fragments

exploring waste-based concrete from construction and demolition waste

Master Thesis Spring 2023 | Bongkodpast Tantipisanu
Examiner: Kengo Skorick | Supervisors: Jonas Lundberg
Chalmers School of Architecture
Department of Architecture and Civil Engineering
Architecture and Planning Beyond Sustainability

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Gothenburg, Sweden

Thank you

Jonas Lundberg
Återbruket
Thomas Eriksson
Peter and Tabita
Samuel Norberg
Kengo Skorick
Family & Friends

Abstract

The generation of solid waste is an inevitable outcome of societies that have undergone industrialization. Economic growth has been observed to lead to a rise in the production of solid waste, which is typically disposed of in landfills and has been found to pollute the environment with waste materials, thereby affecting the quality of soil, water, and air. The current scenario is witnessing a surge in the extraction of raw materials to cater to the increasing demand. Simultaneously, the shortage of land-filling areas, rapid industrial expansion, and the adoption of a take-make-waste linear economy have resulted in a twofold increase in waste accumulation. Consequently, they have instigated a worldwide reevaluation of strategies pertaining to the rethinking of waste and its management.

The thesis explores the potential of utilizing recycled construction and demolition wastes (CDWs) as alternative materials in conjunction with the geopolymer or alkali-activated materials (AAM) technique. This approach enables the CDWs to function as a binder and be mixed with recycled fine and coarse aggregates, thereby eliminating the need for conventional river sand. Additionally, the use of no more than 10% cement allows for room-temperature curing of the materials. The study aims to evaluate the performance of this approach under real-world conditions; therefore, the experimentation involving binders is conducted with the aim of exploring new possibilities for versatility and composition, thereby facilitating the reevaluation of waste materials. This process is also linked to the unique characteristics of the waste sources and connects with the public to gain understandings of ”waste” or secondary materials amidst rapid urban development.

Aiming to focus on the experimentation of manipulating waste-based concrete that can undergo transformation over time and its potential for infinite recyclability. The influence of materials on the design of a building and the ways in which architects can utilize them to foster social connections and a sense of community where waste is sorted through waste-based pavilions The present study aims to investigate the ways in which architects can make well-informed decisions regarding the materials they utilize, taking into account the properties and lifecycle impacts of such materials.

KEYWORDS

waste-based concrete; construction and demolition wastes; recycled aggregates; geopolymer

Contents

1 | Background

Limestone quarry on Swedish Baltic sea island Gotland (Svedjeholm, 2016)

Problem statement

By understanding the planetary boundaries as a reference point for where we are at the moment. It has recently been determined that, due to environmental pollutants and other novel entities, humanity has crossed a planetary boundary (Stockholm Resilience Centre, 2020). This shows that humanity can continue to advance for many generations into the future because we are currently living in a crucial yet transitional time. We do not want to see these boundaries crossed, as doing so increases the possibility of the environment undergoing catastrophic shifts.

The current level of global population is growing the size of the economy and the demand for raw materials, many of which are limited and are running out in areas where there are fewer landfill sites available. Industrial growth is occurring, and the linear economy of take-make-waste has caused waste accumulation to double. As a result, resources are planned and utilized for as long as possible in a circular economy to extract their maximum value and break the cycle of constantly needing to mine for new materials. It is essential to consider the entire system in relation to planetary boundaries in order to comprehend the root causes. Clearly, the designer must be able to respond to changing conditions, assess difficulties, and implement durable design solutions.

Construction and demolition wastes (CDWs), which are rarely managed in the construction industry, result in a large amount of waste that could have been employed or reduced, including the carbon footprint at the production site.

The circular economy gives us, as (future) architects, the chance to consider new paradigm possibilities. We can make a significant contribution to the creation of circular solutions that support sustainability without having to wait for the system as a whole to change. Nothing that can be reused, recycled, or upcycled—items that would otherwise be considered waste but were given a new life through those processes—should be thrown away. Understanding the design, production, assembly, end-of-life, and use of an architecture requires a thorough approach. As a result, we can explore the what, why, and how questions, which leads to new possibilities.

Photo credit : Marafioti, n.d.

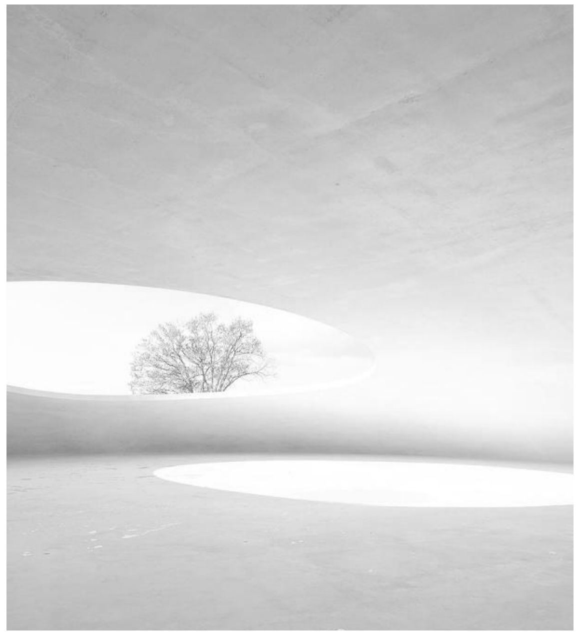


Photo credit : Baan, 2010

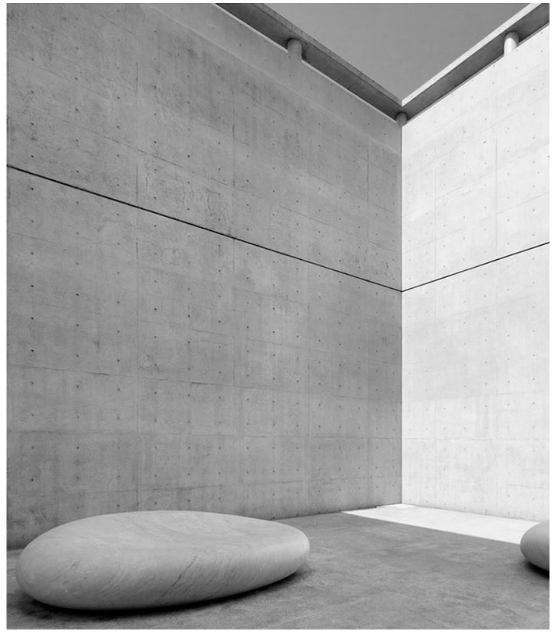


Photo credit : Zhi, 2020

Concrete

Why concrete ?

Today, concrete contributes to 9% of the overall greenhouse gas emissions, while 7 metals namely iron, aluminium, copper, zinc, lead, nickel, and manganese, account for 7% of the total emissions. (OECD, 2018)

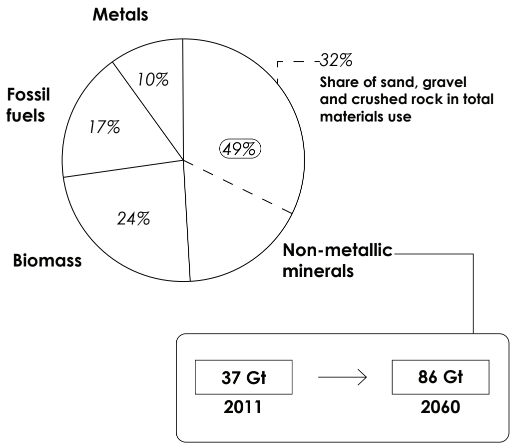


Figure 1: Material use increases (OECD, 2018)

The composition of concrete comprises water, cement, and aggregates. Upon examine the source of these components and their chemical composition, it is evident that the primary ingredient, cement, is comprised of clinkers, which is a fusion of clay and limestone (CaCO3) (refer to figure 2). This process is responsible for a significant portion of CO2 emissions, as the conversion of CaCO3 to CaO + CO2 occurs. Despite utilizing 100% renewable energy, it remains unfeasible to completely eliminate pollution.

The process of producing clinker involves the fusion of limestone, clay, and other materials in a rotary kiln at temperatures that approach 1,500 °C. The kiln is commonly heated using fossil fuels, which account for roughly 40% of the direct carbon dioxide emissions resulting from the process.

Coarse and angular sand is a requirement for the production of concrete. The sand found in deserts and on beaches may not possess the desired angularity, rendering it unsuitable for certain applications and contributing to a shortage of sand. The extraction of sand from riverbeds or coastal areas has severe ecological implications.

This demonstrates the significance of alternative resources in addressing global challenges. According to the OECD (2018), the notable surge in demand for materials indicates a corresponding rise in both primary and secondary material usage, which bodes well for the future of the architecture sector.

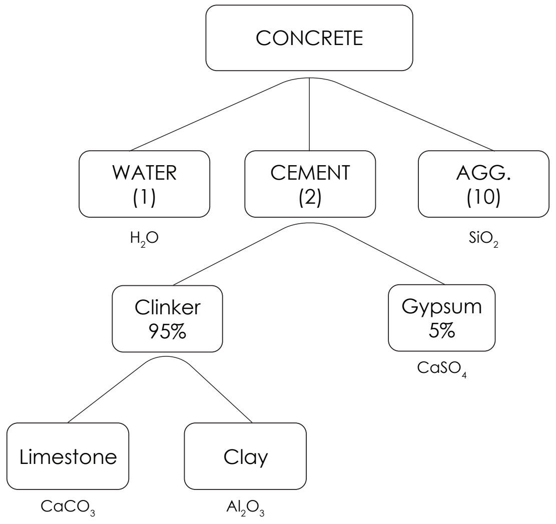


Figure 2: Composition of concrete

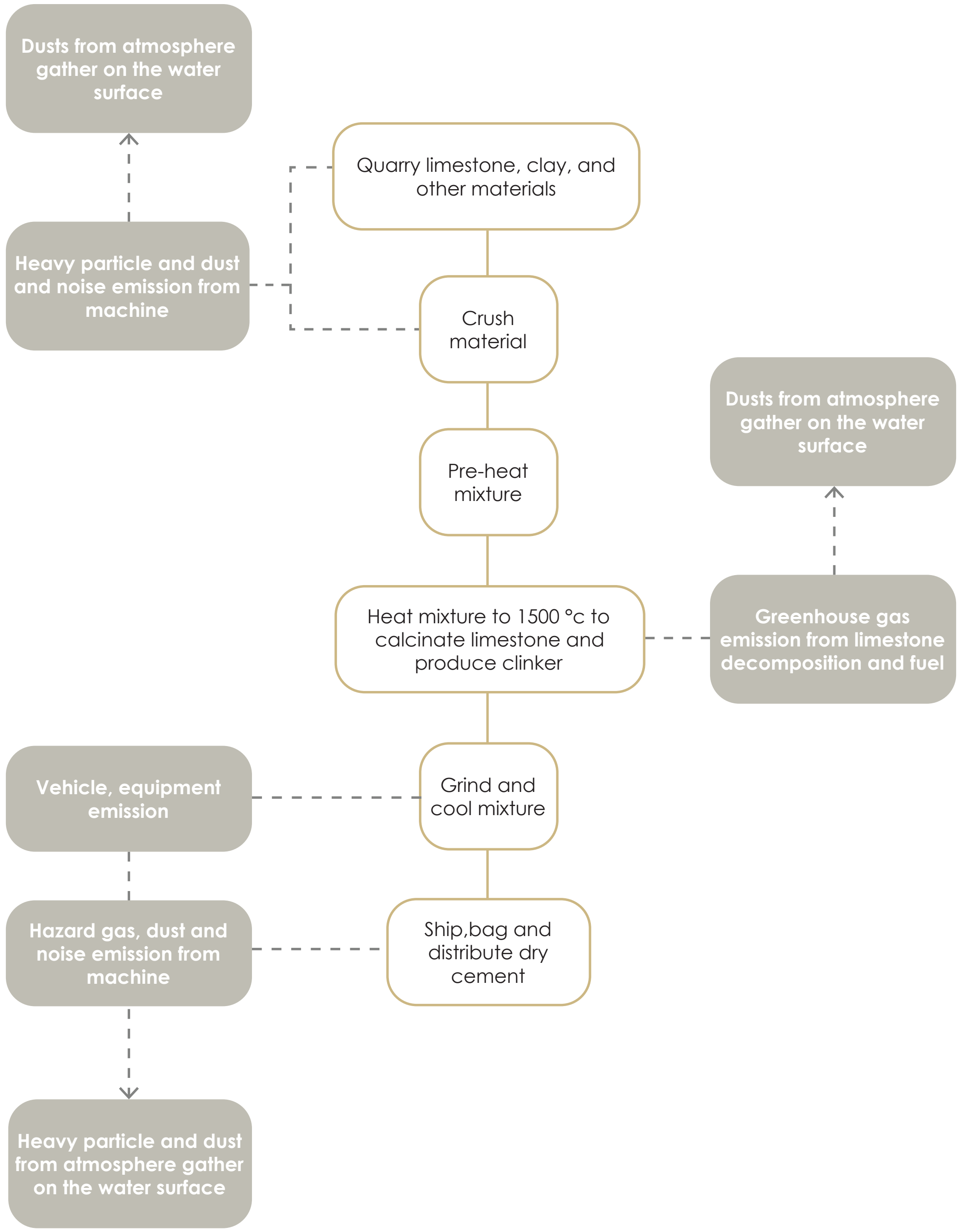


Figure 3: Impact of cement production (Mohamad et al, 2021)

Environmental impacts of cement production

Mohamad et al. (2021) assert that concrete is a highly prevalent construction material globally, owing to its unique benefits over alternative materials. Concrete's extensive usage can be attributed to its remarkable mechanical characteristics and cost-effectiveness. It has been estimated that the global production rate of conventional concrete is approximately 6 billion metric tons annually. It is noteworthy that for more than two centuries, ordinary Portland cement (OPC) has served as a crucial constituent of concrete materials utilized in the field of construction. The utilization of aggregate, particularly limestone, is increasingly crucial in the production of Portland cement, as the demand for cement supply continues to rise. The depletion of non-renewable resources on the planet has emerged as a growing concern, given the significant surge in energy consumption witnessed in the 21st century. The extraction of non-renewable resources for economic purposes by the quarrying and mining industries will inevitably lead to the depletion of reserves over time.

Air pollution

The production of cement is associated with significant pollution resulting from dust emissions. These emissions are primarily generated during the transportation, loading, and unloading of clinker, and are subsequently deposited in the vicinity of the silo. Carbon dioxide (CO2) is a significant contributor to the phenomenon of global warming and constitutes one of the primary emissions of greenhouse gases. During the process of cement production, the formation of CaO is accompanied by the release of CO2 and water vapor at elevated temperatures. Consequently, the elevated concentration of carbon dioxide has the potential to render human-induced climate change a certainty.

Water pollution

According to the Centers for Disease Control and Prevention, the drainage of dust may result in water contamination, which can have deleterious effects on both human and animal health. The discharge of wastewater into the atmosphere has been identified as a significant contributor to the pollution of water sources, including rivers and groundwater reservoirs. Building and urbanization, as well as human activities on land, contribute to soil degradation in areas with a growing population. In addition, inadequate land management practices may pose a threat to soil quality and result in the occurrence of water runoff.

Noise pollution

The cement manufacturing process is responsible for the generation of a significant proportion of noise emissions. The generation of noise pollution was attributed to various activities such as the handling of raw materials, clinker burning, storage of materials, and operation of heavy machinery during the production process. The deleterious effects of noise pollution extend beyond auditory impairment, as it can also adversely affect the anatomy and physiology of various human body systems, including the nervous, digestive, and cardiovascular systems.

Thesis Framework

Aim

Exploratory emerging uses of Construction and Demolition Wastes (CDWs) in the face of resource depletion and scarcity of land-filling areas by transforming waste into waste-based concrete as chemical composition research studies show this can be implemented and uniquely formed without the need to extract new materials.

The utilization of waste-based concrete in architecture has the potential to significantly decrease the environmental impact of the construction industry by up to 70% when compared to conventional Portland cement, owing to its ability to decrease the necessity for the extraction and processing of virgin materials.

Waste-based concrete will ignite architectural design with its materialization and properties. The thesis focuses on the transformation of waste materials into architectural elements such as load-bearing walls and floors in order to explore possibilities at the building's end-of-life. In this way, the material promotes a more resilient and environmentally friendly built environment. Circular design allows for the exploration of design strategies aimed at reducing waste and maximizing resource efficiency.

Thesis Questions

- What is causing the lack of materials derived from waste in architectural design? How can these curiosities be realized?

- Does waste-based material have the potential to be recycled endlessly after its lifespan?

Delimitations

The practical application of solid waste in architecture poses several limitations that present challenges in incorporating them into this thesis. These limitations include the availability of waste, contamination of waste, the process of hand-crushing waste into fine grains suitable for use in binder, and the embodied energy of the industrial scale of the alternative resource.

The aim of this thesis is to establish the significance of architectural design in a tangible manner, with the objective of promoting the implementation of waste-based concrete in architecture and making it more accessible to the general public. The technical aspects are derived from the empirical research conducted in the laboratory. The potential societal implications of replacing a playground area with a pavilion made from waste-based materials have been acknowledged but have not been the main focus.

Method

Literature studies: A comprehensive analysis of literature pertaining to material contents will be undertaken, including books, publications, and articles. This will encompass an examination of the treatment of waste generated from construction sites, with the aim of developing a comprehensive understanding of the capabilities and limitations of the materials in question.

Project references: The project references will be scrutinized during the initial stages of the experimental design to gain insights into its merits and demerits as well as identify potential prospects and areas for improvement.

Material research: The focus of material research should be on identifying materials that possess the capacity to be repurposed or recycled, with a particular emphasis on construction and demolition sites.

Study Trip: The preliminary investigation will involve a study excursion to locations where demolition and reclamation activities are carried out. The objective of the study visit is to conduct an investigation of the nearby waste source, followed by a subsequent on-site visit for the purpose of developing a design proposal.

Material experiments: This study aims to investigate the development and testing of waste-based concrete in both a homemade lab and a pilot project setting. The performance of the material will be evaluated, and potential applications in architecture will be identified. Consequently, an array of experimental material designs is presented.

Spatial experiment: This study seeks to find out the influence of material properties on the architectural experience and the potential for sensory connections between humans and materials. Additionally, the study seeks to explore whether materials can be designed in a circular manner, ultimately determining their sustainability at the end of their lifecycle.

Glossary of terms

Circular economy
A circular economy can be described as an economy where waste essentially does not occur, but where resources can be retained in society's ecocycle or in a sustainable manner returned to nature's own ecocycle (Byggforetagen, 2019).

