Viberscrete's Utilization Report Proposal

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1. Introduction

1.1 Background

Ever since the industrial revolution, the popularity and utilization of concrete around the globe has vastly increased due to its strength and versatility within the construction sector for the advancement of urbanization and civilization. Unfortunately, the constant production of cement and concrete throughout the world has proven its utilization to be far from sustainable. This has been demonstrated by studies determining a rise from 4% (Ghasemi, 2019) to 8% (EcoRI, 2019) in the last 20 years with regards to the industry's contribution towards the total CO2 emissions. Furthermore, these discharges are released through the constant manufacturing of cement/concrete globally, so much so that if concrete/cement production was labelled as a country, then it would be in 3rd place in carbon emission as seen on Figure 1.

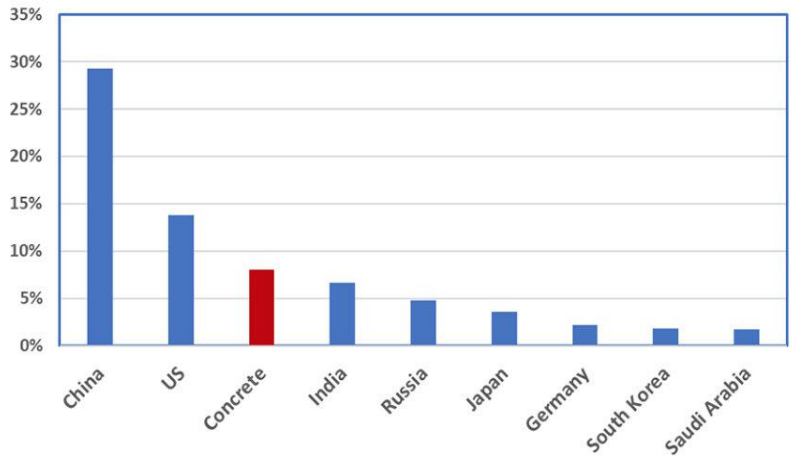

Figure 1: Concrete Emissions as a Country (ecoRI, 2019)

More and more, concrete and cement are being utilized every year for the advancement of urbanization throughout the world, both in developed and developing nations as concrete is widely popular and relatively cheap to manufacture in both low and high quantities. Unfortunately, as effective and efficient as concrete utilization may be, it brings along a strong environmental impact of high carbon emissions since CO2 is released through the heating of limestone as well as from the fossil fuel heated system required to heat the kilns and transport the materials (EcoRI, 2019), all alongside its 4 billion metric tons in production as of 2018 (BBC, 2018). Additionally, alongside concrete's grand carbon emissions through manufacturing, it also faces another backlash due to the depletion of finite resources which are required for its composition. Globally speaking, this issue is of little concern since it would be fair to state how the resources can be transported, albeit causing more carbon emissions. However, the issue arises in more local scale situations where the required components for concrete are not transported over long distances. The global increment of concrete production has resulted in a withdrawal of 9% of the global industry water extractions which is

1.7% of the overall global water withdrawal. This statistic will only rise with the increasing production of concrete. Moreover, by 2050 it is expected that 75% of the water demand from concrete manufacturing will possibly transpire in areas experiencing water stress (Miller, 2018).

Furthermore, with regards to the large market of concrete, only a small portion of it is held by bio-based or green concrete alternatives since their popularities are somewhat low, although an increased in recognition and utilization has occurred throughout the world due to more sustainable and green concrete designs, as well as because of the current importance of sustainability against global warming (Baikerikar, 2014). Additionally, it is vital to describe the terms of bio-based and green concrete as:

- Green concrete is defined as a form of concrete which utilizes waste materials as one of its components or utilizes an environmentally safe production process (Suhendro, 2014)
- Bio-based product are products that is composed, partially or fully, of a biological ingredient and is based on the idea of sustainability and renewability through agriculture (van der Hoeven, 2018)

In order to stimulate the transition of the construction sector towards more sustainable concrete alternatives, this research project aims at envisioning and designing possible applications for a concrete mixture named Viberscrete, a biobased concrete mixture with the potential to rival traditional concrete within different fields of construction and building.

1.2 Problem statement

1.2.1 Vibers Company

Vibers is a green company which focuses on the grand sustainability of products through attempting a bio-based approach. They have applied this logic on the sectors of plastic, paper, and now, concrete. It all started when the founder, Jan-Govert van Gilst, witnessed a global issue whilst travelling. Vast rainforests were destroyed for palm oil and beautiful beaches were inundated with plastic waste.

Furthermore, through investigations and development the Vibers team found out that elephant grass grows quickly, requires very little water and can grow almost anywhere. It absorbs four times more CO_2 than a European forest being a highly sustainable crop (Vibers, 2019). Elephant grass is high in cellulose (Kinhal, 2014); therefore, it is a good resource for producing paper, which was indeed the first product produced by Vibers. After paper, the company investigated bio-concrete and finally bioplastics and was soon nominated for the Top 100 most innovative SMEs in the Netherlands. The core idea of Vibers is not to fight against the plastics industry, large construction companies or paper manufacturers, but the exact opposite: to partner with these companies around the world and make a difference together.

With the same purpose and approach, Vibers has interest in developing their research in the field of construction through the creation of a highly concentrated miscanthus-concrete mixtures for sustainable concrete applications.

1.2.2 Viberscrete and its applications

The aforementioned miscanthus-concrete mixture, named Viberscrete, which is currently under development at the Research group Biobased Construction at HZ University of Applied Sciences, has been chosen based on the experience of a Master's Thesis from the Eindhoven University of Technology in collaborations with Vibers (Ezechiels, 2016). The mentioned study focused on the viability, strength, composition, and performance of a miscanthus-concrete mixture with a low miscanthus concentration. On the other hand, Viberscrete aims at obtaining a high miscanthus concentration. Due to the high concentration of fibres in the mixtures, Viberscrete is generally expected to have low compressive strength (Ezechiels, 2016), however, some reports have determined the opposite. To be more precise, the

addition of grinded miscanthus fibers into the concrete composition increases the compressive and tensile strengths in small percentages, volume wise (Acikel, 2011). However, this possibility has yet to be tested by the Vibers research group.

High fibers concentration also provides other advantages to the mixture, such as better thermal and acoustic insulation (Pude, 2012). Furthermore, Viberscrete is also a much lighter material per m^3, since a larger portion of the concrete mixture is miscanthus, which has lower density than standard concrete aggregates as it is plant-based rather than a complete volume of cement and aggregates (Pude, 2005). This can be seen as an advantage for specific construction applications, a point that will be expanded upon within the market analysis and product comparison subchapters. Further technical details about the laboratory testing and specific mechanical properties of the mixture are out of the scope of this research, and will be published in another technical report by the Research group Biobased Construction.

From an environmental and economic standpoint, based on existing and ongoing tests and secondary comparative research, it is expected that Viberscrete will be a grand new initiative in the green construction field as it utilizes the sustainable, renewable miscanthus plant for a big part of its composition. The plant takes 3-5 years to grow, but once grown it can be cultivated from April to September (Krah, 2019). It is a sustainable, hastily spurring, non-evasive plant without many environmental prerequisites, meaning that it can be grown in a variety of places throughout the world (DEFRA, 2001). It has been recorded to be one of the highest yielding biomass energy crops available today (Pude, 2012). Moreover, the miscanthus plant requires little to no chemical input to grow which results in a lower financial and time investment resulting in greater yield for its agricultural growth (Kinhal, 2014). “During its growth, elephant grass absorbs four times as much CO2 as an equivalent forest area.” – Strukton. For these reasons, the use of miscanthus in concrete mixtures is an interesting application for the concrete market.

On the other hand, it is likely that there will be some challenges ahead with regards to the integration within the concrete and construction market of new products/applications realized with Viberscrete (Suhendro, 2014). The civil engineering world is deeply rooted within a traditional system of methods and materials: due to historical tendencies the materials commonly utilized, such as standard concrete, masonry, and wood, tend to be preferred over more innovative materials (Zilliacus, 2016). In fact, a grand majority of projects are based on past experiences, and due to this it is tougher for new materials, such as Viberscrete, to get into the cycle of choice of project designers (Chiang, 2018). Moreover, with regards to regulations and codes, a new material, or a new variant of an already existing materials, requires the

creation of a new set of guidelines for its safe and reliable application. For example, the Eurocode supports the utilization of reinforced concrete and various other more popular materials but, even though there are existing guidelines for bio-based products, they are mostly general and not as detailed as the Eurocodes (Province of Zeeland, 2020).

All these factors bring a direct challenge towards the application of Viberscrete within the market and the construction sector.

1.3 Research objective

The company Vibers together with the Research Group Biobased construction want to offer a clean, environmental, and sustainable alternative to lightweight standard concrete mixtures.

Vibers hopes to reach the lightweight concrete market through demonstrating how versatile and sustainable Viberscrete can become towards the inner infrastructure of buildings (homes, offices, etc.…) and also towards the construction field as it can be used for sound barriers and thermal panels. This means playing to the strengths of the product rather than focusing on its weakness.

The central task of this thesis will be to determine the most optimal application of the Viberscrete material within the building and construction industry. This will be accomplished by examining several potential designs, such as silence walls, insulation panels, non-bearing inner walls, and comparing them by means of a multi-criteria analysis to finally choose the most promising one. A vital objective of the research will be to fundamentally understand and adequately examine the design on this Viberscrete product, and how it will fit within the market depending on its capacities and limitations. With regards to the product's market competition, the team wants to achieve a successful and equal product that is on the same tier as its potential competitors. This is settled by determining all the direct competitors and their products, as well as the applications and use of the products, and what type of market value their product holds. For this purpose, the Viber's product success will be determined by comparing it with standard concrete or other competitors alternatives, based on pre-selected criteria such as durability, strength, versatility, environmental capabilities, and structural capabilities.

1.4 Research Question

In order to fruitfully explore this thesis to its fullest extent with regards to the design possibilities of the miscanthus based product within the current alternative concrete solutions market, it is vital to state the following research question and sub-questions:

"What final product is the most optimal for the utilization of the Viberscrete high miscanthus concentration mixture within the construction & building field?"

This research question will aim to determine the most optimal final product for the Viberscrete concrete composition. "Most optimal" refers to a product that, through a fair Multi-Criteria Analysis (MCA), will be the most outstanding in terms of practicality, durability, versatility, environmental capabilities, structural capabilities and expected market popularity.

Furthermore, in order to create more diligent and precise results, it is imperative to create a set of research sub-questions which will attempt to catch any sort of data that the central research question might miss. These are:

1. *Which fields of construction & building will all the alternative solutions fit within?*
2. *By taking into account the current bio-concrete market, which sub-field seems to be in demand of different products (walls, pathing, insulation)?*
3. *With regards to the preliminary variants, which of them seem to have direct competition within the sustainable concrete market?*
4. *What external regulations and guidelines must the final product obey for a safe public release?*
5. *What possible changes within the mixture composition may allow the product to become more optimized for public use?*

2. Theoretical Framework

2.1 Market Research Results

It is fundamental to thoroughly discuss the market research results in order to effectively determine the most optimal preliminary and final solutions for the utilization of Viberscrete as a product by taking into account the boundaries and limitations that have been predetermined within the sustainable concrete market. The market research dives into all key angles of releasing a new product into the market, such as the markets and its trends, a competitor analysis, general alternative products comparison as well as more detailed views of product comparisons within different segments of the market, and lastly, a product value chain which ought to establish a fruitful perspective on the production and management of the end product.

2.1.1. The Market

In order to effectively understand all key aspects of the current concrete market, both the standard and sustainable concrete market situations were researched.

The standard concrete market has experienced a constant growth as it is one of the world's most fabricated and utilized construction material (MarketsandMarkets, 2018). This is backed by the grand increase of global urbanization lead by the endlessly accumulating world population all whom require quick and simple structures for their homes, schools, offices, hospitals and more (United Nations, 2018). Figure 2 displays the abovementioned concrete production rise from 1970 until 2018.

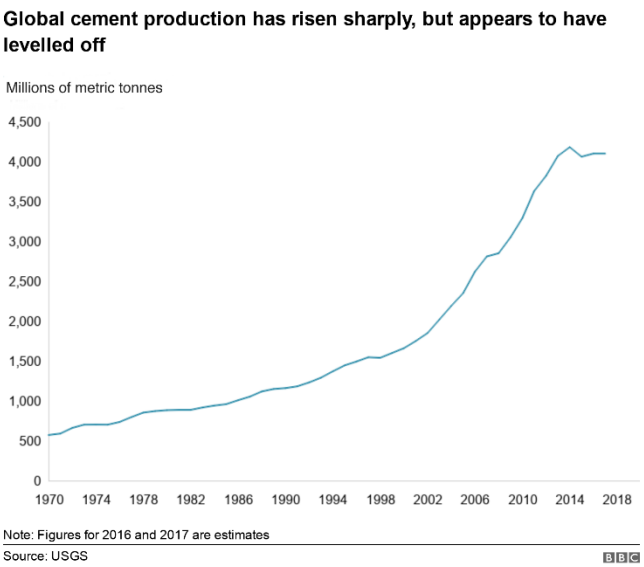

Figure 2: Cement Production (BBC, 2018)

The seemingly constant growth of the standard concrete and cement markets throughout the world can be seen under a positive and negative light. It is indeed ideal, in a world with a rising demand for a building material, to have one such as concrete due to its great availability, feasibility and practicality (Easymix-Concrete, 2015). This

"demand" also demonstrates how there is a rising need for alternative sustainable solutions (Bausset, 2014) and thus, there is a higher chance and interest for Viberscrete to be recognized. On the other hand, the growth in concrete utilization demonstrates a heavy reliance on standard concrete which does not seem to be going away or being threatened by bio-based alternatives. To be more precise, this is due to the fact that, as mentioned before, standard concrete is publicly seen as extremely reliable and durable, thus requiring no immediate substitute as of yet.

However, it is now widely known that standard concrete is fairly unstable towards an environmental perspective since it requires high energy consumption, alongside cement production being 8% of the world's carbon dioxide release (BBC, 2018). "The production of 1 m^3 of concrete requires 2,775 MJ of energy. This energy comes mostly from oil burning, which generates CO2. 2.775 MJ of energy is produced by 0.37 barrels of oil." (Guidetti, 28 August 2017).

Contemporarily, the sustainable concrete market can be seen to be nourishing within the construction materials sector as displayed by Figure 3. The global green concrete market is expected to be increased by rising inclination for environment sustainability, durability and protection (United Nations, 2018). Furthermore, this demand will increase the market shift of manufacturing companies headed for ecofriendly concrete from conventional concrete which in turn will allow the bio-based market to grow substantially (Maximize, 2019). The market is also expected to witness advancements in material technology (Delgado, 2016).

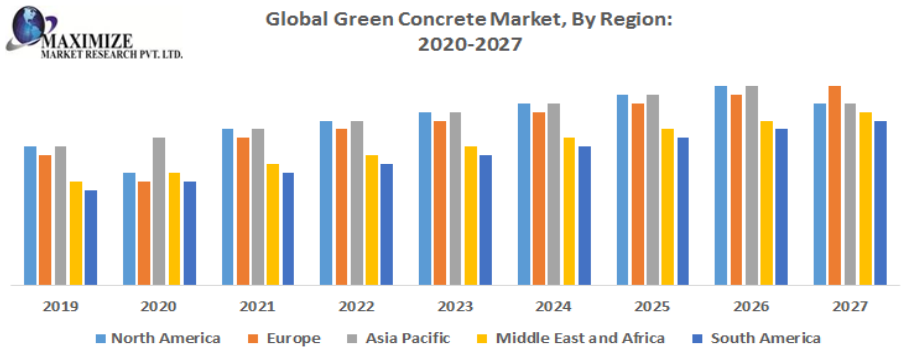

Figure 3: Green Concrete Market Chart

Additionally, as of 2020 the European Union has implemented construction regulations to promote the usage of ecofriendly construction methods and materials through its European Green Deal, specifically the "Just Transition Mechanism" which is a key tool/project which will allocate €150 billion from 2021 to 2027 to projects will apply sustainable methods and materials (European Commission, 2020).

