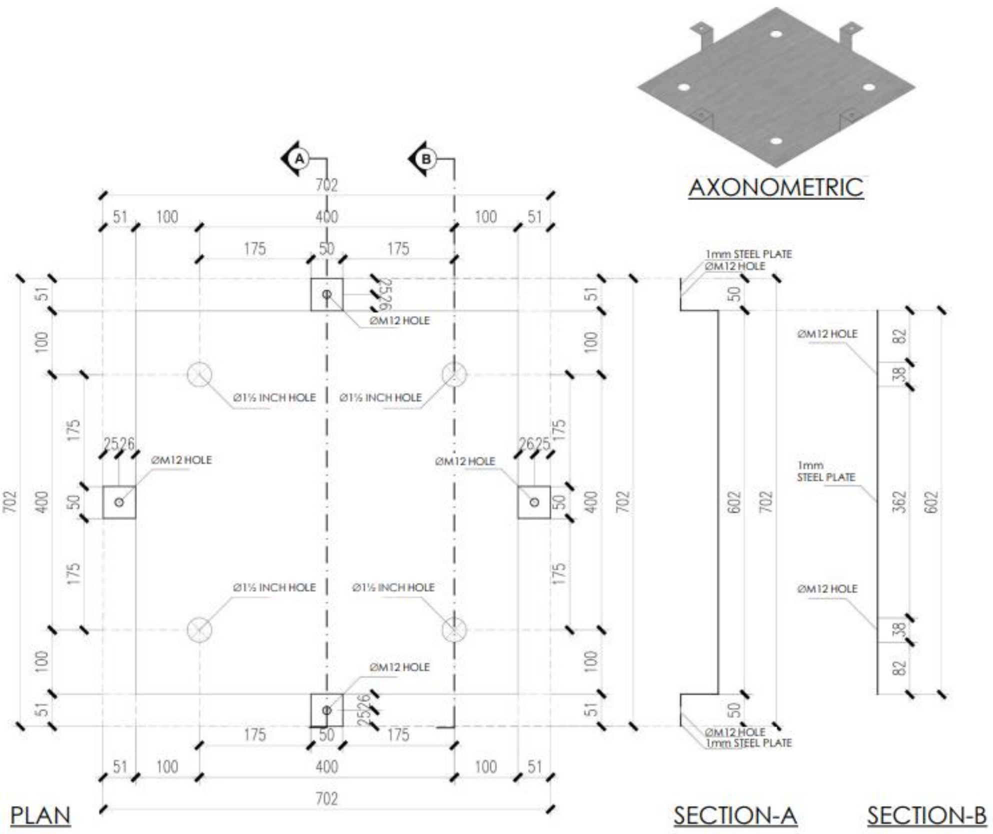


Appendix Graph 6. Gradation zones for fine aggregates Sample 3

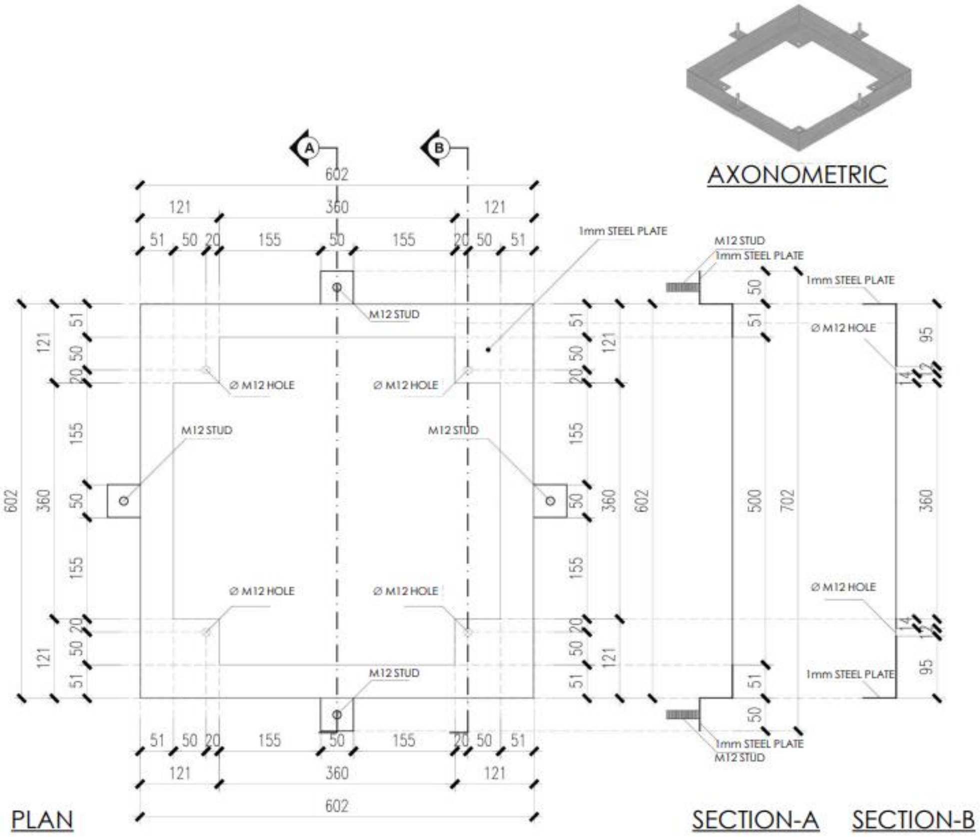
