MYCELIUM; A BUILDING BLOCK FOR PARKSTAD LIMBURG

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ABSTRACT

Global warming, waste pollution and material scarcity due to the current linear economy of the last few centuries. A circular approach is needed that will be beneficial for not only humanity but the whole ecological earth system. Collaboration with natural systems within a holistic approach is offering solutions for these problems. This paper investigates the possibilities of mycelium-based materials form microbiological scale to the regional implementation of Parkstad, Limburg in The Netherlands. Mycelium-based materials are made out of a fiber rich substrate from agricultural waste grown together by the mycelium, the "roots" of a mushroom fungi. The production process need to be done in a sterile environment and can be divided in the phase before growth, the growing phase and the post-processing phase. The properties and qualities of the material is depending on the material characteristics of the fungi and substrate, the environmental conditions during the growing phase and post-manufacturing process. After the growing phase a foam like material can be dried, above 60 °C the mycelium will die and below 60 °C the mycelium will start grow again is the conditions are right. When dried a foam like material that is useful for insulation. When heat pressing the material will become stronger and panels or even bricks can be made. When designing whit mycelium-based materials offer a vary range of materials with different qualities but the temporarily especially in moisture conditions should be considered. The production area can be anywhere if the environment is sterile and can start primitive and can easily scaled up. Within the manufacturing plant the area is divided within the three phases. On small scale the phase before growth consist mainly of lab while storage, growing, drying and post manufacturing takes place outside this lab. However, big scale production the storage, growing, drying and post manufacturing determine the surface and is the lab relatively small in proportion. In Parkstad waste streams like straw, waste wood, cellulose, reeds, heather, stalk and leaf remain can be harvest. Furthermore, Gulpener's brewers' grains waste product form the beer production can be used as a substrate. Zwamburg can be an interesting stakeholder to supply mycelium spawn.

KEYWORDS: *Mycelium, mycelium-based materials, circular economy, temporary architecture, Parkstad*

I. INTRODUCTION

Our current way of consuming is producing a lot of waste which is harming the planet and its inhabitants. Even only a small and prosperous country as the Netherlands is already producing about 60.000 kilotons of waste each year. Even after recycling 78% and using 10% of this waste for other applications, the remaining 12% of waste, 7.200 kilotons per year, does no more than pollute the environment. One of the largest waste producers is the building industry which alone produces 23.752 kilotons of demolition and construction waste material per year. A large proportion (94%) of this waste is already being recycled, but glue and screws makes it hard to recycle this material properly and cost a lot of energy (Afvalmonitor databank, 2018).

Meanwhile we are still depending on natural resources, but these materials are getting scarce and eventually nothing is left for the coming generations. If consumption continues to grow like the way it is currently these natural resources, for instance metals, will be running out in 2040 (Desjardins, 2014). Due to the current linear economy, these useful materials are being burned or are up in landfills polluting the environment resulting to climate change. We need to change this way of thinking and producing into a sustainable circular economy, where waste doesn't exist but is seen as a valuable building material. In line with this idea is the "*cradle to cradle*" approach introduced by Braungart & McDonough (2008), wherein the goal is that materials will always return to the technical or biological cycles they originate from. From this viewpoint we do not simply recycle materials but upcycle the materials into new products that are adding value to the environment. Braungart & McDonough (2018), offer us a positive vision on the future: "*We see a world of abundance, not limits.*

In the midst of a great deal of talk about reducing the human ecological footprint, we offer a different vision. What if humans designed products and system that celebrate an abundance of human creativity, culture and productivity? That are so intelligent and safe, our species leaves an ecological footprint to delight in, not lament?".

When we look at nature, waste doesn't exist. Within the ecosystem, the "*cradle to cradle*" approach is already the norm where the waste of one organism or plant is a resource for other organisms. This fascinating system has been developed and evaluated into perfection over billions of years. Also, we humans are part of this system but tend to ignore this belonging since the industrial revolution. Since this period, we have been taking on the superior power over nature by introducing new technologies and fossil energy supplies. Becoming more independent from nature seems to have resulted into a growing gap between humanity and nature. According to Haraway (2016) and other philosophers and scientists, we had been living in the Holocene; a quite stable geological timescape in which civilization developed. However, we just entered the Anthropocene or the "*age of humans*". This epoch refers to the dramatical effects human activates have on the planet and the increasing centrality of human beings within all scientific and technical activities. Within this era, modern architecture approach housing as a machine to live in. While the architecture itself developed into lifeless buildings that dissociate themselves from the nature by means of air conditioning or artificial light. These buildings often have problems with nature, for example the large glass surfaces provide a lot of heat in the summer and heat loss in the winter. Another way to name this era is the Capitalocene, which asserts that not humans in general but the capital is responsible for the disruption of the ecosystems on the planet.

Against these man and capital centred approaches Harraway (2016) posits a different epoch: "*the Chthulucene"*. In this envisioned timescape, the boundlessness of all living beings comes to the fore. The main point of focus are the biotic and abiotic powers of the earth. Human beings aren't the only important actors that should be envisioned, but from this entangled approach all species and their environments have to become together. Humans are a component within a "*sympoiesis"*, a collective-producing system that do not have self-defined special or temporal boundaries. This view inhabits a vision on how humanity will respond to earth systems. And where we should take our responsibility or what Haraway calls "*Response-ability*" to incorporate the practice of justice and sustainable belonging to survive on this planet. We are all responsible, but all in a different way, for shaping the right conditions where all multispecies will benefit from. All living beings, including humanity, have a different roll within the ecology of the planet. Humans are part of nature, as climate activists during the UN Climate Change Conference in 2015 poetically responds: "*We are not fighting for nature. We are nature defending itself"*.

With the arrival of the mining industry, Parkstad totally lost this entanglement with nature. Parkstad is a region located in the south of Limburg formed by eight municipalities. The region is still known as the Eastern Mining Region (Oostelijke Mijnstreek) and due to its former mining industry, it is a perfect example of the Anthropocenic era. Which makes Parkstad the perfect location to offer an example for this transition towards the *"Chthulucene"*. The mining industry provided great prosperity from the beginning of the 20th century till the 70's. Before that time, agriculture with small farming villages constituted the industry. After closing all mines, many people became unemployed and no new job opportunities where provided which resulted in a decline of the local economy, vacancy and a lack of identity. Migration of the working and younger population followed. This demographic change is still going on resulting in Parkstad being one of the strongest shrinking and aging regions in the Netherlands (IBA, 2015). New circular, ecological and self-build economies could solve these problems.

For a transition towards this *"Chthulucene"* we need to integrate the ecology within the existing building environment and society. As architects we should establish a symbiotic entanglement between ecology and architecture to create alternative adaptable systems. Therefore, a design strategy that is embracing the collaboration with living organisms and that combines ecology, technology and sociology is needed. Through all scales, nature offers a fascinating source of inspiration to find patterns that can be implemented within the design. Everything in nature is in balance by constantly changing and transforming. Opposed to this are our current buildings and projects which are static and designed to last forever. These changing conditions which we find within the ecology should instead be adapted, evolved and incorporated within the design. Architecture now becomes aimed at building things that grow, decay and eventually will disappear in line with the environment they're situated in. This new approach will enable us to live in a more sustainable and balanced way.

This research paper aims to explore the possibilities of applying fungi through different scales within the built environment of Parkstad. By making use of different waste streams of local industries in Parkstad, the "roots" of this living organism called mycelium, can transform this waste into valuable new building materials. In this way a symbiotic entanglement with the ecosystem can be arranged by literally implementing living organisms within the design of a building. This is established by investigating the qualities of mycelium-based materials and ways to build a temporary building that eventually will disappear back into to the ecosystem as nutrients for the soil. Connected to this is the aim to make people more aware of the positive influence of collaborating with living organisms. Hence the main question of this paper is: *What are the opportunities for and how to apply mycelium-based materials from local waste streams within a temporary building in Parkstad*?

This research paper will focus on the mycelium-based materials and how it can be implemented in Parkstad trough different scales from micro and material, component, building to region scale. Starting from the micro and material scale the following sub-questions will be answered: *What is mycelium? What is the role of fungi and mycelium within the ecosystem? What is the production process of mycelium composites? Under what conditions and requirements?* Scaling a bit more up, on building component scale the following sub-questions will be discussed; *what are the advantages and disadvantages? Which factors influence the material qualities and properties? What is the current state of art within the field of mycelium-based materials? What kind of building components can be made for architectural applications? And what are the properties of these products compared to competitive building materials?*

The manufacturing process requirements will be investigated on building scale by answering the following sub-questions; *what are the differences in production scale? How much energy, heat, water, waste, operators and space does the production process need?* The final sub-question will be answered on the largest investigated scale; *What kind of waste streams for the substrate and stakeholders are available in Parkstad?*

In the following chapters the methodology will be described, followed by the results of the research. Finally, the conclusion will discuss the recommendations for architectural application of mycelium within these different scales in Parkstad.

II. METHODOLOGY

In order to achieve a circular implementation of mycelium within the contextual design a holistic approach is needed. Namely the incorporation through different scales diverging from microbiological, material, component, building to regional will be explored. Doing this will safeguard circularity and pays attention to all the complexities that the design will come to deal with within the environment. As showed in figure 2, all aspects are important to be integrated though these different scales. Within this holistic approach, multiple scales and domains are visualized as interacting, having an impact on each other and as of major importance to the whole circular implementation within the context. To establish this circularity, this research will start from the biological and technological aspects of mycelium, understanding their relation and implications in different scale levels, and eventually investigate the relation of mycelium-based materials to architectural incorporation.

Observing, studying and understanding the opportunities and limitations of working with mycelium is needed to design with this material that is produced and acts so differently than conventional building materials. This research is mainly based on literature and case studies, starting with the biological aspects of mycelium within the ecosystem to really understand and collaborate with microbiological organisms within the design. The production process and technical aspects will be studied by looking at existing material tests from literature studies, companies and site visits. On the building scale case studies will be analyzed. Also, a quantitative review of the production process with its flows of in-and-outputs of materials, energy and water will be performed. On the region scale the knowledge of the context will be analyzed to invest the potential of actors and availability of waste streams by potential mapping with help of an atlas.

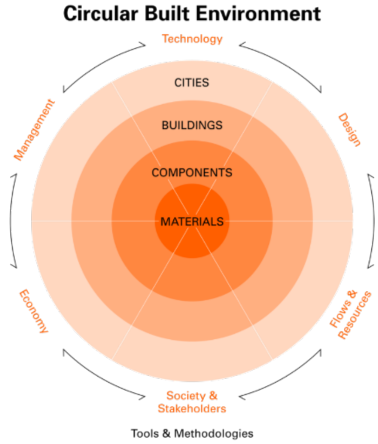

Figure 1. Approaching the research and design trough different scales.
Source: Circular Built Environment Hub, 2018.

III. RESULTS

First the biological and technical aspects of mycelium will be given in chapter 3.1. Secondly chapter 3.2 will describe the properties of different mycelium-based building components. In chapter 3.3 the architectural implementation of the material and its manufacturing process within the built environment will be discussed. The last chapter, 3.4, will explore the material waste streams and stakeholder potentials for mycelium composites within the region of Parkstad.

3.1 Mycelium composites

This chapter will start with a short introduction on the microbiological origin of fungi. The following sections will describe the current research within the production manufacturing processes of mycelium composites.