It can be concluded that the bio-based/green concrete market seems to be expanding in the future (Maximize, 2019) and could potentially lead to a healthy product growth once Viberscrete is introduced in its specific sector, but also more and more competitors are entering the market. This includes, but is not limited to, companies such as Strukton and Bio Bound (discussed later on in this report) which also focus on the implementation of miscanthus based concrete through different applications, such as a sound wall and concrete tiles, respectively.

2.1.2 Bio-Based & Green Market Subdivisions

The bio-based/green concrete market has been further segmented, to better understand the specific positioning of Viberscrete in the market and the potential competitors. The following segmentations are suggested: Low VS High Fibers Concentration, and Circular VS Bio-Based VS Green Concrete. These segmentations are deemed fundamental to specify the technical and environmental characteristics of the final Viberscrete product.

- Low VS High Fibers Concentration
    - Low concentration structures are defined as concrete mixtures which are composed with a small ratio of fibers (biobased) – 0.5% to 4% is the general consensus for a small portion of fibers within the mixture in regards to volume (Vo & Navard, 2017). Some advantages of utilizing lower concentrations of fibers within a concrete mixture are low density as well as the availability of creating more concrete per m^3 with less fibers (Ezechiëls, 2016). However, the most likely disadvantage is the limiting compressive strength given to the mixture when utilizing a lower ratio of fibers (Acikel, 2011). For example, already public miscanthus based concrete product such as the current Viberscrete.
    - High concentration structures are defined as concrete mixtures which are composed with a greater ratio of fibers in comparison to the lower comparison – usually they are above 20% and can even reach about 35% depending on the mixture and product design, with regards to the volume of the mixture. An advantage of utilizing more fibers within a mixture in the case of Miscanthus is that it steadily increases the compressive strength of the mixture Hicran Acikel's Report ("The use of miscanthus (Giganteus) as a plant fiber in concrete production"), as well as the additional benefits of higher thermal and acoustic

insulation (Vo & Navard, 2017). On the other hand, it has the disadvantage of a greater water/moisture consumption within its matrix due to a greater amount, in comparison to a lower concentration (Vo & Navard, 2017). A key example of a higher fiber concentration product is BioBound's miscanthus mixture which uses 0.5 m^3 of miscanthus for every m^3 of recycled cement within their matrix (BioBound). Hempcrete also utilizes a 35% fiber element within its composition (Strandberg-de Bruijn, 2008).

- Circular VS Green VS Bio-Based
    - Circular economy-based concrete is a type of concrete which focuses on the aspects of general reusability, decrease to less CO2 dependent procedures, and recycling within the construction and building field. A prime example of this is LafargeHolcim's "Susteno" based concrete mixture which is mixed granulates from demolished buildings in an attempt to recycle materials. Furthermore, one prime advantage is its waste reduction method as well as how it reduces CO2 emissions (LaFargeHolcim). On the other hand, it can be disadvantageous since it is somewhat of a rigorous process to determine which upcycled demolition materials can be used within the composition due to chemical and mineral requirements (LaFargeHolcim).
    - Green concrete is fairly similar to circular concrete since it also utilizes upcycled materials and aims to be sustainable, however, its primarily different since it also utilizes fly-ash and aluminum can fibers alongside upcycled concrete aggregates (Bambang Suhendro, 2014). Moreover, green concrete can also be defined by its lack of waste and energy consumption through its creation. A prime example of this is Basilisk's self-healing concrete which utilizes micro-organisms that produce limestone in order to fill cracks, an attempt at reducing the maintenance resources as well as increasing the life cycle of the concrete (Basilisk). One advantage of green concrete is its high life cycle sustainability, especially in Basilisk's self-healing concrete since it extends its life cycle and cost through self-maintenance. On the other hand, a disadvantage for these forms of concrete is the regulations for their specific compositions are not as built up as they are for standard concrete.

- Bio-based concrete is a mixture composed of standard cement and aggregates alongside biological elements (in fiber form), such as hemp, miscanthus and fungus (van der Hoeven, 2018). IsoHemp's hempcrete, Strukton's Silent Green Wall are prime examples of bio-based concrete products within the market which have focused on reducing CO2 emissions and their carbon footprint through agricultural applications, which is defined as how each product has been created through agricultural means (IsoHemp & BioBound). Its greater advantage is the fact that it can be sourced from a renewable and sustainable source. However, in general its main disadvantage is the biological degradation of natural fibers within its composition (Ezechiels, 2017).

2.1.3 Competitor Overview

The competitor's analysis is fundamental in understanding Vibers' direct and indirect competitors within the miscanthus & biobased/green concrete markets which will assist in formulating an ideal final product which fairly competes with the listed competitors. Two different types of competitors will be analyzed; miscanthus related companies, and sustainable concrete manufacturing companies which offer an alternative to both standard concrete and miscanthus based concrete.

Miscanthus related competitors

These first section is composed of specific companies which manufacture, design, and/or sell a miscanthus-based concrete product alternative within the same market as Vibers. They are also all active in the Netherlands. Both of the companies in this sector are active in the civil engineering world where they have created specifically defined products. These companies are:

- Strukton, a Dutch civil works company which focuses on the sustainable development of projects in various fields such as rail, bridges, office spaces, roads, and more.
- Bio Bound, another Dutch company whose central focus is implementing their bio-based and sustainable Miscanthus concrete product into new projects and ongoing situations.

Alternative sustainable companies

This section encompasses companies within the sustainable construction materials market which have designed/manufactured an alternative to Viberscrete without the utilization of Miscanthus. Each of the different companies utilize different modes of sustainability through their products such as green, circular, and bio-based concrete types. These companies have a greater international scope in comparison to the first category. These companies can be described as:

- LafargeHolcim is a Swiss global corporation and one of the leading companies in the fields of building materials and solutions throughout the world. They are active in the fields of cement, aggregates, ready-mix concrete, and solutions & products. Due to their extended role in the construction field, they have created a focus on green construction through sustainable products.
- Basilisk is a Dutch company whose primary project and selling point is their limestone & micro-organism based self-healing concrete. They have been included within the competitor's analysis due to their scientific development achieving a successful green concrete initiative.
- Heidelberg Cement is a global corporation from Germany which focuses on the manufacturing of cement, concrete, aggregates, and research and development. Furthermore, they are currently attempting to incite awareness of sustainable construction methods and materials through a circular economy within their projects.
- IsoHemp is a Belgian company that focuses on the design and manufacturing of its own Hempcrete mixture meant to be applied for renovations, inner walls, floors and roofs, as well as insulation proofing. This is the most similar product to miscanthus-based concrete.
- Timbercrete is an Oceanic (Australia and New Zealand) based company which focuses on the creating and growth of their main product, Timbercrete which has been tested to be effective structurally, with heat and sound insulation, and to be extremely versatile as well.
- Iron Shell Material Technologies is a US created company founded by Dr. David Stone focused on the development of alternative construction materials, specifically Ferrock and Polymiron.

vibers

Strukton

BIO BOUND

MISCANTHUS BASED PRODUCT COMPANIES

A member of LafargeHolcim

Basilisk self healing concrete

HEIDELBERGCEMENT

ISOHEMP NATURAL BUILDING

Timbercrete®

IRON SHELL MATERIAL TECHNOLOGIES

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In conclusion, it is vital to analyze and understand each of the competing companies and their methods of applying their goals and aims within the sustainable sector of construction. Furthermore, each of them demonstrates a somewhat successful application of a sustainable and environmental product or methodology which is currently being employed by them within their specific fields and regions. Additionally, it is vital to see the competitors as much more than that and allow for possible collaboration and intercompany communication for the sake of developing the sustainable market in the field of construction materials.

The data and information of each of the aforementioned companies will allow Vibers to move forward effectively with a thorough understanding of its competitors as well as their products. This sort of data will function as a key towards understanding their surrounding in the sustainable products and circular economy field.

2.1.4 Alternative Products Analysis & Comparison

- Products:
    - Viberscrete: Bio-based concrete utilizing a high percentage of miscanthus fibers within its matrix (over 50%)
    - Strukton: Green Silence Wall is Strukton's central miscanthus-based product which focuses on dampening sound wherever placed as a sound barrier
    - Bio Bound's miscanthus-based concrete structures and mixture is put into several forms such as tiles, slabs, and retaining walls
    - IsoHemp: A hemp and limestone mixture which has been the most popular sustainable choice for years.
    - Timbercrete: A sawdust, sand, and cement mixture which promotes strength and flexibility. It is a green alternative as it also captures CO2 during its production.

- Ashcrete: A highly upcycled composition since it uses fly ash from burning coal with recycled materials. Resourceful and sustainable product. (20% ash content per m^3)
- Susteno: LafargeHolcim's product which focuses on reutilizing demolished concrete as aggregates
- Ferrock: Sustainable through the recycling of wasted steel, as well as the fact that it absorbs CO2 during its production (CTP, 2019)
- Self-healing concrete: Basilisk's innovative self-healing concrete utilizes micro-organisms within their limestone-based mixture which are activated with water within the cracks, thus activating the bacteria and producing limestone.
- Concrete: Standard cement which is composed of 1 part cement, 2 parts sand, and 4 parts coarse aggregates. Its production is highly harmful towards then environment due to it being made globally and constantly.

It is vital to clarify that not all aforementioned products originate from the competitors list since the competitor analysis is focused mostly on the direct challenge between Miscanthus-based organizations and various bio-based/green companies within the Netherlands or Europe. However, the alternative product comparison details products such as Ferrock, Ashcrete, and Timbercrete which are not fabricated by any specifically named company due to the fact that they are direct alternatives and challengers towards the Vibers product. They are fabricated internationally and their purpose on this list of alternative products was to bring awareness and understanding of all potential competing products in a broader perspective.

Material/ Product Name	Source/Components	Strength (MPa)	Lifetime (Years)	Environmental	Advantages	Disadvantages
Viberscrete	Miscanthus as a lightweight aggregate mixed with cement	2.5	~100	Agricultural, CO2 consumption	Renewable, and lightweight	Not ideal for heavy weight structures
Strukton		6	~100			
Bio Bound		0.5-5	~100			
Hempcrete (IsoHemp)	IsoHemp hemp & ProKalk limestone	0.5-3.2	120	Agricultural, sustainable	Adaption to building and, locally sourced	Weak structurally, and lack of knowledge
Timbercrete	A mix of sawmill waste, cement, sand, binders, and nontoxic additives.	5-15	100+	Utilizes spare sawmill waste	2.5 times lighter than concrete or clay	Costly in production
Ashcrete	Utilized fly ash (from burning coal) + 97% recycled materials	57.5-75	~100	Extremely upcycle composition	Reduced water waste and, strong chem. resistance	Seasonal limitations, requires burning of coal
Susteno (Lafarge Holcim)	Resource saving cement that uses fine mixed granulate from demolished sites.	~18	~100	Upcycled materials from demolition	Recycles demolished buildings parts	Closest composition to concrete
Ferrock	Iron within waste steel dust reacts with CO2 & rusts to make iron carbonate.	35-51 average, peak of 70	125+	Absorbs CO2 during production	5 times stronger than Portland cement	High cost, not feasible for smaller budgets
Self-healing Concrete (Basilisk)	Micro-organism based self-healing mechanism through limestone	17-30 (same as standard concrete)	120+	Reduces CO2 footprint	Reduces costs and time for maintenance	Still utilized standard concrete mixtures

Standard Concrete	Fine & coarse aggregates bonded together with cement.	17-30	50-100	Harmful	Biggest utilization and. Low cost	High energy required and, High CO2 emissions

Table 1: Alternative Products Analysis

In conclusion, the collection of data displayed above facilitates the creation of a new Viberscrete product since all key elements and characteristics of the current alternative competing products may be utilized to determine the most optimal utilizations and capabilities of a Viberscrete product by creating aspects which the competitors may lack or falter in.

2.1.5 Miscanthus Based Products Comparison –Vibers VS Strukton and Biobound

The direct competitors in terms of miscanthus based products are the companies Strukton and Bio Bound. This exact comparison is of upmost importance towards the marketing report as it analyses and compared the closest competitors and their products since all 3 products are made of a mixture with Miscanthus fibers and are operated within the Netherlands. Furthermore, as demonstrated by Table 1 above, the 3 products created by Vibers, Bio Bound, and Strukton are extremely similar in their composition and application. This allows for the detailed comparative analysis between each of them in order to determine the faults and benefits of each and to move forward with Viberscrete's true available purpose in the market besides Bio Bound and Strukton.

Each company utilizes a similar Miscanthus-based concrete mixture, however, each of their products differentiate from one another due to the companies having different approaches, goals, and methods of utilization for their products. They have dedicated different purposes to each of their products due to market demand, as well as a step in their company's objectives.

Strukton has focused on creating their "Green Silent Wall" which employs miscanthus' favorable noise absorbing abilities in situations where there is expected to be a lot of sound, such as by train tracks and residential areas. Furthermore, they are developing their project further by attempting to create the wall with solar panels, or a fire and sound resistant alternative to be applied within tunnels. They have also conducted a collaborative project where they created benches for Schiphol Airport utilized the miscanthus

mixture as an attempt to integrate it into a more populated and constant-use environment in order to tests its reliability. Strukton's main advantage is that it has popularized its Green Silence Wall with projects with Rijkswaterstaat and ProRail. On the other hand, one could say that their main disadvantage is that they have not done enough with their Miscanthus based composition to support their sustainable views. Deeper exploration into the material would be beneficial for the company and its sustainability.

Bio Bound, on the other hand, focused their Miscanthus-based concrete mixture on various conceptions such as tiles, benches, slabs, retaining walls, and mortar. This approach allows them to create to broader and more available sustainable tactic through its products within their projects. Unlike Strukton whom only has their Green Silence Wall, Bio Bound chose to focus on a variety of construction structures which allow for their own expansion as a company in the sustainable field of civil engineering. Moreover, these miscanthus products and structures also utilized granulates from recycled concrete products in order to stabilize the environmental footprint even further. Furthermore, they utilize a bio-based and circular approach through their product which grants their product a long lifespan. Additionally, the collect their miscanthus plant from fields near Schiphol airport which can be determined to be a competition for popular resources. The fact that Bio Bound has chosen to focus their central company vision and motif through their Miscanthus mixture can be seen as a great advantage over any competitors. On the other hand, doing so limits their scope of work since Miscanthus based concrete is limited with its compressive strength, durability, and form of utilization.

A summary of the 3 products is presented in table 2 together with the desired properties of Viberscrete.

Criteria	Strukton	Biobound	Viberscrete (desired)
Utilization	Sound barriers	Multiple (tiles, slabs, retaining walls, benches)	Sound/Heat insulation, Wall/Roofs (non-bearing), multiple usage
% Concentration	Low	Low, mixed with reused concrete	High
Durability	Medium (no contact, just sound barrier)	High	Medium-High
Strength (required)	Low	High	Medium-High
Versatility	Low	High	High
Circular VS Green VS Bio-Based	Bio-Based	Circular and Bio-based	Circular and Bio-based
Self-Flowing VS Vibrating Settling Methods	Unknown	Vibrating	Vibrating

Table 2: Miscanthus-based Company Comparisons

In conclusion, Viberscrete ought to be able to compete fairly with Bio Bound's varied structures since a higher concentration of Miscanthus within its matrix, if done correctly, will allow it to reach a substantial compressive strength in comparison to Strukton's mixture (Acikel, 2011). Furthermore, the Viberscrete product may also fill the role of being utilized as walls/roofing as non-bearing structures, as well as insulating panels for interiors due to its central characteristics.