Detail Engineering Drawing for Panel Molding



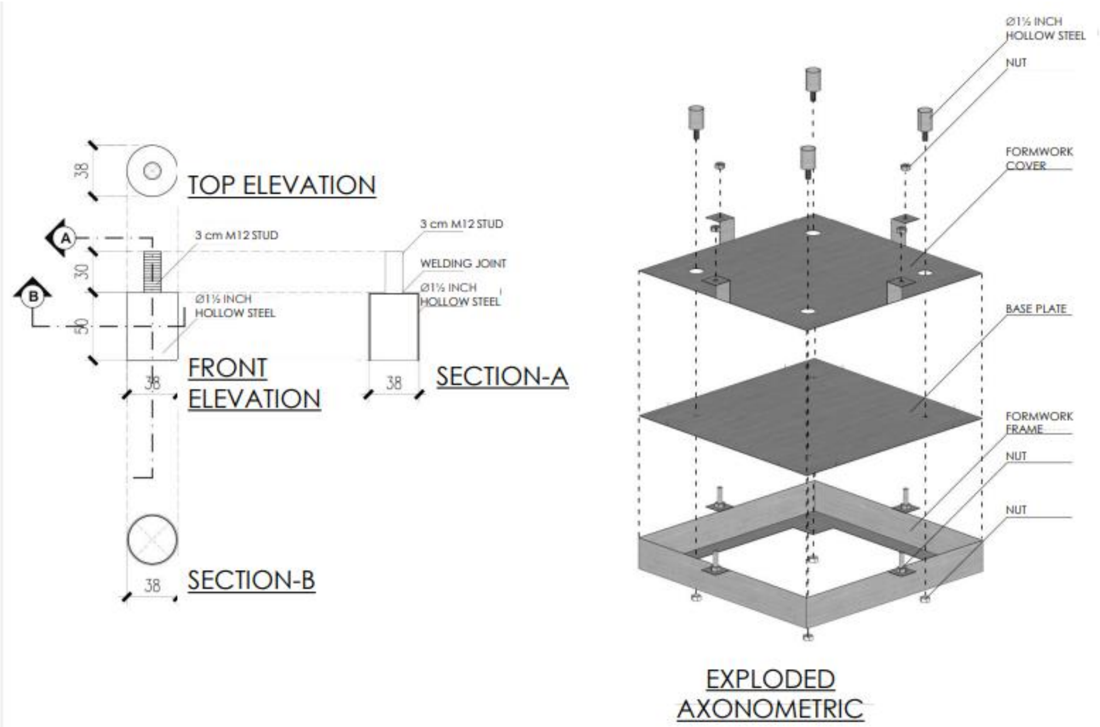
Appendix Figure 1. Plans and sections for panel moulding