3.1.1 The microbiological origin of fungi

The first thing that comes to mind when people think of micro-organisms and fungi in particular are things like bad smell, uncleanliness, unhealthiness and mushrooms. These are mainly negative associations, but fungi are extremely important within the ecosystem since they are sources for food, antibiotics, enzymes, clean water and soils.

Living organisms can be classified in three groups within the biological system: bacteria, archaea and eukaryote. This classification is based on DNA similarities (Lelivelt, 2015, p. 25). Fungi are classified as Eukaryote, likewise are animals which means fungi are more related to humans and animals than to plants. Within the branch of fungi there is a great diversity of different species. Around the world about 100.000 fungi species have been discovered, but it is estimated that there may exist 1.5 million species (Reece, Urry, Cain, Wasserman, Minorsky & Jackson, 2010, p. 636). These species can be divided in five major groups of fungi: Chytrids, Zygomycetes, Glomeromycetes, Ascomycetes and Basidiomycetes (Reece et al., 2010, p. 642). The Basidiomycetes are most appropriate for mycelium-based materials because they are able to create much longer and more complex “root” structures than other fungi (Lelivelt, 2015, p. 26). This structure is called mycelium, it is the vegetative and largest part of a fungal. Figure 2 shows how mycelium consists of a branched network of tiny filaments called hyphae. The largest part of these hyphae is usually growing underground. Mycelium composes fungal colonies in and on the soil and in many other substrates. Within the right conditions, from a single mycelium network multiple fruiting bodies called Basidiocarps, generally known as mushrooms, are formed above the surface (Reece et al., 2010, p. 637).

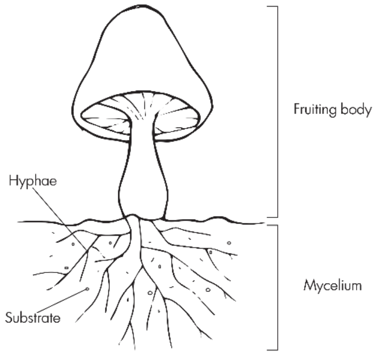

Figure 2. Schematic illustration of the structure of Basidiomycetes fungi.

Mycelium plays an important role within most ecosystems by decomposing organic material into nutrients for the soil as a source of chemical elements for other organisms. Fungi are heterotrophs that don’t need light like plants do but that absorb nutrients from the substrate as a source of energy (Reece et al., 2010, p. 636). First, across the world mycelia generate the hummus soil and hold soil together. Second, mycelium is very strong and can hold up to 30.000 times its mass. It forms networks between plants that function as multi-directional transferors of nutrients. Third, mycelium is the largest found living organism in the world. In Eastern Oregon a massive honey mushroom (*Armillaria Ostoyae*) mycelial mat was found on a mountaintop. This organism covers more than 9.4 km^2 and is possibly more than 2.000 years old (Reece et al., 2010; Stamets; 2018).

3.1.2 Mycelium-based materials and production process

Mycelia are mainly cultivated for the mushroom industry but there are more ways to cultivate mycelium-based materials for different purposes. Blauwhoff (2016, p.44) distinguish three ways to cultivate mycelium: trough static culture, liquid shaken culture and natural growth. These different methods lead to four different types of mycelium. This paper is focused on mycelium composites, the type that is cultivated trough natural growth. Mycelium composites are produced by inoculating an individual strain of fungi in a substrate. The substrate is the growing medium for mycelium that consist of organic fibres. These fibres makes the mycelium composite a more robust material compared to the thin layers of pure or synthetic mycelium produced with static or liquid shaken culture. The mycelium is used as a “natural glue” that grows the substrate with all the loose particles together into a mycelium composite. The mycelium grows well on lignocellulosic biomass, i.e. fiber rich substrates such as sawdust, straw or other agricultural waste streams. Different types of fungi that belong to the Basidiomycato can be used to grow mycelium. The Oyster mushroom (*Pleurotus Ostreatus*), Turkey tail (*Trametes Versicolor*), the Reishi mushroom (*Ganoderma Lucidum*) and the Dryad's saddle (*Cerioporus Squamosus*) are suitable to grow mycelium-based materials. These species have the characteristics to create dense mycelium networks, grow fast and aren’t easily infected by competing organisms which make them easier to grow (Blauwhoff, 2016; Lelivelt, 2015).

The production process of mycelium composite materials can be divided into three phases: the phase before growth, the growing phase and the post-processing phase (see figure 3). The quality and properties of the materials is determined of the characteristics of the substrate and fungi specie within the first phase, the environment within the growing phase and the processing during the last phase (Blauwhoff, 2016; Appels, Camere, Montalti, Karana, Jansen, Dijksterhuis, Krijgsheld & Wöstena, 2018). The growing phase can be stopped by drying or heating the material. When the mycelium is dried, the mycelium stays in a “hibernated” mode and the mycelium will restart to grow again under the right environmental growing conditions. Heating will kill the mycelium and will stop its growth permanently. After heating the mycelium composites, they show similar properties to polystyrene or other foams but after heat pressuring the mycelium composite will be more dense and stronger similar to natural materials like wood (Appels, et al., 2018).

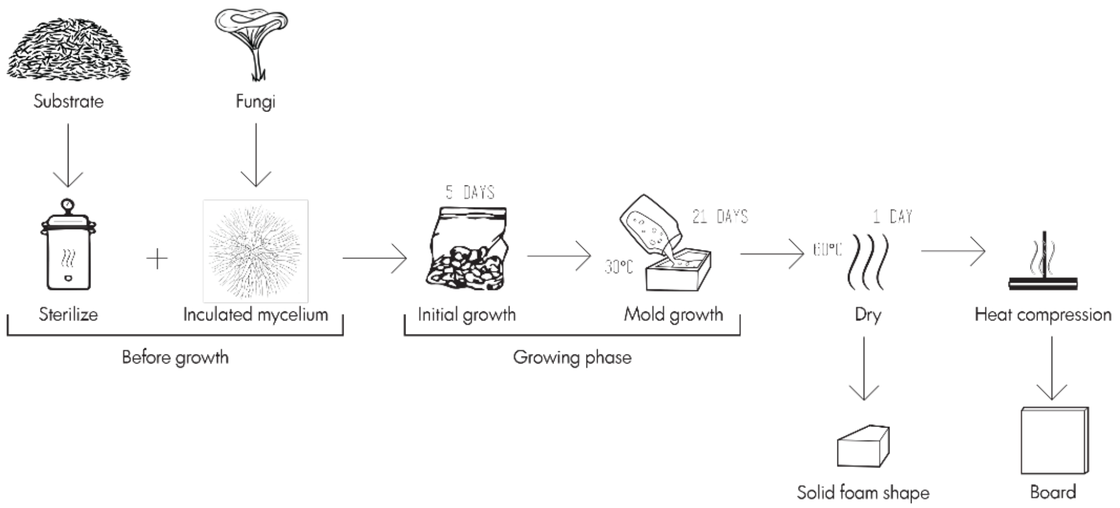

Figure 3. Schematic diagram of the production process of mycelium-based composite.

3.1.3 Manufacturing process of mycelium-based materials

The fabrication process of mycelium consists of different steps. The previous section divided the conventional production process into three phases. This section will give more details and step by step explanations of the manufacturing process, see figure 4. Primarily it is very important to work in a proper sterilized environment to achieve appropriate developments and to prevent organisms from infecting the products. Everything, all the tools, the table and the gloves you wear, can be sterilized with alcohol (70%). Whenever something could have been exposed to non-disinfected surface, it should be disinfected again (Poncelet, 2018).

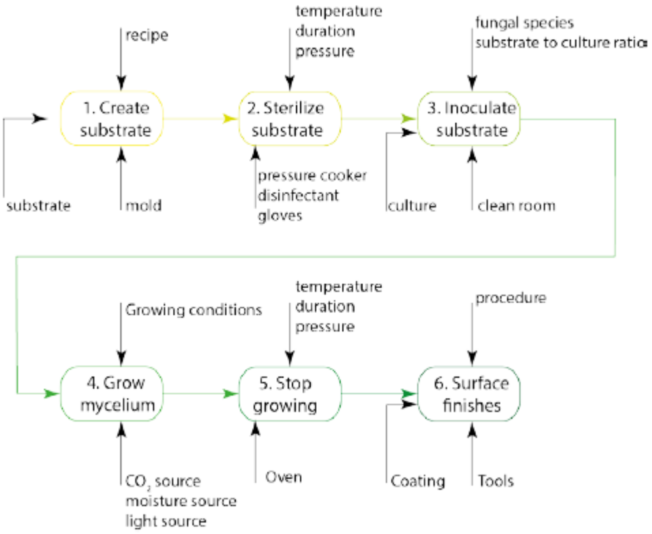

Figure 4. SADT-scheme of the manufacturing process.
Source: Lelivelt, 2015, p.29.

When the environment is sterilized the first step is to sterilize or pasteurize the substrate, depending on the strength of the mycelium specie and the expected organisms that may be present in the substrate. Sterilization can be done by high pressure cooking up to a temperature of 123°C and a pressure of 100 kPa for 20 minutes. This process is suitable to kill all organisms which reduces the chance for infection of the material but it will also kill useful organisms and is an energy consuming technique. A preferable technique is pasteurization. When the substrate is pasteurized, it will be heated up to 60-80°C for 60 minutes. Most harmful organisms will probably die and useful ones will survive. Although there is no absolute certainty, pasteurization is easier and cost less energy (Lelivelt, 2015, p. 30; Poncelet, 2018).

Simultaneously the pre-grown mycelium spawn must be prepared. The spawn is a readily developed mycelium network in an energy and nutrient rich medium, like grains and sugar. In this the mycelium can already grow a strong network and will be less prone to contamination. In order to create very pure and reliable spawn, you need to work under very specific conditions that suit the fungi strain. This step is preferably done by specialists, and can be supplied by different local mushroom suppliers (Lelivelt, 2015, p. 30; Poncelet, 2018).

The next step is mixing the pre-grown spawn and the sterile substrate, this process is called inoculation. The inoculated substrate can be transferred to a mold and should be stored in a controlled environment where light, temperature and moisture are managed and maintained for optimal growing conditions. These conditions vary depending on the used fungi specie. However, in general, most species grow well in the dark with a temperature around 30°C and a humidity around 60-65%. The temperature can vary from 15°C to 35°C, the lower the temperature, the slower but possibly stronger the material will grow. Whereas at a higher temperature, the mycelium will grow faster but the risk of infections will be higher. The material is fully colonized in about 2-3 weeks, depending on its volume (Blauwhoff, 2016; Montalti, 2018). When a white layer appears on the surface, the mycelium is grown through the entire substrate and the mold can be removed. The shaped material can be placed on a clean surface and grow under the same conditions for another 5-7 days (Poncelet, 2018).

When a very specific shape of mold is desired which can't be properly sterilized, the substrate needs to grow in bags before it can be transferred to the mold for further development. The mycelium will colonize the substrate by using its nutrients for initial growth and will develop dense networks within 5 days (Blauwhoff, 2016, p. 67; Tazelaar, 2017, p. 38). Currently, the molds are usually thermoformed and made of PETG. Although molds made of other materials could be used as well, PETG molds are preferred because these are easier to clean, seal, for following the growing process and maintaining humidity. The molds can be used again if they are properly sterilized (Montalti, 2018).

