Quay walls Greening with Mosses

Master Thesis by Roberto Li

"How can quay wall elements be designed with improved bio receptivity to stimulate high moss growth coverage that will add social and environmental values to Amsterdam citizens' wellbeing?"

By

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Summary

Amsterdam city is currently facing problems of old quay walls and bridges renovation, followed by insufficient greening in the city. This study aims to propose a method to increase Amsterdam's greenery that will add social and environmental value through the renovation work of quay walls. The main objective is investigating how the quay walls can be redesigned to gain improved moss colonization as the primary greening method.

The research question is: ***"How can quay wall elements be designed with improved bio receptivity to stimulate high moss growth coverage that will add social and environmental values to Amsterdam citizens' wellbeing?"***.

It is further divided into six sub-questions to gain knowledge of bio receptive definitions and concepts first, followed by the study of bio receptive construction materials properties in the second part. The third part aims to gain fundamental moss knowledge. Afterward, a moss field survey is conducted on construction materials in The Netherlands as the fourth part. The fifth part consists of the moss cultivation technique and experiment to gain more practical knowledge of the construction materials. Finally, with the acquired results, a bio receptive quay wall design with other practical considerations is proposed in the last part.

Initiated with fundamental literature research on existing bio colonization works, followed by more specific building materials properties and moss knowledge studies on the first three parts. Afterward, a simple field survey on twelve sites has been conducted to determine moss growth conditions on building materials related to quay walls. Later on, an indoor moss cultivation method through the use of terrarium has been done to gain insights into material properties, ideal growing condition for mosses and moss cultivation technique. Based on the acquired knowledge, a simple quay walls element is redesigned to promote moss growth, keeping the site orientation in mind and moss cultivation practicalities.

The first three parts' results will not be described since these are basic definitions and knowledge needed for the following three parts.
During the field survey, the importance of moisture for moss growth on building materials is crucial. Therefore, not one specific material property value margin is needed, but a set of material properties and environmental conditions should be satisfied to gain successful moss growth. The duration of direct sunlight exposure will influence the site's moisture condition, which will further affect moss growth. Only twelve moss species were found and identified that are able to grow on construction materials, which is used for the moss cultivation method on the construction materials during the experiments.
The use of a terrarium to test moss growth on construction materials followed by a moss cultivation idea gained interesting moss growth results. It turns out that the mosses' growing temperature should be below 25 degrees Celsius at all times, especially during the germination phase, followed by a humidity level above 80 percent. For this reason, significant moss growth results on the terrarium test samples are only gained during the end of the fall season and the winter season when the temperature is below 25 degrees Celsius. Sadly, this method is still uncommon, therefore, not fully understood and controllable; improvement on the temperature and lighting control of the terrarium test method is needed to further develop the terrarium test method into a moss receptivity testing method.
Finally, the redesign of the quay wall element focus is to increase moisture gain through capillary action on the masonry finish of the quay walls. This can be achieved by using bricks with an Initial rate of absorption value above 3.0 kg/m^2*minute and pointing made of either trass lime or lime

mortar to promote capillary absorption of the masonry finish. Site consideration regarding quay wall orientation should be taken into account since this will influence the moisture condition and the moss cultivation technique time of application during winter and protection against external factor that prevents moss germination.

It is concluded that moss growth on quay walls can be stimulated by particularly improving the moisture condition on the quay walls exterior finish, as moisture was found to be the key parameter that determines the presence or absence of mosses on concrete structures such as quay walls. Resulting in an increase in greenery in Amsterdam city, which can be further translated into social and environmental values such as better air quality by filtering airborne dust, stimulating the ecosystem by producing food for the primary consumer and followed by an increase in the benefits of access to nature to human health.

How citizens will perceive the green moss quay walls is unknown, especially since the moss growth comes with other organisms' growth and is not evergreen throughout the whole year and how will the moss growth influence the durability of the material over a long period. Therefore, more studies and experiments regarding moss greening should be conducted to understand this greening method better.

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1.Introduction

Amsterdam is the most visited city in the Netherlands by tourists from all over the world, composed of 600 kilometers of canals and 1800 bridges followed by beautiful scenery full of historical values (Canals of Amsterdam n.d., RTL Nieuws 2020). Full of museums, shops, restaurants, and tourist attractions that make up part of Amsterdam's vibrant city nightlife. A city that can be toured around by boat as well, compared to many cities that are limited by transport on land. Sadly, the whole town is subjected to the danger of the collapse of bridges and quay walls due to improper maintenance over the past decades.

At the beginning of September 2020, approximately twenty meters in length of a quay wall located on the "Grimburgwal" collapsed (NOS 2020). Luckily no one was injured, but it does pose a serious threat to the whole city. Similar incidents happened in 2018 and in 2019, where parts of the quay wall underwent vertical deformation (Herter 2020). A study done in January 2020 (NU.nl) states that ninety percent of the quay walls and bridges are not checked for safety yet, mainly due to labor-intensive work. In the past two years, only 18 out of 202 kilometers of quay walls in high risk were checked for safety, while only 9 out of 850 bridges are checked for safety in one year.