Construction and demolition waste (construction waste)
Waste that occurs during construction and demolition works (during demolition, construction, extension, rebuilding, renovation and building measures relating to property management) (Byggforetagen, 2019).

Demolition
All demolition works (both entire buildings or parts of a building), demolition during modifications (rebuilding and extension) and maintenance are designated as demolition. The legislation lacks a definition for the term "demolition" (Byggforetagen, 2019).

Geopolymers
Geopolymers as alternative binder systems are attracting increasing interest in research and development. They can display outstanding technical properties, such as high strength, high acid resistance, and/or high temperature resistance (Weil et al, 2014).

Material inventory
Inventory of materials and products affected by the demolition works. (Expanded significance in relationship to BFS 2013:15 Riv 1) (Byggforetagen, 2019).

Recycling of waste
Means that the waste is seen as a resource and treated accordingly. The possibility is thereby created to replace newly produced material with recycled material (Byggforetagen, 2019).

Waste
Waste (or wastes) are unwanted or unusable materials. Waste is any substance discarded after primary use, or is worthless, defective and of no use (Wikipedia,n.d).

Waste handling
The collection, transport, recycling, disposal of or other physical dealing with waste or actions which do not involve physical dealing with waste but which are intended to ensure that waste is collected, transported, recycled, disposed of or changes owner or holder (Chapter 15, Section 5, Swedish Environmental Code) (Byggforetagen, 2019).

2 | Introduction

Figure 4: Linear economy

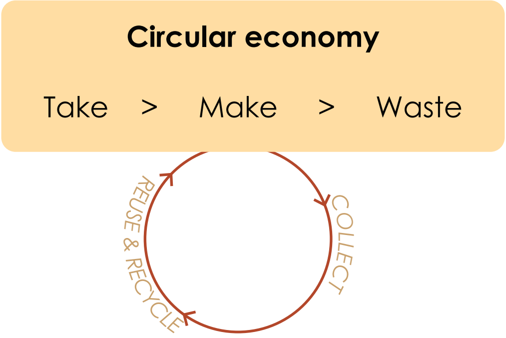


Figure 5: Circular economy

Linear Economy vs. Circular Economy

In several ways, a circular economy differs from a linear economy. The linear economy model entails extracting raw materials, processing them into finished products, and finally disposing of them. In the context of a circular economy, the entire raw material cycle is self-contained. Recycling alone would not be enough to effectively complete these cycles. The preceding statement refers to the modification of processes involved in the creation and preservation of value, the adoption of sustainable manufacturing practices, and the application of alternative business models. Increasing the system's eco-effectiveness achieves the goal of sustainability within a circular economy. Reduced environmental impact, according to Kjaer and Pigosso (2019), is associated with positive ecological, economic, and social outcomes.

The linear economy is defined as a business that relies on a steady supply of natural resources, resulting in a take-make-waste strategy. The strategy is based on resource extraction, production of goods and services, and post-consumer waste disposal. This strategy, on the other hand, is under increased scrutiny due to its negative effects on the environment and the economy. It appears to have both ecological and economic disadvantages; in terms of ecology, it appears that the production of goods is at the expense of the productivity of the planet's ecosystems. Excessive stress on these ecosystems jeopardizes their ability to provide essential ecosystem services such as air, water, and soil purification (Kenniskaarten, 2021). This economic model also makes material supply difficult. This uncertainty is caused by fluctuating raw material prices (which raise market risks), material scarcity (some materials are only available in limited quantities), geopolitical reliance on various materials, and rising demand (due to population and welfare growth). In other words, the scarcity of raw materials works against rising demand. Furthermore, the product's lifespan is reducing its quality, not because of the product's specific condition or ability, but because of how it is discarded before its lifespan has even begun.

To overcome this, it remains dependent on each other's environmental willingness to collaborate in a circular business model (ecologically centered) rather than a linear business model (economically centered), as the latter is likely to involve longer-term investments and contribute more to sustainability. The global construction industry consumes the most raw materials and resources. As they gain greater control over resource streams throughout the value chain and the ability to identify and capture added value, governance, regulations, and business models will play a critical role in easing or strengthening the transition to the circular economy.

The UN recommends the circular economy to achieve Agenda 2030's many goals. Construction is closely related to Goals 11 and 12, Sustainable Cities and Communities, and Responsible Consumption and Production.

Figure 6: The Sustainable Development Goals (SDGs) relating to the construction industry

Primary materials vs. Secondary materials

Primary materials are defined as unprocessed materials that are sourced from the natural environment and are utilized in the early stages of a production process.

Secondary materials are defined as materials that are derived from industrial processes and are subsequently reused in the production process of new goods.

The replacement of primary resources with secondary resources has potential to advance sustainability efforts through the preservation of natural resources and the streamlining of material life cycle management (Van Eijk, 2020).

In contemporary times, the majority of the natural resources utilized by humans are primary raw materials. The rapid increase in global population growth will continue to sustain the surge in demand for raw materials. Given these circumstances, it becomes imperative to contemplate how we can optimize resource utilization, reduce primary raw material consumption, strengthen the application of secondary raw materials, or aim for a raw material balance in the projects.

Secondary raw materials are derived from sources that are not natural, albeit not in a direct manner. On the contrary, they are generated through the process of reprocessing primary raw materials. **Recycling** yields secondary raw materials, and an increase in the quantity and quality of recycling efforts leads to a corresponding increase in the availability of secondary raw materials. In general, rethinking the utilization of secondary materials over primary raw materials is more advantageous due to their lesser environmental impact.

What is waste?

Waste (or wastes) are unwanted or unusable materials. Waste is any substance discarded after primary use or that is worthless, defective, and of no use. A by-product, by contrast, is a joint product of relatively minor economic value. (wikipedia, 2021)

Waste is the term for byproducts of production and consumption. The waste definition says that: "Waste refers to...every object, material or substance that the owner disposes of, intends to dispose of or is responsible for disposing of."

Waste hierarchy

The waste hierarchy, which offers direction on the appropriate handling and treatment of waste, has been incorporated into the Swedish Environmental Code, SFS 2016:782, as of 2016 (Miljödepartementet, 2016). The waste hierarchy indicates that the initial priority for waste management is to prepare it for reuse, followed by material recycling if reuse is not feasible. Subsequently, the waste should be subjected to other recovery methods, and finally, disposal should be considered. As the waste hierarchy is descended, the product experiences a decrease in both value and utility. Additional energy is required to reintroduce waste into the production process following waste treatment. The expenditure incurred due to waste management has significant implications for both the planet and the environment (Alenius L., 2022).

Waste hierarchy

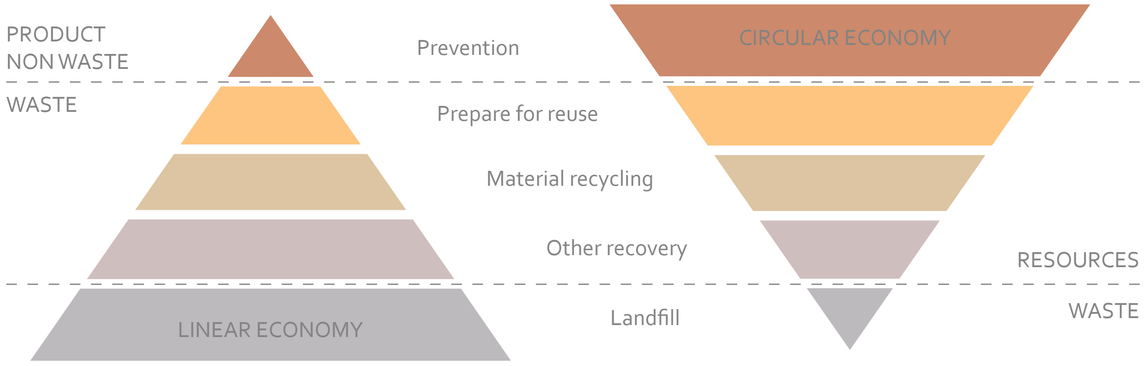


Figure 7: Waste hierachy

Therefore, it is crucial to prioritize the treatment of waste at the uppermost level of the waste hierarchy. In the context of circular economy, the intermediate stages of the process are considered circular actions, whereas disposal or incineration of products results in a loss of value and utility. The depletion of resources necessitates the extraction of new resources from our planet. The depiction of the waste hierarchy as a pyramid is attributed to a specific rationale. The idea is to represent the actual implementation of waste management practices. Subsequently, it is a straightforward task to invert it and demonstrate the correct approach. The primary objective is to avert the transformation of a product, material, or edifice into refuse. In instances where waste generation cannot be circumvented, it is recommended that the waste be repurposed as a valuable resource at the uppermost tier of the waste hierarchy. If the objective of inverting the pyramid is achieved, it would result in the implementation of a circular economy model in place of a linear one.

Prepare for reuse

The process of preparing waste for reuse involves the utilization of the entire product in a novel manner or context, without necessitating its conversion into its constituent parts.

Material recycling

The process of material recycling involves the conversion of waste into its constituent raw materials, such as glass, paper, or steel. The aforementioned materials possess the potential to serve as substitutes for primary materials in the production of novel commodities.

Other recovery

Alternative methods of recovery involve the utilization of resources, such as through incineration, to extract energy from them. Following the waste treatment process, the resource is rendered unusable and its value is consequently lost.

Demolition sites

Construction & Demolition wastes (CDWs) in Sweden

According to Tchobanoglous et al. (1993), construction waste refers to a collection of relatively uncontaminated, diverse building materials that arise from different construction processes. Construction, renovation, and demolition activities generate waste.

Construction waste poses a significant threat to the environment. The construction industry is facing mounting pressure to devise suitable environmental conservation tactics for all domains of the economy, construction included. The quantity and composition of construction waste generated by various projects may vary depending on the specific conditions and materials utilized. Asbestos and impregnated wood are classified as hazardous construction and demolition waste and require proper handling procedures.

Recycling is a viable approach to mitigating the hazards associated with construction waste. The development of appropriate technology for the recycling of these materials holds significant importance. Recycled aggregate can be produced by utilizing crushed concrete scrap.

As per the findings of the Swedish Environmental Protection Agency, the construction sector is responsible for 40% of the total waste produced in Sweden, excluding mining waste. The national waste plan and waste prevention program prioritize the disposal or landfilling of construction and demolition waste (Avfall Sverige, 2021).

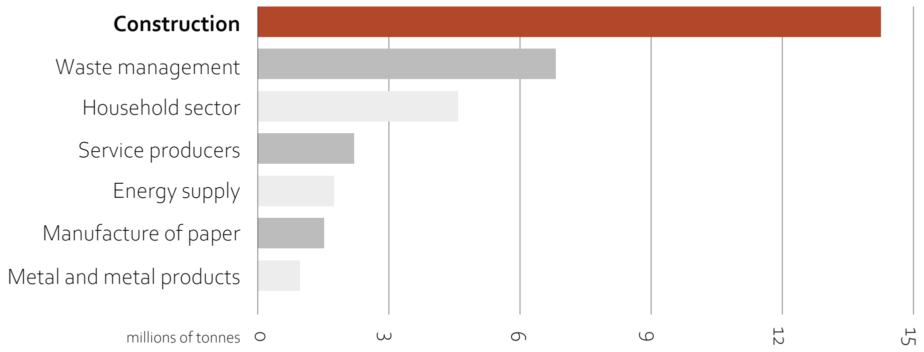


Figure 8: Total waste generated in Sweden, excl. mining waste 2020 (Avfall Sverige, 2021).

Rotor DC in Brussels, Belgium

Återbruket in Gothenburg, Sweden

Sources of Construction & Demolition Waste stream

Construction waste can be generated from multiple sources, including the design, procurement, material handling, operation, residual, reclaimed, and other sources. This thesis will focus on the recycling and reclamation of sources, as they are regarded as the final stage before end-of-life waste. If left unused, such waste materials will be directed to landfills. Two study trips were undertaken at two reclaimed sources, namely RotorDC in Brussels and Återbruket in Gothenburg, as illustrated below:

Rotor DC
A company headquartered in Brussels, Belgium, aims to establish partnerships with demolition contractors, non-profit organizations, and other businesses, with the goal of contributing to a regional network focused on the extensive reusing of construction materials. It can be observed that a significant proportion of the available material originates from either the renovated section of the building or surplus materials from the construction site.

Återbruket
The organization known as Återbruket, situated in Gothenburg, Sweden, is dedicated to the management of waste recycling, with a specific emphasis on Construction and Demolition waste. Additionally, the facility is engaged in the reclamation and reusing of a diverse range of materials. The various types of waste are classified into over twenty categories, including but not limited to masonry, ceramic, concrete, timber, and hazardous materials.

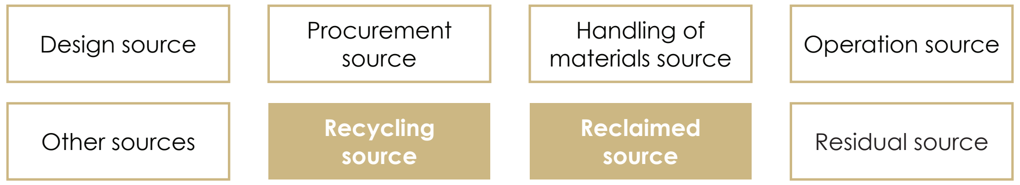

Design source
Procurement source
Handling of materials source
Operation source
Other sources
Recycling source
Reclaimed source
Residual source

Figure 9: Source of constrution and demolition waste stream


1


2


3


4


5


6

1-3 : Waste-based bricks (StoneCycling, 2012)
4-6 : Plastic Island (Goksyr, 2018)

Waste-based materials

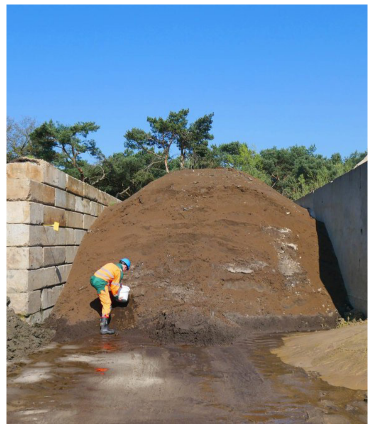
The concept of what defines waste may no longer be relevant in the twenty-first century, when the planet generates at least 3.5 million tons of plastic and other solid waste a day, which is ten times more than it did a century ago (Leahy, S., 2021). It is crucial that we "rethink" the holistic view of how future materials will be used in architecture and take action. This calls for the reuse and recycling of massive amounts of waste, or, to put it another way, "secondary materials." In this section, four case studies, in particular, focus on waste and the locations where secondary materials originated so that new materials could be created without the need to extract raw materials. The results look distinctive, are safe, and are sustainability-focused.

Waste-Based 1: Waste-based bricks (StoneCycling, 2012)

The Dutch company StoneCycling demonstrates the need for better alternatives for the construction industry. They pointed out that the raw materials, like clay and sand, required to create new building materials are not readily available worldwide. Consider construction sand, which demands particular technical properties. They predict a sand shortage within ten years, and in recent years, geopolitical tensions in the area have already become apparent. Illegal mining has also increased in order to keep up with global construction. Sustainability and design are equally important to StoneCycling. A brick that generates 85% waste, comes in a variety of colors and textures, and reduces CO2 emissions by 45%

Waste-Based 2: Plastic Island, (Goksyr, 2018)

The condition of the world's oceans is rapidly deteriorating due to rising sea levels and constant plastic consumption. Erik and Emily-Claire Goksyr, architects, considered whether this plastic could be used in architecture rather than thrown away or burned. The team created three prototypes by conducting a thorough material study in order to put forth this theory. Plastic samples were gathered from the Swedish Koster Islands' shores and examined for their various material performances in relation to areas including color, texture, light, and translucency. The project aims to alter this way of thinking by turning waste into a valuable or desired product through aestheticization. It serves as a reminder that this accumulation is harmful by highlighting the visual characteristics of plastic on building facades and aims to inspire people to keep oceans free of waste by doing so.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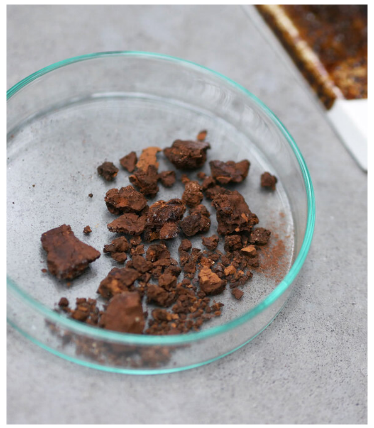
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7-9 : Ignorance is Bliss (Kucerenkaite, 2018)
10-12 : 3D printing to rebuild Notre-Dame (Concr3de, 2019)

Waste-based materials

Waste-Based 3: Ignorance is Bliss (Kucerenkaite, 2018)

In the project Ignorance is Bliss, Lithuanian designer Agne Kucerenkaite highlights the value of industrial metal waste by using it to create vibrant ceramics. The possibilities of what man could create seemed limitless during the industrial revolution, according to Kucerenkaite. She procured raw materials from commercial establishments like a water treatment facility and a company that specializes in soil remediation. Depending on where the factory is located, the metal waste appears as "sludge" and is composed primarily of iron as well as a mixture of manganese, aluminum, magnesium, barium, and zinc. Although no extraction is needed, the sludge must go through a preparation process that includes drying, milling, and sieving before it can be used as a pigment. She aimed at promoting a circular economy and explored how industrial metal waste can be turned into powdered dyes, which can be used to color porcelain tableware and ceramic tiles.

Waste-Based 4: Rebuilding Notre Dame with 3D Printing (Concr3de, 2019)

The Dutch company Concr3de has proposed using 3D printing for rebuilding parts of the wrecked Notre-Dame Cathedral and printed a replacement gargoyle. The famous gargoyle, which was added to the cathedral's roof during the 19th-century restoration by architect Eugène Viollet-le-Duc, was replicated using a mixture of limestone and ash that was similar to the materials discovered after the fire. Concr3de believes that restoring Notre-Dame to its original design while using new materials would pose some philosophical issues that could be resolved by using the materials that were left over after the fire.

To sum up, StoneCycling and Ignorance is Bliss products are made from "waste" that has been neglected and untreated; as a result, the waste is cleaned up, lowering the demand for virgin raw materials, cutting carbon emissions, and producing future construction projects that are more environmentally friendly. And lastly, CONCR3DE has demonstrated that 3D printing is a medium of material interaction that connects knowledge, skill, craft, and design in an efficient way. Creating architecture in a humble manner involves considering how memories of history and the importance of experiences interact with materiality. Additionally, it provides design possibilities and what they can offer when combined with long-sustained artisanship and digital tools.