After the growing phase, the created composite needs to be dried to kill the mycelium and prevent further growth. When the material composite is heated at a temperature above 60°C for a few hours depending on the volume, all organisms are killed and further growth is permanently stopped. Under a temperature of 60°C the mycelium "*hibernates*", the mycelium will grow further when the conditions are right and mushrooms can sprout when the material is exposed to light (Blauwhoff, 2016, p. 68). Montalti (2018) recommends to pre-dry the composite in the sun or in a room with a high temperature till it's almost dry. After the pre-drying, the mycelium composites will be heated at a temperature between 70 to 90°C to be certain the growing process has stopped. Using a higher temperature risks changing the quality or burning the mycelium. The heating process can take a day to dry a very thick material to the core. But in general, the heating process of a mycelium-based material with a thickness of 5 cm takes about one to one and a half hours.

In the post-manufacturing phase, the material can be further shaped, heated or given surface treatment to achieve the appropriate properties of the end product. In order to get more stiff, dense and stronger qualities, the material can be heat (150°C) and cold (20°C) pressed for 20 minutes at F<30kN (Appels, et al., 2018). The surface can be treated with oils or waxes to make the material more water resistant, which is comparable to wood treatment. However, this is not the best option since these layers need to be maintained. Natural polymers like shellac can be a good permanent solution but are very expensive. However, shellac will create a layer that will close the pores of the material which makes the material unable to ventilate (Montalti, 2018).

3.2 Mycelium-based building components

This chapter will describe how mycelium-based composites become building components for architectural applications. The advantages and disadvantages of different properties compared to conventional building materials are listed in this section. Also, the influence of the manufacturing process on the quality and properties of the products are clarified. The last sections will provide the current material developments of three different building products with illustrative case studies.

3.2.1 General advantages and disadvantages

The most important quality of mycelium-based materials is the biodegradability that is significantly higher compared to conventional building materials. When mycelium-based materials are exposed outside on the ground it will be composed in about six weeks and returns to the ecosystem as a useful nutrient for plants. But if the material is maintained under stable and favorable conditions, it has a lifespan of approximately 20 years. This property makes the material perishable and temporary. Compromises can be made by adjusting the materials into not fully natural ones to make them more durable. In our current economy, where we believe everything should last forever, these kinds of compromises can be needed. But seen from an ecological point of view everything that exists is temporary which makes compromising on the natural state of the material not a desirable option (Ecovative, 2018; Montalti, 2018). Furthermore, the energy consumption and embodied emissions of mycelium-based components are considerably lower compared to conventional building materials. For example, Burzynski (2016) calculated that its costs 4,667 MJ of energy and releases 462 kg of CO_2 into the atmosphere to produce 1 m^3 of polystyrene. While the production of 1 m^3 of mycelium-based material uses 652 MJ and releases 31 kg of CO_2, see figure 5 & 6. This is because mycelium-based materials are made of agricultural wastes that are locally available and because of the fast-growing qualities of mycelium, while polystyrene uses petrochemical extraction. In addition, there´s no risk on environmental and health damages during the manufacturing process because no toxic chemicals are used or produced.

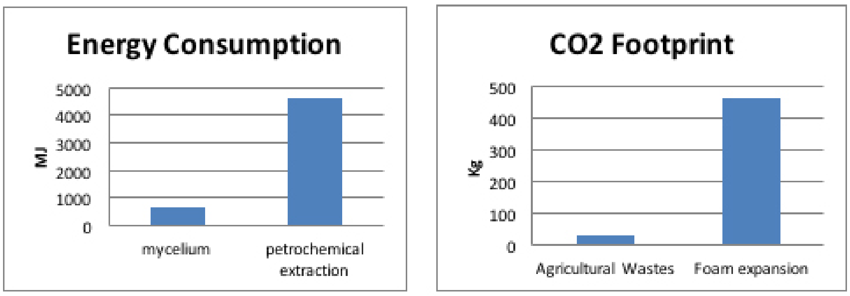

Figure 5 & 6. Energy consumption and CO_2 footprint of mycelium compared to petrochemical foam. Source: Burzynski, 2016.

In general, mycelium-based materials grow fast and easily into any shape which makes the costs of the manufacturing process quite low. Furthermore, mycelium-based materials have a low density, low thermal conductivity and are naturally fire resistant. By compressing the density will increase but the strength and stiffness will increase as well. Relative to its weight, mycelium is stronger than concrete. Although this is misleading because the compressive strength of around 30 psi is far from comparable to the 4000 psi of concrete. Another advantage is that the fungi recognizes itself, so when placing individual living (dried below 60°C) bricks together they grow together into the appreciated solid form. This self-binding property negates the need to use toxic glues.

However, the material has some weak points which need to be taken into account. The most important disadvantage is the fact that the water resistance of mycelium decreases overtime which makes it vulnerable to mold and humidity (Critial Concrete, 2018). Moreover, the materials can be easily infected during the production process which can make things complicated. Another disadvantage is the bad association's people might have with fungi which can make it harder for mycelium to be socially accepted, despite the fact that these materials are odorless and healthy.

3.2.2 The manufacturing influences on the materials properties

As mentioned in previous chapters, the material qualities and properties of mycelium-based materials are strongly related to material characteristics of the fungi and substrate, the environmental conditions during the growing phase and post-manufacturing process. The study of Appels et al. (2018) analyses these fabrication variables in relation to the properties. Within this research nine material samples (see figure 7), are the result of growth of *Trametes multicolor* on sawdust (TBN) and straw with (TRH) or without (TRN) heat pressing and growth of *Pleurotus Ostreatus* on cotton with heat pressing (PCH), cold pressing (PCC) and without pressing (PCN) and on straw with heat pressing (PRH), cold pressing (PRC) and without pressing (PRN). The results of these study’s shows that the mushroom strains have different influences on the colonization level and the thickness of the “*fungal skin*”: air-exposed mycelium. This colonization level and skin thickness as well as the material characteristics of the substrate affect the stiffness and water resistance of the materials. But the stiffness, strength and homogeneity mainly increase by heat pressing the materials. After the heat pressing process the performance of the materials transforms "*from foam-like to cork- and wood like*". Furthermore, the visual appearance remarkably changes due to these different parameters, see figure 7.

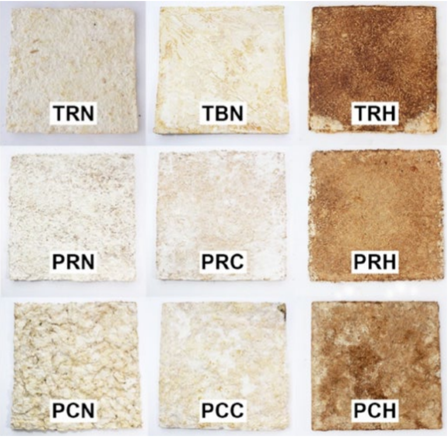

Figure 7. Mycelium-based material samples.
Source: Appels, et al., 2018, p. 66.

The introduction of mycelium-based materials was just about a decade ago, we are now still standing at the beginning, and the more we experiment with the material and evolve within these production processes the more opportunities for the use of this material will arise. The following sections will describe the current state of three different architectural applications. The various range of properties that can be achieved with these different manufacturing variables will be compared to competitive building materials.

3.2.3. Material properties of mycelium-based insulation foam

Evovative was the first player on the field of mycelium-based materials. In 2007, Eben Bayer and Gavin McIntyre started this company based in Green Island, New York. They originally started with insulation made of mycelium and agricultural waste but the past few years they've changed their focus mainly on compostable packaging. Ecovative produced different types of thermal and sound insulation foam; Mushroom® Insulation (see figure 8), MycoFoam, and Greensolation. The average density and strength of these foams is competitively compared to other foams. Unfortunately, they have protected patents on the manufacturing process and the specific strains for the different products they use. Table 1 shows the properties of Ecovative's insulations foam (Ecovative, 2018b) compared to EPS foam.

Within Europe is Mogu an active player in this field. The Italian firm is represented by the Maurizio Montalti. Montalti was student at the Design Academy in Eindhoven and did his master thesis about the potential of mycelium in collaboration with the Microbiology department of Utrecht University. Since his graduation project in 2010, Montalti has been working with an interdisciplinary team to explore and design creative projects in collaboration or inspired with living systems and organisms, known as Officina Corpuscoli. Mogu has developed different materials that will be on the market soon, unfortunately the properties of their products are not available yet. Figure 9 provides a promising sample of their soft insulation material grown by the Oyster mushroom on a cellulose substrate.

In the Netherlands, in the past few years a few entrepreneurs started businesses or experimental labs with mycelium-based materials. Studio Klarenbeek & Dros are the first ones to have started 3D printing with living mycelium. Since 2010 they started developing this technology, in 2014 the design of the Mycelium Chair became famous and now they have started a company called Krown. Krown is selling their own designed products and DIY grow kits but also products from Ecovative with the aim to bring the applications of mushroom packaging to Europe (Krown Design, 2018). In 2017 the Centre of Expertise Biobased Economy and Avans Hogeschool opened a research lab for the applications of fungi within the building industry in Rosmalen. Davine Blauwhoff is one of the main researchers in this lab, she graduated in 2016 at the TU Delft on the topic "*Mycelium based Materials*" and is working there with an interdisciplinary team of researchers and students (Avans

Hogeschool, 2017). Fungalogic is a young start-up in Den Hague, since 2017 they have been doing research and have been creating building materials out of agricultural waste and mycelium. They recently designed a meeting room out of mycelium insulation components, built at the ministry of Economic Affairs in The Hague (Fungalogic, 2018).

Figure 8 & 9. Insulation of Ecovativ (left) and Mogu (right).
(8. Ecovative, 2018b and 9. own picture made at Fungalogic[1])

Table 1. Properties of mycelium-based insulation.

	Ecovative	EPS foam
Fungi strain	Patented	-
Substrate	Patented	-
Density (kg/m^3)	122	30
Thermal Conductivity/R-value (W/mK)	0.039	0.035
Compression (kPa)	124	124
Elasticity (kPa)	1138	242
Tension (kPa)	234	208
Compostability (days)	30	Forever
Water Vapor Permeation (dry cup)	30	3.5
Flame Spread Index	20	<25
Smoke Emission	50	<450

3.2.4. Material properties of mycelium-based panel

Another material that Evovative launched are the wood-like panels. Ecovative produced different types of panels staring with MycoBoard (figure 8) and MycoComposite (figure 9). After 4 days of mycelium growth the materials are heat pressed into these solid panels. The average density, stiffness and strength of these foams is competitively compared to MDF or particleboard. Table 2 shows the properties of Ecovative's MycoComposite 570 (Ecovative, 2018a) and MycoBoard compared to MDF. The results of the proprieties may change because Ecovative is still developing their materials but protected patents and closed sources are making it difficult to follow these latest developments.

Figure 10 & 11. Mycoboard (left) and MycoComposite (right) of Ecovative.
Source: Ecovative (2018).

Table 2. Properties of mycelium-based panel.