Appendix Figure 2. Axonometric 1 and sections for panel moulding

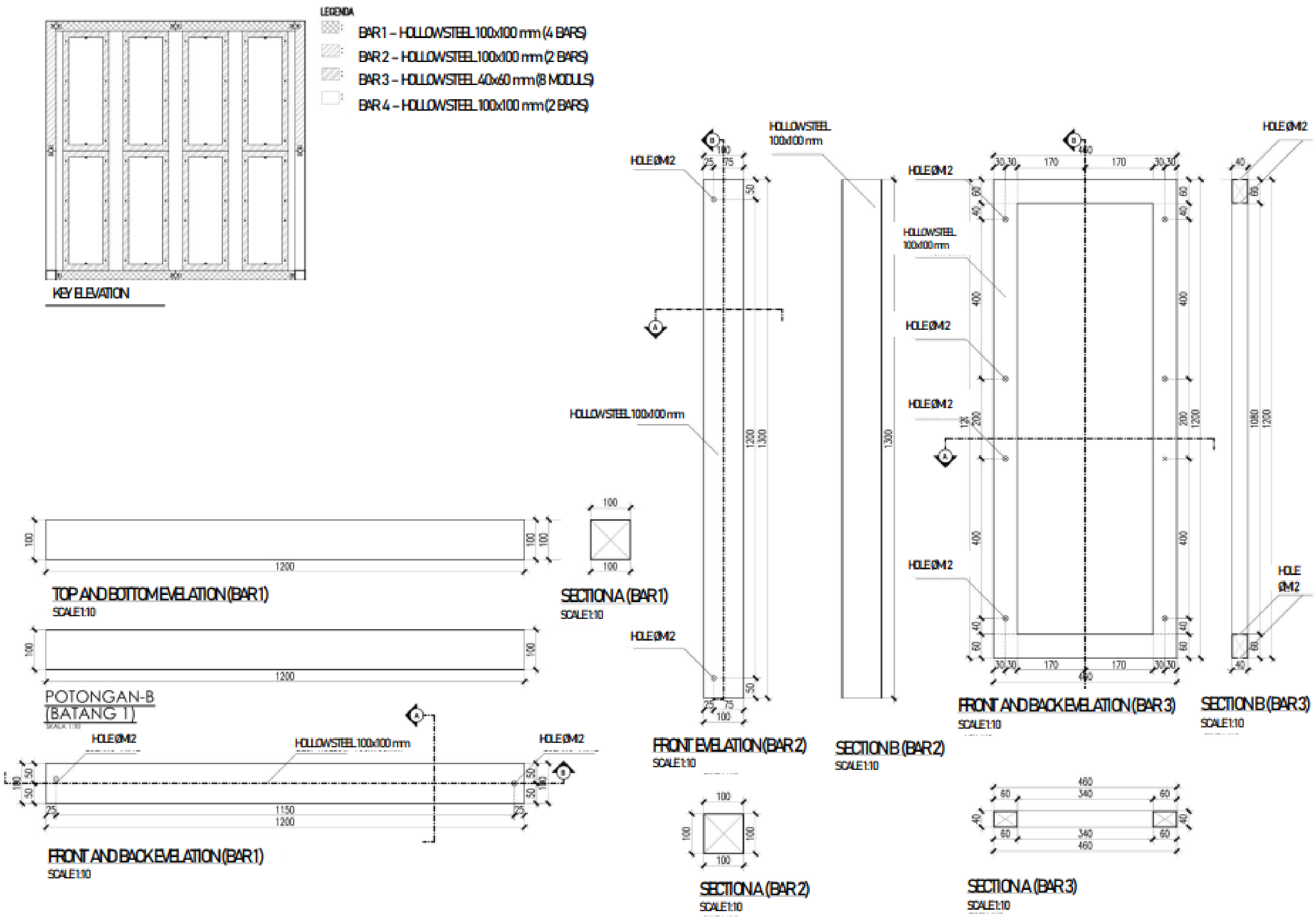


Appendix Figure 3. Axonometric 2 and sections for panel moulding