2.1.6 Miscanthus VS IsoHemp Product Comparison VS Timbercrete

IsoHemp is, outside the other miscanthus alternatives, one of the closes comparative products to Viberscrete since it encompasses extremely similar elements and capabilities as well as the form of utilization it typically achieves.

First of all, IsoHemp Hempcrete is a popular bio-based lightweight concrete which is generally used for exterior and interior heat insulation of buildings whether it is poured into the wooden framework or applied directly onto the wall. It follows a very similar composition and characteristic as miscanthus based concrete since it is obtained from an abundant renewable agricultural source, it is a light alternative to standard concrete, and it would be a direct competitor within the insulation field

Secondly, Timbercrete which is composed with 3 parts sawdust, 2 parts sand, and 1 part cement, is another bio-based green concrete which focus on a sustainable approach within the construction materials sector. Timbercrete has a larger insulation value than standard concrete and it is stronger for load bearing as well. It has been estimated to be 250% lighter than concrete (Justwoodfurniture, 2020). Furthermore, from the sustainable point of view, it traps CO2 into itself rather than releasing it, and we as the fact that it reuses waste materials such as sawdust and recycled timber fibers (Timbercrete, 2015).

However, as mentioned earlier, highly concentrated miscanthus mixture appear to have a higher compressive and tensile strength than low concentrated mixtures in accordance to the referenced Hicran Acikel's work. Furthermore, low concentrated mixtures already surpassed hempcrete in terms of strength as seen within Table 1, thus now it is a greater difference and an even greater display of which product can be superior within the construction sector. To be precise, Hempcrete has an average compressive strength of 0.5-3.2 MPa whilst highly concentrated Miscanthus mixture may reach up to 40 MPa. Secondly, Viberscrete would be able to insulate both heat and sound whilst hempcrete is limited to mostly heat, this shows another advantage towards Viberscrete's potential.

Criteria	Miscanthus	Timbercrete	Hempcrete
Utilization	Varied (Insulation, walls, flooring, and sound barriers)	Load bearing walls, flooring, fences, and retaining walls.	Walls (external and internal), bricks, roofing,
% Concentration	50%	50% sawdust	90% (Fibers and Shives)
Durability	Medium-High	Extremely High	High
Strength (required)	High	Extremely High	High
Versatility	High	High	Medium
Circular VS Green VS Bio-Based	Bio-Based	Green / Circular	Bio-Based
Self-Flowing VS Vibrating	Vibrating	Unknown	Vibrating

Table 3: Miscanthus, Timbercrete, and Hempcrete Comparisons

Through this table it can be seen how compositions such as Miscanthus and Hempcrete are somewhat at a disadvantage when compared to Timbercrete due to its generous and advantageous qualities. Hempcrete and Miscanthus-based concrete are extremely similar from their source, composition, utilization, limitations and capabilities, so for this reason they compare equally unlike with Timbercrete.

2.1.7 Existing Applications of Miscanthus-based Concretes

In order to get a better understanding of the possibilities and options that the Viberscrete product has in becoming, it is vital to demonstrate all currently existing applications of Miscanthus-based concrete products which Vibers will may have to directly compete against or attempt to replace within the sustainable construction materials market.

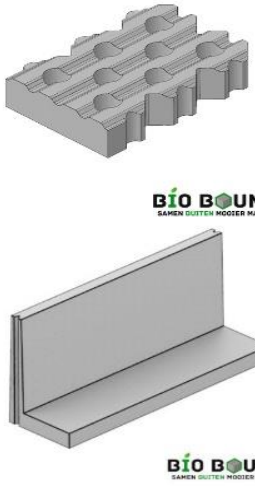


Figure 4: BioBound Miscanthus-Based Items

As mentioned within the Competitors Analysis and Product Alternatives within the market research, some of the currently existing applications of Miscanthus Concretes are held by possible competitors, Strukton and Biobound. Furthermore, Biobound has additionally demonstrated the extent that Miscanthus concrete can reach through the creation and application of various products which utilize it, such as tiles, slabs, Bicycle pathing, grass-concrete tiles, sidewalks, retaining walls, street furniture, and steps. All of these existing applications by Biobound demonstrate the extended range that Miscanthus concrete can reach through testing and optimizing. Figure 4 displays some of these applications.

On the other hand, Strukton optimized their product and focused it on one of Miscanthus' primary points of attention, its acoustic insulation abilities. With their "Green Silence Wall" as shown in Figure 5, they chose to demonstrate how Miscanthus concrete may be utilized in different areas of industry as they have applied the wall alongside railroads and highways to minimize the emitted sound pollution from the appropriate vehicles.

Figure 5: Strukton's Silence Green Wall

Figure 6: Miscanthus House (ValBiom)

Another important demonstration of utilizing Miscanthus concrete in the real world is ValBiom's Miscanthus House which utilizes wooden beams/frames as a structural skeleton to which support and stabilize the structure, shown in Figure 6. This conception of making a house mostly out of Miscanthus concrete is vital in demonstrating the possibilities and extent that bio-based construction materials can bring to the world.

Additionally, even though it is not Miscanthus-based, it is critical to mention how great the similarities between Miscanthus and Hempcrete are, and thus allowing this thesis to demonstrate the current utilizations and applications of Hempcrete in order to be able to create preliminary variants which focus on competing/replacing these products in the market. Hempcrete, due to its fairly weak structural strength of 1 MPa is generally utilized as a lightweight construction material, tends to be utilized as minor load-bearing structures, floor slab and roof insulation (panels), retrofit infill panels, roads, sidewalks, bicycle paths, and outside furniture in public spaces.

Lastly, it is vital to mention that most of these existing applications utilize a fairly low percentage of Miscanthus fibers within their matrix. Since Viberscrete is aiming to uphold a greater than 50% fiber content, it will be a new challenge within the construction materials field in terms of structural abilities and utilizations.

2.1.8 Product Value Chain

The product's value chain is meant to demonstrate all of the stages required for the complete production of the product.

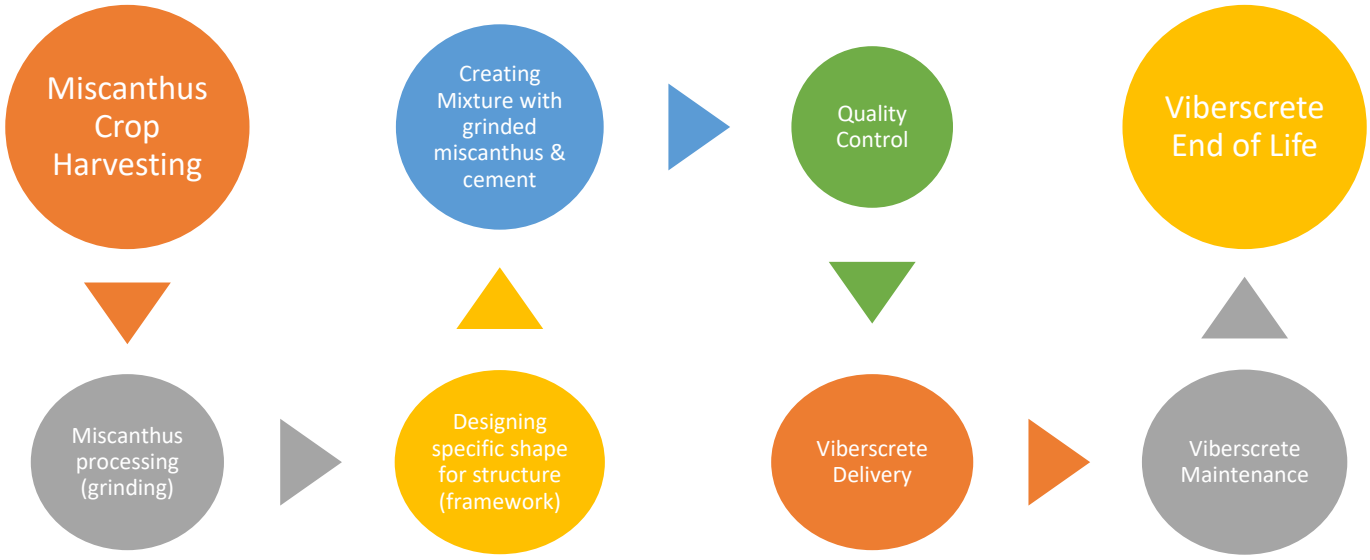


Figure 7: Product Value Chain

This product value chain attempts to determine the complete life cycle of the Viberscrete product from its creation until its end of life. All steps within the chain must be further explained:

- Miscanthus Crop Harvesting: The starting stage where the miscanthus cropped are grown and cultivated
    - Requirement: Large supply of Miscanthus plant through plantations and cultivation sites; such as Schiphol Airport's surrounding area which is popularly utilized for the growth and cultivation of Miscanthus
    - Cost:
        - Planting: €3100 per hectare
        - Ground: €1250 per hectare
        - Harvest: €500 per hectare

        - Miscanthus: 20 cents (€) per KG

    - Expertise: The required expertise of harvesting miscanthus will be deployed on the farmers and cultivating facilities.

    - Facilities: Different cultivation facilities and plantations are available for the growth of miscanthus throughout the Netherlands. Schiphol Airport area is an example of one of the most popular ones

    - Time: It takes about 4 years for the miscanthus plant to reach a maximum yield, they grow from April to September. From September to March the stalks dry and then again in April the miscanthus can be effectively harvested.

- Miscanthus processing: This step regards the process of collecting the harvested miscanthus plants and proceeding to break it down to a grinded dust which is the most optimal form of fibers for the concrete mixture.

    - Requirement & Facilities: To be able to grind the collected miscanthus plant, an industrial grinded would be required which a specific facility would likely be required for it. However, a smaller grinder can be purchased and utilized

    - Cost: 500 – 700 € for 1 plant grinder

        - Hanchen Plant Grinder Soil Crusher Pulverizer Grinding Machine Superfine Herb Disintegrator Continuous Operation 1400rpm for Lab Equipment

    - Time: Grinding the miscanthus should not take too much time once all the plants have been harvested, collected, and brought onto the same facility. Several days should be enough.

- Designing specific shape for structure: Depending on what the final product(s) ends up being, a design must be done to create the specific parameters of a structure for the client in the same way Bio Bound executes their product by creating different forms of miscanthus concrete such as panels and retaining walls for specific projects and requests. Moreover, this step goes hand in hand with creating the mixture with grinded miscanthus and cement.

    - Requirements: The main requirements would be a concrete mixing station to put together the miscanthus with cement and water. Once a mix has been created it ought to be cast

into a specific shape per requested or production with the help of wooden frames. This can be done at a mixing facility for prefab concrete. Furthermore, a vibration settling equipment will be required.

  - Time: Several weeks for the request fulfilment duties. However, casting ought to be done less than 90 minutes after mixing.
  - Cost: approximately €1000-2000 for prefabricated casting requests, and a concrete vibration machine for approximately €800

- Quality control: This step is vital in assuring that all fabricated Viberscrete is stable and usable for construction.
  - Requirement: Compression / load testing equipment within laboratories, as well as chemical testing kits to determine the structure is stable
  - Facility: Laboratories and construction sites
  - Time: It ought to be done before concreting, during concreting and after construction.
    - Before: Control test on ingredients, and check of specification requirements. Quality of cement, aggregates, miscanthus fibers, and overall mixture
    - During: The ongoing mixture must be workable, the ingredients fairly mixed and distributed, and it should be in regular room temperature.
    - After: Once the product has been completed, it must be checked thoroughly for cracks and deformations before delivery
- Viberscrete delivery: Once the structure has been designed, created, and checked, it must then be delivered to the destined location for its construction process.
  - Requirements: Possibly trucks for transportation of prefab structures
  - Time: Delivery time from manufacturing plant to construction site
- Viberscrete Maintenance: The maintenance of any construction material is vital towards extending its lifespan. Since Viberscrete utilizes a less than popular component, it is ideal to make sure the structures are being structural maintained through thorough inspection.

- Requirement: Due to the structural abilities and compound of miscanthus, it is a vital requirement to check its internal structure when in contact with water as it could damage it over time
- Time: Several days of inspection and maintenance is required

- Viberscrete end of life: Lastly, after an expected number of years (50-100), the Viberscrete structure would not be suitable for its current situation due to aging, cracks, and instability. An attempt at recycling would be the most ideal way forward to maintain the sustainable aspect of the product.

In conclusion, the value chain has been analyzed for the sake of understanding all the steps that must be thoroughly taken for a successful approach in designing, creating, checking, and delivering the Viberscrete product within the market's demand.

2.2 Miscanthus Analysis

Miscanthus is a genus plant, also referred as “Elephant Grass”, which has been found to be very fast growing with a stable supply of water in somewhat arable land, meaning it can be grown in most places (Wageningen University, 2017).

To get a deeper understanding of the miscanthus plant and its fibers’ potential within the sustainable concrete industry, an analysis will be done through literature research on various aspects of the miscanthus plant such as its biological aspects, its cultivation and harvesting process, its technological potential and technical infrastructure in the case of concrete based miscanthus fibers, its economical aspect, and lastly, its regulatory characteristic with regards to civil engineering guidelines. By covering all of these key aspects of the miscanthus plant, it will allow a more effective final product creation by abiding towards all ideas, systems, and methods found through the literature research.

2.2.1 Biological and Chemical Aspects

The Miscanthus x Giganteus is the primal form of miscanthus which will be utilized for the Viberscrete product and thus it will be the primary research focus for this analysis. It is known to grow to a yearly height of approximate 3 to 3,5 meters and it cultivates surprisingly well during the winter seasons, which is optimal for the Netherlands. The crop is able to grow rapidly due to its C4 photosynthesis abilities, and has a low nutrition requirement. Since the crop is sterile, it requires propagation through a process known as rhizome division, a process is done by hand (Anderson, 2011). These rhizomes also function as a nutrient storage system for the crop during winter or harsh seasons. Additionally, the plant has shown no signs of diseases and it requires virtually no pesticides for its development and lifespan, rendering it an extremely safe plant (Cradlecrops, 2019). Finally, the plant has an extensive ability in trapping CO2 since one hectare of miscanthus can store 40 tonnes of CO2 (Vo & Navard, 2017).

Additionally, it has been discovered that the chemical composition of a fiber is a key factor when creating a concrete matrix/substance. Cellulose, hemicellulose, and lignin are some of the most important components since they have a direct influence on the concrete strength, the water absorption capabilities of the fibers, as well as the hydration reaction of cement.

Fiber Type	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Jute	64.4	12	11.8
Flax	64.1	16.7	2
Sisal	65.8	12	9.9
Coir	43	0.3	45
Bamboo	26-43	30	21-31
Miscanthus	**40.2**	**43.2**	**17.9**

Table 4: Fibers Biochemical Composition (Ezechiels, 2017)

Table 4 compares miscanthus with other plants commonly used and analyzed in the construction industry. The cellulose content for miscanthus appears to be approximately 40.2 % which is fairly lower than some other plants, however, it still allows for the mechanical utilization of the fiber within a concrete matrix (Ezechiels, 2017). In a contrast to the cellulose, lignin is generally greater than most alternative bio-based concrete fibers, which allows a greater compatibility with cement (Le Ngoc, 2011). Finally, hemicellulose poses as the greatest difference between the miscanthus fibers and the alternatives, which affects the water absorption of the fiber (Ezechiels, 2017). In conclusion, the chemical composition of the plant, if analyzed in comparison with other bio-based alternatives, guarantees the product's mechanical stability within the concrete mixture.