	MycoComposite	MycoBoard	Particleboard
Fungi strain	Patented	-	-
Substrate	Aspen chips	-	-
Density (kg/m^3)	190	720	720
Thickness (cm)	5	-	-
Thermal Conductivity/R-value (W/mK)	0.061	-	0.07
Compression (MPa)	0,2 - 0,41	-	-
Elasticity (MPa)	3,4 - 4,2	-	-
Tension (MPa)	0,04 - 0,14	-	-
Flexural Modulus (MPa)	10 - 16	3275	2413
Flexural Strength (MPa)	0,12 - 0,21	15	12,4
Internal Bond (MPa)	-	0.58	0.45
Screw hold (lbs)	-	122	225
Fire Resistance	-	Class A	Class C

3.2.5 Material properties of mycelium-based brick

For the art installation of MoMa PS1 in 2014, the architect David Benjamin and his architectural team The Living designed a temporary tower out of mycelium bricks called the Hy-fi. Ecovative manufactured these 10.000 bricks to construct this 12-meter-tall tower. The bricks are grown in 5 days and dried below 60 °C so the mycelium is still living. After de event the bricks where disassembled, broken up and placed in a composting bin. Within six weeks the bricks returned into high quality soil for the local gardens. Figure 12 shows how the bricks are designed to function as an ecosystem; from growth, decay to disappearance (Shaw, 2014). Although these bricks just have a compressive strength of 0,2MPa, the low density of 43 kg/m^2 of the bricks makes it possible to bear its own weight (Interesting Engineering, 2017).

Figure 12. Mycelium bricks of the Hy-Fi tower at MoMa PS1 in New York.
Source: Shaw, 2014

Another similar company is MycoWorks based in San Francisco which started in 2013 and was founded by Phillip Ross. Ross originally cultivated mushrooms but became fascinated by the mycelium roots as a way to construct materials. He started to experiment, grow and design with mycelium processes and has become an artist and inventor within this field. In 2009, he designed a small teahouse called the Alpha (figure 14) as his first piece of "*Mycotecture*" which has been exhibited around the world. For the bricks of this piece of art he used the Reishi mushroom and a mix of sawdust and wood chips as substrate (Roth-Johnson, 2014). Furthermore, Ross and a team of researchers (Travaglini, Noble, Ross & Dharan, 2013) investigated the mechanical behavior of mycelium composites. Table 3 shows their results of the properties of their brick compared to Ecovative's brick for the Hi-Fy and a general concrete brick.

Figure 13 & 14. Mycelium brick (left) of the Alpha tea house (right) by Phillip Ross. Source: Roth-Johnson, 2014.

Table 3. Properties of mycelium-based brick.

	Ecovative[1]	MycoWorks	Concrete brick
Fungi strain	Patented	*Ganoderma Lucidum*	-
Substrate	Corn stalks	Wood chips	-
Density (kg/m^3)	43	318	2,400
Compression (kPa)	0,2	0,49	28 - 70
Modules of Elasticity (MPa)	-	1,3	1400

3.3 Manufacturing buildings

This chapter describes how mycelium-based materials can be manufactured and researched on a small and large scale. The current mycelium labs of Avans Hogeschool in Rosmalen, the startup growing lab of Fungalogic in Den Hague and the factory of Evocative will be discussed and compared. The requirements of energy, space, materials, water and operators are compared. A visualization of this data can be found in the appendix.

3.3.1 Manufacturing plants

As mentioned in previous chapters, the production process requires a clearly organized and defined space with different production environments. Clear steps and procedures within the production chain thus define the organization of possible large-scale production. The three phases of mixing and molding the substrate with the mycelium and water, the growing phase and the post-manufacturing all need different environmental requirements within the production chain. It is very important to ensure bacteria free, clean working environments during the manufacturing process.

Currently the production of mycelium products for various usage is still occurring on a small scale. An example of this small-scale production are the mycelium labs of Avans Hogeschool in Rosmalen and Fungalogic in Den Hague. These labs are small secluded spaces placed within the building. The lab of Avans Hogeschool is made of wooden panels and is about 20 m^2 (see figure 15). However, the lab of Fungalogic is a more primitive plastic tent that is about 10 m^2 and can be easily replaced (see figure 16). To keep the lab clean and bacteria free, the operators need to wear gloves, lab coats and their hair tied. An extra space of approximately 50 m^2 is needed for the storage, growing, drying and post manufacturing of mycelium. The fridge with the mycelium spawns and closet with bins filled with different substrates are stored outside the lab to prevent infections. Avans Hogeschool has a small high-pressure boiler inside the lab while Fungalogic has a bigger boiling tube outside the lab to sterilize the substrate. The mixing and molding phase takes place within the lab under sterile conditions in the vicinity of a vertical flame to kill bacteria. The mixture consists of 5% mycelium spawn and 30% fiber and 65% water is needed during the whole process. The inoculated substrates will be stored in a sort of refrigerator for higher temperatures where the temperature, moisture and light are maintained during the growing phase. Avans Hogeschool has an inoculation "refrigerator" within the lab while Fungalogic has small a "greenhouse" like inoculation room outside the lab. After a few days when the mycelium is fully grown, the materials are dried. For this purpose, Avans Hogeschool has a small oven inside the lab where they dry the material for one day above 60°C to prevent further growth. Fungalogic has a small oven but if possible, they dry the material in a local greenhouse as some sort of solar oven to save energy. A solar oven uses the sun as a source of energy to dry the materials to a certain temperature (Montalti, 2018). The energy consumption of the labs is about 10 kwh/hr.

Figure 15 & 16. Small scale production labs in Rosmalen (left) and Den Hague (right).

Different from the experimental setting of the small-scale production, companies like Ecovative (see figure 17) or MycoWorks are focusing on a much larger scale of production. Similar to the small-scale production process, this industrial factory can be divided into the three phases of cleaning, mixing and molding, the growing phase and the post-manufacturing phase that all need different environmental requirements. Based on measurements on google maps and photos (see appendix) of Ecovative, the company's manufacturing plant is about 3.000 m^2. In 2016 they opened their second factory of 1858 m^2 (Ecovative, 2016). The sterilization of the environment within the factory is controlled through various sanity measurements.

While on a small scale the cleaning, mixing and molding phase is the central place, on the big scale most space is mainly needed for storage. The process starts with the agricultural waste supply from local farmers that need space for storage. From the storage the substrate will be placed on a production line that is running through the lab that first sterilizes the substrate, then inoculates the substrate with the mycelium and finally puts it in molds. The filled molds will be stored under the right growing conditions for a few days. Depending on the amount of materials and days of growing the volume that is needed to store the materials during will increase exponential the growing phase. After the growing process, the molds can be removed and cleaned to be used again, while the grown materials will be dried for 1 day in the drying space. Depending on the needed properties the materials can be heat pressured to make the materials stronger or CNC milled. Before the materials are delivered to the client a final storage space for products is needed.

The manufacturing process is almost fully automated. There are 46 plant operators working in the factory of Ecovative, which is less compared to the 167 lanes that are running during the process. This automatic manufacturing process cost a lot of energy, 95899 kwh per hour. However, 40 tons of substrate, 31 tons of water, 4 tons of nutrient and 0,25 ton of mycelium spawn is consumed per hour to produce 215 m^3 of mycelium-based materials per hour (see appendix).

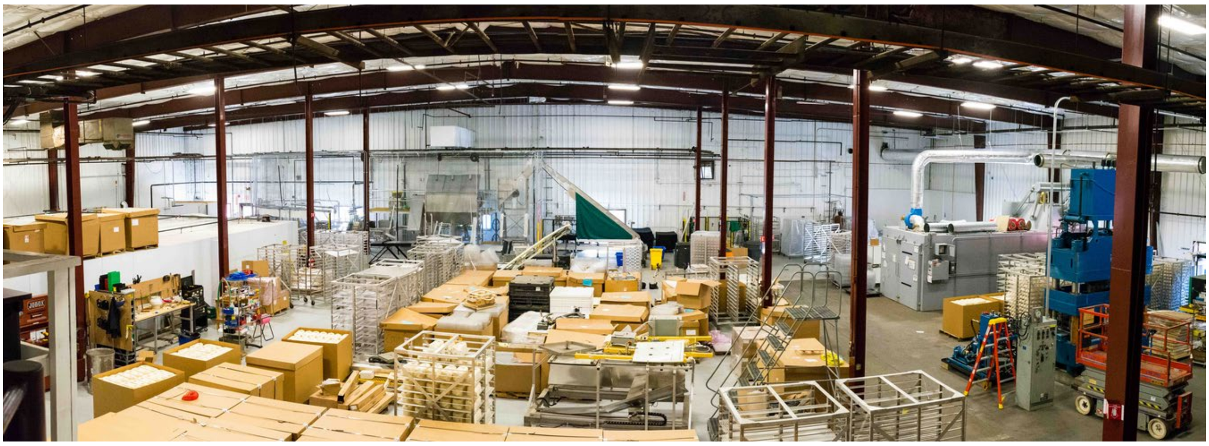

Figure 17. Large scale production factory of Ecovative in New York.
Source: Ecovative (2016).

Based on the small- and large-scale case studies the production process is always divided within these three phases of cleaning, mixing and molding, the growing phase and finishing with the post-manufacturing phase. Staring from a primitive lab the production process can be easily scaled up as long as there is enough space for storage during the growing and drying phase. When scaling up, the space for storage during the growing and drying phase is growing exponentially compared to the size of the lab. The production environment is very important to achieve the appropriate qualities and properties of the materials. So, the better the space is organized and closed, the better the material. However, the production lab can basically be placed anywhere like the labs in Rosmalen and The Hague.

3.3 Local waste streams and stakeholders in Parkstad

This chapter investigates the potential waste streams available in the context of Parkstad Limburg that could be used as a source for the substrate to manufacture mycelium-based materials. Local supply of substrates is essential to reduce the carbon footprint and upcycle waste into valuable materials. This section will analyze potential stakeholders and material availability on the regional scale with help of mapping and visualizations. The used data of CBS (2018), emails, calculations and further visualizations can be found in the appendix.

3.3.1 Stakeholders

Before the mining industry from the beginning of the 20th century till the 70's, the industry in Parkstad consisted of agriculture with small farming villages. As showed in the potential map of figure 18, a large part of this agricultural land use still remains. Especially the west side of Parkstad within the municipality of Nuth, Voerendaal and Simpleveld have potential to find farmers to collaborate with as an agricultural waste supplier.

Located in Schimmert the mushroom farmer Zwamburg is growing mushrooms on wasted coffee ground of local restaurants. Zwamburg is an interesting stakeholder to contact for local mushroom spawn suppliers, accompany for knowledge and other collaborations to strengthen each other's identity. Another interesting stakeholder is Gulpener, an organic beer brewery in Gulpen closely located to Parkstad. During the beer production a large amount of brewer's grains is produced as waste stream which might be interesting to grow mycelium on. The water treatment plants (RWZI's) are indicated in blue on the map, new filter systems in the near future can filter cellulose or toilet paper form the sewage system. The recycling centres of Rd4 in Heerlen, Kerkrade, Brunssum and Landgraaf are interesting suppliers for wood waste, sawdust and other kinds of organic demolition waste. Staatsbosbeheer can be an interesting stakeholder for reeds, heather, stalk and leaf remains.