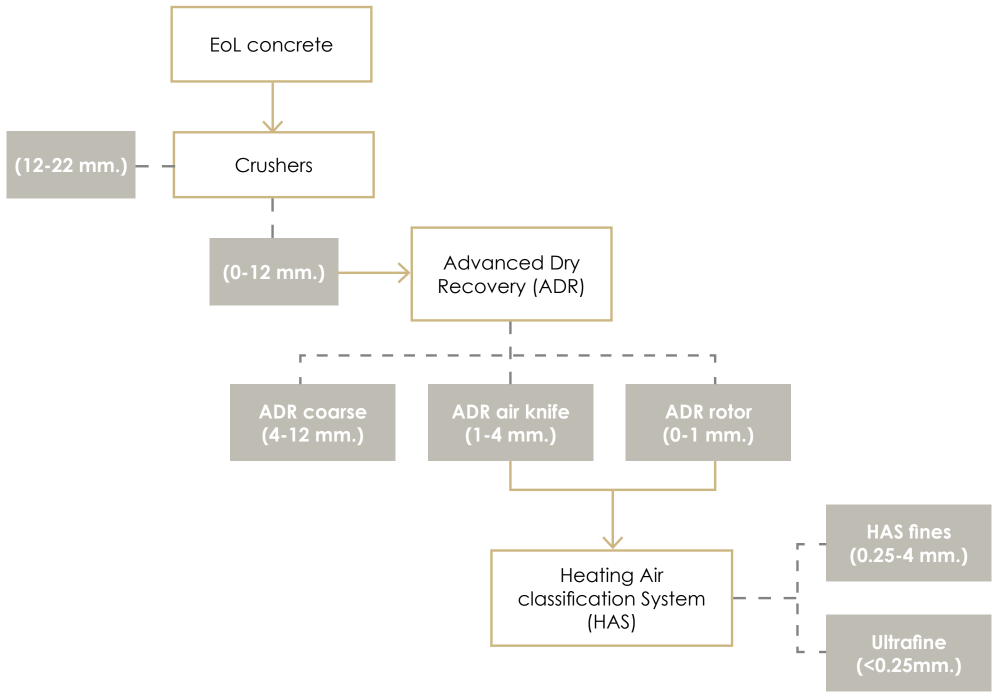


Figure 10 Illustration of processing EoL concrete by using ADR and HAS technologies (Rem et al., 2020)

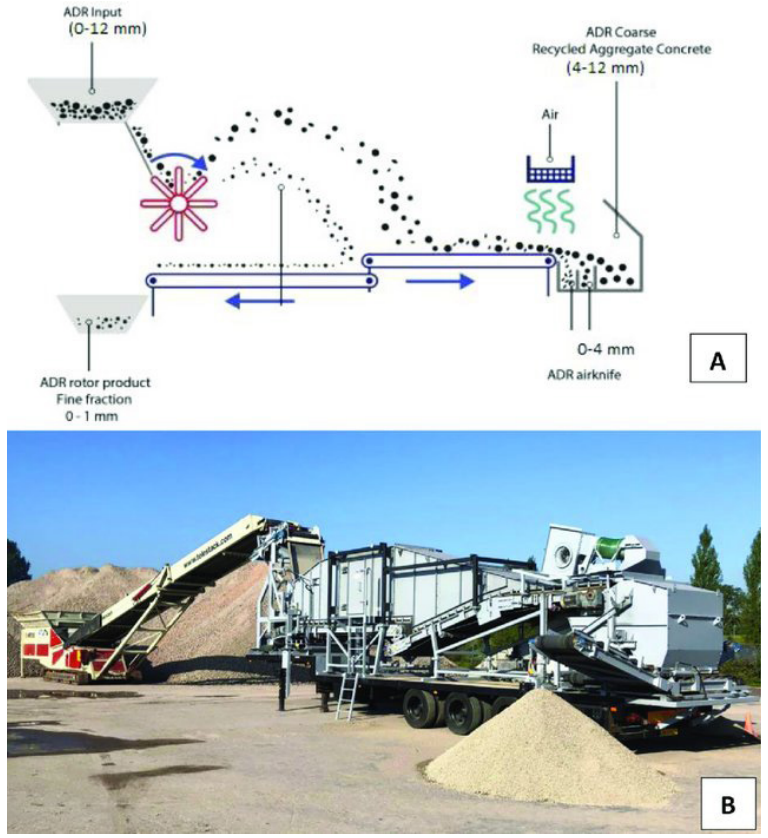


Figure 11 A sketch of ADR working principles (A) and ADR installation on site (B) (Rem et al., 2020)

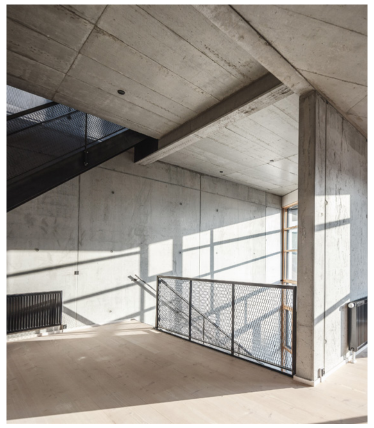
Concrete recycling

The largest structural material by volume is concrete, which costs about €35 per ton or €90 per m^3. The EU produces about 300 million m^3 of ready-mixed concrete every year. During the **End-of-Life** stage, concrete is typically disposed of in landfills or repurposed as road-based aggregate (RBA), frequently in combination with other mineral waste materials (such as bricks and tiles) originating from the same building. In the long run, both land filling and road building are not viable options for managing concrete waste sustainably. However, recycling concrete into **recycled concrete aggregate (RCA)** presents significant benefits such as the recovery of steel rebars, reuse of crushed concrete in appropriate applications, and minimal transportation of bulk materials, including energy and dust, especially when utilizing mobile crushing installations at the demolition site.

The current research at Delft is to develop a recycling process with more effective environmental sustainability for end-of-life (EOL) concrete that is economically competitive with the RBA route. This advanced recycling method **transforms crushed EOL concrete into aggregates** for new concrete and **a fine cement paste** concentrate for the production of new low-CO2 cementitious binders.

Initially, the procedure involves the gentle **milling** of the **crushed concrete** to eliminate a significant portion of the cement paste and fine sand adhering to the concrete particles' surface. Subsequently, the cement fines, wood, and other lightweight impurities are segregated to obtain a cement paste concentrate. One of the most difficult aspects of the research is **making the process fully mobile for application on the demolition site** while also controlling and certifying the quality of the aggregate products to the point where they are widely accepted as a replacement for primary aggregates by regulatory agencies, mortar facilities, and end-users. Advanced online sensors are being developed to record the composition and grain-size distribution of each truckload of aggregate, enabling direct shipment of the material from the demolition site to the mortar facility.

Using concrete in such a circular way means reclaiming the raw material from buildings and separating it into gravel, sand, and cement. *"These materials will then once again be made into concrete,"* explained Prof. Peter Rem. *"The recycled concrete is indistinguishable from other variants made from river sand, gravel, and cement from limestone quarries."* Since cement produces between five and ten percent of the world's combined carbon dioxide emissions, recycling concrete will enable considerable cuts in CO2 emissions (Rem et al., 2020).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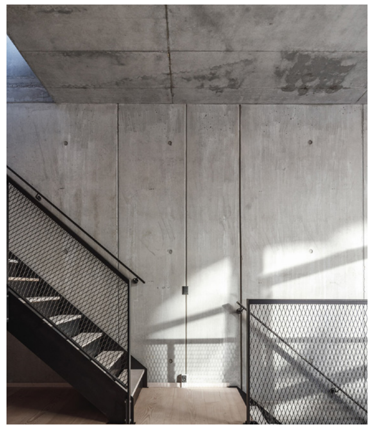
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1-3 : Upcycle Studios (Lendager Group, 2022)
4-6 : Design Museum Gent extension (Carmody Groarke, 2023)

Recycled concrete projects

Upcycle Studios
Location : Copenhagen, Denmark
by Lendager Group

The architecture of Upcycle Studios is based on the principles of the circular economy. The project demonstrates how 3,000 m2 of row houses can save 45% of CO2 and turn 1,000 metric tons of waste into building materials. Lendager Group has used recycled concrete, windows, and wood, which had a previous life in another house. The materials are processed, so they, both in quality and function as well as aesthetically, appear as newly produced materials without producing new materials (Lendager Group, 2022).

The objective of this initiative was to address the issue of housing shortages in Denmark, while simultaneously upholding the principles of a circular economy and minimizing the carbon emissions associated with the construction process. Through the implementation of an innovative recycling methodology, approximately 850 metric tons of concrete were recovered from the construction of the Copenhagen metro, resulting in a significant reduction in carbon dioxide emissions. The social and urban outlook of the group went beyond a mere emphasis on sustainable design, and instead facilitated the creation of new employment opportunities.

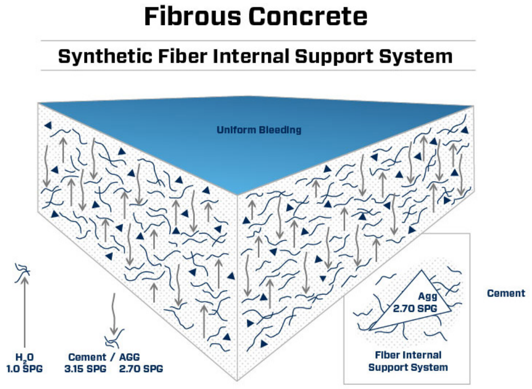
Design Museum Gent extension
Location : Gent, Belgium
by Carmody Groarke

The Design Museum Gent's new wing will be constructed using a brick that has been developed by architecture studios Carmody Groarke and TRANS Architectuur Stedenbouw in collaboration with material researchers. This brick has been created using locally-sourced construction waste.

In collaboration with a circular economy expert, the Gent Waste Brick is claimed to possess a low-carbon footprint. It is purportedly capable of carrying only one-third (with 0.17 kilograms of CO2e/kg.) of the embodied carbon content of an average Belgian clay brick. The brick is composed of 63% recycled municipal waste obtained from Ghent, which was procured from a nearby recycling facility for concrete and glass demolition.

The bricks are cured in a humid environment for two weeks and then left to air-dry rather than being fired, reducing the amount of energy needed to manufacture them (Dezeen, 2023).

The collaborative efforts of the team and the Design Museum Gent have resulted in the creation of a highly crafted, tailored material artifact that encapsulates the institution's culture and values, challenging the material qualities and aesthetic properties of a traditional brick.



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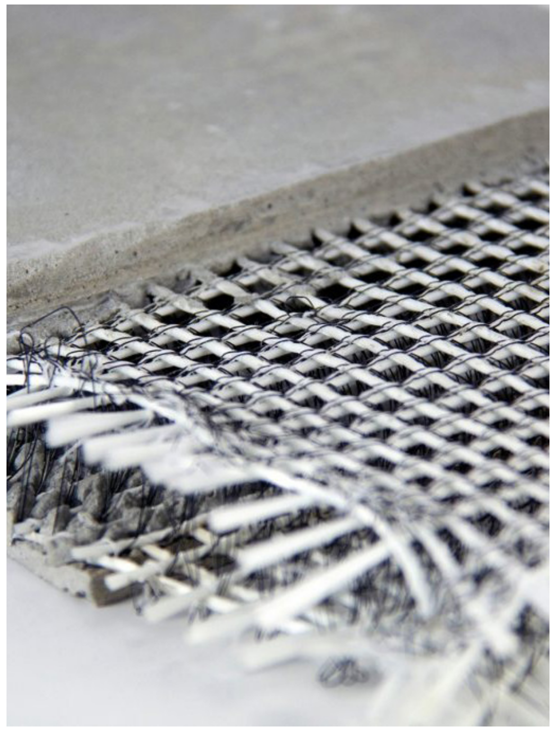

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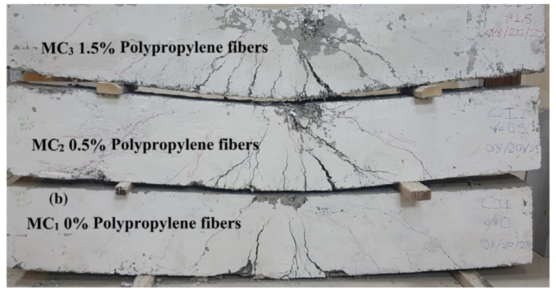


4

1 Fibrous concrete : Synthetic fiber internal support system (Fibermesh, n.d.)
2 Polypropylene fibres (Sundaramurthy et al., 2022)
3 Close-up of a piece of textile-reinforced concrete (Wikipedia, 2013)
4 Fiber-reinforced concrete compressive strength test (Zheng, Z. et al., 2018)

Fiber-reinforced concrete

Fiber-reinforced Concrete is a composite material that is composed of fibrous material, which enhances its structural integrity. The composition comprises a blend of cementitious materials such as cement, mortar, or concrete and appropriate fibers that are uniformly dispersed in a discontinuous, discrete manner. In order to mitigate the occurrence of plastic shrinkage and drying shrinkage-induced cracking, fibers are commonly incorporated into concrete. These materials have the ability to decrease the permeability of concrete, resulting in a reduction in water bleeding.

Fibers for concrete are available in different sizes and shapes. The major factors affecting the characteristics of fiber-reinforced concrete are the water-cement ratio, percentage of fibers, diameter, and length of fibers. Some of the different types of fiber-reinforced concrete used in construction are the following: steel fiber-reinforced concrete, glass fiber-reinforced concrete, polyester fibers, carbon fibers, macro-synthetic fibers, micro-synthetic fibers, natural fibers, cellulose fibers, and **polypropylene fiber-reinforced (PFR) concrete**.

To conclude, from durability to aesthetics, fiber-reinforced concrete has the potential to add value and technical aspects to the building. It has been rapidly growing throughout the construction industry and is gaining increasing interest among the concrete community for its reduced construction time and labor costs.

Advantages of Fiber-reinforced concrete

1. Fibers Reinforced concrete may be useful where high tensile strength and reduced cracking are desirable or when conventional reinforcement cannot be placed.

2. It improves the impact strength of concrete, limits crack growth, and leads to a greater strain capacity of the composite material.

3. Adding fibers to the concrete will improve its freeze-thaw resistance and help keep the concrete strong and attractive for extended periods.

4. Improve mix cohesion, improving pumpability over long distances.

5. Increase resistance to plastic shrinkage during curing.

6. Minimizes steel reinforcement requirements.

7. It controls the crack widths tightly, thus improving durability.

8. FRC’s toughness is about 10 to 40 times that of plain concrete.

9. The addition of fibers increases fatigue strength.

10. Fibers increase the shear capacity of reinforced concrete beams.
(Constro Facilitator, 2020)

Waste sorting warehouse


Analyzer tool

Examples of plastic types


PLASTIC ISLAND project in the exhibition area

Sotenäs Marina Återvinningscentral

Bohuslän, Sweden

In recent years, marine plastic waste has attracted more attention due to the potential threat it poses to humans and wildlife. According to Zhang, Y. et al. (2023), the majority of plastic waste in the ocean is derived from terrestrial sources through riverine discharge or coastal zone erosion. Only about 25 percent of the total terrestrial discharge comes from shipping and fishing activities.

“Even though plastic found in our oceans or on our beaches may appear to be free, it must still be collected, and in order to be recycled, it must undergo an extensive sorting and cleaning process in order to be reused in its original condition.” “Even then, due to the potential degradation of the plastic, it may be difficult to ensure the product’s quality” (Goksyr, 2018).

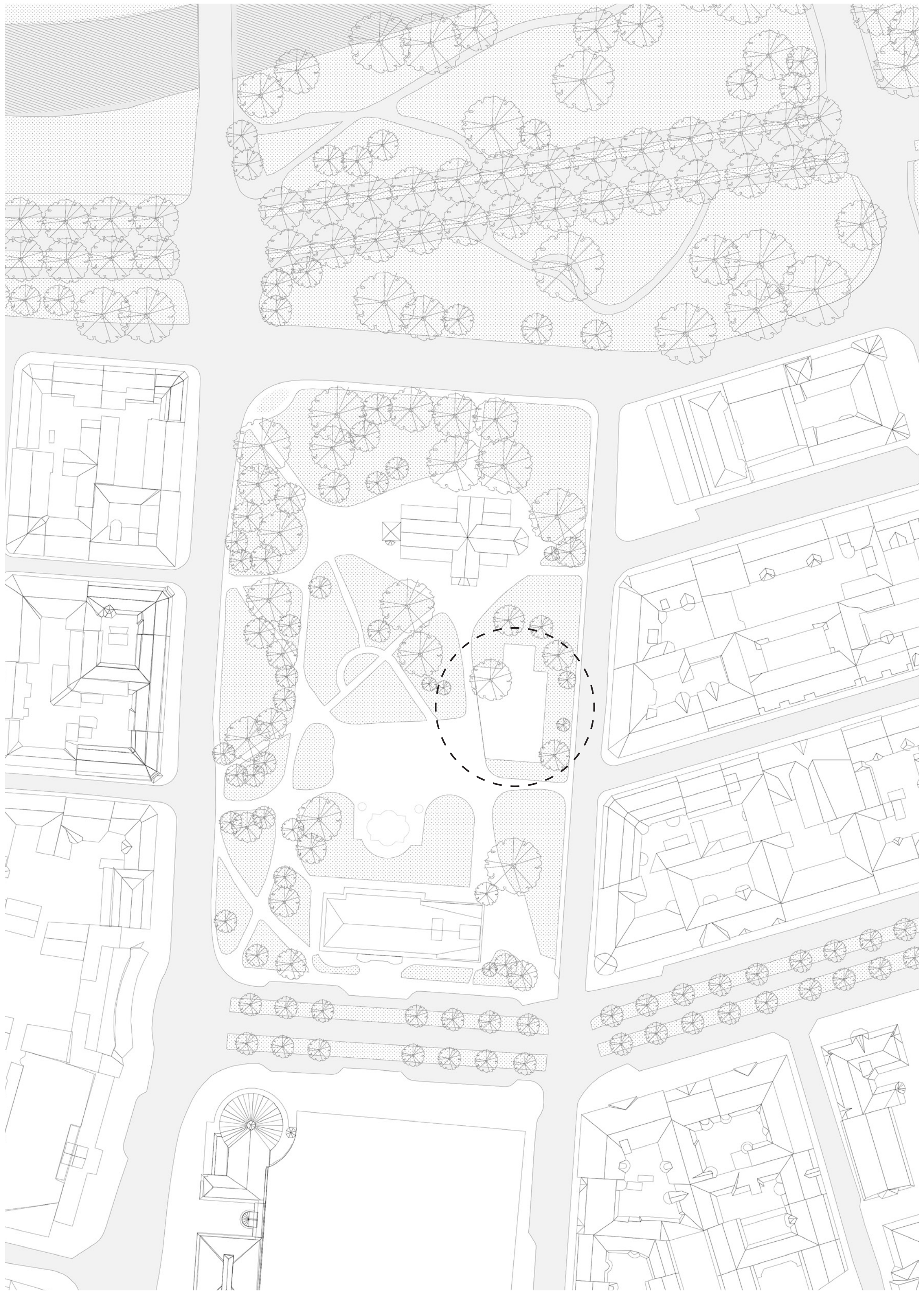
In 2018, the Sotenas Marine Recycling Center, the first marine recycling facility in Sweden, collected more than 34 metric tons of marine waste in the municipality of Sotenas. This facility handles marine waste gathered from beach cleaning, used fishing equipment from the fishing industry, and ghost fishing nets and cages collected from the sea. At the Marine Recycling Center, waste is disassembled, divided into fractions, and sorted into plastic types using an analyzer tool for material identification, thereby reducing the amount of waste disposed of in landfills and burned and increasing the amount of waste recycled and reused (Symbiocentrum, n.d.).