2.2.2 Cultivation Process

Despite the general good performances, there are several required preconditions for the ideal cultivation of the crop. These factors are a suitable soil for planting, the right temperature, a good water supply, and an ideally selected geographical location.

The crop performs reasonably well in multiple sorts of soils ranging from sandy soils to clay soils, which is vastly ideal for the Netherlands since a majority of its soil is clay and sand-based soils (Spijker, 2012). When it comes to the pH level of the soil, miscanthus is relatively resistant, however, the most optimal pH is between 5.5 to 7.5 (CradleCrops, 2019).

Secondly, the temperature during the planting and early development of the crop must be selective since it could determine if the crop will fully develop or if it will be troubled by damage cause from low temperatures. Furthermore, photosynthesis cannot occur effectively in low temperature (Hendrickson 2004). The plant will only be productively active with a temperature of 6 degrees Celsius or above. This temperature is fairly lower than other C4 crops such as corn, which demonstrates how miscanthus has a longer growing season, which is beneficial in the Netherlands' climate (CradleCrops, 2019).

A constant water supply from irrigation or rainfall is key towards a fruitful development of the crop. When selecting a location for the initial planting of the crop it is important to examine the availability of water since a precipitation of 700-900 mm is ideal (CradleCrops, 2019), with 500 mm seen as the absolute minimum for the plant to develop. Miscanthus has a deep root structure, with root hairs up to 2 meters deep which allow extensive osmosis throughout the soil into the roots.

With regards to the outcome of a miscanthus plantation, it is estimated to be approximately 14 to 20 tons per hectare annually, which may be affected by various factors such as precipitation/irrigation, temperature, soil type, general climate, and number of crops per m^3 which is typically from 1 to 3 (Brosse, 2012). Furthermore, it is worth noting that the yielded amount progressively increase within the first 5 years as the crop grows to eventually stabilize at 14-20 per ha annually.

2.2.3 Technological and Technical Aspects

The goal of this sub-chapter is to identify and analyze the currently existing technological and technical possibilities which utilize miscanthus/elephant grass fibers or elements within a concrete/cement matrix through a literature review.

Various alternative technological conceptions have been formed which incorporate Miscanthus X Giganteus fibers/elements. To be precise, these are: concrete mixtures, which either utilize the fibers or grind those fibers into the matrix, polymer composites, particle boards, and masonry bricks. This report will focus on the use of the fibers in concrete mixtures.

Regarding its technological and technical aspects, it is vital to mention that variations in the mechanical performance may be caused by intricate reactions between the biological part of miscanthus against the chemical components within a concrete mixture. As the porous miscanthus biomass is mixed into the matrix, it decreases the pressure stability while on the other hand, increasing the acoustic and heating insulation capabilities of the concrete. One central technical issue with this concept is the water absorption caused by the biomass since an ideal concrete/cement mixture requires a stable matrix bond which does not get affected by particle shrinkage or separation due to reactions with excess water particles. Alkaline leaching and/or chemical pre-treatment may allow for the reparation of this issue (Moll, 2020). Furthermore, depending on the type of binder utilized as well as the mixture of concrete and form of miscanthus utilized, a bio-based miscanthus concrete sample may reach a 7-day compressive strength ranging from 0.95 to 5.84 MPa with a thermal conductivity of 0.7 W/ (m.K) at 20%RH and 20 to 60 degrees Celsius (Vo & Navard, 2017). According to the same research, miscanthus stem fragments may reach a 25 MPa compressive strength at 28 days without treatment, alongside a fairly weaker flexural strength of approximately 3 MPa.

With regards to thermal and acoustic performance of miscanthus-based concrete's, it has been discovered that when applying miscanthus fibers into a mixture, 2-4 mm fibers lead to higher acoustic absorption coefficient with a wider frequency band. Furthermore, in order to achieve a high sound absorption above 0.6 at a frequency range of 600 to 1200 Hz, the utilized miscanthus fiber percentage must be more than 20% (volume) of 2-4 mm fibers. Whilst with regards to the thermal insulation, it has been shown that thermal insulation enhances due to air voids and gaps created due to the fibrous miscanthus particles (Chen, 2020).

2.2.4 Regulatory Aspect

A primary EU based grant/benefit, called "'Just Transition Mechanism", promises to allocate at least **€**150 billion into industries which are transitioning into a more sustainable and environmental approach, such as Vibers. To be precise, they have mentioned that companies and industries "supporting the transition to low-carbon technologies and economic diversification based on climate-resilient investments and jobs" will be between those who benefit (European Commission, 2020).

Additionally, The Netherlands has implemented "A Circular Economy in the Netherlands by 2050" which is a program that aims to develop a circular economy in the Netherlands by 2050 through a reduction of 50% of raw materials such as minerals, fossils and metals (The Ministry of Infrastructure and the Environment, 2016). Miscanthus and Viberscrete have a direct involvement within this topic.

Another vital aspect to take into account are regulations and guidelines on lightweight concrete as well as bio-based concrete forms which are viable to possible updates due to the aforementioned regulations.

2.3 Preliminary functional and Technical Requirements

The functional requirements are determined as the direct functions of the design in accordance with the client's wishes. They are the product's features.

- Functional requirements:
  - Heat insulation
    - thermal conductivity of 0.7 W/ (m.K) at 20%RH and 20 to 60 degrees Celsius
  - Sound insulation
    - in order to achieve a high sound absorption above 0.6 at a frequency range of 600 to 1200 Hz, the utilized Miscanthus fiber percentage must be more than 20% of 2-4 mm fibers
  - Structurally capable in accordance with other lightweight concrete
  - Versatile
  - High moisture storing capacity
    - Porosity ratio of approximately 75%
  - Lightweight focus
    - The product must have an average density of between 50 and 70 kg/m^2
  - Product must be scalable in terms to utilization
  - Product must follow a circular economy approach within its production phase
  - The cost, and feasibility, of the product must

Technical requirements detail specific technical data such as expected numeric values in terms of weight, volume, strength, durability, or expected lifetime. These values act as benchmarks in accordance with the functional requirements as they represent the numeric side of things from the aspects mentioned in the functional requirements.

- Technical requirements:
  - Must have a compressive strength of approximately 1 MPa (Mechanical Strength), similarly to Hempcrete which represents a strong similarity that ought to be exploited within the design and market implementation of the final product
  - Volume of 200 to 500 kg/m^3
  - Must have low Carbon Footprint due to its sustainable aim
  - Must follow sustainable concrete regulations

Furthermore, a variety of pillars which are integral into the design aspect of all preliminary variants have been taken into account within their designs, these are:

- Practicality / Ergonomic
  - How practical the product is in terms of utilization?

- In what situations can it be utilized
- Ease of set-up / manufacturing
- How functional is the product in terms of common usability?

- Performance
  - Each variant must be able to attend towards its expected performance;
    - Housing blocks must have some compressive strength
    - Exterior furniture / tiles / pathways must be able to uphold their expected average loads
  - All variants must be able to accommodate towards their expected performance of heat and sound insulation, specifically those which are meant to be within living/working spaces
- Life expectancy
  - The product is expected to uphold a minimum life expectancy of at least 50 years, however, this is also dependent on its utilization and situation
  - The product must be able to maintain its central abilities, such as heating and sound insulation, effective throughout its lifespan
- Guidelines and Standards
  - All products must abide their respective guidelines and standards with respects to their field of utilization
- Safety
    - Depending on their respective situation, each product ought to offer a standard level of safety to the users/customers when being utilized
    - The product does not harm the environment in any way
- Social / Political Implications
  - The product needs to clearly demonstrate an environmental, sustainable, and positive approach by utilizing clean and renewable sources
- Durability
  - The product must be stable and durable during its lifespan
  - The product must be able to maintain a stable degree of stability throughout constant utilization, specifically for tiles/housing blocks
- Versatility

- The product must be versatile in its potential applications within the construction and building sector

- Structural capabilities
  - The product requires a higher grade of structural capabilities due to its circumstances and utilizations
  - The product must be able to safely sustain its expected load for an extended timespan
- Expected market popularity
  - The product's existence must take into account concurrent competition, and general supply and demand within the market in order to determine how successfully it will be business-wise
- Thermal / Acoustic Insulation
  - The product utilizes Miscanthus' central abilities of thermal and acoustical insulation within its utilization
- Carbon footprint / CO2 emissions
  - The product upholds its sustainability stand by attempting to reduce CO2 through its application
- Cost – The cost of each product is determined centrally by its production and transportation. The product must be able to uphold a feasible and financially reasonable sum price for the sake of profit within Vibers.
  - Production
  - Realization
  - Transport

2.4 Preliminary Variants

The preliminary variants encompass all potential final designs which aim to primarily please the client's wishes by delivering a product which upholds all functional and technical requirements, and will be eventually filtered through a Multi-Criteria Analysis to determine the most feasible and versatile final solution in accordance to the client's wishes and the market opportunity.

Insulation Panels

Insulation panels are fundamental towards the inner construction of living spaces in countries where winter is a common season, such as throughout most Europe. With regards to their functionality, as their name suggests, their central purpose is to "insulate" heat and/or sound within a room or to maintain heat/sound out of a home. Some insulation panels may also be utilized as cladding as seen on Figure 9 below. This is the case for example of hempcrete insulation panels.

Figure 8: Insulation Panels (Hempcrete)

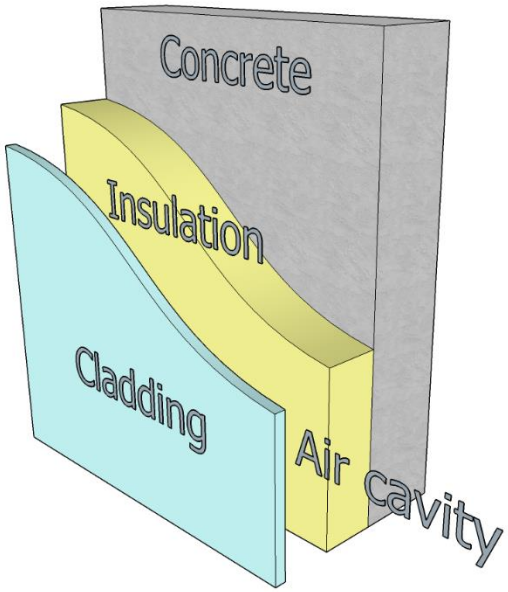


Figure 9: Cladding and Insulation positions

Additionally, cladding is key within the inner structure of a room since it is the first layer of the wall which will receive and interact with the surrounding temperature and sound, and thus, must be able to insulate well enough.

Floor Insulation – Heat Focus

Another vital implementation of Viberscrete could potentially be floor insulation for homes as it is become more and more popular due to the comfort it provides within a home, as well as the logical heating concept since heat tends to go up it is always ideal to reheat the floor as to maintain a tempered room.

Figure 10 below demonstrates the installation and cross-sectional structure of IsoHemp's Hempcrete floor insulation which can be similarly adjusted to fit Viberscrete.

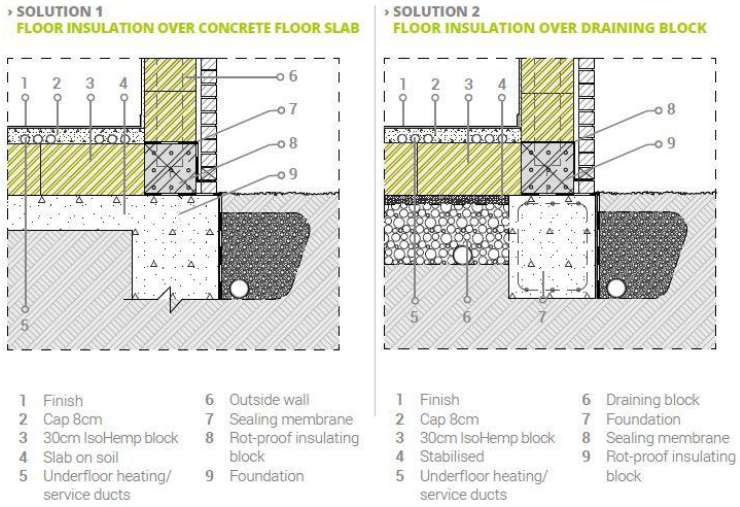


Figure 10: Floor Insulation (IsoHemp)

Partition Walls

Non-load bearing partition walls are commonly utilized in homes all around the walls to divide large rooms into smaller segments for privacy and to create more rooms per individuals. Viberscrete formed partition walls would be ideal for this concept due to their acoustic and heat insulation natural properties, as well as the fact that they are not structurally sound to withstand the bearing load but can still be utilized within the interior structure. Furthermore, the benefits that miscanthus-based partition walls bring can be strongly demonstrated in other areas such as offices, and schools since these sorts of rooms generally accommodate a lot more noise than homes and it would be suitable to utilize a noise-dampening solution rather than a typical partition wall made out of wood, bricks, or drywall. This form of walls may be done through the placement of the lightweight concrete blocks or as a solid plane (thin) wall. Figures A and B below demonstrate the different compositions between utilizing blocks, and a plane form of the product, both of them are made through Hempcrete however. Depending on the situation and requirements, blocks may be preferred over the panel or vice versa.

Figure 11: Partition Wall with Hempcrete blocks

Figure 12: Partition Wall with flat-board design

Building blocks

Following up with the aforementioned miscanthus blocks which would attempt to replicate Hempcrete as a marketing strategy with further developed and optimized features, they can also be utilized as building blocks for housing. Furthermore, the miscanthus features are tremendously useful in terms of taking into account the environmental factors both the interiors and exteriors of a house. With Viberscrete blocks, the housing will also benefit from the acoustic and thermal insulation without a strong need for extra insulation. However, one important aspect to mention is the likely requirement of reinforcement through the usage of steel, wood or masonry along the load-bearing sections of the housing, walls, and flooring.

Furthermore, IsoHemp has demonstrated the utilization of their Hempcrete blocks for the purpose of housing as seen on Figure X. Since Hempcrete has a similar internal matrix and composition to Viberscrete, with a high percentage of fibers/shives in the mixture, it demonstrates how Viberscrete could succeed in this utilization.

Figure 13: Hempcrete Building Blocks (IsoHemp)

Road / Tiles / Pavers

Another vital utilization of Viberscrete could be exterior tiles meant for bicycle paths, pedestrian sidewalks, and even automobiles for limited areas and speed levels, such as marking zones or “free space” zones. Furthermore, BioBound has created an exemplary product with the utilization of recycled concrete and elephant grass which demonstrates the grand possibilities of utilizing Viberscrete under the same circumstances. Figures A and B further demonstrate the different forms the tiles/pavers would take.

On the other hand, one possible concern would be that the product is somewhat too brittle to handle the constant moving pressure from vehicles.

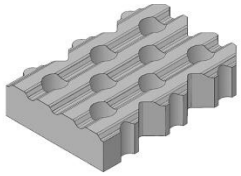


Figure 14: Road tiles (IsoHemp)

3. Methodology

3.1 Methodological Approach

The central goal of this Methodology is to provide an insight into the inner workings and approaches which have been, and will be, taken to reach the final goal and answer the research questions. To reiterate, the main research question was:

"What final product is the most optimal for the utilization of the Viberscrete high miscanthus concentration mixture within the construction & building field?"

Alongside it, these are the supporting sub-questions which are meant to create a more clear and concise potential results by focusing on alternative aspects of the research.