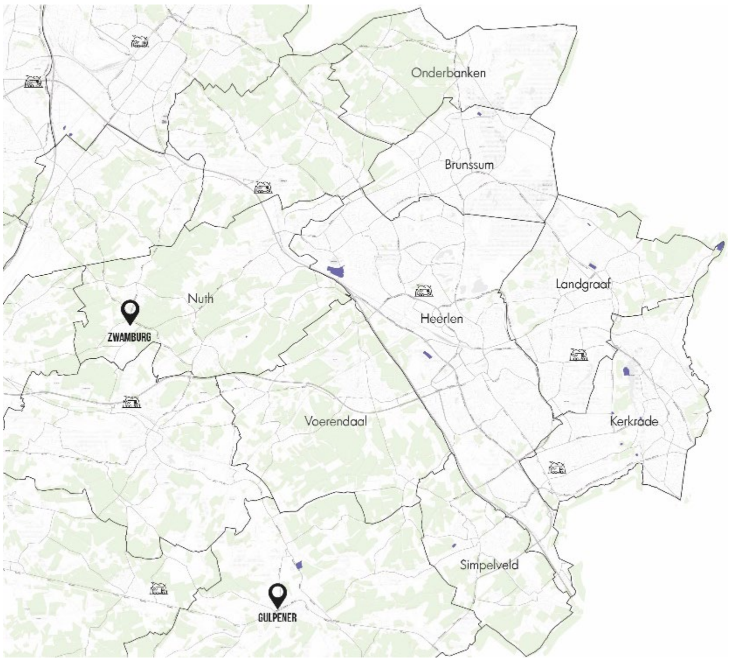

Figure 18. Potential map of Parkstad.

3.1.2 Waste streams for substrate

The following sections will give further quantitative details per substrate supplier.

Straw

Parkstad is using 1.656 hectares of land for cultivating cereals (CBS, 2018a). As shown in figure 19, Voerendaal, Nuthe, Simpelveld and Onderbaken are the main suppliers of these cereals. Depending on the type of grain, in the Netherlands we harvest roughly about 8 tons of grain per hectare. Roughly 1 hectare produces about 4 tons of straw. So, 1/3 of the cereal harvest can be seen as crop waste. So, 1.656 hectare is 6,625 kilotons straw or 1.332.480 hay bales (1ton = 50 bales) is produced in Parkstad per year.

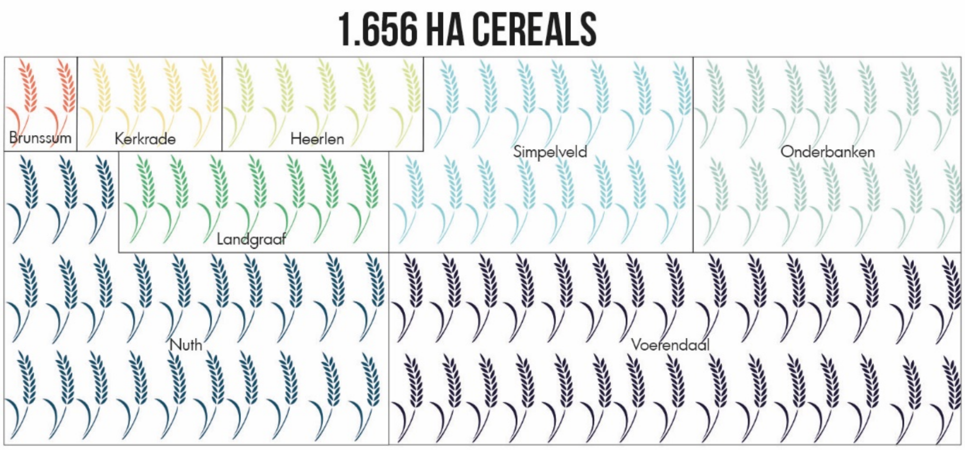

Figure 19. Amounts of agricultural land use for cereals in Parkstad per municipality.

Currently, the straw is used for the cattle industry. One cow is consuming approximately 1,5 tons or 75 hay bales per year. The cattle industry of Parkstad has about 10.000 cows that are consuming 15 kilotons of straw or 750.000 hay bales. A goat is using 0,5kg straw per day so 178 kg per year. Parkstad has 2313 goats using 411714 kg straw or 20586 hay bales per year. A pig is using between 60kg (meat pig) till 350kg (breeding sow) straw per year so about 150 kg per year. Parkstad has 7821 pigs using 1173150kg straw or 58.658 hay bales per year. This means that there are 503.236 hay bales of straw (38%) left for other uses.

Brewer's grains
Gulpener is producing 50.000 kg on average of brewer's grains as a rest product per week. On yearly basis about 2,6 kilotons of grains is produced by the brewery. The beer grain is suitable for human or animal consumption. 99.9% of the brewing goes to cattle farms as animal feed. Just a really small part (0.1%) of the brewing goes to a local bakery that bakes beer bread. The brewer's grains consist of: barley (70%), wheat (18%), rye averaged (4%), spelt (4%) and oats (4%).
Furthermore, they also produce liquid yeasts in addition to beer toast. This is a residual flow from the yeast tanks and is 1000 kg per week on average. This liquid yeast is also disposed of as animal feed.

Cellulose
Per water treatment plant (RWZI) about 5000 kg cellulose per day can be filtered with the help of the new filter systems. In the near future an installation that is using this new filtration method can harvest 1.8 kilotons of cellulose per year. Parkstad has 13 RWZI's of different sizes and some are not working so it is hard to say how much cellulose could be harvested.

Wood & sawdust
In Limburg about 29 kilotons waste wood per year is produced (CBS, 2018b). Parkstad will produce approximately 25% of this waste wood, so about 7 kilotons can be used.

Biomass of reeds, heather, stalk and leaf remains
In Parkstad about 0.1 kiloton of reeds and heather per municipality per year is harvested. This also applies to the harvest of stalk and leaf remains. In total, Parkstad is collecting approximately 1 kiloton of reeds and heather and 1 kiloton stalk and leaf remains per year (RIVM, 2018).

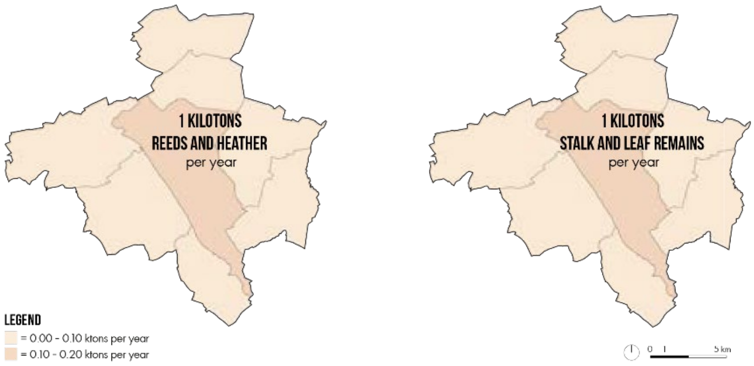

Figure 20. Amounts of reeds, heather, stalk and leaf remains in Parkstad per municipality.
Source: RIVM (2018).

Other self-grown natural fibres
Other interesting natural fibres that are very suitable as substrate are hemp, elephant grass and flax. These fibres are a sustainable alternative because it can store CO^2, can be locally grown and are fast growing.

IV. CONCLUSIONS

In a time where human kind is polluting the earth with waste, by abusing natural resources and hereby causing global warming, we need to change our way of living. When we look at nature, waste, scarcity and pollution doesn't exist. We need to take what Haraway (2016) calls the "*Response-ability*" to incorporate the practice of justice and sustainable belonging to survive on this planet. Humans are part of the ecosystem of the planet and instead of feeling superior to nature. We need to entangle with nature because as climate activists said; "*we are not fighting for nature. We are nature defending itself*".

As architects we should establish a symbiotic entanglement between ecology and architecture to create alternative adaptable systems. Therefore, a design strategy is needed that embraces the collaboration with living organisms and which combines ecology, technology and sociology. With the arrival of the mining industry, Parkstad totally lost this entanglement with nature. Within this research a new way to collaborate with nature within the build environment of Parkstad has been explored by investigating the possibilities of mycelium though different scales for architectural applications.

In summary, mycelium is a living organism that is more related to humans and animals than to plants. Mycelium are the "roots" of a fungal and play an important role within the ecosystem by forming a network in the soil that decomposes organic material into nutrients as a source of chemical elements for other organisms. When the conditions are right mushrooms can sprout out on the surface. Mycelium composites can be cultivated trough natural growth of the mycelium on a substrate that consist of organic fibers.

The production process of mycelium materials can be divided into three phases: the phase before growth, the growing phase and the post-processing phase. First, the used substrate must be sterilized by high pressure boiling to be sure the material will not be infected by other bacteria. Then the substrate can be inoculated with the pre-grown mycelium spawn to grow in a dark room with a temperature around 30°C and a humidity around 60%. The material is fully colonized within 2-3 weeks when a white layer appears. Now the mixture can be put in a mold for further growth for about 5 days. The mold can be removed and shaped products need to be dried. When the material is baked above 60°C for a day the mycelium will be killed and prevented form further growth. When drying below 60°C the mycelium will grow further and mushrooms can sprout under the right conditions. In order to get stiffer, denser and stronger qualities, the material can be heat (150°C) and cold (20°C) pressed. Further shaping, heating or surface treatment can be done to achieve the appropriate properties of the end product.

The biodegradability of the mycelium-based building components is an advantage and a disadvantage at the same time. The water resistance of the material decreases overtime and outside on the ground it will be composed in about six weeks and return to the ecosystem as a useful nutrient. If the material is maintained under stable and favorable conditions, it has a lifespan of approximately 20 years. The energy consumption and embodied emissions of mycelium-based components are considerably lower compared to conventional building materials. Moreover, they have a low density, low thermal conductivity and are naturally fire resistant. In general, mycelium-based materials are growing fast and easily into any shape which makes the costs of the manufacturing process quite low.

Mycelium-based building components have a various range of properties and quality's due to the material characteristics of the fungi and substrate, the environmental conditions during the growing phase and post-manufacturing process. The mycelium species have different influences on the colonization level and the thickness of the "*fungal skin*" that is affecting the stiffness and water resistance of the materials. When using cellulose or other substrates with small soft fibers, a soft, light weighted, well bonded and foam like material can be achieved. Longer and harder fibers like wood chips makes the material stiffer, stronger, harder and heavier. During the growing phase the material will grow between a temperature of 15°C and 30°C, the lower the temperature the slower but stronger the mycelium will bind the substrate together. The stiffness, strength and homogeneity mainly increase by heat pressing into a more wood panel like material. The strength of mycelium bricks is much lower compared to the conventional bricks but in relation to its density, the mycelium is stronger than concrete. Mycelium materials can be used as insulation, panels and bricks but are not suitable as heavy construction material.

Designing with mycelium will always be a temporarily building. Mycelium is not strong enough for construction. Designing architecture that is built to grow, decay and eventually will disappear.

The manufacturing plant on building scale are organized within the three phases of mixing and molding the substrate with the mycelium and water, the growing phase and the post-manufacturing phase. All these phases need different environmental requirements within the production chain. A clean production environment with the desired conditions is very important to achieve appropriate product qualities and properties. The better the space is organized, closed and cleaned, the better the mycelium-based products. However, a small mycelium lab can basically be built anywhere. Staring from a primitive lab the production process can easily be upscaled. When scaling up, the space for storage during the growing and drying phase is growing exponential compared to the size of the lab.