This thesis investigates the possibility of using ocean waste, specifically fishing nets, to replace steel bars and conventional fiber-reinforced materials in concrete. This project recycles not only construction and demolition waste, but also ocean waste. Despite the fact that this project will not solve global pollution, it will open up new possibilities when looking at “waste” or secondary materials in the combining of waste from two major sources, and it has individually given light to the author as someone with a background in architecture and as a freedriver who spends the majority of her time underwater. It demonstrates, from one perspective, that architecture can be an agent of environmental activism by starting the process of reusing waste into architecture while also cleaning up waste from both the ocean and landfill sites.

3 | Design Research

Location : Haga, Gothenburg

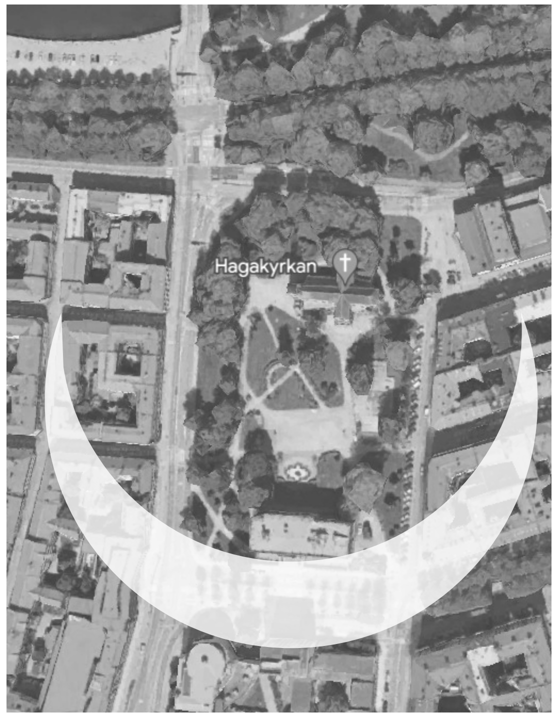
57.698749, 11.962563



The aim of the project is to improve the learning setting of the Haga Kyrkoplan playground. This location is surrounded by historical landmarks, including Hagakyrkan and Samhallsvetenskapliga Library. Moreover, according to the city's development plan, the area will experience an increase in commuter traffic due to the new Westlink station entrances. In terms of environmental impacts, the ongoing replacement of the old building's construction and deconstruction sites with new buildings aligns with the thesis project's objectives.

Within the context of the experimental project, it is obvious that the construction industry must prioritize waste management. The architecture allows for showcasing the recycling of waste or "secondary materials," making them more accessible and gaining public understanding. This development brings us closer to comprehending the feasibility of waste management as the era of massive waste production approaches, leading to the urge to try out and experiment with what we can do as architects to handle the future repercussions.

Playground area in Haga Kyrkoplan



Sun orientation

Haga ongoing development

Haga is one of the oldest neighbourhoods in Gothenburg. Haga Nygata, a pedestrian thoroughfare, is adorned with impeccably maintained residences, a majority of which are built in the distinct Gothenburg fashion known as "landshövdingehus". These structures feature a brick foundation and a wooden framework. Currently, the area accommodates an array of independent shops and restaurants.

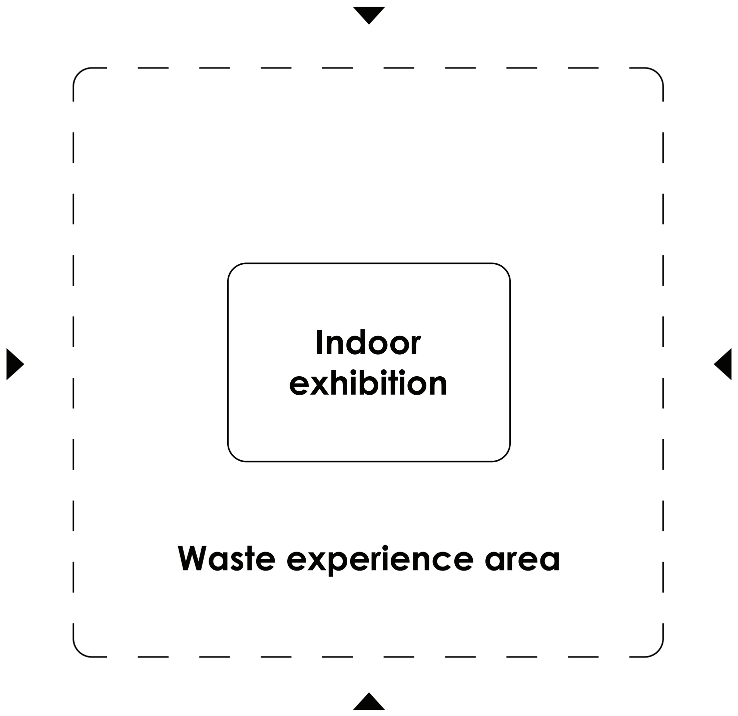
The Haga area is currently undergoing continuous development in relation to the underground railways of the West Link project, which are interconnected beneath the central area of Gothenburg. The West Link project aims to connect the urban and regional areas of Gothenburg through the implementation of an underground railway link that traverses the central district. This initiative involves the establishment of three novel train stations, namely Central, Haga, and Korsvägen, which are intended to alleviate the existing congestion issues at the current Central Station. It is anticipated that the initial trains will start traveling the tunnel in 2026.

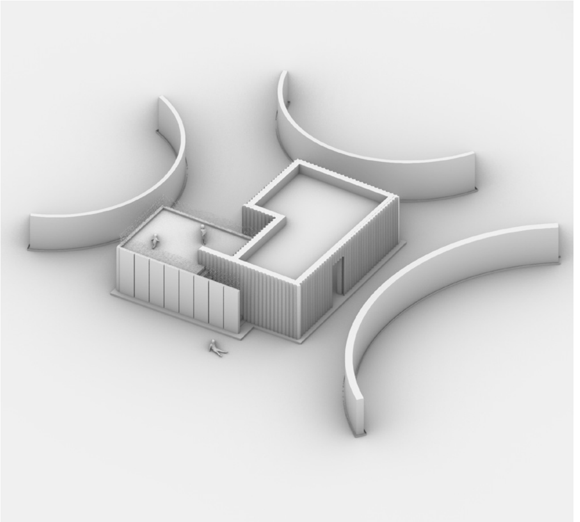
The Haga Kyrkoplan will consist with three entrances to the underground, indicating its preparedness to accommodate an increasing population, commuters, and tourists in the future.

In addition, the municipality has demonstrated a consideration for the artistic aspect of the project, as indicated by the statement, "One aspect of the project is the creation of a series of public artworks for the city, with the vision of incorporating artists into the process of shaping new public spaces for everyone in Gothenburg to share."(Göteborg Konst, 2023)

As per the findings of Göteborg Konst (2023), "Chronotopia" is an art initiative that employs site-specific artistic exploration that explores the contemporary world, the latent possibilities of the past, and plausible narratives of the future.

4 | Design and applications





Waste-based pavilion

Design intention:

A study of how architecture can, to a greater extent, support and inspire a closeness and deeper understanding of the revaluing end-of-life of the CDW (construction and demolition waste) and thus develop a stronger awareness between the place and the visitors.

The objective of the project is to improve the area by providing educational exhibitions on waste generated from construction and demolition, as well as waste within the ocean, within the "Waste-based Pavilion."

House of Waste by expressing the waste-based materials as senses: visual, touch, sound, remiscense, place, and history. Moreover, to perform its characteristics regarding the materialization , namely, compressive strength, thermal conductivity, and other findings.

Reused Box is made up of reused steel panels, which not only show the capability of reusing material but also provide the user with the ability to sense the temperature change of the House of Waste.

Moreover, the project provides visitors with an opportunity to experience the transformation of waste materials into valuable resources that benefit both the community and the environment. The primary aim of the Texture and Crumbling Park is to facilitate visitors exploration and uncovering of the various layers of materials present on the site.

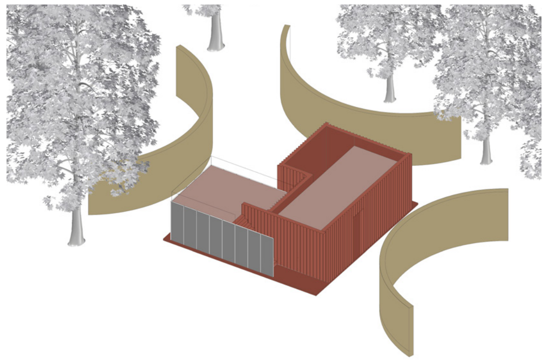
This, in turn, fosters creativity and a sense of place, thereby enabling intriguing possibilities for making the castle akin to a sandbox.

Program :

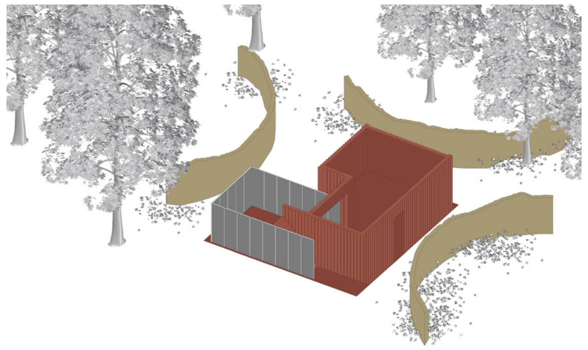
House of Waste Experience the senses (touch, temperature, exhibition)	35 m^2
Reused box Reused/reclaimed materials s part of the structure	18 m^2
Small terrace	13 m^2
Texture and Crumbling park Processing and awareness	200 m^2
Total	266 m^2

Site Plan

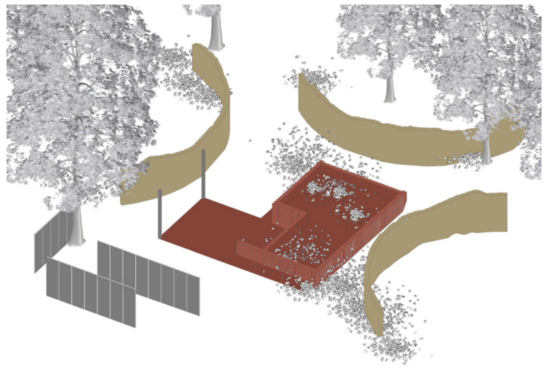
Collection of CDW waste



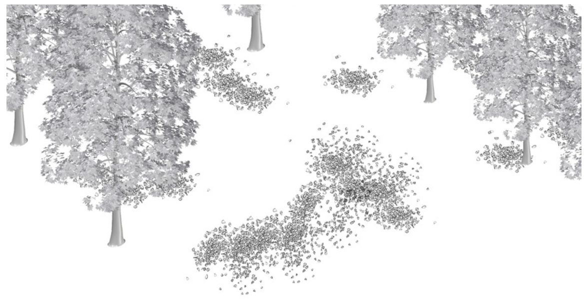
Building & Operation phases



Decaying over time



Dismantling of the reused box



EOL for the new beginning

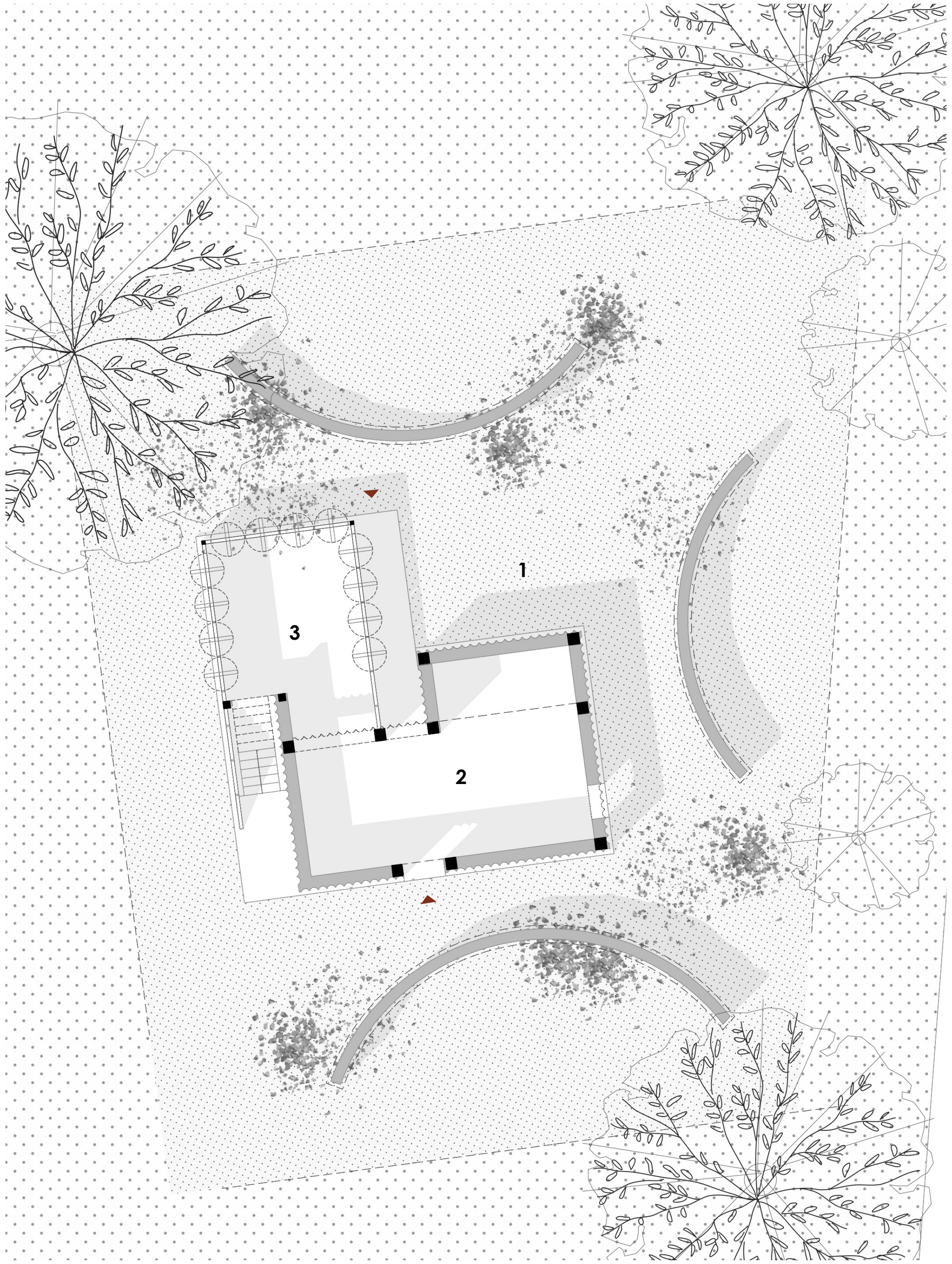
EOL to EOL

Currently, architects are provided with an expanding range of materials that can be implemented in their architectural designs. The architect is required to evaluate diverse design criteria to make a choice from the extensive range of materials that are available. As per the findings of Wastiels, L., et al. (2008), the procedure of material selection in the field of architecture encompasses a broader spectrum than merely selecting the most durable, economical, or prominent materials that are readily available. When designing buildings, architects tend to select materials that are either expressive, formal, functional, or locally sourced.

Conversely, there has been an increase in the quantity of construction and demolition waste. Therefore, it is pertinent to question the rationale behind seeking new virgin material when recycling the waste could be a viable alternative. The redefinition of the term "waste" has resulted in the attribution of value to waste generated by humanity. This thesis endeavors to provide an additional approach to address the global challenge. It is noteworthy that the proposed solution not only attains cost-effectiveness, robustness, and distinctiveness but also exhibits positive mechanical performance and versatility, as evidenced by the study.