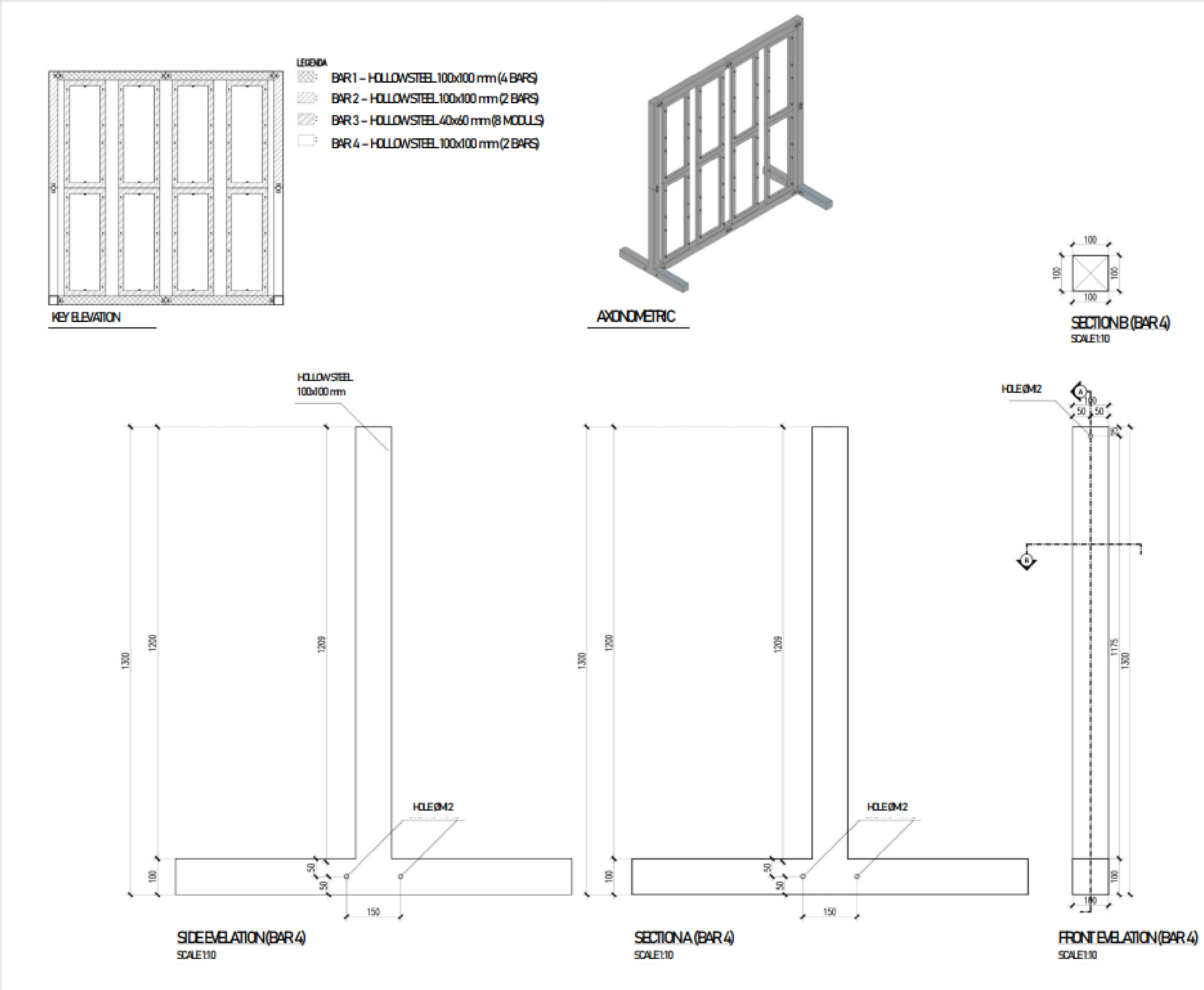


Appendix Figure 4. Exploded axonometric for panel moulding

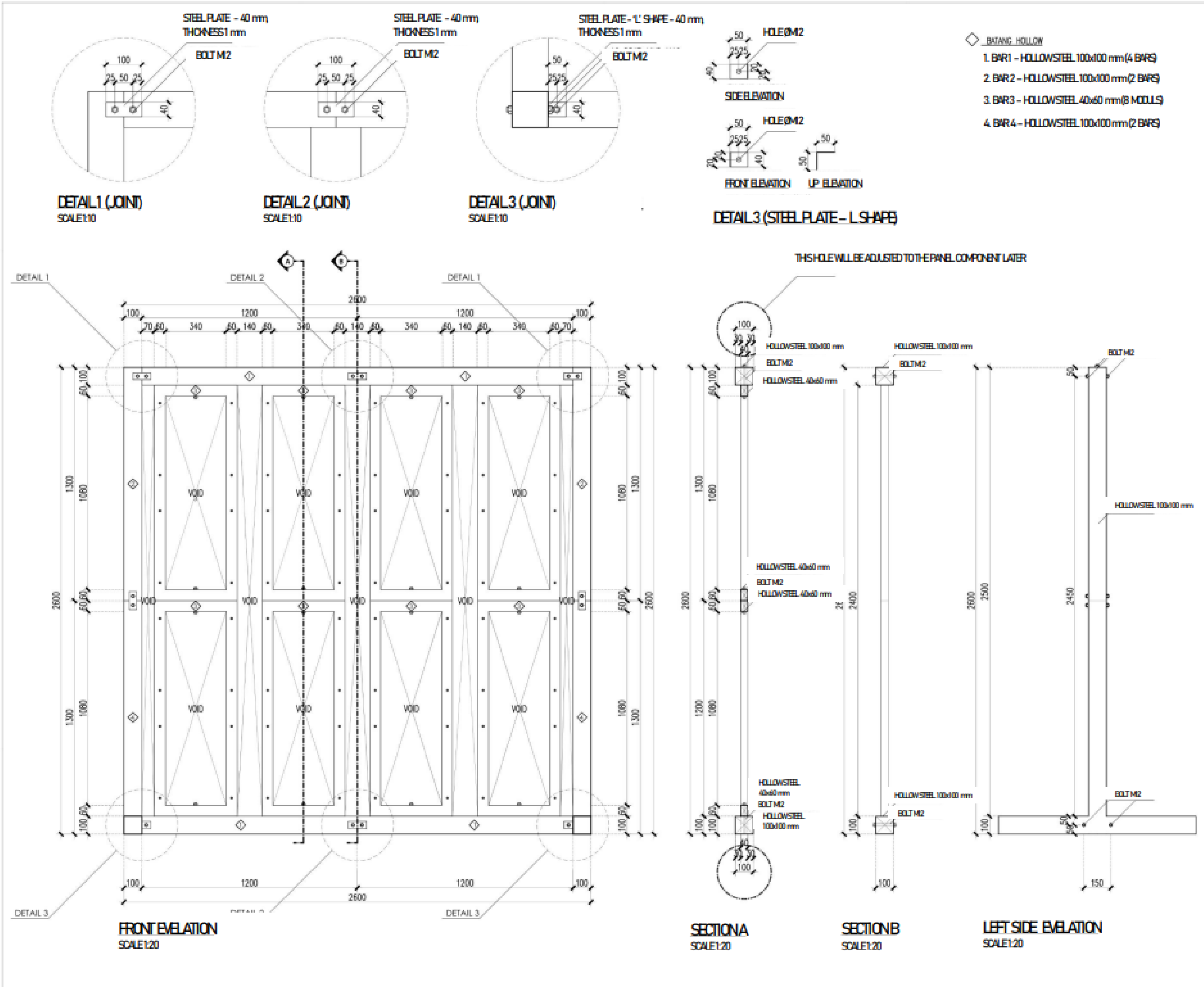
Detail Engineering Drawing for Frames of Housing



Appendix Figure 5. Top-bottom and front-back elevations and sections for frames



Appendix Figure 6. Side elevations and sections for frames



Appendix Figure 7. Details of joints for frames