Small scale labs have a surface of about $20m^2$, extra space of approximately 50 m^2 for storage, growing, drying and post manufacturing. For the production of mycelium-based materials approximately 5% mycelium spawn, 30% fiber and 65% water are needed during process. The devices that are needed consume about 10 kwh per hour. Big scale manufacturing plants like Ecovateve need a surface of 3000 m^2. The automated process uses 167 lanes compared to the 46 plant operators and consume 95899 kwh per hour. Moreover, 40 tons of substrate, 31 tons of water, 4 tons of nutrient and 0,25 ton of mycelium spawn is consumed to produce 215 m^3 of mycelium-based materials per hour.

In Parkstad provides several potential stakeholders that could supply their organic waste as substrate for mycelium-based materials. The cultivation for cereals uses 1.656 hectares of land that is producing 6,625 kilotons straw per year. The cattle industry is using 64% resulting of 503.236 hay bales of straw that are left for other uses. In Parkstad about 7 kilotons of waste wood is produced per year. Parkstad is collecting approximately 1 kiloton of reeds and heather and 1 kiloton stalk and leaf remains per year. In the near future new filter systems will make it possible to filter 1.8 kilotons of cellulose per water treatment plant installation (RWZI) per year. Gulpener is producing 2,6 kilotons of brewer's grains per year. It would be interesting and relevant to look into the qualities of brewer's grain as substrate type to grow mycelium-based composites. The mushroom farmer Zwamburg in Schimmert is an interesting stakeholder to contact for local mushroom spawn suppliers, accompany for knowledge and other collaborations to strengthen each other's identity.

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APPENDIX A – MANUFACTURING PROCESS

BUILDING

SMALL SCALE (LAB)

Who much space, energy, heat, water, waste, workers per material does the production process need?

INPUT

10 KWH/HR
200 M^2
65% WATER
30% FIBRE
5% MYCELIUM
OPERATORS

AVANS, ROSMALEN


Storage


Lab


Sterilize by high pressure boiling


Desinfected/sterile lab


Mycelium and substrate fridge


Mix and mold in the vicinity of a vertical flame


Inculation


Baking

FUNGALOGIC, DEN HAGUE


Storage substrate


Lab


Sterilize substrate


Inculation in laminar crossflow-cabinet


Mix and mold


Storage for growing process


Drying


Post manufacturing

OUTPUT


Test materials


Test materials

BUILDING

BIG MANUFACTURING SCALE

Who much space, energy, heat, water, waste, workers per material does the production process need?

INPUT

95899 KWH/HR
3.000 M²
31 TON PER HOUR
40 TON PER HOUR
4 TON NUTRIENT PER HOUR
0.25 TONNES PER HOUR

46 OPERATORS

ECOVATIVE, NY

Storage & manufacturing

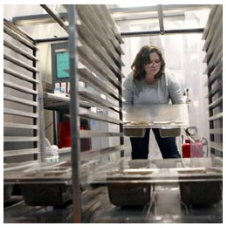
MIXING AND MOLDING PHASE

Supply

Cleaning

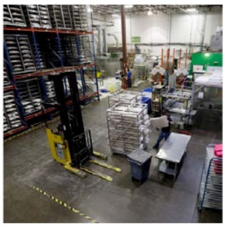
Sterilize and mix with mycelium

GROWING PHASE



Put in mold

Storage for growing process



Storage

POST-MANUFACTURING PHASE

Remove mold

Dryer

Heat pressure

OUTPUT

215 M² MATERIAL PER HOUR

Foam

Bricks

Panels

Source: Ecovative
https://www.youtube.com/watch?v=zmDENxTPn8Q&feature=youtu.be

Ecovative, NY

FULL SCALE LANE PLANT $133MM REV

Compost Facility Footprint	1000000	ft^2
Lane Width	15	ft
Lane Length	400	ft
Number of lanes	167	
Annual Production	66,300,000	ft^3
Annualized Rate	7568	ft^3 / hr
Moisture @ growth	60%	
Final dry density	12	lbs / ft^3

RAW MATERIALS	Usage (lbs/h)	Price ($/lbs)	Cost $/ft^3
Dry Wood	88160	$ 0.05	$ 0.6204
Water	67883	$ 0.00	$ 0.0048
Nutrient	8816	$ 0.04	$ 0.0519
Wet spawn	562	$ 0.51	$ 0.0380
		TOTAL	$ 0.7150

spawn % 0.6%

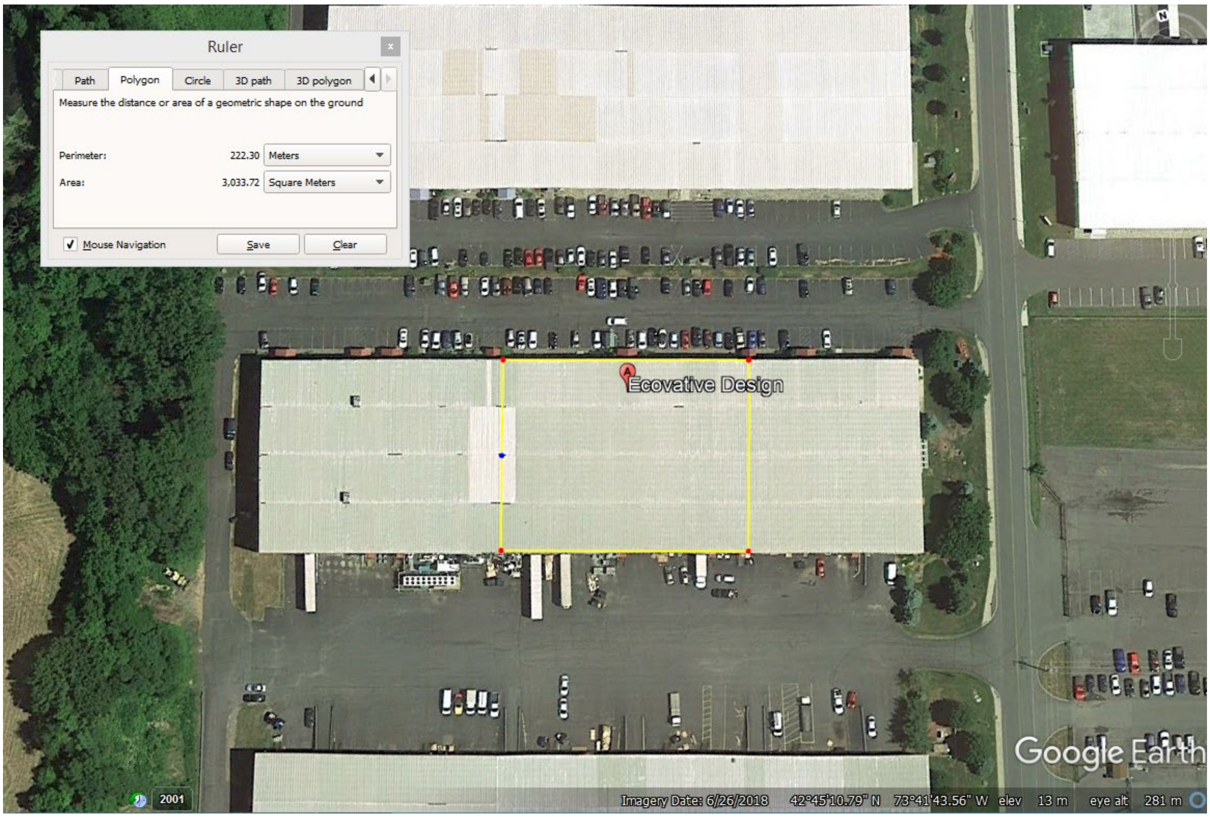
LABOR	Operators	Labor Price	$/ft^3
Plant Operators	46	$18	$0.0260
		TOTAL	$0.0260

UTILITY	kWh / h	Price	$/ft^3
Pretreatment Steam*	4868	$ 0.02	$ 0.0145
Electricity (Primary Aeration)	31300	$ 0.05	$ 0.2150
Drying Steam*	59731	$ 0.02	$ 0.1776
		TOTAL	$ 0.4071

CAP EX.			$/ft^3 over 5 yr
Pretreatment Equipment	$ 3,604,900		$ 0.0109
Installation, controls, handling	$ 5,120,020		$ 0.0154
Compost lane infrastructure	$ 23,935,120		$ 0.0722
Installation, controls, handling	$ 17,553,680		$ 0.0530
		TOTAL	$ 0.1515
Total Capital	$ 50,213,720		

OPERATIONS SUMMARY

Cost per ft^3	$ 1.30	$/ft^3
Panel thickness	3	inches
Square feet per year	265200000	ft^2
Cost per ft^2	$ 0.32	$/ft^2
Yearly cost	$ 86,161,575	$/yr
Sale Price	$ 2.00	$/ft^3
Yearly Revenue	$ 132,600,000	$/yr
Margin	35%	



Measure the distance or area of a geometric shape on the ground

Perimeter: 222.30 Meters

Area: 3,033.72 Square Meters

☑ Mouse Navigation

Imagery Date: 6/26/2018 42°45'10.79" N 73°41'43.56" W elev 13 m eye alt 281 m

APPENDIX B – WASTE RESOURCES DATA

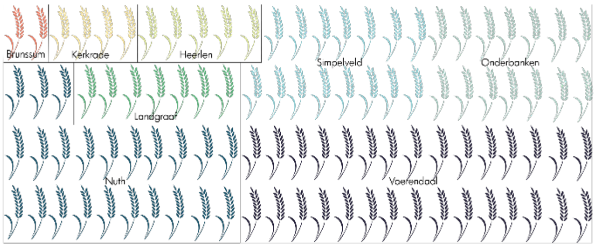
WASTE_HARVEST_PARKSTAD

region scale

What organic waste flows and stakeholders are available in parkstad?

Total Parkstad

1.656 HECTARES IS USED FOR CEREALS



4 KILOTONS STRAW
per year

ZWAMBURG

Zwamburg is collecting 200kg coffee grounds per weekfrom local restaurants

On this coffee grounds Zwamburg is producing about **80 KG MUSHROOMS** a week.

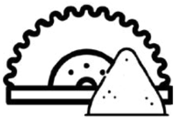
GULPENER

Gulpener produces
100.000 LITERS BEER
per year

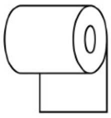
20 KILOTONNES OF BREWERS GRAINS
(per 100 liters 19,84 kg brewers grains is left)

De bierbostel bestaat uit:

Gerst	gemiddeld 70 %
Tarwe	gemiddeld 18%
Rogge	gemiddeld 4%
Spelt	gemiddeld 4%
Haver	gemiddeld 4%



About **7 KILOTONS WASTE WOOD**
per year



About **1.8 KILOTONS CELLULOSE**
per waste water treatment plant (RWZI)
per year

1 KILOTONS
REEDS AND HEATHER
per year

LEGEND
- ▢ = 0.00 - 0.10 ktons per year
- ▨ = 0.10 - 0.20 ktons per year

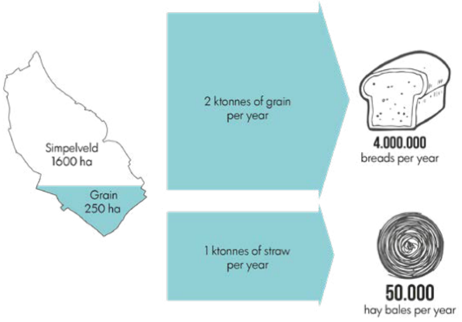
1 KILOTONS
STALK AND LEAF REMAINS
per year

PARKSTAD

region scale

What is being done nowadays with the current waste streams?