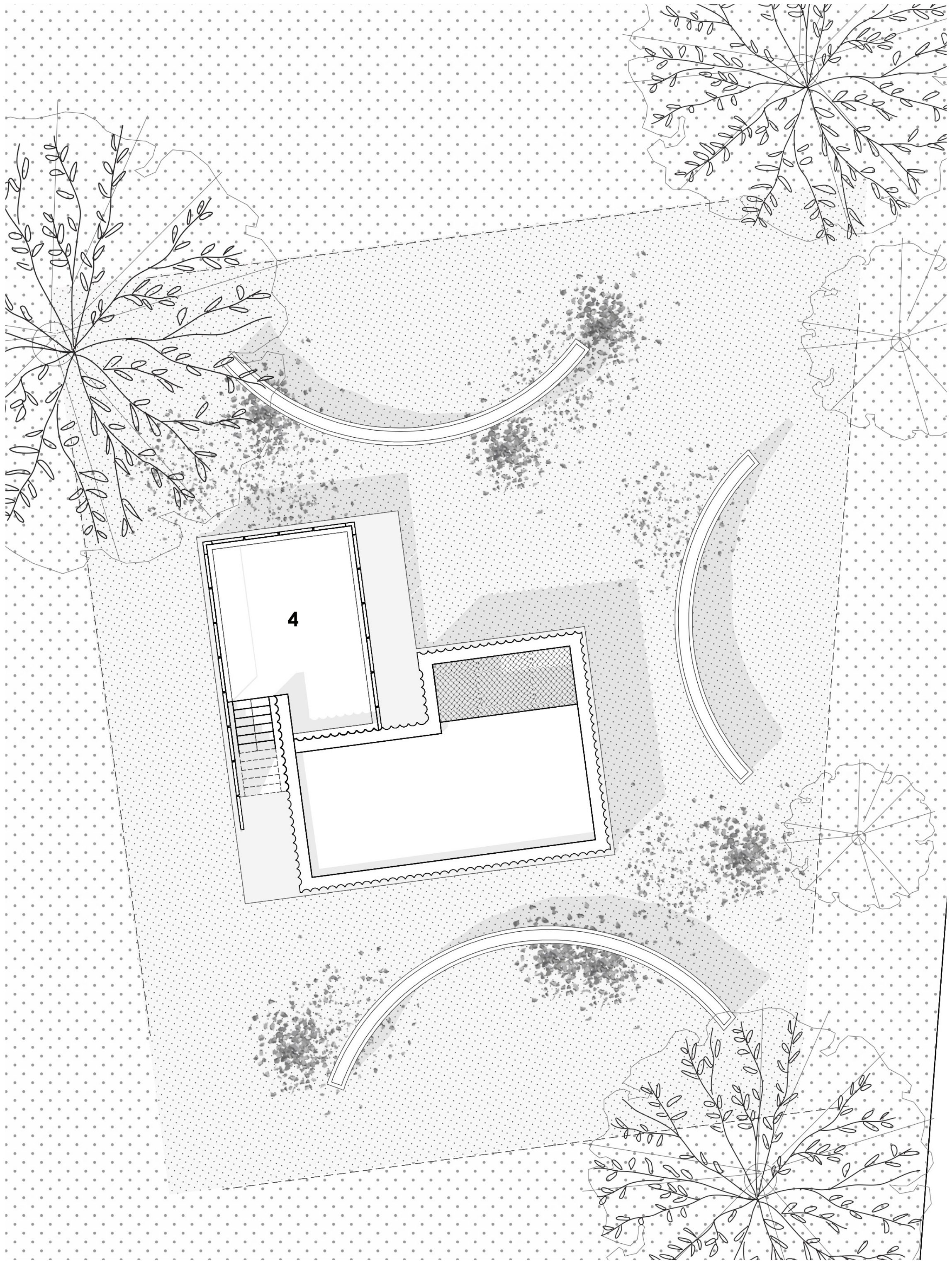
Looking ahead to the next 50–100 years, it is worth considering the impact of demolished buildings being deposited in landfills on the global climate. Given the rapid extraction of minerals from the earth and the resulting pollution of the ecosystem, it may be prudent to rethink our approach to waste management and prioritize sustainable alternatives to conventional materials. Many studies are currently being conducted to optimize the recycling process of waste materials that have accumulated and are available for use, beginning with the end-of-life (EOL) stage and ending with the new start.

Plan



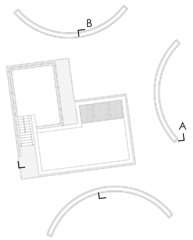
1 Texture and crumbling park | 2 Waste experience hall | 3 Secondary material exhibition

Roof plan



4 Terrace

Sections



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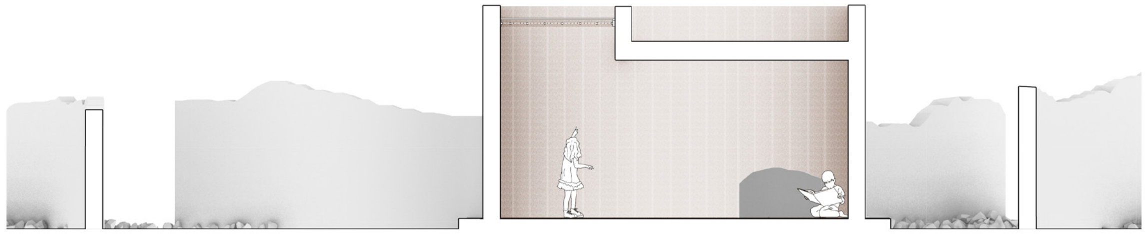

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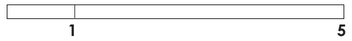


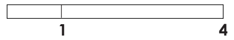
Elevations

West

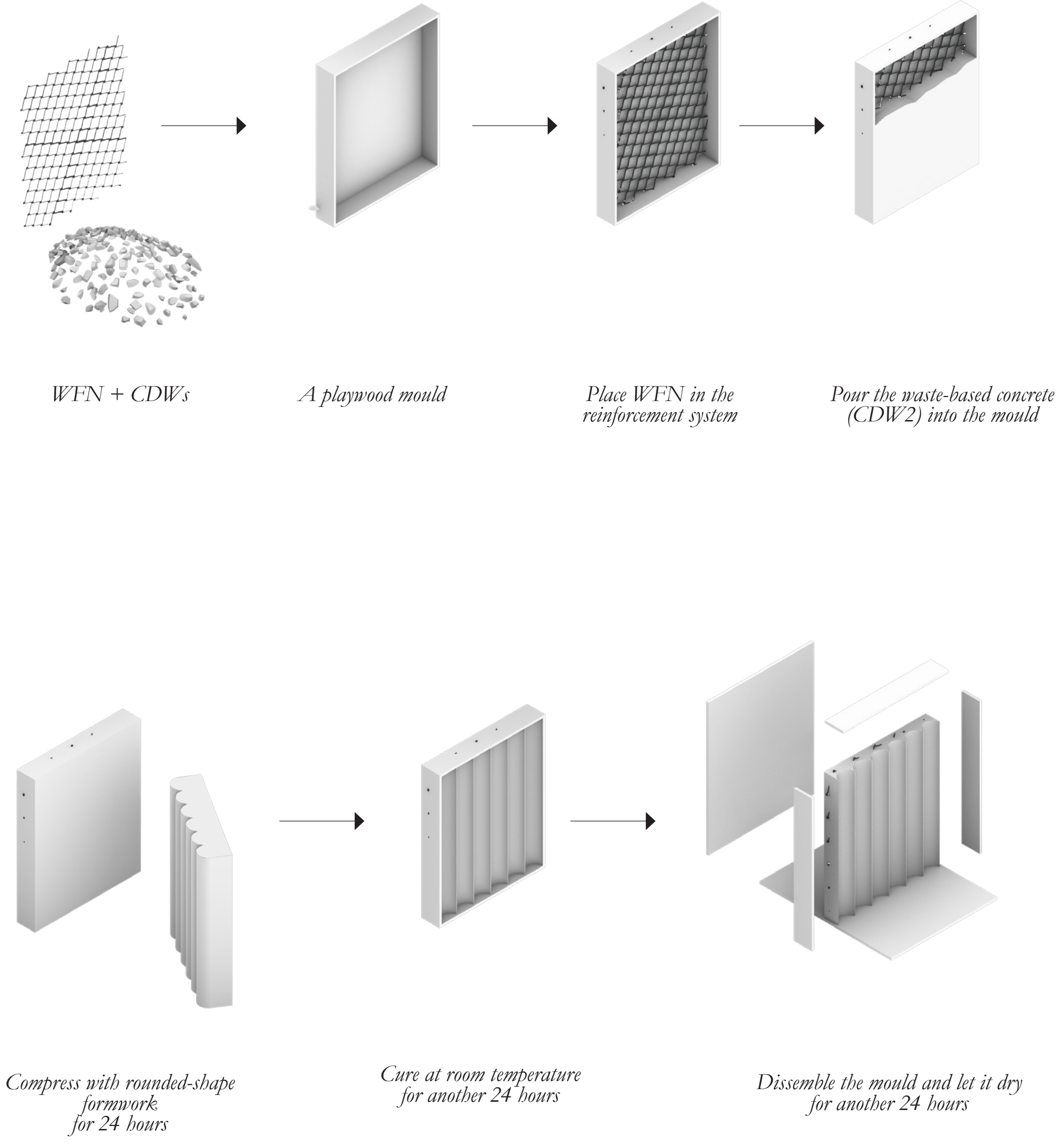
South

North

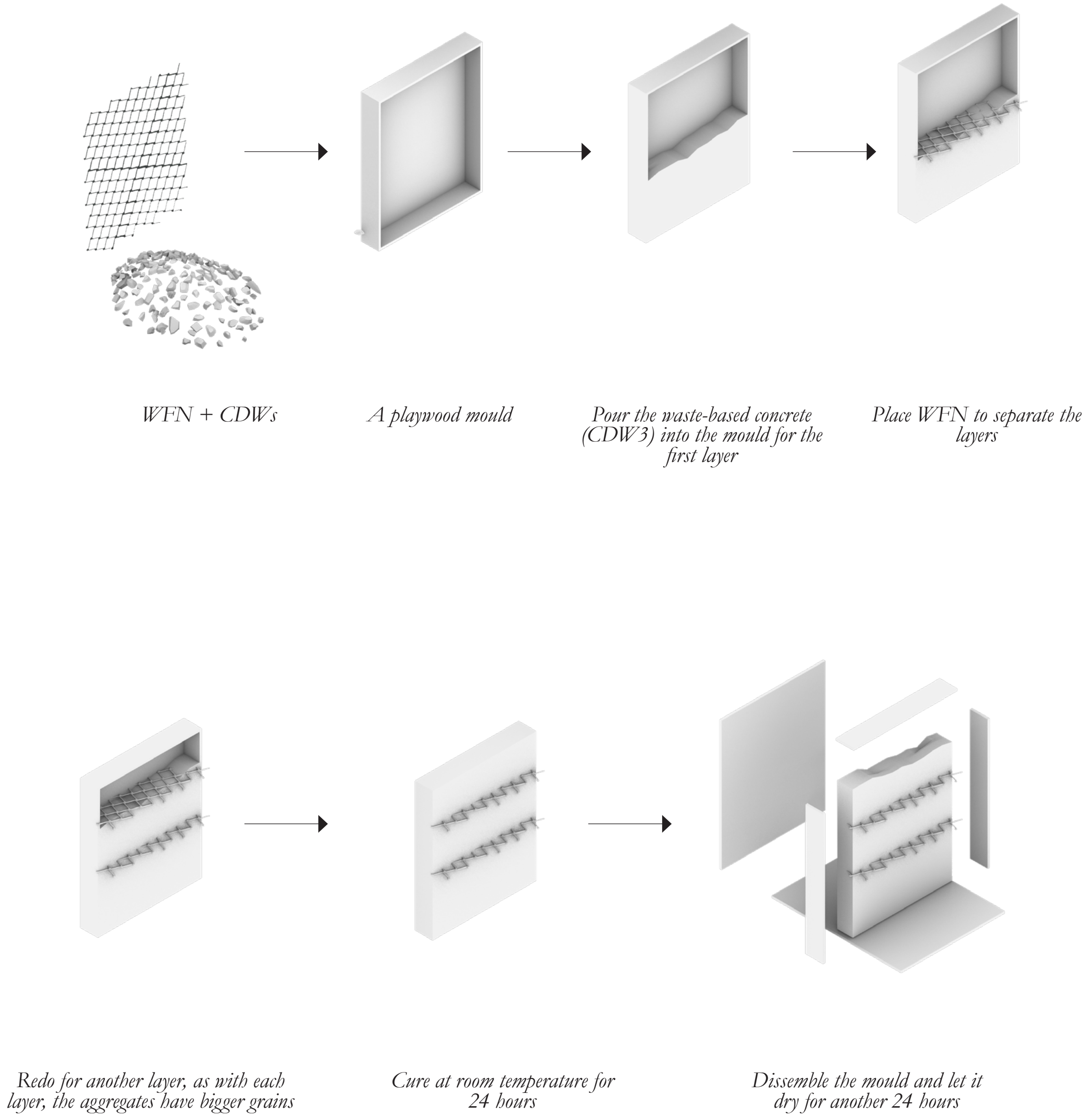
East



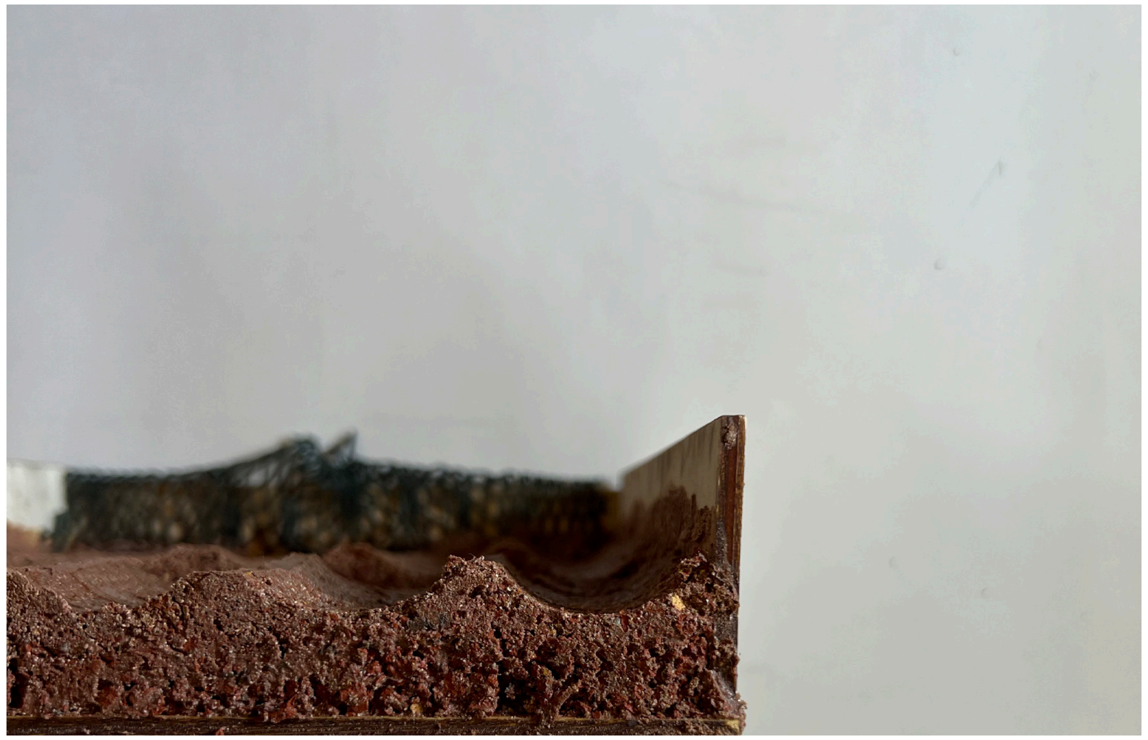
Process :
House of waste



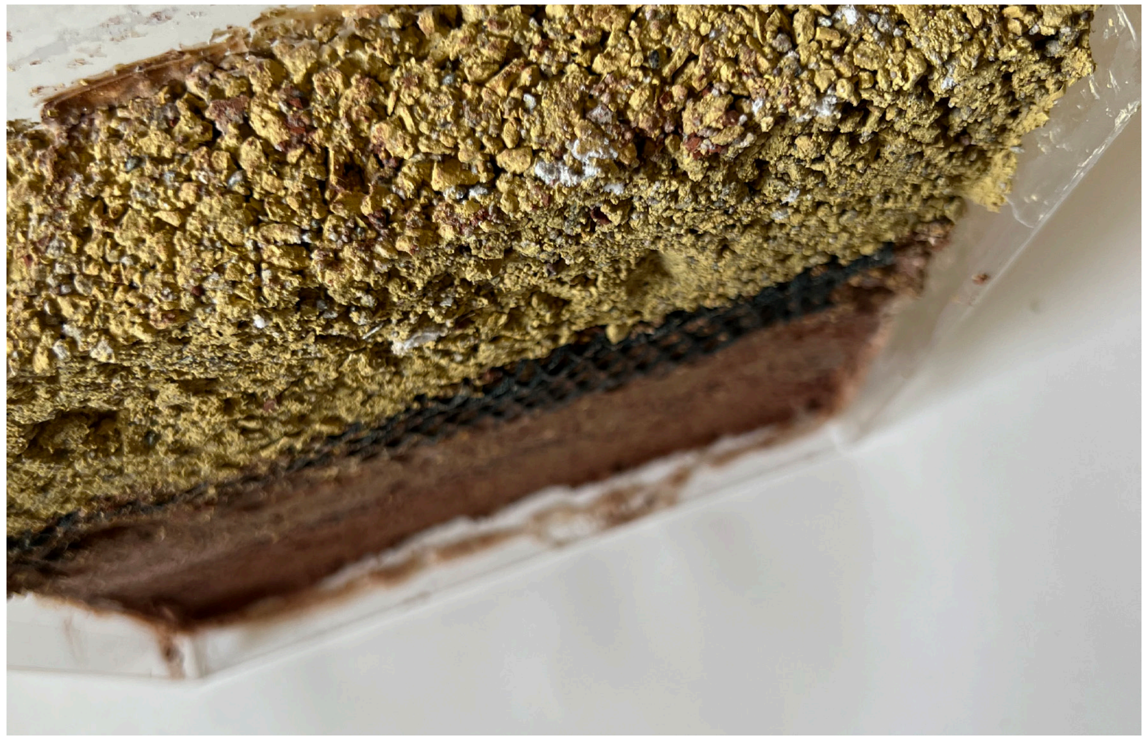
Process :
Texture & Crumbling park



Mould 01 : House of waste



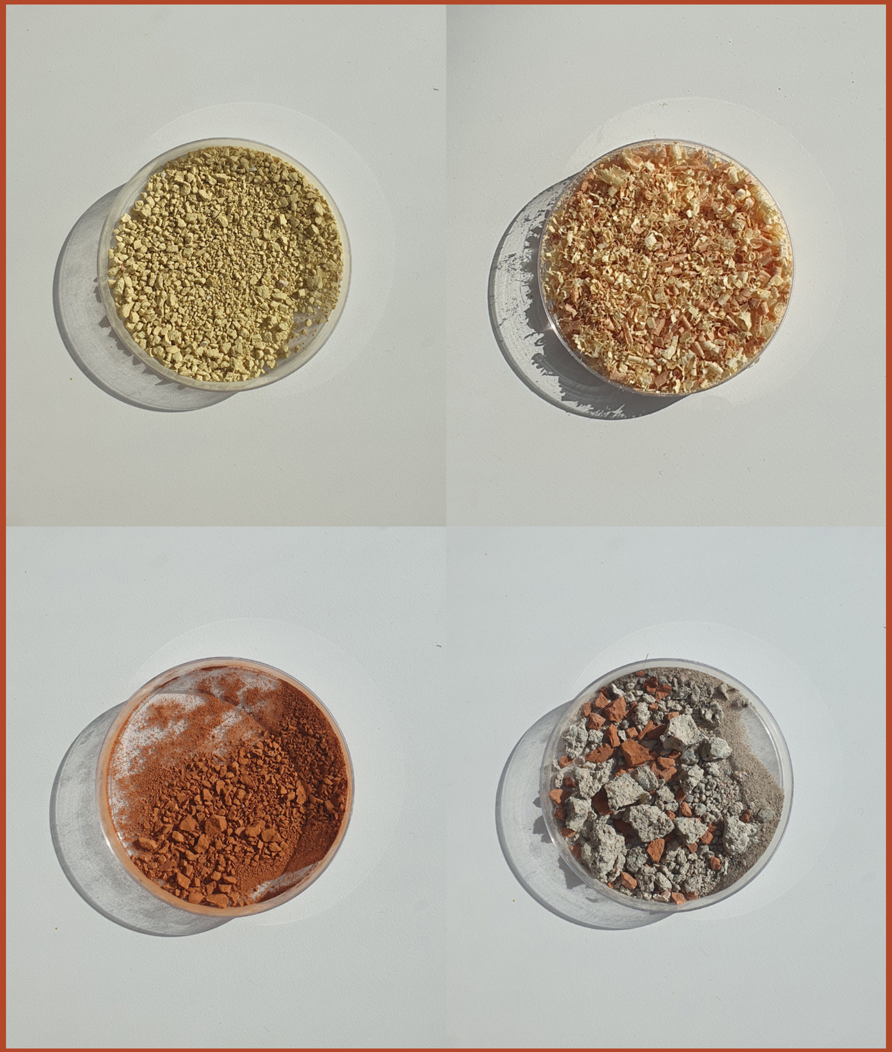
Mould 02 : Texture & Crumbling park



5 | Materialization

“The biggest obstacle to a more widespread use of recycled concrete is **awareness**.”