1. *Which fields of construction & building will all the alternative solutions fit within?*
2. *By taking into account the current bio-concrete market, which sub-field seems to be in demand of different products (walls, pathing, insulation)?*
3. *With regards to the preliminary variants, which of them seem to have direct competition within the sustainable concrete market?*
4. *What external regulations and guidelines must the final product obey for a safe public release?*
5. *What possible changes within the mixture composition may allow the product to become more optimized for public use?*

First of all, the aim of this research was to systematically come up with a set of preliminary potential solutions towards the utilization of the Viberscrete product by taking into account the existing market situations (products, supply and demand), the functional and technical requirements, the clients' wishes, and finally, the product's essential abilities and selling points, such as the heat and sound insulation.

With regards to the type of data collected and required, a majority of the utilized data within the theoretical framework is qualitative data gathered from multiple reports and websites regarding Miscanthus-based lightweight concrete and the possible utilization of similar materials in the fields of construction and building, with Hempcrete being an iconic example. Thus, the data gathered was secondary data.

3.2 Methods of Data Collection

Several methods of data collection have been, and will be, implemented within this thesis to achieve its ultimate goal. Each of them will aim to collect thorough and useful data to be utilized through the systematic final design criteria analysis.

The methods of data collection are split up between quantitative and qualitative methods, each of which contains several more specific routes to gather first and second-hand data. All methods were chosen to assist the preliminary variants design and criteria assessment with the hopes of achieving a successful final design with the accumulated data as support.

It must be mentioned that due to current Corona restrictions data collection has become somewhat limited because of lack of procedures, laboratories not being as available, and collaboration amongst colleagues.

3.2.1 Quantitative Methods

The quantitative method, as the name state, will focus on numerical and statistical forms of data/information collection through several sources such as ongoing laboratory experiments being worked on by Viber colleagues to determine the product's base properties and potential, and already existing data conducted through literature research, and lastly, another laboratory experiment focused on the analysis and testing of the preliminary variants in a smaller scale.

First of all, the currently ongoing laboratory research being conducted by Viber associates is fairly preliminary and focused on the base properties and values of the Viberscrete material such as water content, fiber content percentage, water absorption mechanics, etc. This laboratory experiment is fundamental in understanding the product's true potential, and determining if some of the more complex preliminary variants are realizable, such as the housing application since it would require a greater amount of structural strength compared to its peers.

Second of all, a literature review has been conducted regarding articles and reports about various topics such as Miscanthus lightweight concrete, Hempcrete, and Bio-based/Green concrete utilizations. Furthermore, Miscanthus research was a priority within the literature review as the central point for this thesis, and thus more focus was put into researching different aspects, properties, and utilization of

currently existing Miscanthus-based lightweight concrete products. It was vital to understand other report's, experiences, and perspectives of Miscanthus-based concrete in order to determine the known possibilities of the product. However, it is important to mention that all reports regarding lightweight Miscanthus concrete were focused on low fiber concentration samples which are fairly useful for this thesis, however, the difference in fiber concentration could result in disparities between the products and thus, it is vital to be careful when comparing their low concentration products to Viberscrete, although most abilities and utilizations ought to be similar.

Third of all, another laboratory experiment would be beneficial in testing each preliminary variants' concepts in order to check their potential within their desired situations. Two particular variants which would directly benefit from testing and laboratory assessments are the "housing" and "Road tiles". This is because both of them would be utilized in situations with high stress/loads from the house's weight and the movement of cars/bikes/pedestrians, respectively.

Lastly, all these quantitative methods, whether they have been done or have yet to begin, are fundamental in achieving a successful final design decision since each of them detail vital data which will allow for the fair assessment of all preliminary variants.

3.2.2 Qualitative Methods

The qualitative methods of data collection have, and will, focus on more flexible and subjective forms of information gathered from desk research and literature reviews, as well as an eventual set of interviews aimed at collecting firsthand information from individuals involved in the field of Miscanthus-based lightweight concrete product.

First of all, existing data was gathered similarly to the quantitative method. However, the information collected can be considered to be sided more towards the qualitative side since a majority of it was descriptive and imagery rather than numeric. This form of information is extremely supportive towards understanding the currently existing utilization of Miscanthus-based lightweight concrete since it allowed for the deeper understanding and visualization of the products through thorough text and demonstrations through images. Furthermore, all the materials were collected from various reports, articles, and websites regarding several aspects of Miscanthus, not just as a lightweight concrete but also as a crop since it was crucial to understand its growth and harvesting process before attempting to manufacture it. On the other

hand, information regarding Hempcrete and similar products to Miscanthus were also heavily studied within the qualitative literature research since it holds such strong similarities to Miscanthus in its composition and potential utilization as a lightweight concrete.

Second of all, a set of semi-structured individual interviews will be eventually executed among a selected few, approximately 2-4 people, all of whom will be chosen due to their roles in the Miscanthus lightweight concrete world. Specifically, the designers or manufacturers of BioBound's and Strukton's Miscanthus-based products since their input will be valuable towards the progression of Viberscrete within the market, since they will be direct competitors depending on the winning variant. Furthermore, each participant will be asked a series of question regarding their product/design, the way their company behaves within the market, the composition of their Miscanthus product and its purpose, their experience within the bio-based concrete market, and lastly, more details about the utilization of their product, specifically towards BioBound since they utilize Miscanthus in various products such as tiles, slabs, and exterior furniture. Moreover, all this firsthand collected data will be necessary in determining, through Viber's competitors experience and perspective, which variants will be more crucial within the market's demand. Moreover, the preliminary variant assessment will be partially guided by the information gathered from the interviews due to it being a true insight into the systematic world of Miscanthus-based concrete with experienced perspectives on the topic.

To conclude, a majority of the overall gathered information can be said to be qualitative since most reports/websites utilize usefully formatted text and imagery to convey their finds. The literature review has allowed for the large sum of gathered data which has created a foundation for the construction of the preliminary variants and the multi-criteria assessment. Additionally, the interviews will further support the gathered information through the participant's experience within the field.

3.3 Description of Methods of Critical Analysis

The focus of this subchapter is to emphasize and explain the critical analysis which will be executed on each preliminary variant in order to determine the most optimal final design for the utilization of the Viberscrete product.

First of all, it is vital to state that the quantitative and qualitative methods of data collection and analysis are, and will be, fundamental in effectively analyzing each preliminary variant thoroughly by utilizing the collected information as filters to reach the ultimate design. Furthermore, in order to achieve the ultimate design and utilization of the Viberscrete product, a Multi-Criteria Analysis (MCA) must be employed as mentioned within the Theoretical Framework. The central goal of the MCA will be to score each preliminary variant in accordance to a set of criteria which encompass both the aforementioned design criteria, and the client's ultimate wishes for the final design.

The criteria will have a scoring system where the preliminary variants will be assessed through. The grading system will be based on a 0-to-3-point system, with 3 being the highest/greatest a variant could score in each criterion. All criteria will weight the same as to create a fair assessment. Finally, the variant with the highest accumulated points throughout all categories will be triumphant in becoming the ultimate design choice for the Viberscrete product. The criteria for the MCA are:

- **Cost** – The average cost of the product per m^3 by taking into account production and transportation, as well as the estimated required amount and weight per order
- **Feasibility** – How viable is it to produce and transport the product by taking into account its required materials and demand
- **Versatility in utilization** – How many potential utilizations does the product provide
- **Market Demand / Competition** – How is the product expected to behave within the market once its released. Takes into account the currently competing similar products and potential demand for the specific variant
- **Miscanthus' abilities utilization [selling points]** – Does the variant promote and utilize the thermal and acoustic insulation from the Miscanthus fibers within its utilization and situation?
- **Safety –** Does the variant promote and guarantee the customer's safety through its usage? Is there room for accidents, issues, or imperfections within the utilization?
- **Design** – The variant's design is innovative and practical whilst utilizing Viberscrete strengths
- **Client's preference** – The variant integrates the client's wishes into its utilization and purpose

3.4 Methodological & Design Choices Evaluation and Justification

The purpose of this subchapter is to expand on the methodological choices and execution which occurred throughout this thesis. The methodological choices in question are those previously mentioned within subchapter 3.2 and 3.3 since those two thoroughly detail all the steps that have been, and will be, taken throughout this thesis to achieve the results.

First of all, the methodological method of data collection which was centrally utilized throughout a majority of this thesis is desk research and secondary data gathering from online documents, websites, and reports. This can be justified by the ongoing global pandemic due to COVID-19 and the social inconveniences that it created since further development could have been achieved if it were not for the social lockdowns, this includes laboratory experiments and real time studies of different lightweight bio-based construction materials, specially Hempcrete since it is the closest example.

Second of all, the design choices which were taken within the preliminary variant were based around two primary concepts; the aforementioned design criteria pillars which uphold the Viber's vision, as well as the inspiration acquired from Hempcrete due to its fundamentally strong similarities to Miscanthus Concrete. Firstly, Viber's vision for the utilization of the product, along with any project's client, are vital in designing a product's structure and concept since their wishes are of top priority. Secondly, taking inspiration from Hempcrete's design and current utilizations was an ideal concept due to its strong similarities with Miscanthus such as both of them being superior heat/sound insulators, having a lightweight structure, and being resourced from agricultural means. Furthermore, Viberscrete can also be seen as a potential competitive product against Hempcrete by replicating its current designs but optimizing them.

In conclusion, a majority of the methodological and design choices which were, and will be, executed throughout this thesis have been done with the hopes of achieving a successful and purposeful final design which Viberscrete can prosper with.

3.5 Tools Required for Preliminary & Final Design Assessments and Testing

A fundamental aspect of thoroughly assessing the preliminary and final designs is to utilize software and physical methods to examine the composition, structural capabilities, environmental aspect, and production/construction feasibility.

With regards to the software utilized, AutoCAD and Inventor which are both Autodesk software, will be utilized to digitally model the preliminary variants and create a clear realization of each variant's 3D structure with the goal of demonstrating a detailed version of the variants which can be utilized to distinguish each of them within the "Design" criteria in the MCA. Furthermore, Technosoft, which is a structural analysis software, will be utilized to determine the structural capabilities of each variant thoroughly in order to determine their "safety" and "design" capabilities within the MCA. This software assessment is primarily crucial towards the examination of the building blocks, and tiles/pavers variants since those two will require a decent structural competence due to their utilization.

Moreover, several websites/programs such as Ecochain and Carbon Footprint Calculator will be utilized to get an idea on each variant's sustainability and potential Carbon Footprint produced throughout its manufacturing and transportation phase. This is a vital step since the final product, as well as Vibers itself, aims to promote a sustainable approach to construction and building.

Last but not least is the laboratory experiments which aim to create small scale mock ups of each preliminary variant with the Viberscrete mixture in order to have a direct and clear perception of each of their true capabilities, and to be able to check if the theoretical requirements came to fruition if put into practice, such as the sound and heat insulation abilities. These tests will require a somewhat finalized sample of the Viberscrete product, as well as full access to the laboratory and tools such as wooden frames to carefully model and create the variants.

4. Preliminary Variant Analysis / MCA

4.1 Introduction

The central goal of this chapter will be to thoroughly investigate, analyze, and understand all preliminary variants before attempting to compare them against each other within the Multi-Criteria Analysis. It is vital to analyze each variant through the aforementioned criteria which the MCA is based on, as this will allows for simpler and more direct observations, and straightforward analysis of the variants through the research.

The research criteria are:

- Cost
- Feasibility
- Market demand
- Miscanthus' abilities utilization
- Safety
- Design
    - Durability
    - Lifespan
    - Scalability
    - Versatility in application
- Client's Preference

Furthermore, each variant will be designed within AutoCAD / Inventor with respect to the Eurocode's regulations in order to get a thorough understanding and vision of their individual design specifications, as well as the expected production requirements per m^3 or per piece (specifically for the building blocks or road tiles). Below, every variant will be described in terms of their respective elements and requirements which are depending on their application and utilization. These elements/requirements will further allow for a fair analysis and comparison of all variants within the MCA by acknowledging their internal components and connecting them to the aforementioned list of criteria.

The cost, feasibility, safety, and design will be some of the most crucial criteria that will be defined by the descriptions of the variants' elements since these 4 are more dependent on physical elements than the rest of the criteria.

4.2 Variants' Exploration & Components

Before exploring and explaining all components and methods which go into each variant's matrix/structure that may affect their production and application procedures, it is vital to mention that the central Viberscrete (volume) mixture will be composed of:

- Cement
- Gravel
- Sand
- Miscanthus Fibers
- Water

However, their respective rations per cubic meter are dependent on the Viberscrete mixture that has been chosen for each variant. To be more specific, there is the Default Viberscrete Mixture, and the Alternative Viberscrete Mixture. Below both mixtures have been detailed in terms of content ratio, costs, CO2 emissions, and durability.

Default Viberscrete Mixture

General Description

The default Viberscrete mixture follows the information and recipe per 1 m^3 provided by the Vibers laboratory team, as such:

- Cement (10%) – 216 kg // at €0.50 per kg
- Gravel (40%) – 961.2 kg // at €0.20 per kg
- Sand (30%) – 523 kg // at €0.20 per kg
- Miscanthus Fibers (20%) – 228 kg // at €2 euros per kg
- Water – 150 kg/liters // at €1 per m^3

Total price is approximately €862 for 1 m^3 of the default Viberscrete mixture.

The actual weight in kilograms was calculated utilizing each elements' known densities and their respective rations within a cubic meter of the Viberscrete mixture. Furthermore, the costs shown are relatively low since they are per kilogram whilst most of the material are purchased in bulk (tons at a time), meaning that the price would rise as production increases. Additionally, the carbon footprint calculations for this first mixture were gathered through EcoChain's Mobius website as shown below on Figure 4.2.1.

CO2 Emissions

Before exploring all variants and their critical components, it is vital to calculate and demonstrate the expected carbon footprint of 1 m^3 of Viberscrete including the constituents mentioned above. EcoChain's Mobius software was utilized to gather and calculate the different CO2 footprints caused by the different elements and process utilized for the ultimate creation of Viberscrete.

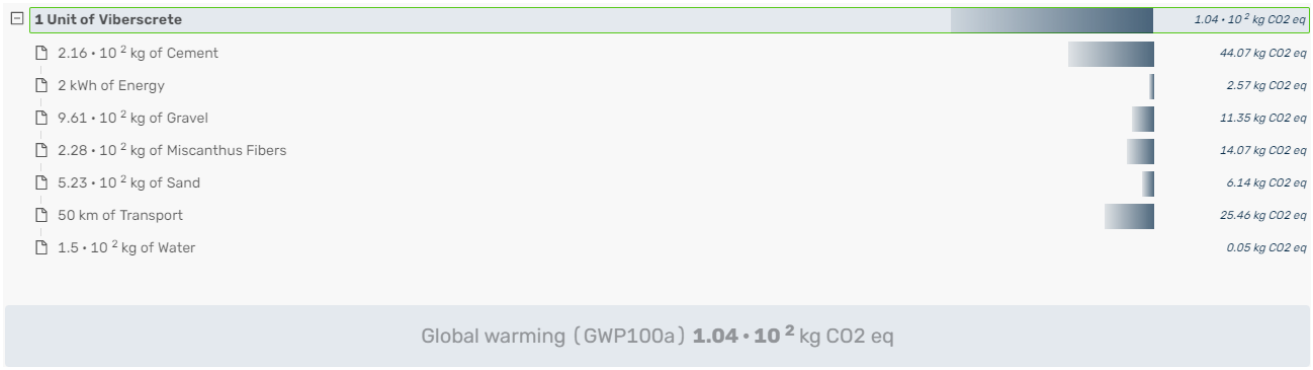


Figure 4.2.1: CO2 Emissions

Moreover, it must be restated that Miscanthus is a carbon negative crop / material which is its central purpose in the utilization variants for the Viberscrete product. In total, it is estimated that *104 kg of CO2 are emitted per m^3 of Viberscrete created*. On the other hand, standard concrete emits approximately 2400 kg of CO2 per m^3 due to its grander utilization of cement. Furthermore, since Viberscrete also utilizes cement within its mixture, it is vital to be critical about the variants which have a greater cement percentage than others.