PER MUNICIPALITY



Simpelveld
1600 ha

Grain
250 ha

2 ktonnes of grain
per year

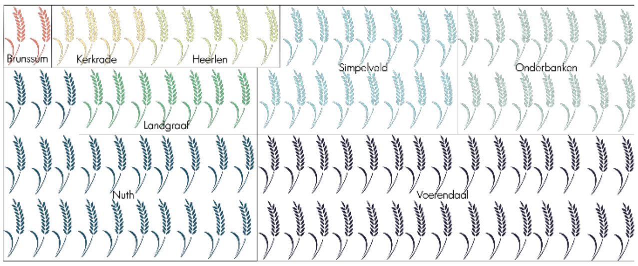
4.000.000
breads per year

1 ktonnes of straw
per year

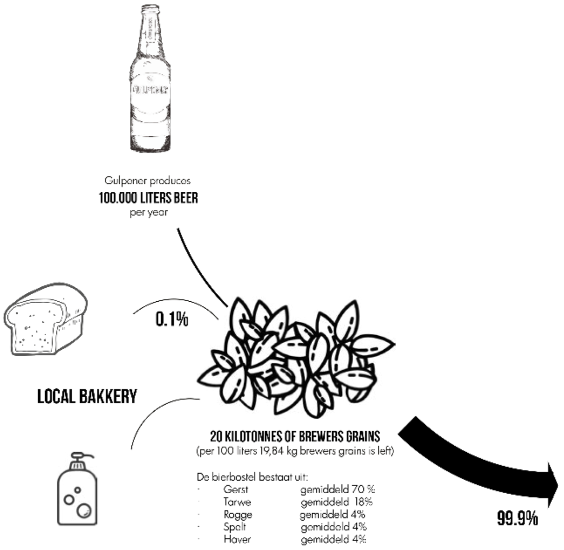
50.000
hay bales per year

Total Parkstad

1.656 HECTARES IS USED FOR CEREALS



GULPENER



Gulpener produces
100.000 LITERS BEER
per year

0.1%

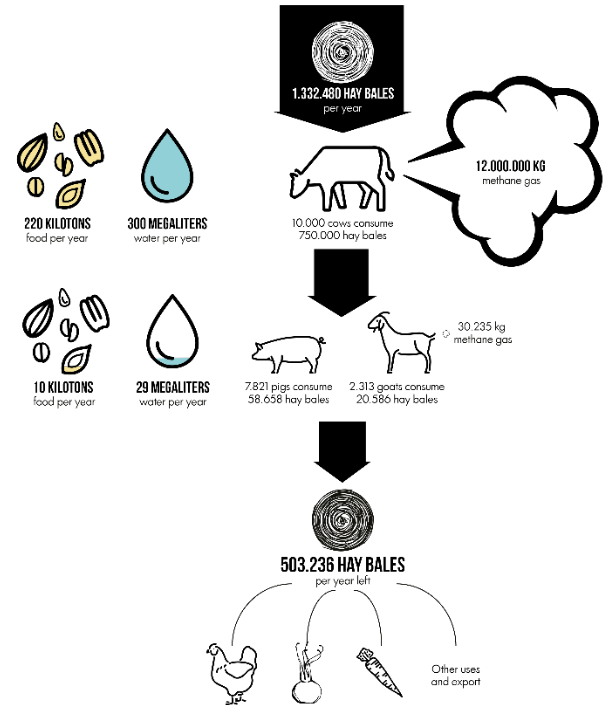
LOCAL BAKKERY

99.9%

20 KILOTONNES OF BREWERS GRAINS
(per 100 liters 19,84 kg brewers grains is left)

De bierbostel bestaat uit:

Gerst	gemiddeld 70 %
Tarwe	gemiddeld 18%
Rogge	gemiddeld 4%
Spelt	gemiddeld 4%
Haver	gemiddeld 4%



220 KILOTONS
food per year

300 MEGALITERS
water per year

10 KILOTONS
food per year

29 MEGALITERS
water per year

1.332.480 HAY BALES
per year

10.000 cows consume
750.000 hay bales

12.000.000 KG
methane gas

7.821 pigs consume
58.658 hay bales

2.313 goats consume
20.586 hay bales

30.235 kg
methane gas

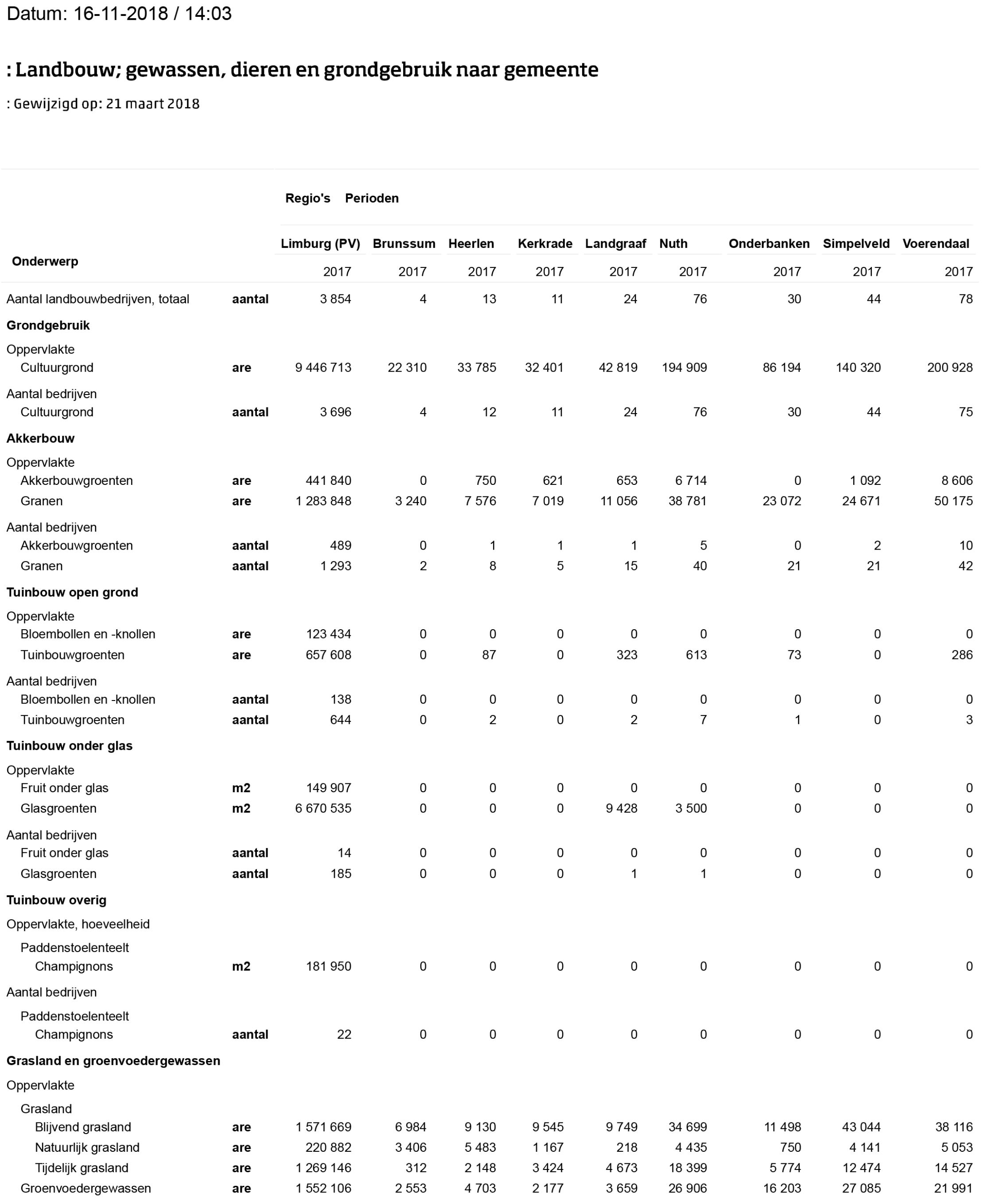
503.236 HAY BALES
per year left

Other uses
and export

Zwamburg

Zwamburg is collecting 200kg coffee grounds per week to grow about 80 kg of mushrooms on per week (http://zwamburg.nl/).

CBS



Datum: 16-11-2018 / 14:03

: Landbouw; gewassen, dieren en grondgebruik naar gemeente

: Gewijzigd op: 21 maart 2018

Regio's Perioden

Onderwerp		Limburg (PV)	Brunssum	Heerlen	Kerkrade	Landgraaf	Nuth	Onderbanken	Simpelveld	Voerendaal
		2017	2017	2017	2017	2017	2017	2017	2017	2017
Aantal landbouwbedrijven, totaal	aantal	3 854	4	13	11	24	76	30	44	78
Grondgebruik										
Oppervlakte										
Cultuurgrond	are	9 446 713	22 310	33 785	32 401	42 819	194 909	86 194	140 320	200 928
Aantal bedrijven										
Cultuurgrond	aantal	3 696	4	12	11	24	76	30	44	75
Akkerbouw										
Oppervlakte										
Akkerbouwgroenten	are	441 840	0	750	621	653	6 714	0	1 092	8 606
Granen	are	1 283 848	3 240	7 576	7 019	11 056	38 781	23 072	24 671	50 175
Aantal bedrijven										
Akkerbouwgroenten	aantal	489	0	1	1	1	5	0	2	10
Granen	aantal	1 293	2	8	5	15	40	21	21	42
Tuinbouw open grond										
Oppervlakte										
Bloembollen en -knollen	are	123 434	0	0	0	0	0	0	0	0
Tuinbouwgroenten	are	657 608	0	87	0	323	613	73	0	286
Aantal bedrijven										
Bloembollen en -knollen	aantal	138	0	0	0	0	0	0	0	0
Tuinbouwgroenten	aantal	644	0	2	0	2	7	1	0	3
Tuinbouw onder glas										
Oppervlakte										
Fruit onder glas	m2	149 907	0	0	0	0	0	0	0	0
Glasgroenten	m2	6 670 535	0	0	0	9 428	3 500	0	0	0
Aantal bedrijven										
Fruit onder glas	aantal	14	0	0	0	0	0	0	0	0
Glasgroenten	aantal	185	0	0	0	1	1	0	0	0
Tuinbouw overig										
Oppervlakte, hoeveelheid										
Paddenstoelenteelt										
Champignons	m2	181 950	0	0	0	0	0	0	0	0
Aantal bedrijven										
Paddenstoelenteelt										
Champignons	aantal	22	0	0	0	0	0	0	0	0
Grasland en groenvoedergewassen										
Oppervlakte										
Grasland										
Blijvend grasland	are	1 571 669	6 984	9 130	9 545	9 749	34 699	11 498	43 044	38 116
Natuurlijk grasland	are	220 882	3 406	5 483	1 167	218	4 435	750	4 141	5 053
Tijdelijk grasland	are	1 269 146	312	2 148	3 424	4 673	18 399	5 774	12 474	14 527
Groenvoedergewassen	are	1 552 106	2 553	4 703	2 177	3 659	26 906	16 203	27 085	21 991

Straw calculations and current use

Depending on the type of grain, in the Netherlands we harvest roughly about 8 tons of grain per hectare. (source: https://www.rvo.nl/sites/default/files/2018/06/Raming-oogst-2018-gemiddelde-opbrengst-per-hectare.pdf)Roughly 1 hectare produces about 4 tons of straw. So, 1/3 can be seen as crop waste.