(Armin Grieder, the head of engineering at Zurich’s building surveyor’s office)



“By reusing debris from abandoned constructions near the site’s surroundings, the concrete façade tells the story of the building’s emergence as it strives to **express a sense of community and integration**.”

(Studio Gang)

Alternative binders

A binder is a glue that holds components together. The binder of choice is Portland cement. The advantages are that the properties are well known and that they can be applied almost anywhere. The disadvantages are the shortage of raw materials and high CO2 emissions.

After examining the traditional concrete composition in figure 11, there are myriad ways (see figure 12) to replace highly CO2-emitting raw materials, namely, cement or limestone, as well as aggregate from river sand, which have a negative effect on other biodiversity.

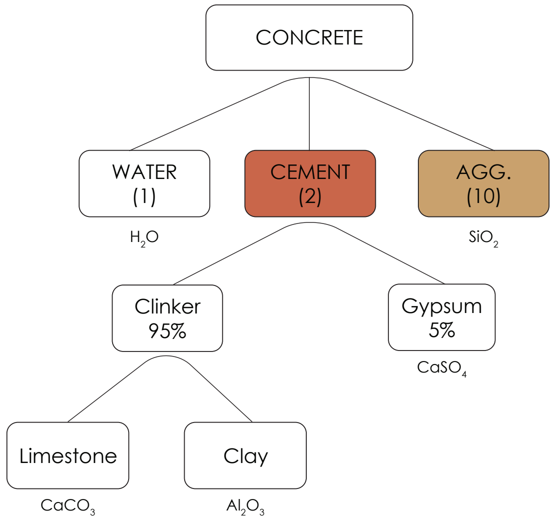


Figure 11: Composition of concrete

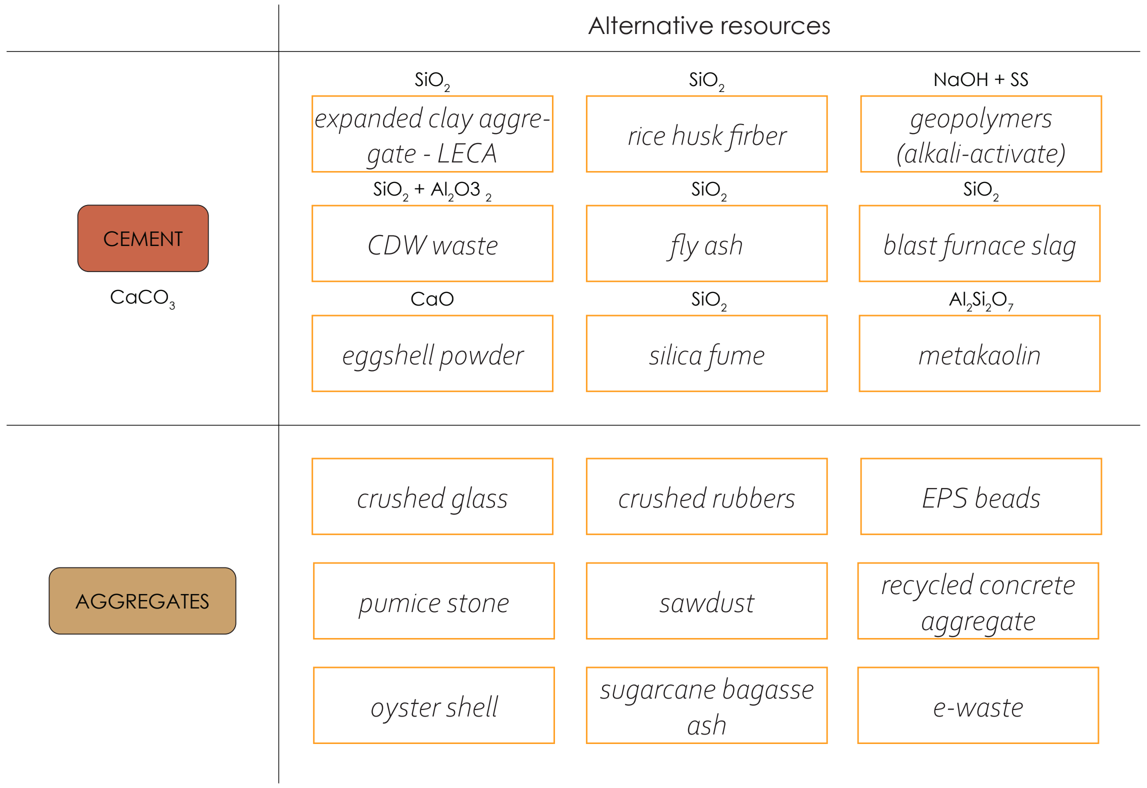


Figure 12 : alternative secondary resources

Approaches to lower the CO_2 emissions of binders

1. Use of lower-energy alternative materials
2. Use of waste-derived materials to replace fossil fuels
3. Highly reactive Portland cement clinkers to reduce material use with the same concrete strength
4. Blended cements by diluting Portland cement clinker with other constituents

Experimental design

According to the approaches above, the first experiment is carried out with the aim of working with no cement added to the mixture. Using "sawdust" waste and "ground expanded clay" in the binder However, as can be seen from the outcomes, there is no such thing as sawdust that can be used as a binder without using high heat (400 °C) to activate the critical point of "lignin pyrolysis" that can be turned into a binder. The second experiment focuses on the procedure that can be carried out by closely examining the chemical composition of the CDWs that exist and are left untreated, which can be chemically replaced by the OPC.

Robayo-Salazar et al., 2020, state that alkaline activation technology, also known as "geopolymerization," is one of the latest and most widely discussed methods for using this kind of waste. This technology involves the reaction of an alkali activator and a solid aluminosilicate powder (or precursor) to create a hardened binder. Alkali-activated binders come in three varieties: low-calcium alkali-activated aluminosilicate, high-calcium alkali-activated aluminosilicate, and hybrid, which is made by combining the precursor to aluminosilicate with the activator and Portland cement in a ratio less than 30%.

CDW precursor

The characterization of raw materials suggests that the chemical composition of the CDW precursor (concrete waste, masonry waste, ceramic waste, and mortar waste) and the aluminosilicate nature (SiO2 + Al2O3 = 58.8%) of the geopolymeric precursor are highlighted.

	SiO_2	Al_2O_3	CaO
CDW precursor	47.6	11.2	21.2
OPC	17.9	3.9	62.3

Figure 13: Chemical composition of the raw materials (Robayo-Salazar, R. et al., 2020)

The CDW binder revealed a maximum compressive strength of 43.9 MPa, and was categorized as a cement with low-heat hydration and general-use properties, as per the standards outlined in ASTM C1157. The cement and crushed aggregates derived from construction and demolition waste (CDW) yielded concrete with a compressive strength of 33.9 MPa after 28 days of curing at room temperature (25 °C). Moreover, the concrete was found to be suitable for the production of high-quality structural blocks, with a strength of 26.1 MPa as per ASTM C90 standards. The findings propose a potential approach to utilize CDWs as both binder and aggregates through the application of alkaline activation technology, which complies with the concept of the circular economy and its zero-waste objective (Robayo-Salazar et al., 2020).

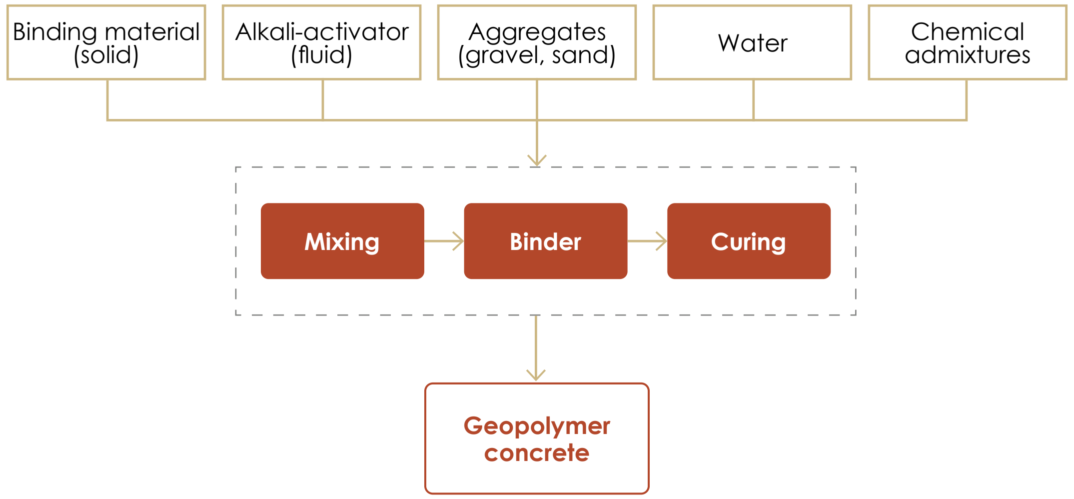


Figure 14 : Geopolymer production process (Weil et al., 2014)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1. Sodium hydroxide (NaOH) or
2. Sodium silicate (SS) or waterglass
as alkaline activators

Geopolymer / Alkali activator material

Geopolymers are a class of aluminosilicate materials with potential applications for greenhouse gas emission minimization and niche applications, as well as an advanced material for use in fire-proof composites and refractories. These materials are among the best substitutes for Portland cement (TU Delft, n.d.), as they maintain performance that is comparable to or better than that of conventional cementitious binders and require only moderate amounts of energy to produce. In comparison to Portland cement, a reduction in greenhouse gases of 80% or more is one of the advantages. By using waste or by-products from other industries to create geopolymers, the construction industry could advance the development of more sustainable and carbon-free materials. (TU Delft, n.d.)

By substituting secondary resources for primary raw materials, a geopolymer composition's environmental effects (and costs) can be minimized. The LCA (Life-cycle assessment) results recommend this type of optimization, but when good technical performance is desired, it is actually associated with several issues. Compared to primary raw materials, secondary raw materials typically have a wider range of chemical compositions (Weil et al., 2014). The availability of secondary resources, particularly those with a desirable low variation in chemical composition and a low content of heavy metals or impurities, is also mentioned by Weil et al. as a problem. Even if the availability varies a lot worldwide, the problem remains the same, as other traditional or new systems compete for these secondary resources. For instance, Germany already uses blast furnace slag in conventional cement-based systems. The introduction of a new technology to the market is not made easier by competition with a more conventional use of the same secondary resource. Thus, secondary resources that are not already extensively used as raw materials in other industrial sectors should be given preference when creating geopolymer mixtures for various applications.

The environmental impact of products should be reduced to a minimum. In order to create more environmentally friendly materials, the material designer needs to have some understanding of the environmental drivers of new material mechanisms as well as the environmental effects of competing traditional materials. In order to achieve different properties that make them suitable for a variety of applications, geopolymers can be produced from a variety of raw materials under a variety of processing conditions. As a result, the question of how geopolymers affect the environment is a rather complex one. Additionally, this investigation shows that both the solid and fluid components should be carefully considered when choosing raw materials. The replacement of silicate solution and NaOH solution shows great promise for enhancing the environmental profile of geopolymers (Weil et al., 2014).

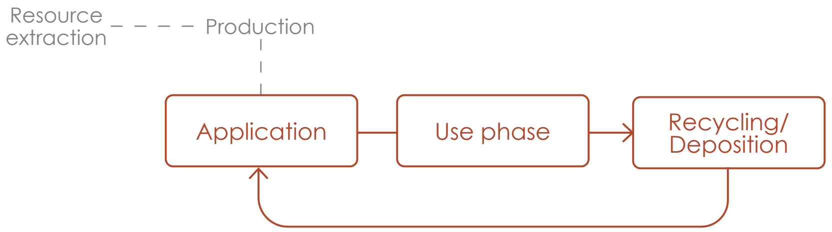
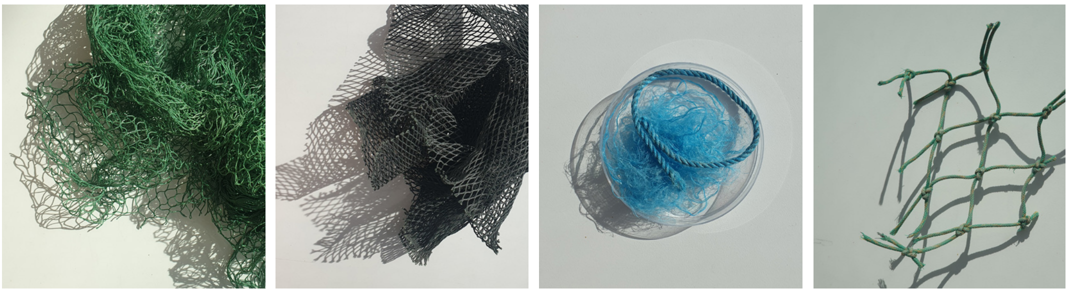


Figure 15 : Life cycle of geopolymer (Weil et al., 2014)



Nylon/polyamide (PA) Polypropylene (PP) Polyethylene (PE)

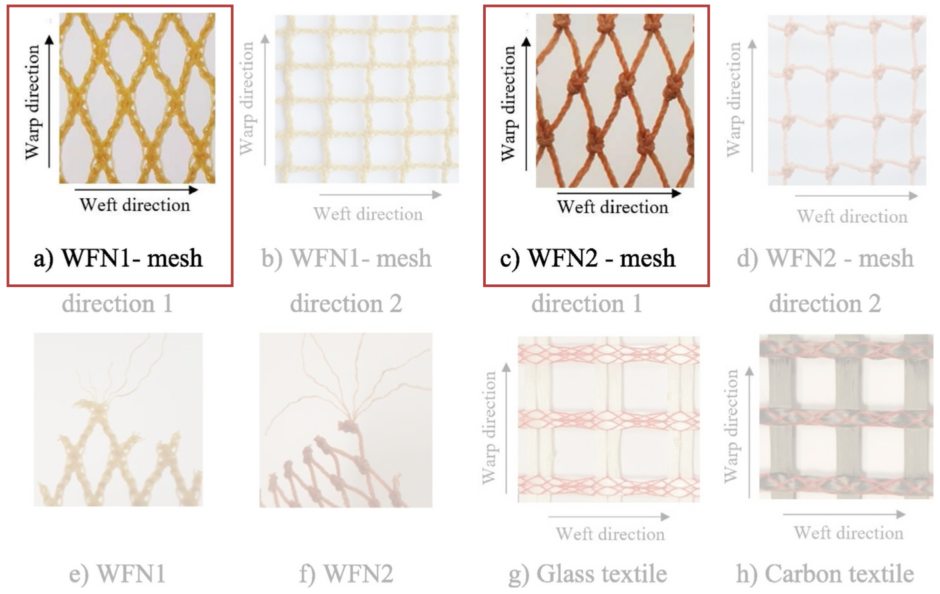
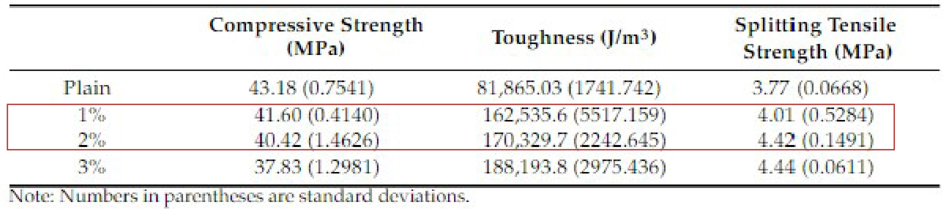


Figure 17 : Photos of waste fishing nets (WFNs) and commercial textile (Truong et al., 2020)



	Compressive Strength (MPa)	Toughness (J/m³)	Splitting Tensile Strength (MPa)
Plain	43.18 (0.7541)	81,865.03 (1741.742)	3.77 (0.0668)
1%	41.60 (0.4140)	162,535.6 (5517.159)	4.01 (0.5284)
2%	40.42 (1.4626)	170,329.7 (2242.645)	4.42 (0.1491)
3%	37.83 (1.2981)	188,193.8 (2975.436)	4.44 (0.0611)

Note: Numbers in parentheses are standard deviations.

Figure 18 : Table of Compressive strength test and splitting tensile strength test results (Nguyen et al., 2021)

WFN (Waste fishing net) as reinforcing materials

Fishing nets and trawls that still have a high tensile strength despite their degradation when discarded into the ocean can be recycled. Polyethylene (PE), polypropylene (PP), and nylon/polyamide (PA) are frequently utilized materials for the fabrication of fishing nets due to their non-corrosive properties. Additionally, the recycled WFN has shown potential in terms of mechanical properties (see Figure 16).

Conventional concrete constructions are fortified with steel reinforcement bars, which exhibit the drawback of corroding in inappropriate circumstances. According to Bertelsen et al. (2016), the aforementioned method is commonly employed in cases where the tensile strength of the concrete structure is inadequate.

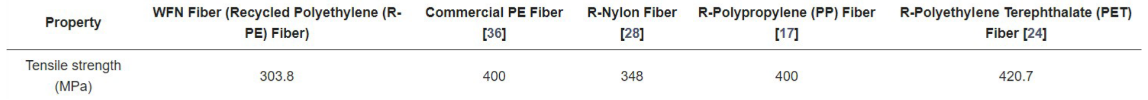
Subsequently, the selected WFNs will be cleaned with water to remove any organic and inorganic contaminants, as well as any saline residue present on the surface of the WFNs. Prior to conducting any tests, Truong et al. (2020) subjected the WFNs to a drying process at a temperature of 20 °C. Truong et al. (2020) conducted a study indicating that, as depicted in Figure 17 a and c, for WFNs with mesh direction 1, the warp direction, which exhibits a higher breaking load of fabric under tension, was chosen to be parallel to the applied tensile load. The transversal direction was then chosen as the direction of the weft. This selection resulted in higher mechanical performance when the WFNs were applied to reinforced concrete.