Durability

With regards to the mixture's durability, it is important to mentioned that its service life and expected durability is altered by its application, utilization, and its internal matrix which has been shown above. The goal of this text is to thoroughly expand on the different aspects of durability from the side of the mixture's elements rather than from its application, since each variant will have different applications and physical requirements which will be expanded upon throughout this chapter.

Firstly, this default Viberscrete mixture utilizes a similar base to standard concrete with the inclusion of cement, gravel, sand, and water. This combination allows for an extended durability and service life as seen with standard concrete which as an average lifespan of 50 to 100 years. However, the addition of Miscanthus fibers into the mixture alters the expectations and behavior of the complete product since durability itself is defined against resistance to weathering, chemical/physical impact, and environmental inflictions. For example, miscanthus' long term behavior during freezing/thawing is fairly unexplored in a long-term scope since miscanthus based concrete is fairly new to the field of constructions materials, but water interaction with the fibers is a very delicate circumstance since the water absorption capabilities of the fibers could lead to insufficient water in the matrix and alter the overall structural strength of the product.

General Description

The main difference between the aforementioned default mixture and the alternative is the adjusted ratio for the gravel and Miscanthus Fibers within the volumetric mixture, as well as the intended purpose behind this change with regards to the utilization for specific variants. The composition, per 1 m^3, will be as followed:

- 523 kg of sand (30%), €0.20 per kg
- 240 kg of gravel (10%), €0.20 per kg
- 216 kg of cement (10%), €0.50 per kg
- 570 kg of Miscanthus fibers (50%), €2 per kg
- 1 m^3 of water for €1

Total cost is approximately €1,402 per m^3

As seen here, this composition favors a higher percentage of Miscanthus Fibers per cubic meter. The goal of this decision was to create an alternative mixture which could be focused on variants with little to none structural requirements whilst increasing the heating and sound insulation capabilities from Miscanthus.

CO2 Emissions

Due to their central focus on heat and sound insulation rather than structural support a matrix change will be applied onto this variant which increases the volumetric percentage of Miscanthus Fibers within the matrix to 50% by reducing Gravel to 10%. This will allow for an increment in the heat/sound insulation capabilities per m^3 whilst reducing the gravel content will ultimately reduce the weight and structural capabilities of the product, which would not be required either way due to its application. Unfortunately, the increased amount of miscanthus fibers within the mixture, per cubic meter, has displayed an increment in the overall CO2 emissions for said mixture per m^3.

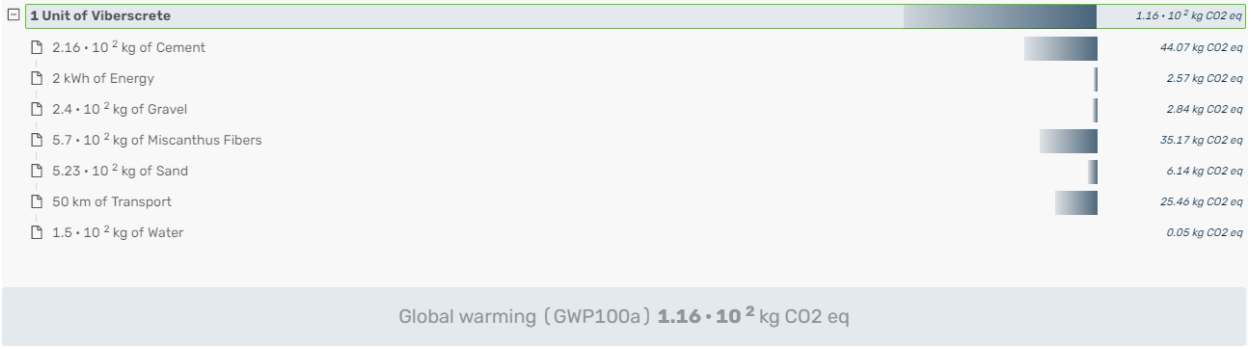


Figure 4.2.2: Alternative Viberscrete Mixture CO2

As seen on Figure 4.2.2 above, the total volumetric CO2 emissions for the alternative Viberscrete mixture is higher than the default mixture. This is due to the increment in miscanthus utilized, since it requires more energy usage to thoroughly cultivate and process miscanthus plants into fibers, whilst the depleted gravel from the default mixture does not emit as much CO2 per kg due to its simplicity in its collection and processing phase. To be precise, miscanthus must be grown for several years, then cultivated, and finally grinded through machinery, all of these being stages which require constant energy, labor, or water to be provided to the plant. On the other hand, gravel is broken down rocks/stones which can be found already broken down or pulverized. This process is much quicker which is why the CO2 emissions are lower.

Durability

The durability of the alternative Viberscrete mixture must be built on what was mentioned earlier about the durability of the default mixture. That being that the miscanthus fibers might weaken/alter the overall composition during time if exposed to direct water in the case of freezing/thawing process. Since this mixture has a higher content of miscanthus fibers per cubic meter (50%), it is more susceptible to internal impairment due to water content rising by miscanthus absorption which, as mentioned before, would possibly alter the structural and physical composition of the product. However, the purpose of this mixture was to be utilized for situations without structural loads, such as insulation.

It must also be mentioned that miscanthus-based concrete does not have an extensive experience, thus it is somewhat tougher to estimate its expected lifespan or durability. However, Hempcrete which is a close counterpart to Viberscrete, is composed mostly of hemp fibers and limestone, and it is able to be durable for approximately 50 years. On the other hand, Viberscrete has cement, gravel, and sand on its mixture which might allow it to surpass the 50-year threshold.

General Description

The insulation panels, as mentioned before, are an integral part of the inner structure of an accommodation/office space. Furthermore, Figure 4.2.3 below demonstrates the expected dimensions, structural composition and installation of the insulation panels within a wall sector.

This design has been specifically formulated for the Viberscrete product to be applied simply as an insulation material within a wall. To be more specific, the envisioned insulation panels will measure 3 meters long, 1 meter wide, with a thickness of 0.1 meters. It will also require railing/support frames which support and connect the insulation panels along the internal wall structure.

This variant, due to its application and situation not requiring structural support, will utilized the alternative Viberscrete mixture which will additionally allow for more insulation abilities due to the greater miscanthus content.

Costs

Each panel has a volume of 0.3 m^3 which according to the aforementioned cost of 1 m^3 of the alternative Viberscrete mixture would equate to approximately €420 per panel. This price may be altered depending on material costs, processes, product finalization, and the final business model.

Furthermore, the panels have a reduced need for maintenance and repair since they will be supported by the aforementioned frames as shown below on Figure 4.2.3 with the sketches. Their placement between concrete/masonry wall and a cladding/external wall allows for their long-term service life since it will be protected on both sides.

Design

The variant's design takes into account its situational safety towards the users, the scalability, and its versatility in different utilization approaches. Firstly, since insulation panels require no structural supporting system, the client's safety is fairly guaranteed in its application because there is no room for failure. Secondly, it can be widely scalable as shown in the sketches below since its placement and overall

composition only requires the set of support railings which hold the panels from all sides between both walls. Each panel semi-structure can be placed besides one another to be supported by the bolts on the top frame as well as its set-up against the load-bearing walls. Thirdly, the insulation panels are not the most versatile product since they are meant to be placed on walls. However, they can be modified by its shape or its support structure to be placed elsewhere such as ceilings.

Market Demand

Currently, the most popular insulation materials are Fiberglass, mineral wool, and Polystyrene. All of these materials are harmful towards the environment as they either produce toxic air pollutants, utilized animal-sourced industry, or can liter its surrounding from landfills due to its light density, all respectively.

For this reason, there is a potential demand for a sustainable, carbon negative, and environmentally friendly solution such as Viberscrete. However, there is competition in Hempcrete based insulation currently in the market which could falter its demand. One possible pushback against this it's the utilization of the alternative Viberscrete mixture which composes of 50% Miscanthus, guaranteeing higher heat and sound insulation. For this reason, this variant also has a high miscanthus utilization in comparison to other variants such as the pavers, especially since its main and only purpose is to insulate.

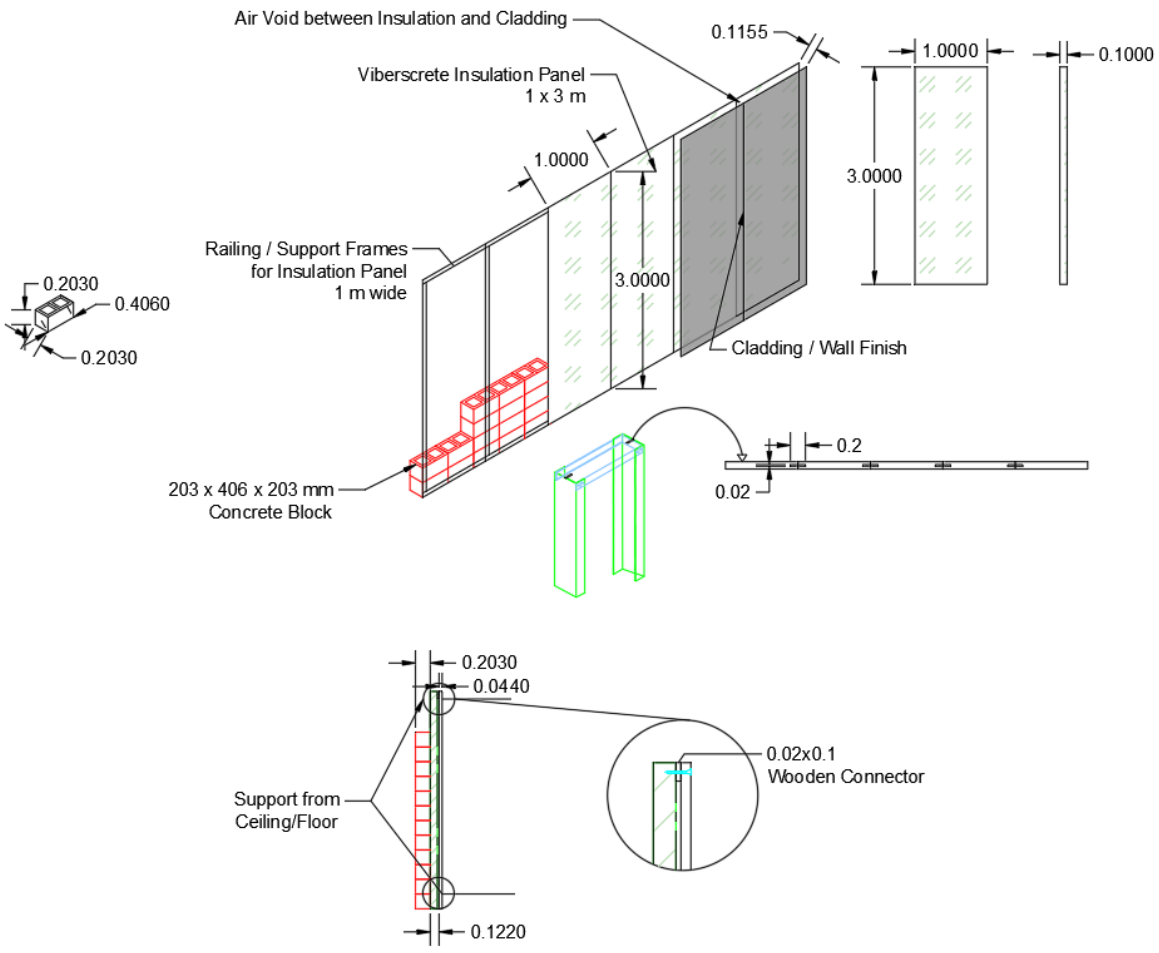


Figure 4.2.3: Variant 1

Variant 2 – Floor Insulation

General Description

Similarly, to variant 1, the second variant focuses on insulation within the floor/ground section of an accommodation space. However, due to its position within the general structure of the building, it is ideal to maintain the default Viberscrete mixture composition with a higher gravel percentage. This is due to the possible load that could be pressed onto the floor boards/insulation structure within the floor.

Furthermore, the dimensions of the floor insulation are 1 x 1 m^2 with a thickness of 0.1 meters, per piece. As shown below in Figure 4.2.4, its placement and overall structural composition within the floor sector can be varied depending on the requirements of the user/client. Additionally, the insulation will be placed on top of a slab (concrete/wood) which is above the foundation. There will also be joists in between the insulation slabs to support the floor board and pass its load onto the foundation. However, the floor insulation can be exposed to a portion of the floor load due to its cement and gravel base mixture.

Costs

The volume of a single floor insulation slab/panel is 0.1 m^3, since it aims to utilized the default Viberscrete mixture, its cost per slab will be €86.2 per slab. This shows a relatively low cost per item in comparison to other variants. Furthermore, it is a positive since environmentally friendly materials have a tendency of being more expensive than the commonly used items.

Design

This design's safety towards the customer/user must be guaranteed since, depending on the set-up and floor layout, some of the living/dead load may be transferred to and through the insulation. This is the reason why the stronger mixture has been picked, in order to be able to support a portion of the load transfer. With regards to scalability, it is extremely possible to do so since they are square-shaped units which can be cut and divided to the customer's needs. Lastly, it is not the most versatile product because it is meant to be used as floor insulation. However, within the field of floor insulation, it can be set-up in different situations and patterns depending on the customer's wishes.

Market Demand

Similarly, to variant 1, the floor insulation market is occupied by spray foam, fiberglass, and Polystyrene panels. All of these products have environmental short sights whilst Viberscrete would be able to replace them as a carbon negative solution. However, Hempcrete has also created a floor insulation system which our product directly competes with. However, one advantage that Viberscrete has is its greater compressive strength.

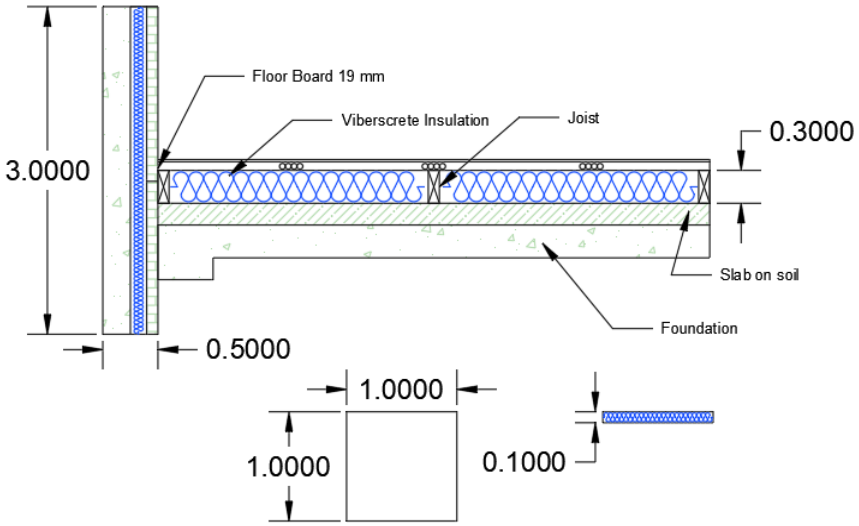


Figure 4.2.4: Variant 2

Variant 3 – Partition Walls

General Description

The partition walls will utilize the default Viberscrete matrix composition due to its structural requirements as standing walls which will likely be interacted with by living loads since it is exposed to direct contact. Furthermore, as shown by the sketches in Figure 4.2.5, the partition walls will be supported by wooden frames and studs which the Viberscrete partition panels will be nailed onto. The dimensions of each unit are similar to the insulation panels, that being 3 meters long by 1 meter wide with a thickness of 0,2 meters. The vertical wooden frames have been placed with a standard gap of 0.5 meters between each other (middle to middle). This follows a standard partition wall design which is utilized by drywall-based walls.