A hay bale is about 20 kg, so 200 bales from 1 hectare of land (1ton=50 bales). So, 1.656 hectare is 6,625 kilotons or (1656x4x20) 1332480 hay bales per year (source: http://edepot.wur.nl/181701).

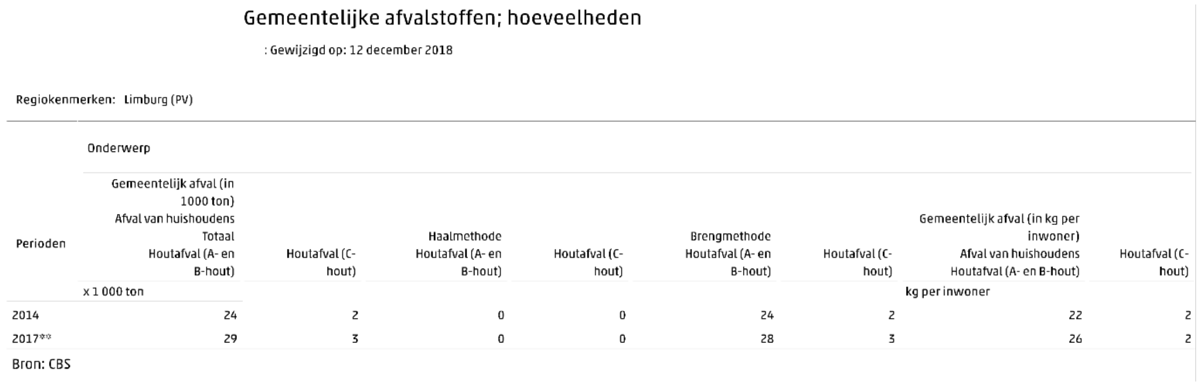
Currently, the straw is used for the cattle industry. One cow is consuming approximately 1,5 tonnes or 75 hay bales per year. For example, Simpelveld has 3000 cows, so they consuming 225.000 hay bales. The cattle industry of Parkstad has about 10.000 cows that are consuming 15 ktones of straw (750.000 hay bales). (Sources: https://www.vetvice.nl/upload/files/Stallenbouwadvies/Vetvice%20handleiding_strohokken_dec2011-.pdf, https://www.verantwoordeveehouderij.nl/upload_mm/6/4/d/d1935fa4-b3b6-4ba3-b1c4-72063728c052_201409%20stro%20een%20alternatief.pdf & http://www.veldverkenners.be/vraag-van-de-maand-wat-eet-een-koe).

A goat is using 0,5kg straw per day so 178 kg per year (http://edepot.wur.nl/15472). Parkstad has 2313 goats using 411714 kg straw or 20586 hay bales per year. A pig is using between 60kg (meat pig) till 350kg (breeding sow) straw per year so about 150 kg per year. Parkstad has 7821 pigs using 1173150kg straw or 58.658 hay bales per year (https://library.wur.nl/WebQuery/wurpubs/fulltext/34221).

The cattle industry is one of the biggest polluters on earth. Especially cows are producing a lot of the greenhouse gas methane that causes global warming. A cow is producing 120 kilograms of methane per year a pig 1,5 kg and a goat 8kg (https://www.livescience.com/52680-the-role-of-animal-farts-in-global-warming-infographic.html). The cattle industry in Parkstad is producing 10.000 cows x 120kg = 12.000.000kg (99,7%) methane gas due to cows and 30235 kg (0,3%) methane gas (7821 pigs x 1.5kg = 11.731 kg & 2313 goats x 8kg = 18.504kg). In total 12.030.235kg per year.

A cow drinks 30,000 litters of water per year and 22 tons of feed. So, in Parkstad 300,000,000 liters or water 220 kilotons or food per year is needed for the cattle industry (https://thedailymilk.nl/wat-eet-een-koe/) Pig eats 1 ton per year 3500 liters per year x 7821 tons and 27373500 liters. Goat drinks 2 liters a day and eats 2.5 kilos so eat about 900 kilos and 730 liters. 2313 goats thus 2081 tons and 1688490 liters. Pigs and goats consume 29,061,990 liters of water and 9,902 tons together (http://edepot.wur.nl/15481).

Sawdust from waste wood



Gemeentelijke afvalstoffen; hoeveelheden

: Gewijzigd op: 12 december 2018

Regiokenmerken: Limburg (PV)

Perioden	Onderwerp							
	Gemeentelijk afval (in 1000 ton)						Gemeentelijk afval (in kg per inwoner)	
	Afval van huishoudens						Afval van huishoudens	
	Totaal		Haalmethode		Brengmethode			
	Houtafval (A- en B-hout)	Houtafval (C-hout)	Houtafval (A- en B-hout)	Houtafval (C-hout)	Houtafval (A- en B-hout)	Houtafval (C-hout)	Houtafval (A- en B-hout)	Houtafval (C-hout)
	x 1 000 ton						kg per inwoner	
2014	24	2	0	0	24	2	22	2
2017**	29	3	0	0	28	3	26	2

Bron: CBS

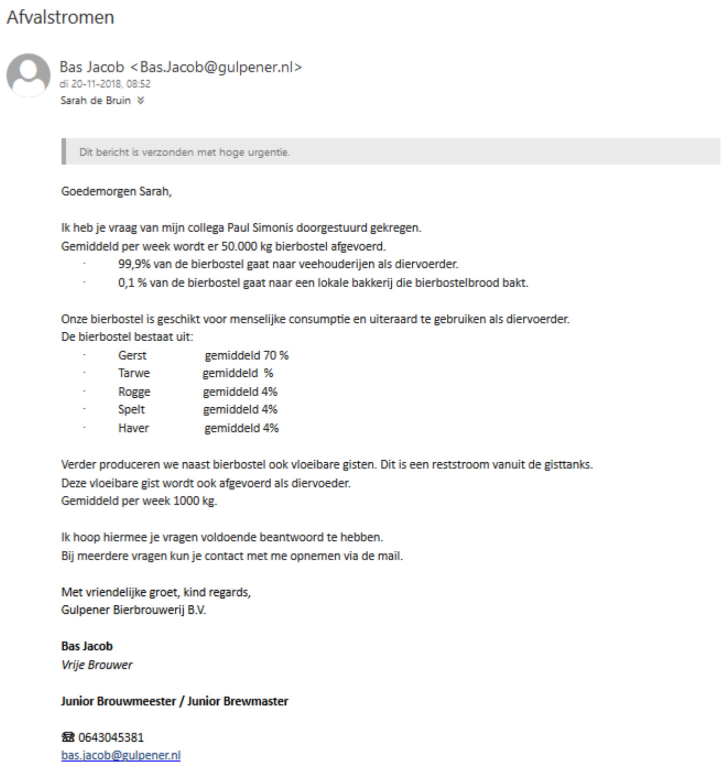
About 29 kilotons waste wood per year in Limburg Parkstad will be approximately 25% about 7 kilotons (https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83558NED/table?ts=1546651446170).

Cellulose

Per water treatment plant installation (RWZI) about 5000 kg cellulose per day can be filtered. So 1.8 kilotons a year per installation that uses this new filtration method (https://www.aaenmaas.nl/pagina/bij-u-in-de-buurt/werk-in-uitvoering/laarbeek/uitbreiding-rwzi-aarle-rixtel.html).

Brewers grains from Gulpener

Gulpener produces 50.000 kg brewers' grains per week. 52 x 50.000= 2.600.000 kg/ 2,6 kilotons per year.



Afvalstromen

Bas Jacob <Bas.Jacob@gulpener.nl>
di 20-11-2018, 08:52
Sarah de Bruin

Dit bericht is verzonden met hoge urgentie.

Goedemorgen Sarah,

Ik heb je vraag van mijn collega Paul Simonis doorgestuurd gekregen.
Gemiddeld per week wordt er 50.000 kg bierbostel afgevoerd.

- 99,9% van de bierbostel gaat naar veehouderijen als diervoerder.
- 0,1 % van de bierbostel gaat naar een lokale bakkerij die bierbostelbrood bakt.

Onze bierbostel is geschikt voor menselijke consumptie en uiteraard te gebruiken als diervoerder.
De bierbostel bestaat uit:

- Gerst gemiddeld 70 %
- Tarwe gemiddeld %
- Rogge gemiddeld 4%
- Spelt gemiddeld 4%
- Haver gemiddeld 4%

Verder produceren we naast bierbostel ook vloeibare gisten. Dit is een reststroom vanuit de gisttanks.
Deze vloeibare gist wordt ook afgevoerd als diervoeder.
Gemiddeld per week 1000 kg.

Ik hoop hiermee je vragen voldoende beantwoord te hebben.
Bij meerdere vragen kun je contact met me opnemen via de mail.

Met vriendelijke groet, kind regards,
Gulpener Bierbrouwerij B.V.

Bas Jacob
Vrije Brouwer

Junior Brouwmeester / Junior Brewmaster

☎ 0643045381
bas.jacob@gulpener.nl

APPENDIX C – MATERIAL PROPERTIES SHEETS

GROWN, NOT GLUED

Myco Board

Mycelium + Crop Waste = Myco Board

Rapidly Renewable
Biobased
Tree-Free
No Formaldehyde or VOCs
High Screwhold Strength
Compostable

Flat Myco Board

Myco Board combines the benefits of honeycomb and particleboard into one, more functional product. This core material can be produced at several densities and is strong enough to hold fasteners at any point, with superior strength to weight ratios compared to MDF. Myco Board can be grown into wood veneers, entirely avoiding glue. And because it's grown with agricultural waste and without synthetic resins, Myco Board is healthy for people, and better for our planet.

Molded Shapes

Not only is Myco Board healthier and lighter than MDF, it can also be molded into shapes. This means your product and process designs can break free of the confines of a rectangle, without generating the dust and waste of milling with CNC routers. This approach builds on the same technology that powers our Mushroom® Packaging platform, and grows strong, durable and natural materials in almost any shape.

SUSTAINABLE FURNISHINGS COUNCIL MEMBER

CERTIFIED cradletocradle CM GOLD

Performance Specifications

Metric	Standard	Ecovative
Flatness/Squareness	ASTM D1037, EN 324	0.02 in/ft
Density	ASTM C303, EN 323	42.74 lbs/ft^3
Modulus of Elasticity	ASTM D1037, EIN 310	776649 psi
Flexure Strength	ASTM D1037, EIN 310	2772.44 psi
Screw Withdrawal	ASTM D1037	110 lbf
Core Shear	ASTM D143, EN 319	55 lbf
Fire Resistance	ASTM E84	Class A
Formaldehyde Emission	ASTM E1333	0.01-0.03 ppm
	CARB Phase II	< 0.04 µg/m^2

Ecovative uses fungi to grow revolutionary materials and products. These environmentally responsible Mushroom Materials are high performance and cost effective. At the intersection of ecology and innovation, we're producing materials for a sustainable future.

Performance properties are based on test samples manufactured by Ecovative. These results may change as materials are further developed. Ecovative's Mushroom® Materials are protected by issued and pending patents. Mushroom® is a registered trademark of Ecovative Design, LLC. To date, Mushroom® Materials are Cradle to Cradle Certified^{CM} Gold. Cradle to Cradle Certified^{CM} is a certification mark licensed by the Cradle to Cradle Products Innovation Institute.

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