This thesis investigates two potential methods for strengthening the WFN fibers in the CDW binder.

1. The addition of WFN as a reinforcing agent for the CDW binder through the application of monofilament derived from twisted multifilament composed of polypropylene (PP) is attributed to its related resistance to alkali (the alkali-activator utilized in the CDW binder).

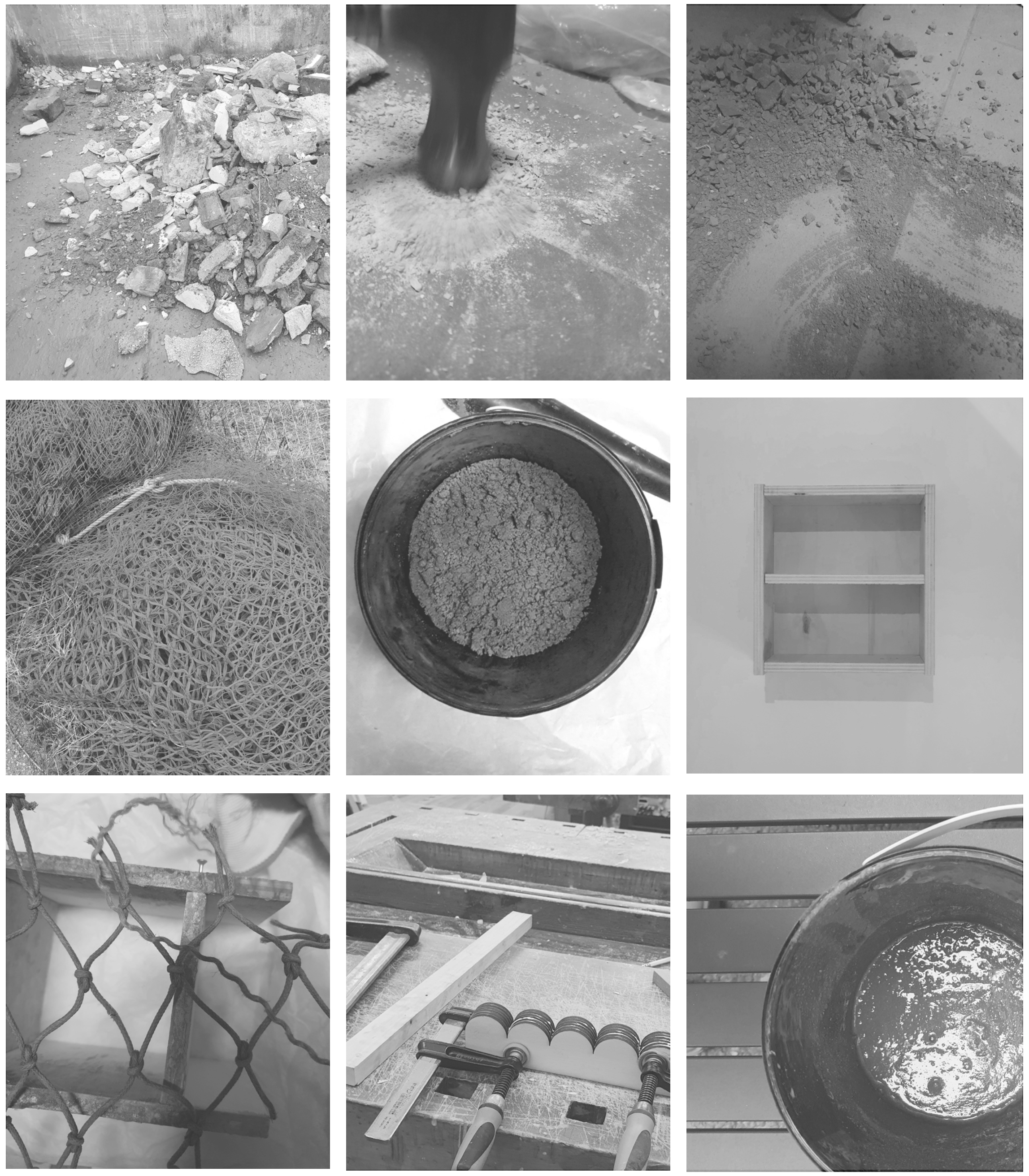
2. The WFN mesh, composed of either polyethylene (PE) or nylon/polyamide (PA), can be appropriately sized through cutting. Subsequently, the CDW concrete wall is constructed by positioning elements within the sections of the formwork.

According to Robayo-Salazar et al. (2020), the CDW concrete has the ability to attain an average compressive strength of 34 MPa following a 28-day self-curing period. The incorporation of WFNs results in enhanced bond strength with the cement matrix (see Figure 18) (the proportions of 1% and 2% are recommended for practicalapplications owing to their structural requirements) thereby potentially augmenting the mechanical characteristics of reinforced concrete (Truong et al., 2020). Furthermore, it has been proven that WFN fibers offer advantages in terms of crack arrest, leading to enhanced post-cracking performance and the conversion of concrete from a brittle to a quasi-brittle material (Nguyen et al., 2021).



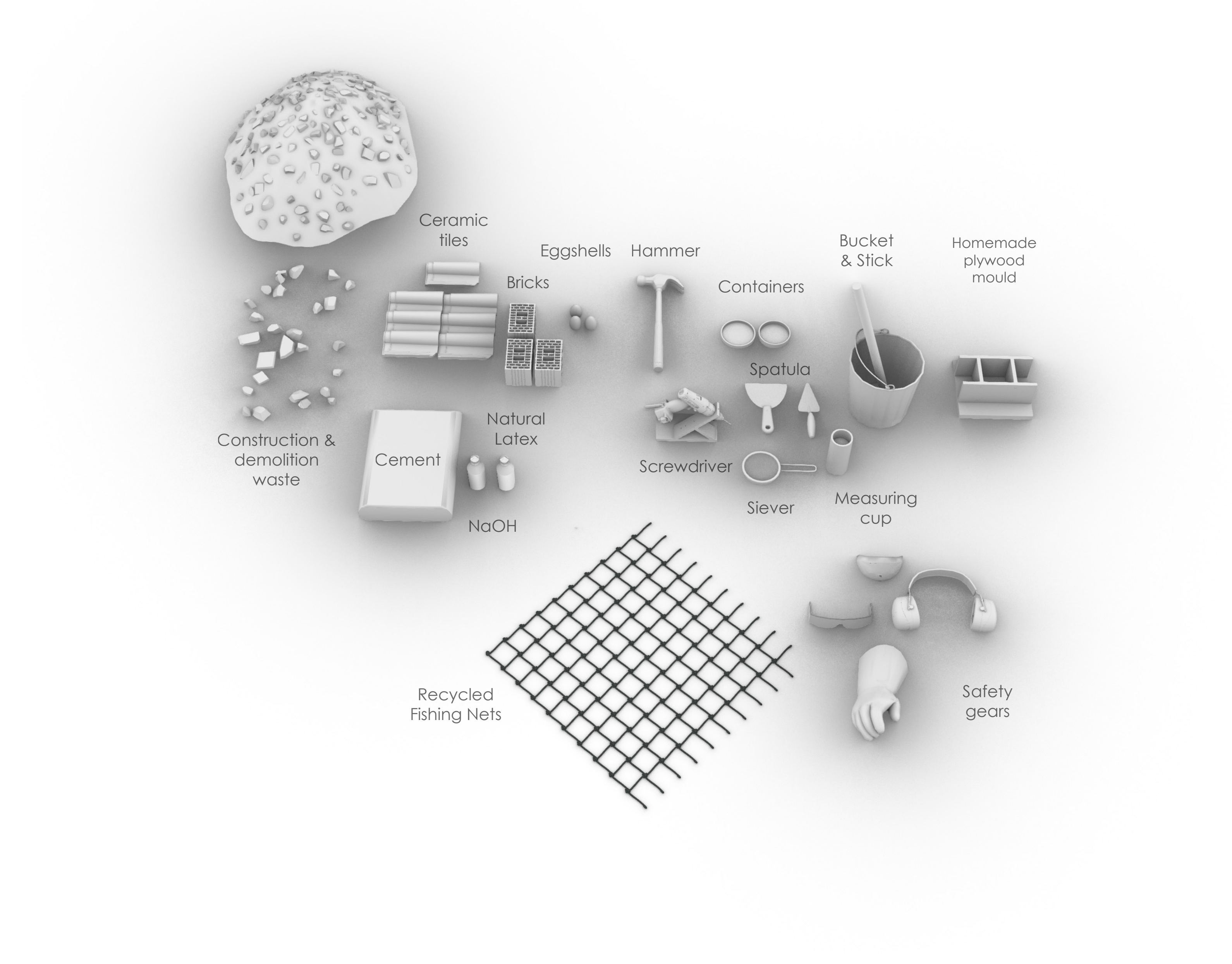
Property	WFN Fiber (Recycled Polyethylene (R-PE) Fiber)	Commercial PE Fiber [36]	R-Nylon Fiber [28]	R-Polypropylene (PP) Fiber [17]	R-Polyethylene Terephthalate (PET) Fiber [24]
Tensile strength (MPa)	303.8	400	348	400	420.7

Figure 16 : Comparison of tensile strength of fibers (Nguyen et al., 2021)



Setup and processes

The Lab



	EC+SD1	*EC+SD2*	*CDW1*	*CDW2*
				
experiments #	1.1	1.2	2.1	2.2
main component	EC (1) SD (5)	EC (1) SD (1)	CDW,AAM	CDW,AAM ESP
visual appearance	flaky fragmented	flaky fragmented	brittle flat surface	crumbling porous
crumbling	5/5	5/5	4/5	2/5
identity & history	some	some	some	strong
texture	rough	rough	rough	very rough
durability & strength	0/5	1/5	3/5	4/5
weather protection	n/a	n/a	1/5	5/5
thermal conductivity*	n/a	n/a	0.1-0.3 (w/mK)**	0.1-0. (w/mK) **
compressive strength	n/a	n/a	n/a	34.6 MPa**

EC = Expanded Clay, SD = Sawdust
CDW = Construction and Demolition waste, AAM = Alkali-Activator Material, ESP=eggshell powder
WFNF = Waste Fishing Net fibers, WFNM = Waste Fishing Net mesh

	CDW3	*CDW4*	*CDW2+WFNM1*	*CDW2+ CDW3+ CDW4+WFNM2*
				
experiments #	2.3	2.4	3.1	3.2
main component	CDW,AAM Latex	CDW,AAM WFNF	CDW,AAM WFNM	CDW,AAM WFNM
visual appearance	flat dense	grainy porous	fragmented layered	fragmented layered
crumbling	1/5	2/5	2/5	varied
identity & history	weak	strong	strong	strong
texture	smooth	very rough	varied	varied
durability & strength	4/5	4/5	4/5	4/5
weather protection	5/5	5/5	5/5	5/5
thermal conductivity*	0.1-0.3 (w/mK)**	0.1-0.3 (w/mK)**	0.1-0.3 (w/mK)**	0.1-0.3 (w/mK)**
compressive strength	n/a	34.6 MPa**	40-42 MPa***	40-42 MPa***

* - Higher the thermal conductivity value, greater the heat flow through the material (Jhatial et al., 2017).
- Normal concrete is shown to have a thermal conductivity of ~2.25 w/mK (Youm et al., 2014).
- The larger pores – usually 2-4% of a concrete - have such a low thermal conductivity (Wadsö et al., 2012).

** With 10% OPC to allow the mixture to cure at room temperature (≈25 °C). The compressive strength achieved by the CDW binder-based mortar was 34.6 MPa. (Robayo-Salazar et al., 2020).

***According to Nguyen et al. (2021)

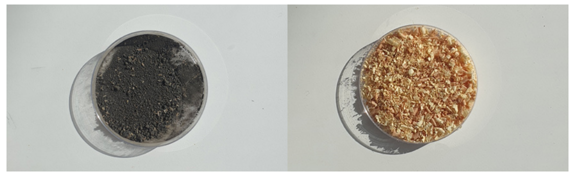
1.1

Expanded clay + Sawdust

Ingredients:

- Expanded clay (2)
- Sawdust as structural filler (10)
- Water (2)

Oven heated @ 200°C for 3 hours



Result :

The outcome shows failure in the chemical composition, as it can be seen that the binder mixture is not working and there is no such thing as sawdust that can be used as a binder without using high heat (400 °C) to activate the critical point of "lignin pyrolysis" that can be turned into a binder.

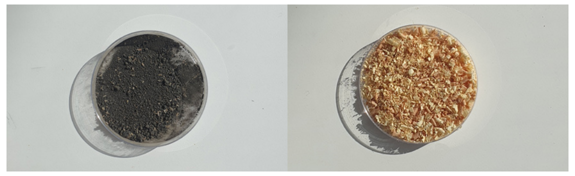
1.2

Expanded clay + Sawdust

Ingredients:

- Expanded clay (4)
- Sawdust as structural filler (4)
- Water (2)

Oven heated @ 200°C for 3 hours



Result :

The second trial turned out to be improved as the composition was ground so finely that the binder of expanded clay and water combined had better viscosity properties. However, the heat provided was not high enough to activate the binder, and as a result, they started to fall apart.

2.1

waste-based concrete

Ingredients:

- CDW precursor* (2)
- Alkali activator (1.8)
- OPC (0.2)
- Recycled fine aggregates* (red brick) (3)
- Recycled coarse aggregates** (3)

Cured at room temperature (15-25 °C)

*CDW precursor & RFA (≤4.76 mm)
**RCA (≤25.4 mm)

Result :

The hand-crushing of the aggregates, which left numerous air bubbles in the mixture and was cured at unheated room temperature, the material consequently becomes brittle and crumbling but remains fixed at standard room temperature.

2.2

waste-based concrete + ESP

Ingredients:

- CDW precursor* (2)
- Alkali activator (1.8)
- Eggshell powder (ESP) (0.1)
- OPC (0.2)
- Recycled fine aggregates* (3)
- Recycled coarse aggregates** (3)

Cured at room temperature (25 °C)

*CDW precursor & RFA (≤4.76 mm)
**RCA (≤25.4 mm)

Result :

The experiment alternates between using secondary materials in place of cement, such as eggshell, which was collected, crushed, and calcined and has a chemical composition of calcium oxide that is comparable to OPC (Hamada et al., 2020). The outcomes are pleasant after reducing the OPC ratio and adding eggshell powder to the binder.

2.3

waste-based concrete + latex

Ingredients:

- CDW precursor* (2)
- Alkali activator (1.8)
- Latex (0.2)
- OPC (0.1)
- Recycled fine aggregates* (3)
- Recycled coarse aggregates** (3)

Cured at room temperature (25 °C)

*CDW precursor & RFA (≤4.76 mm)
**RCA (≤25.4 mm)

Result :

Latex is one of the options chosen to mix with the CDW binder in order to test the material's versatility. The outcome reveals a smooth surface with less crumbling and dries more quickly than the other binders.

2.4

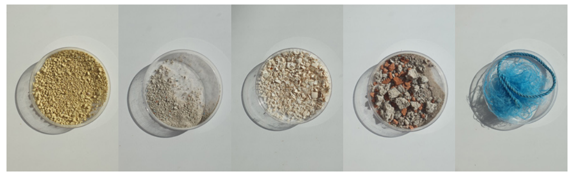
waste-based concrete + WFNF

Ingredients:

- CDW precursor* (2)
- Alkali activator (1.8)
- Eggshell powder (ESP) (0.1)
- OPC (0.2)
- Recycled fine aggregates* (3)
- Recycled coarse aggregates** (3)
- Waste fishing net fibers (2% of total volumn)

Cured at room temperature (25 °C)

*CDW precursor & RFA (≤4.76 mm)
**RCA (≤25.4 mm)



Result:

This investigation not only explores the use of waste fishing net fibers as reinforcing materials, but also shows how intentionally pigments can be selected from the brick color. Waste is readily evident, aesthetics are desirable, and research indicates that mechanical properties are optimal with this choice.

3.1

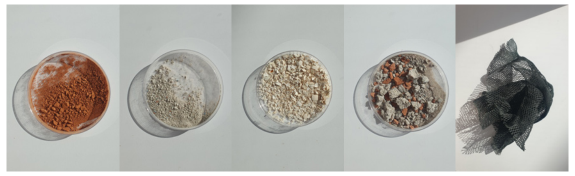
waste-based concrete + WFNM

Ingredients:

- CDW precursor* (2)
- Alkali activator (1.8)
- Latex (0.2)
- OPC (0.1)
- Recycled fine aggregates* (3)
- Recycled coarse aggregates** (3)
- Waste fishing net mesh (1 piece)

Cured at room temperature (25 °C)

*CDW precursor & RFA (≤4.76 mm)
**RCA (≤25.4 mm)



Result:

Construct CDW2.2 walls using waste fishing net mesh as the reinforcing material between layers of differing concrete coarseness and observe the results. It is intended that the inner layer serve as the load bearing structure, while the outer layer serve as the grainy exterior. The wall's architecture's materiality becomes visible with the passage of time.

3.2

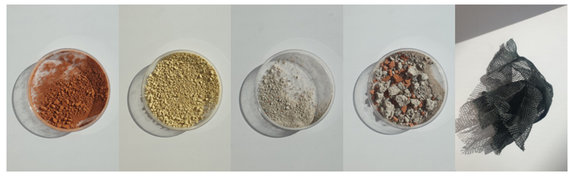
waste-based concrete + WFNM

Ingredients:

- CDW precursor* (2x3)
- Alkali activator (1.8x3)
- Latex (0.2x3)
- OPC (0.1x3)
- Recycled fine aggregates* (3x3)
- Recycled coarse aggregates** (3x3)
- Waste fishing net mesh (2 pieces)

Cured at room temperature (25 °C)

*CDW precursor & RFA (≤4.76 mm)
**RCA (≤25.4 mm)



Result:

The creation and crushing of CDW from fine aggregates to coarse aggregates and sectioning by 2 meshes are investigated in this experiment. As might be expected from a core structure, the first and second layers are the densest, while the top layer is relatively coarse and more grainy.

6 | Findings

Identity

The majority of Gothenburg's historical buildings are made of brick; however, during the city's development time, some brick buildings were demolished because their function was unrelated to the development. As a result, not only brick but also other demolition waste ends up in a landfill or, ideally, at a recycling station such as Aterbruket, Gothenburg, which is specifically for construction industry waste.