Costs

The partition walls have a volume of 0.6 m^3 per wall with the default Viberscrete mixture, meaning that the cost per unit would be €517. The cost is somewhat high in comparison to standard drywall partition

walls, however, a grand selling point of the Viberscrete partition wall is the insulation abilities which standard walls do not have since their design is too thin to accommodate additional insulation.

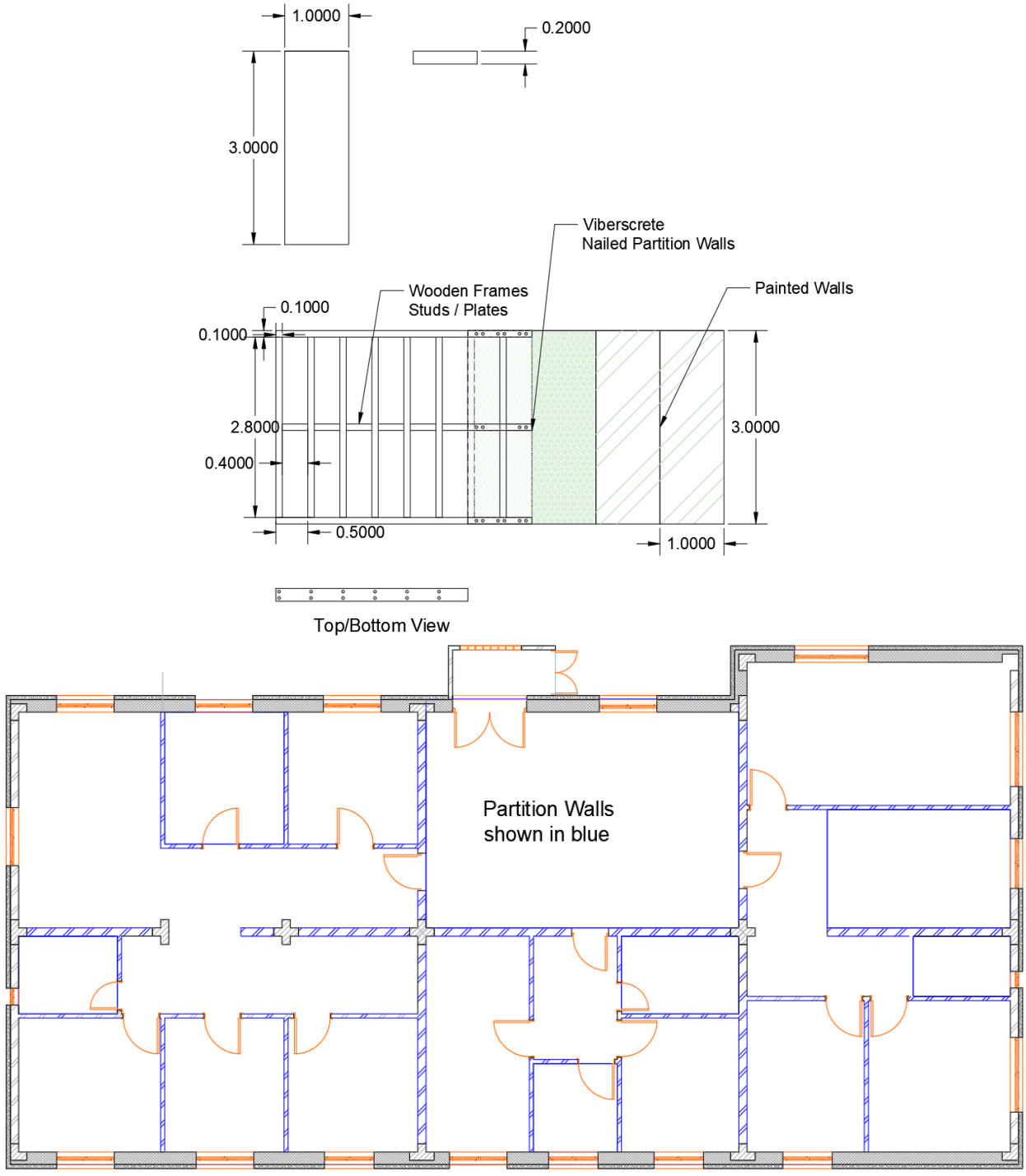
Design

Due to the sturdy infrastructure provided by the default Viberscrete mixture, the safety of the product is satisfiable to be treated as normal partition walls are meant to be treated. They ought to be able to handle small live loads such as paintings/clocks being hung or items being leaned against them. They are also extremely scalable as seen within Figure 4.2.5 since they follow the standard partition wall infrastructure design with the wooden frames and studs which can be placed in regards with the customer's wishes and spatial design. Moreover, the partition walls can be reshaped and formed to fit the client's designs. Lastly, with regards to the products versatility, it can be said that the partition walls are fairly versatile as they can be set up in a variety of ways and situations, especially due to their insulation abilities.

Market Demand

Currently one of the most popular materials for partition walls is drywall which produces potentially lethal hydrogen sulfide gas when left to decompose in landfills. Other popular materials tend to be masonry, timber, or plaster. All of which have environmental issues due to their initial processing, or how they decompose and are managed once they are put to waste. For this reason, a Viberscrete based partition wall would be beneficial towards the market.

Figure 4.2.5: Variant 3



General Description

The Viberscrete building blocks are expected to be the most structurally dependent variant out of all due to their utilization as both the exterior and interior building material and will require the most load bearing performance due to their application. It will follow the default Viberscrete mixture variables since it is vital to uphold the company's vision with the Miscanthus abilities of sound and heat insulation. Additionally, as shown by Figure 4.2.6 below, the blocks will have a dimension of 0.45 meters long, 0.15 meters wide, and 0.24 meters thick which follows a standard building block dimension. Moreover, the block will also consist of a dual square gap/hole from top to bottom as shown below. The purpose of this hole is to be utilized for additional reinforcement within a construction sector through the application of either steel/wooden beams or poured mortar through them. Beams would work on either method of laying brick since the dual hole would line up if the bricks are laid symmetrically on top of one another or as a zig-zag pattern.

Cost

The volume of a single block is 0.01376 m^3, taking into account the dual hole. Thus, this means that each block will cost approximately €12. A standard pallet of bricks/blocks typically hold 500 units which would then equate to €6,000 per pallet.

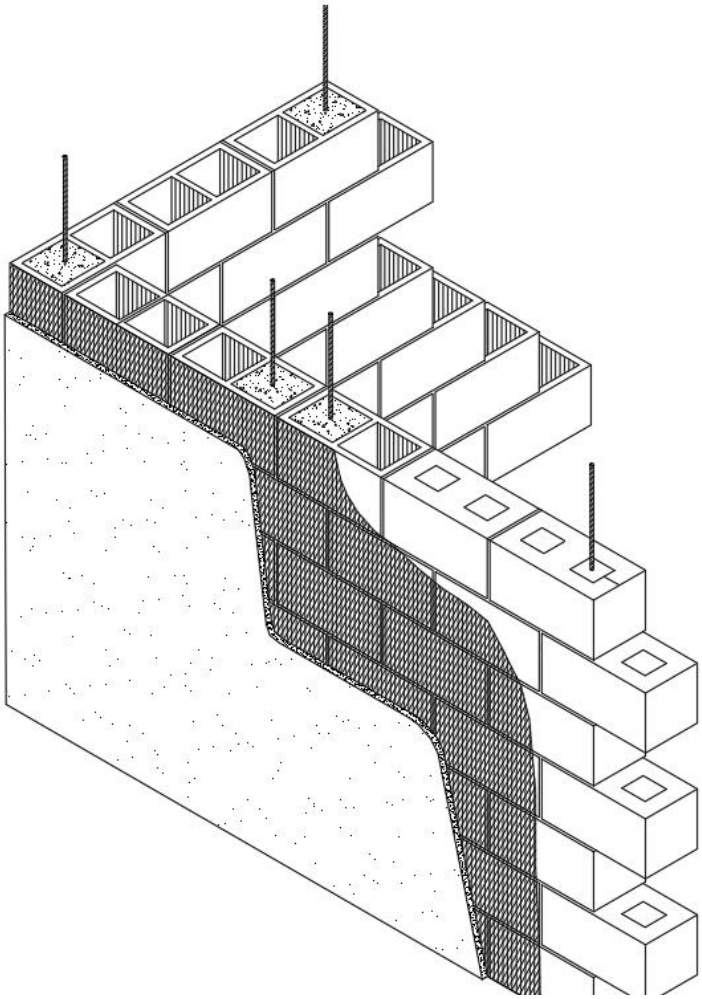
Design

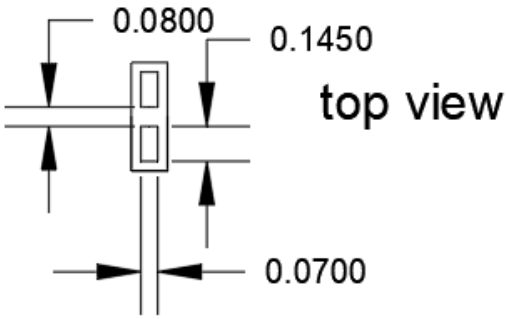
The building block follows a fairly standard design which mimics that of a cinder block. This variant has one of the most crucial safety aspects from all 5 since building blocks would be utilized as semi load-bearing construction materials that must be able to provide a high level of safety and protection towards the customers. Two design choices have been done to achieve that; firstly, the utilization of the default Viberscrete mixture which encompasses gravel, sand, and cement. All of which are sturdy substances when mixed together, and will allow for a strong and stable structural system. Secondly, the gaps/hole designed into the blocks which allow for additional structural elements such as piles/beams or mortar/cement. The blocks are also effectively and efficiently scalable as mentioned before and as

demonstrated on the sketches below. And lastly, they are fairly versatile in their application as they can be used for external or internal constructions.

Market Demand

Masonry bricks and blocks tend to be somewhat environmentally neutral since they do not emit harmful substances, and can be recycled frequently. However, cinder blocks which are made from concrete consume large amounts of energy and also emits severe amounts of CO2. For these 2 reasons, the Viberscrete based building blocks are a fairly advantageous choice since they provide additional abilities over the standard masonry bricks through greater heat/sound insulation, and they are environmentally friendly.





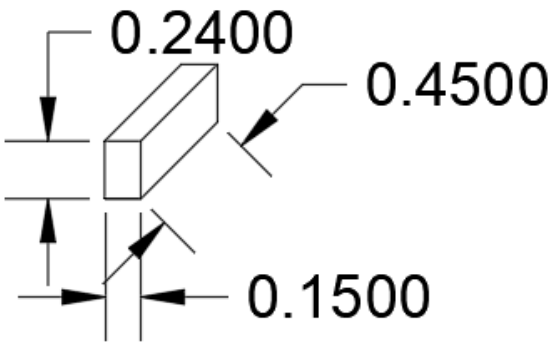


Figure 4.2.6: Variant 4

General Description

Road tiles, or pavers, are another variant which will utilize the default composition of the Viberscrete mixture due to its application and environment which is expected to be fairly rough due to constant movement friction and live load variables from vehicles and pedestrians walking on them in public. Their dimension and a rectangular shape, as seen on Figure 4.2.7 below, are fairly basic with a length of 0.2 meters, width of 0.1 meters, and a thickness of 0.06 meters. Additionally, its placement form will be fairly simple by having it laid on top of a sand bed which is above a crushed rock / cement subgrade. Lastly, the pavers must have sand fillings in-between them.

Costs

The total volume of a single unit/paver is 0.0012 m^3 which would equate to about €1 per paver. A pallet tends to uphold 500 units so in this case one pallet of Viberscrete pavers would be €500.

Design

The safety of this design is quite important since it will be in constant use by heavy-load vehicles and pedestrians in an external environment. For this reason, the default Viberscrete mixture was chosen since it has a greater structural capacity. Furthermore, its overall composition also aims to satisfy a high level of safety since a sand bed on top of crushed rock / cement subgrade will be mantled down below the pavers to create a stable foundation for the load transfers. Additionally, this design allows for an endless standard of scalability and expansion since, as shown below, the design is that of a simple rectangular cuboid which can be repeated. Lastly, this variant is versatile in the sense that it can be placed and applied in different situations such as for open spaces, roads, parking zones, parks, sidewalks, and bike lanes.

Market Demand

Currently, most road pavers are made from asphalt and concrete, both of wish are extremely harmful towards the environment due to the gases they emit during their production. Thus, a more sustainable solution can be utilized, especially for such a large-scale used product.

However, it is vital to mention that BioBound also manufactures Miscanthus based pavers which might affect its behavior in the market as it would be a direct competitor to an already existing product.

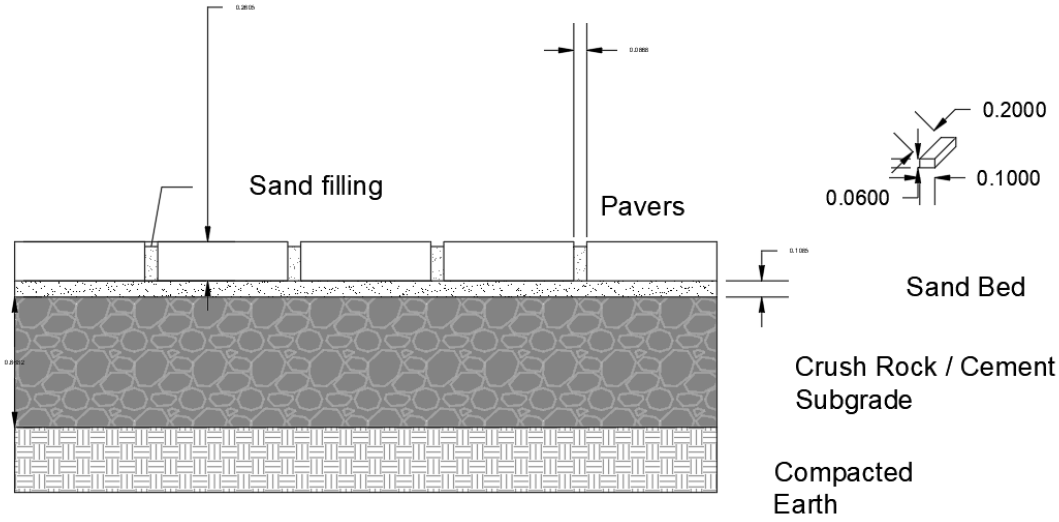


Figure 4.2.7: Variant 5

4.3 Multi-Criteria Analysis Execution

The collected analytical information above will allow for a thorough, detailed, and fairly executed Multi-Criteria Analysis where all 5 variants are pitched against each other to determine which one is the most optimal utilization of Viberscrete depending on the criteria.

As mentioned within the Methodology, the MCA will utilize a grading system based on a 0-to-3 score management, with 3 being the highest a variant could score per criteria. Each criterion holds the same weight as one another, and the variant with the greatest number of points will be the decisive final design for the utilization and application of Viberscrete.

Criteria	Insulation Panels	Floor Insulation	Partition Walls	Building Blocks	Road Pavers
Cost	1	1	2	3	3
Feasibility	2	2	2.5	2	3
Versatility	1.5	1	3	2.5	1.5
Market demand	2.5	2	2.5	1.5	0.5
Miscanthus abilities	2	2	3	3	0
Safety	3	3	3	3	2.5
Design	2	3	2.5	2	2
Client's preference	1	2	3	2	1.5
Total	15	16	21.5	19	14

As shown on the table above, Partition Walls has been fairly selected as the final design for the utilization of Viberscrete. The central points for its selection were its practicality, its costs, the way it can provide insulation abilities in a field of construction which typically do not have insulation, and lastly, the client's preference.

5. Final Design – Partition Walls

5.1 Base Concept

As shown within the preliminary variant's exploration, the objective of the partition walls is to create an environmentally friendly option within a demanding and open market which can be benefitted from the technological advancements of the product through integrated insulation within the material rather than an additional layer.

Furthermore, several preparatory steps must be taken in order to successfully finalize the product. These steps include the concrete properties, structural check, business model plan, as well as a construction and set-up display. It is also vital to mention that partition walls are also known as "non-bearing walls" which is a purpose that this design will follow. However, the estimated compressive strength will be about 5.84 MPa (Vo & Navard, 2017). This means that even though the wall will not be utilized to bear the weight of the ceiling/roof system, it can still handle external loads from living/dead variables such as items being hung or leaned against it. Moreover, its model infrastructure will also allow for additions to the wall system such as electrical outlets/lights/windows.

5.2 Concrete Properties

The final design's selling points are its properties and abilities in terms of sound/heat insulation. Thus, they must be thoroughly described in numerical standards.

Density: All ULMC combinations have fresh densities of roughly 700 kg/m3 as measured by EN 12350-6 (2009). The high porosity and water absorption of MF (Miscanthus Fibers) is the cause of this behavior.

Compressive Strength: The compressive strength of the reference mixture is measured on cubes with dimensions of 150mm x 150mm x 150mm, and the strength at 7 and 28 days (Standard EN12390-3) is 3.99 MPa with 30% 2–4 mm MF replacement of EWG.

Flexural Strength: The flexural strength of ULMC concrete bars measuring 40 mm x 40 mm x 160 mm was tested at 7 and 28 days (Standard EN 196-1) With the addition of 2–4 mm MF, the flexural strengths of Miscanthus concrete ranges from 1.09 MPa to 1.59 MPa.

Acoustic Absorption: Chen (2020) reports that 30% MF has the best sound absorption efficiency. At a frequency of 841 Hz, the sound absorption efficiency hits 0.89. The sound absorption efficiency greater than 0.5 has a band width of 333 Hz, extending from 712 to 1050 Hz. As a result, using 2–4 mm MF in lightweight concrete can increase sound absorption and cover a wider range of frequencies, allowing Miscanthus Concrete to successfully absorb more sound. This is because porous and lightweight materials absorb sound more effectively than thick materials.

Glé, Gourdon, and Arnaud (2010) found that compacted long hemp fibers can have a sound absorption value of 0.9 at frequencies ranging from 400 to 1000 Hz, corresponding to Miscanthus fibers. Additionally, the porosity of ULMC may rise with the addition of 2–4 mm MF, as indicated by the porosity test. As a result, these elements contribute to ULMC's increased acoustic absorption.

5.3 Structural Check

As mentioned before, the final design of a partition wall must be seen and utilized as a non-bearing wall/structure within its potential application, however, a structural check must be accomplished as partition walls may be subject to external loads from attachments such as shelves, hanging items, or leaning items. The wall will **not** support loads from ceiling/other walls, and since it is meant for internal usage, it does not need to account for external variants such as wind/snow forces.

First of all, it is vital to calculate the self-weight per unit of the partition wall, as this will act as the support load for all potential loads that may be placed on or against the walls. This means that as long as the exerted weight from the aforementioned items is not greater than the overall weight of the wall units, it should remain structurally sound.

- 1 Viberscrete Panel unit
  - Dimensions: 1 x 3 x 0.2 m = 0.6 m^3
  - Density: 2050 kg/m^3
  - Unit weight: 0.6 x 2050 = 1230 kg, or 12 kN
- Wooden Frame (Timber – Density of 560 kg/m^3)
  - 2 Horizontal Panels
    - Dimensions: 1 x 0.1 x 0.2 = 0.01 m^3
    - Unit weight: 0.01 x 560 = 11.2 kg x 2 = 22.4 kg, or 0.22 kN
  - 2 Vertical Studs
    - Dimensions: 2.8 x 0.1 x 0.2 = 0.056 m^3
    - Unit weight: 0.056 x 560 = 31.36 kg x 2 = 62.72 kg, or 0.62 kN
  - 2 Bridging
    - Dimensions: 0.4 x 0.1 x 0.2 = 0.008 m^3
    - Unit weight = 0.008 x 560 = 4.48 kg x 2 = 8.96 kg, or 0.09 kN

The total self-weight of a singular unit of a Viberscrete partition wall panel, including the wooden frame is approximately 13 kN whilst the average weight of an average hung item is less than 1 kN, meaning that they can safely be hung/leaned against the wall.

5.4 Business Model

The product's business model with be categorized into 7 different stages:

- Audience
- Business Processes
- Product Resources
- Value Preposition
- Business Partners
- Demand Generation Strategy
- Innovation Ahead

Audience

The central goal of this initial steps is to identify the specific audience which the Viberscrete partition walls would be aimed towards. It is crucial to understand the market's needs and find specific groups of buyers which may be interested in the product because of what it can offer through its insulation abilities, and/or because of its sustainable approach. To be more precise, it is beneficial to select a social demographic and social sector as a target audience since it will facilitate business process due to their already existing interested in similar products. In this situation, the target audience would be sustainable construction companies and retailers such as Alibaba or Buildsupply, projects requiring insulated partition walls, and individuals seeking a sustainable replacement for their accommodations such as young families which tend to have a greater focus for sustainability.

Business Processes

The business processes take into account all functions that the product will provide within its scope of utilization. The product's responsibility is to safely and successfully provide heat and sound insulation whilst creating a divisive section within a room with a sustainable vision being held. These processes must be thoroughly construction, developed, amplified, and advertised towards the specific audience and market in order to achieve a successful business conduct.

Product Resources

A product's resources are an essential part of its initial growth and how far it can reach. This stage takes into account the required resources, in terms of materials, equipment, capital, advertisement, and personnel that the product/business will require to continue its growth and become a reliable product in the market. With regards to the partition walls, it is fundamental to gather the required materials of cement, gravel, sand, water, and specially processed Miscanthus Fibers to allow for a sustainable growth of the product without oversights. Warehouses for storage are also primary resources as they allow the bulk storage of the product alongside effective transportation to the customers.

Value Proposition

The value preposition is defined as what makes the product stand out among its peers within the market. In the case of the Viberscrete partition walls, its ability to offer heat/sound insulation in a thinner structure than standard partition walls are a strong highlight. Furthermore, one of its potential competitors will be Hempcrete's partition walls. However, Viberscrete has a higher compressive strength than Hempcrete which allows for the customers to utilize the walls with less worries about the possible deformations/loads that may occur on them.

Business Partners

Another vital aspect in the growth of the business and the product is developing relations with essential business partners and collaborators that could push the product beyond its expected potential. In the case of the final design, it would be beneficial to the business to partner with a Miscanthus cultivation plantation which could provide a bulk amount Miscanthus plant at lower costs.

Demand Generation Strategy

This fairly late stage focuses on the building interest in the product and company which would assist in generating leads and closing sales effectively. A big part of it is advertising and product management. One way to do this is to promote the partition wall in a variety of websites and markets, such as Alibaba. This will allow for a greater namesake of both the product and the company.

Innovation

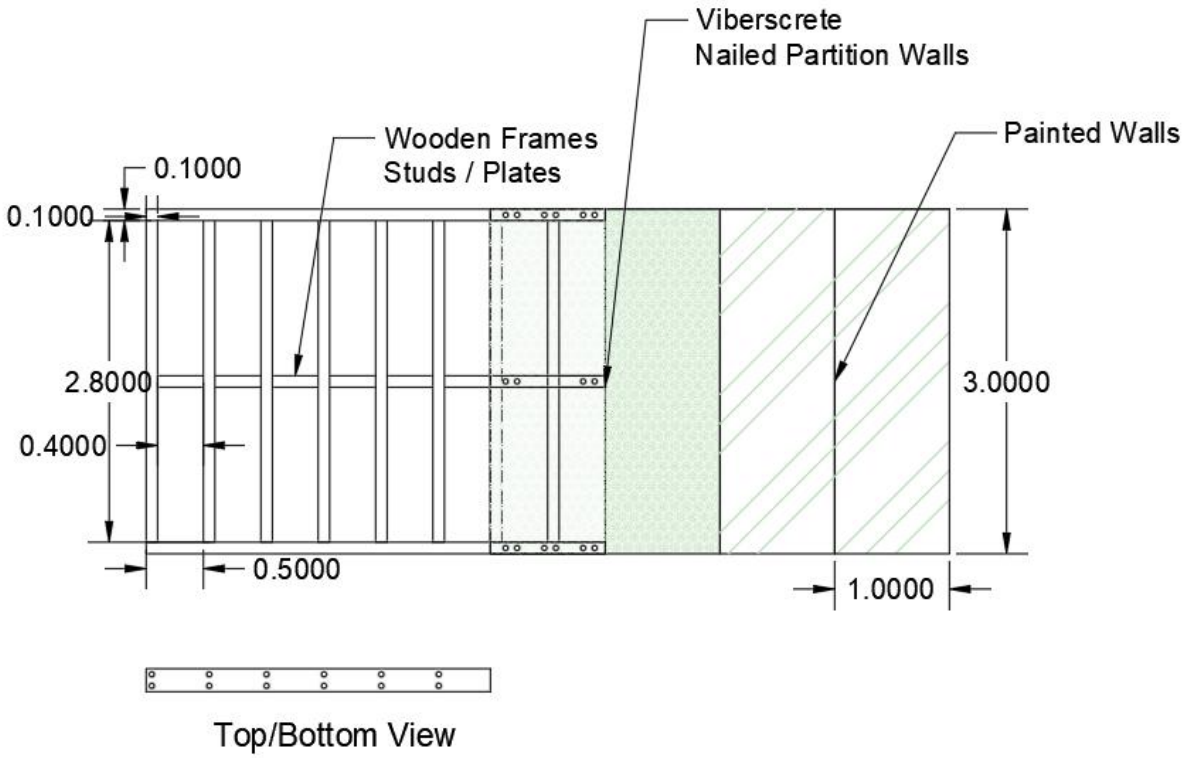
Lastly, a product's innovation is fundamental in its long-term existence within a market because if it were to remain the same it would likely be overtaken by other products with newer technology or innovative designs. In the case of the partition walls, it has a fairly strong design potential and can allow for modifications in its abilities and design for the sake of innovation within the market.

5.3 Construction Set-up

The focus of this chapter is to give a detailed overview of the construction set-up and steps required for the partition walls to be successfully erected. A complete partition wall requires 2 major elements, the wooden frame which upholds and supports the wall, and the façade, also known as the wall which will be the part made of Viberscrete. Items required:

- Wooden Frame
    - Base / Top Plates
    - Vertical Studs 0.5 m center-to-center
    - Bolts/Nails for cojoining them
- Façade
    - Bolted/Nailed on the top, middle, and bottom horizontal studs

Furthermore, the partition board wooden frame must also be screwed onto the floor or another supporting sector since it can not stand on its own. Figure 5.3.1 displays the stages of construction a partition wall as well as the bolt/screw locations for the wall itself.



Structurally speaking, the bolts on the top/bottom plates are extremely important as they hold together the vertical studs which are additionally connected by the horizontal studs in the middle as to not allow for excessive movement or pressure on any vertical beam. Lastly, paint can be added onto the Viberscrete surface wall for a more smooth and aesthetic appearance.

6. Conclusion

The grand objective of this research report can be reiterated by the main research question, which was:

"What final product is the most optimal for the utilization of the Viberscrete high miscanthus concentration mixture within the construction & building field?"

To be precise, the research report aimed at thoroughly understanding the sustainable lightweight concrete market, as well as the potential that Miscanthus-based concrete has as a product within that market, in order to create several potential designs for the utilization of the Viberscrete product. Additionally, the utilization of the Multi-Criteria Analysis was fundamental in reaching this goal as it allowed for the fair analysis and comparison between all preliminary designs. The outcome of the MCA was the partition walls, as mentioned before, which uphold the sustainable vision of Vibers whilst attempting to fill a gap within the sustainable construction materials market.

Moreover, the final decision of utilizing Viberscrete for Partition Walls is fairly satisfactory as the product will be able to benefit customers with its cost saving insulation abilities, as well as the carbon negative aspect of Miscanthus that can combat global warming in the construction and building sector, which more and more people are becoming conscious about. For this reason, the final design also follows the aforementioned terminology behind "most optimal" in the research question, which refers to the product being practical, durable, versatile, with structural capabilities, and that might have expected market popularity.

With regards to the research sub-questions, it is important to answer them directly below:

6. *Which fields of construction & building will all the alternative solutions fit within?*

Internal division walls, sustainable constructions, offices spaces, pre-built spaces.

7. *By taking into account the current bio-concrete market, which sub-field seems to be in demand of different products (walls, pathing, insulation)?*

Currently the sub-fields of pathing, pavers, and blocks seems to be fairly competitive due to various companies attempting new products. However, through research it was discovered that there are not as many partition walls sustainable solutions which offer as strong insulation as Viberscrete.

8. *With regards to the preliminary variants, which of them seem to have direct competition within the sustainable concrete market?*

Road pavers, insulation panels, building blocks, and partition walls all have direct competition due to Hempcrete. However, with marketing and superior insulation abilities, this can be contended.

9. *What external regulations and guidelines must the final product obey for a safe public release?*

It must obey the Eurocode Regulations, the European Committee for Standardization, and the Construction Product Regulations. As well as different rules depending on the country. However, for the most part the Viberscrete material and the partition wall are in the clear for any production and utilization within Europe.

10. *What possible changes within the mixture composition may allow the product to become more optimized for public use?*

As it stands, the default Viberscrete mixture ought to satisfy customers' needs since it provides an astute level of insulation alongside a structurally capable strength for its intended purpose.

In conclusion, this research can be seen as a satisfactory success with regards to finding a suitable application for the Viberscrete mixture within a growing market.

7. Discussion & Recommendations

7.1 Discussion

The discussion chapter is key as it allows the further interpretation and analysis of the final result of this research. One vital point of analysis is the wall's durability and expected service life through its utilization. This observation strongly depends on how the wall is being used, and what environmental circumstances it is in since climate, and loads might alter its lifespan. However, this issue is relevant to discuss because Miscanthus-based concrete is a relatively new material and thus, there is not a lot of information regarding its aging since it has not been experienced.

Another important point of discussion, which also lacks research and experience on the topic of Miscanthus based concrete, is the behavior with water since Miscanthus absorbs water and that could alter its structural abilities. Furthermore, this is dangerous in the usage of Miscanthus concrete in insulation as a freezing/thawing process could expose the material to direct water. The partition walls may be subjected to plumbing pipes within them which could leak and cause internal damage to the overall structure.

Lastly, with regards to the result's implications and why such results matter in the field of construction/building, it must be reiterated that sustainable materials are vital for the future of construction materials which currently do not truly captivate enough attention, especially with the current climate concerns and how much CO2 emissions are caused by concrete production.

7.2 Recommendations

These recommendations will be based on the overall experience in researching this topic, writing this report, and understanding/predicting the product and company's behavior in the future:

- Due to time and spatial constraints no laboratory tests or mockup of the variants were able to be conducted. This would have been fruitful as it would have allowed further primary research information to come to light regarding Viber's own mixture.
- More research regarding the different abilities and expectations of the different Viberscrete mixtures would have also been productive.

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