Since 90% of the mixtures are waste, the identity of the experiment naturally reflects construction and demolition waste and ocean waste; therefore, a closer look at the blocks reveals a rich history of concrete, masonry, ceramics, and fishing nets. Aside from the identities that can be archived, the surfaces take on a fragmented, pixelated appearance, resulting in a complex, peculiar, and intriguing surface.

Texture

The mixture and sizes of recycled aggregates determine the texture of CDW concrete.

The CDW2.1 is brittle and has a predominantly flat surface because the curing temperature was insufficient (8-10 °C), causing it to cure more slowly.

CDW2.2 is the result of mixing CDW2.1 with eggshell and the appropriate temperature, resulting in the desired appearance of fragments of the CDW sources and a crumbling, porous surface.

However, the CDW2.3 with latex produces a smoother mixture, resulting in a flat and smooth surface after curing at room temperature (25 °C). The expression the smooth surface of this option imparts greater strength and durability.

CDW2.4 manifests itself as a combination of a hard surface and waste fishing net fibers that soften the mixture.

CDW2.1

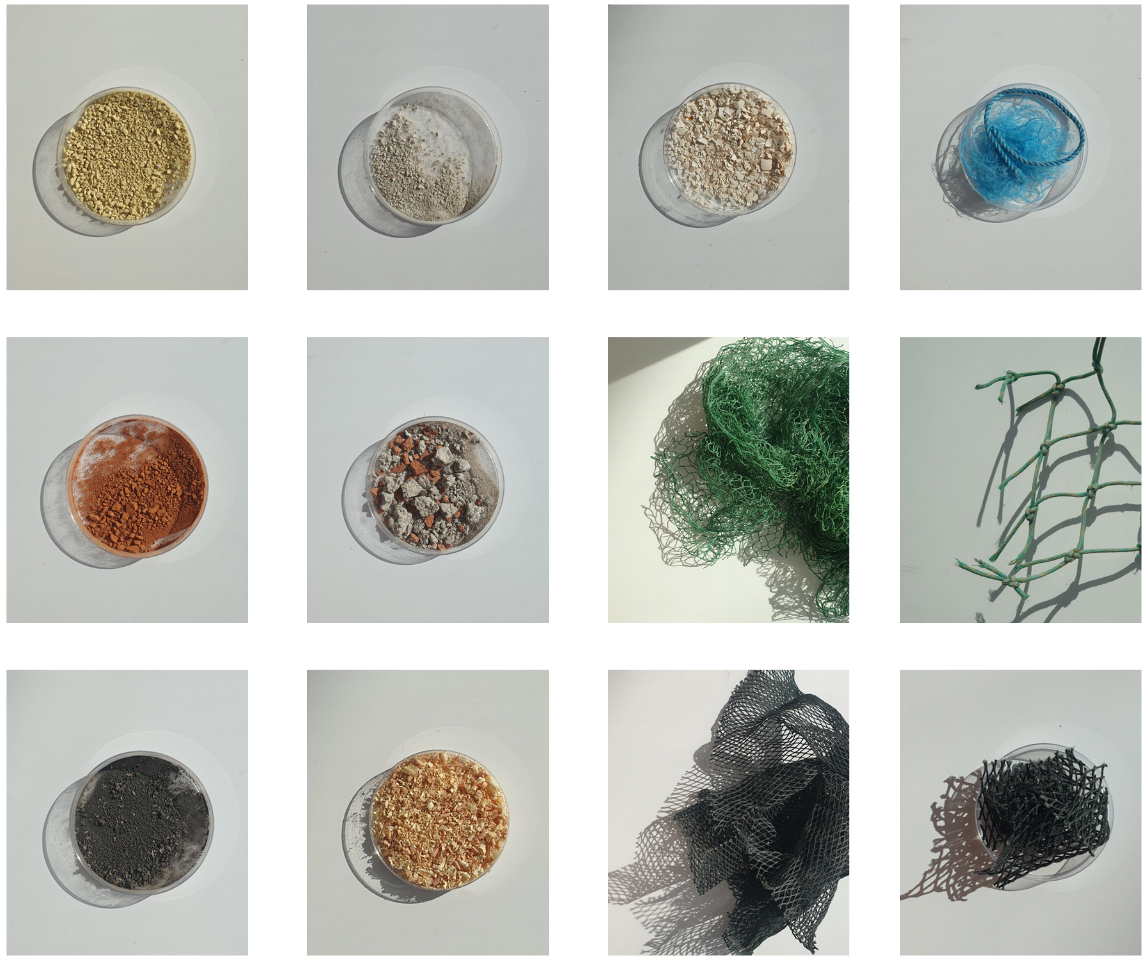
CDW2.2

CDW2.3

CDW2.4

Colour

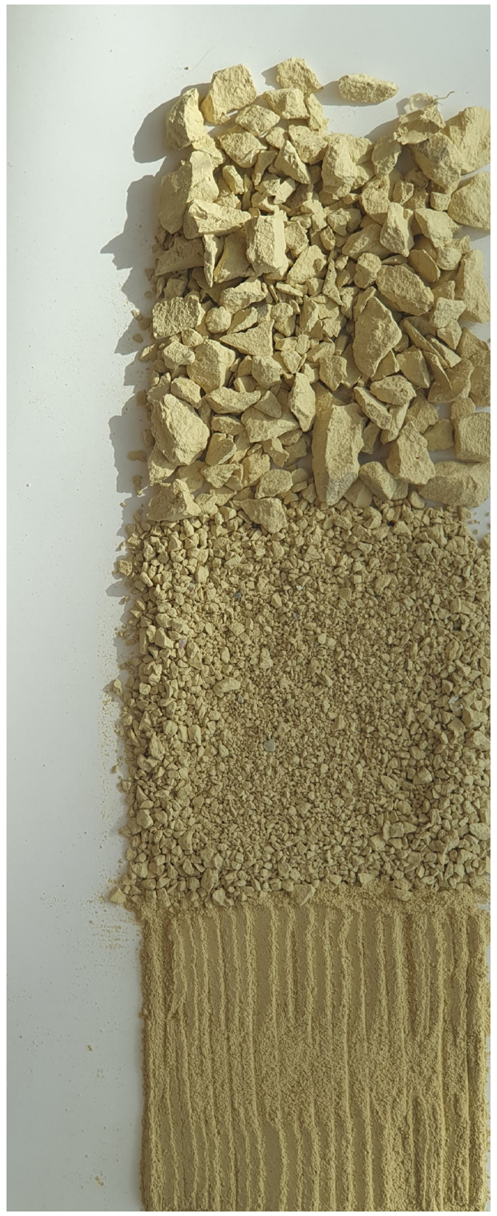
In this study, the color is evident, and the materiality of the waste is also evident without being stated. The color is able to speak for itself regarding its origin and previous state. The study also investigates the possibility of creating additional pigments in relation to recycled fine aggregates (RFA), which control the overall pigmentation of CDW concrete. For example, the CDW is sorted for only white color and crushed into RFA, the overall color on the mixture becomes white. This is yet another method of preserving the material's purity. Due to the fact that the mixture is dependent on the AAM (alkali-activator material), it is essential to keep track of any bleaching or decolorization that may have occurred, in order to determine the time period when the color faded or another scenario in which the colors completely changed from the precursor color.

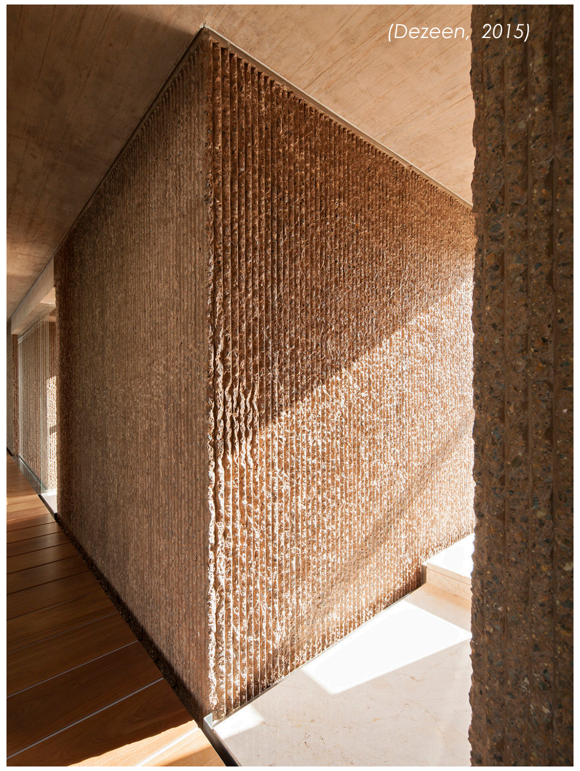


Formation

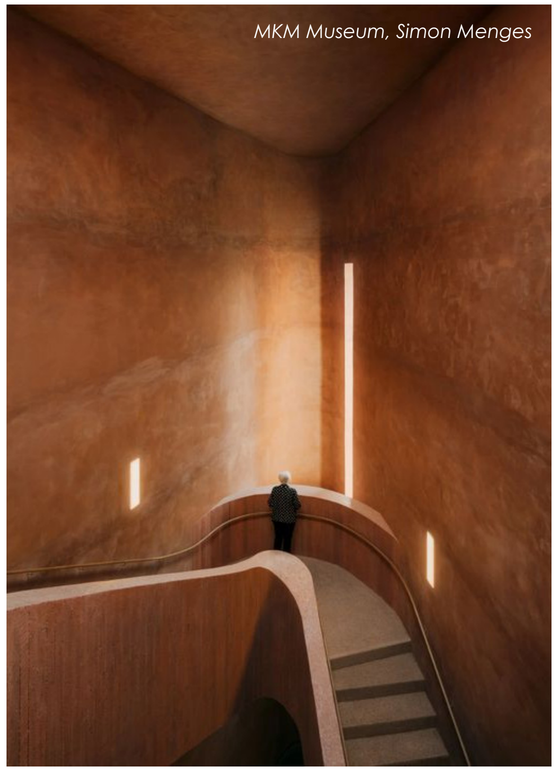
The formation of aggregates is investigated extensively in the thesis. Time is spent thoroughly sourcing the CDW, crushing and sieving the grains, and categorizing them for different uses of the CDW concrete.

Beginning with a large chunk of brick, concrete, or ceramic tiles, they are crushed into ever-smaller particles. The denser and smaller the particles, the less pourous in the mixture, and thus the greater the duability. They convey not only the process but also the deterioration of the overall architecture over time. This demonstrates the possibility of recycling CDW concrete indefinitely.





(Dezeen, 2015)



MKM Museum, Simon Menges

© Javier Anton

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Materiality

The notion of materiality pertains to the practical application of materials in constructing a physical structure, thereby transforming the abstract sketches on paper into tangible reality. The final design incorporates a means of expressing thought. Architecture functions as an intermediary that translates abstract concepts into tangible structures, molding diverse shapes and spatial configurations.

During ancient times, the notion of materiality was commonly observed with regards to proximity, where the materials that were conveniently accessible were utilized for the construction of a given space. The historical periods were designated as the stone age, copper age, bronze age, iron age, steel age, and silicon and polymer age, representing the dominant material utilized during each epoch. This categorization underscores the significance of materiality and its comprehension among designers.

The interdependence of Immateriality and Materiality is a crucial aspect in the design of any given space, as the absence of either element would result in a lack of substantial presence. According to Palassma's publication, "The Eyes of the Skin," architecture encompasses sensory experiences that interact and merge with one another, rather than being solely reliant on visual perception. As such, a user's experience of a space is also a means of expressing its intangible qualities through sensory engagement (Re-thinking future, 2020).

Phenomenology Theory

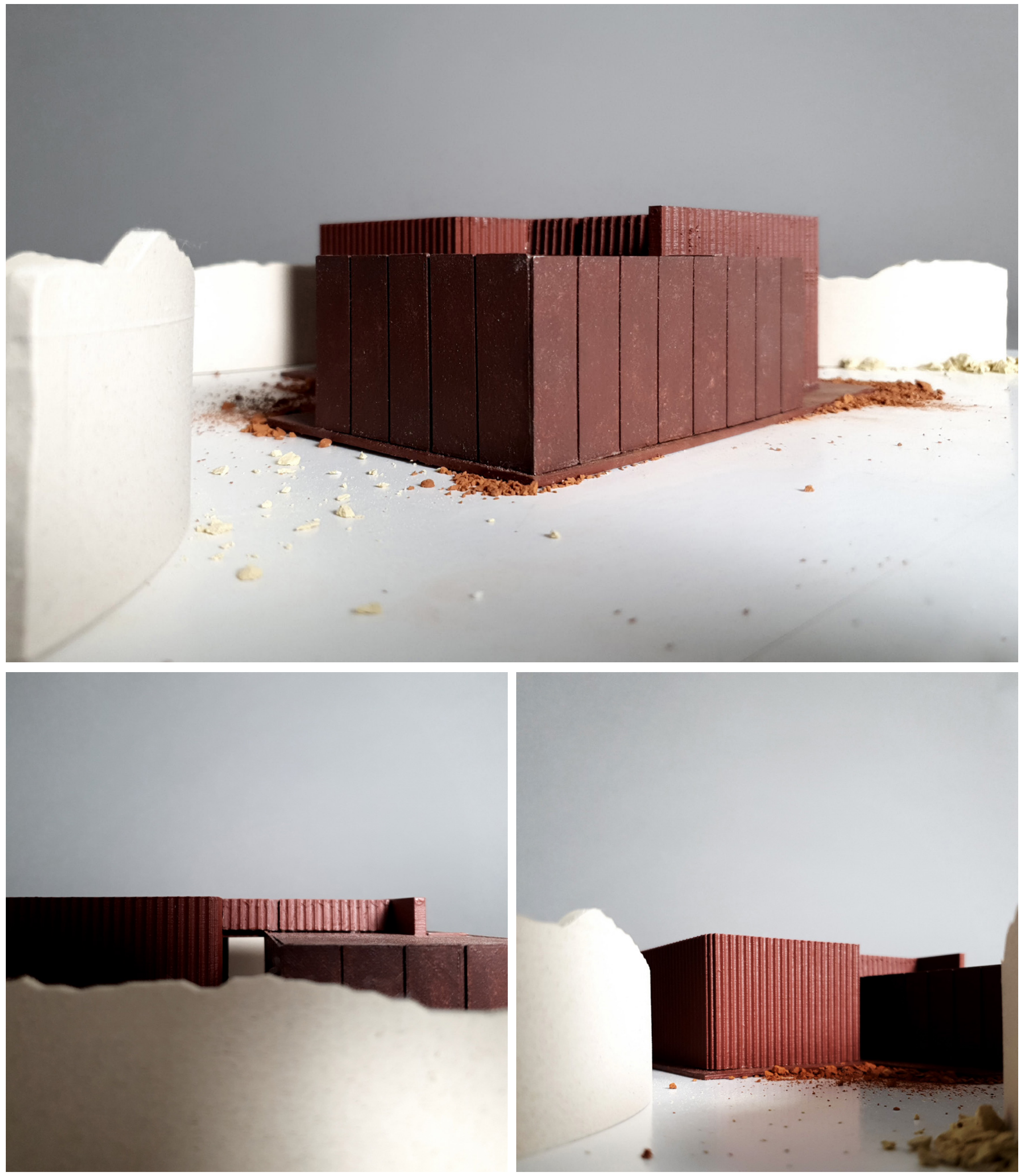
Phenomenology is a philosophical inquiry that examines the fundamental structures of consciousness from a subjective viewpoint. Phenomenology, within the realm of architecture and design, pertains to the examination and investigation of the corporeal encounter with edifices, construction materials, and their perceptible attributes.

The primary mode of experiencing architecture for an individual with intact sensory faculties is through visual and aesthetic perception. Similar to visual perception, the senses of hearing, smell, and touch are not solely physiological processes, but also cognitive abilities that can be acquired through learning.

Some spaces are specifically crafted to immediately stimulate our senses upon entering. The acoustic, lighting, and thermal characteristics of a space are interdependent on the construction type and materials employed. The sensation of interconnectivity among individuals, surroundings, and items is attained by means of the more effective craftsmanship exhibited in the piece.

7 | Final model

Final model



8 | Reflection

Final Reflections

This thesis explored the feasibility of recycling construction and demolition waste (CDW) and ocean waste. It aimed to give the public a glimpse of the result of a indifferent method of sourcing materials.

Crushing is one of the greatest challenges when it comes to CDW, as it would be more efficient to use tools rather than a hammer. This is ongoing research, and numerous studies are being conducted to make this procedure more practical and, eventually, accessible to the general public.

The experiment generated endless new possibilities. Such as the ability to render CDW concrete floatable and translucent, etc. However, they are limited due to CDW and AAM technologies. For example, the waste fishing nets collected are made of nylon (PA) mesh; however, according to the research, nylon has a lower temperature resistance to chemical reactions, specifically alkali or acid. To advance this study, it is necessary to conduct an experiment and observe its results beyond the scope of this research.
Given a shortage of time and manpower to crush the CDW into proper sizes and grains, the experimental designs are based on research. To create a cube size for multiple compressive strength tests requires extensive time, which is not the purpose of this thesis. If the building were to be constructed, a comprehensive examination of the compressive strength and splitting tensile tests should be conducted.

The acceleration of the global waste rate, attributable to an endless demand, underscores the importance of recycling construction and demolition waste (CDW) and ocean waste. This approach not only facilitates the cleanup of the current mess but also reduces the demand for new extraction of raw materials. The project exhibits a closed-loop system that potentially enables self-sustenance by generating its own requisite resources for future use.

Through its materialization and architectural design, this thesis has presented an unusual method for revaluing and recycling waste in architecture. It has illustrated the waste's life cycle and highlighted the endless recycling potential of CDW concrete in architecture.

In conclusion, the thesis has marked a turning-point in the recycling of CDW in architectural design; its vasatility and adaptability to other chemical compositions are highly intriguing and give us hope for a better and healthier (built) environment in the future.

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Contact

Bongkodpast Tantipisanu
+46 73 486 2504
bongkodpast@gmail.com

Education:
MSc Architecture & Planning Beyond Sustainability
Chalmers University of Technology, Sweden | 2021 - 2023
Material Turn (Thesis) 2023
Sustainable architectural design 2022
Design and planning for social inclusion 2021

Erasmus+ Exchange Year
TU Eindhoven, Netherlands | Autumn 2022
Materials Panorama 2022
Architectural expression 2022
Circularity in the Built Environment, 2022
Inner city modular high rise, 2022

BSc in Architecture and Urban Planning
Thammasat University, Thailand | 2014 - 2017

Work experience:
Self-employed
Architectural designer, Thailand | 2020 - 2021

Blink design group
Junior architect, Singapore & Thailand | 2018 - 2020