The maintenance of quay walls and bridges are done poorly since the year 1980, where limited funding for maintenance work is available from the municipality. The primary reason for limited financing is because it is "not a sexy topic", the spending preferences would go to social or environmental livability projects (Dijksma 2020). The recent quay wall collapse should serve as a wake-up call for the Amsterdam municipality to address the maintenance issue properly.

The renovation of the quay walls and bridges project in Amsterdam is won by three major combined parties: G-Kracht, Kade 2020 and Koningsgracht. The renovation will be a massive challenge due to the complexity of limited working space on both land and water, the renovation pace needed, limited noise pollution in the mix used area and little disturbance on daily activities. Therefore, innovative renovation strategies are in dire need to tackle this problem keeping every other aspect in mind (van de Laar 2020)

Another issue caused by rapid development in the city itself is limiting open areas for greenery. As the continual densification process in cities will lead to further loss of urban green space for both the public and private sectors in Amsterdam's compact town, the necessity of effective urban green space planning and management will be crucial. Furthermore, the risk of having insufficient green space will increase, followed by a decrease in green space quality (Haaland and Konijnendijk van den Bosch 2015); therefore, the benefits of access to nature to human health will be reduced over time. For instance, residents' family interaction in public housing complex is better when living near green space, a college student living in a dorm with a window facing a natural setting can acquire better cognitive test results; elderly adults, regardless of social or economic status, tend to live longer when living near green spaces (University of Illinois 2009).

Another problem that comes with cities' densification is the urban heat island effect, which is a hotter built-up area compared to the nearby rural area. The urban heat island effect is caused by reducing albedo value through the modification of land surfaces (Wong , et al. 2010) and waste heat generated by energy consumption (Oke 1973). The elevated temperature caused by the urban heat island effect can affect the quality of the living environment. Secondly, the increase in temperature due to heat released in combustion will also lead to a rise in energy consumption for cooling purposes, which will generate waste heat again.

From a sustainability perspective, the building environment is responsible for approximately forty percent of the global emissions, which consumes the earth's finite natural resources and causes greenhouse gas emission (Pulselli, et al. 2007).

The cons mentioned above, accompanied by urbanization, can be solved by increasing the green areas. For sustainability, greenery will absorb CO_2 gas, which is one of the emitted greenhouse gasses. Simultaneously, greenery, such as gardens, has a lower temperature than other urban locations, with a more considerable temperature difference during the evening (Zoulia, Santamouris and Dimoudi 2008). The greenery increase also indicates that the accessibility to nature with its accompanying benefits enlarges; therefore, strengthening the greenery idea is a great strategy to improve Amsterdam's living quality.

However, the idea of introducing nature back to the city is limited due to the densification. Moreover, the greening of urban space has been an ongoing practice for years. Attaining more greenery is the key to improving the urban living environment. An innovative solution to this problem is the greening of building envelopes, which will also impact the whole urban landscape (Wong , et al. 2010). Planting vegetation on walls and roof surfaces is not an entirely new idea; it has many obstacles that prevent extensive scale application in urban cities. The problems for the application of green roofs and green facades will be described below.

Green roofs

The application of green roofs is typically on commercial and office buildings, despite a high amount of residential building roof surfaces in the city. Alcazar and Bass (2005) examined the thermal performance of buildings with green roofs based on roof to envelop ratio. The impact of a green roof is a reduction of 12 percent of cooling energy consumption during peak days and a reduction of 1 percent of the total annual energy consumption. However, only the first three levels below the green roof will reduce cooling energy consumption, where the floor directly below the green roof will have the most considerable reduction. The impact from the fourth level below the green top to the ground floor is negligible. Another research finding resulted in a 6 percent cooling energy reduction in the summer for a multi-family building located in Madrid, Spain (Saiz, et al. 2006). Thus, the energy reduction is mainly due to the reduced cooling needed for the building during the summer season, which is location-dependent.

Another advantage of having a green roof is reducing the urban heat island effect, where the applied soil medium gives off water vapor by using the excess heat. Sequestering of pollutants and carbon dioxide in the grown biomass and providing recreational benefits and aesthetical values and finally, improving the building acoustics performance and biodiversity (Dunnett and Kingsbury 2004). The soil's stormwater retention reduces the loading on the water drainage system (Stovin 2009, Bliss, Neufeld and Ries 2009). It is also assumed that a green roof's service life is much longer than a conventional roof due to less heat exposure to the membrane, the ponding of water is reduced and the waterproofing standard is stricter (Dunnett and Kingsbury 2004). Lastly, a shadow cost analysis showed that the green roof strategy is a cost-effective method for stormwater management and greenhouse gas reduction (Blackhurst, Hendrikson and Matthews 2010).

There are two types of green roofs, namely, extensive green roofs and intensive green roofs. The intensive green roof has a minimum soil depth of 150 millimeters that can accommodate a wide range of plants (including trees), followed by a high initial cost and maintenance requirements (Carter and Rasmussen 2006). An extensive green roof can be applied on lightweight construction due to limited soil depth. Plants are limited to sedum species, bushes and shrubs accompanied by lower initial and maintenance costs (Hui 2006).

If one chooses an extensive green roof instead of an intensive green roof, the initial and maintenance costs are lower and applicable for lightweight construction. Why is this not used on a larger scale knowing all the myriad benefits?

The main problem is that all the benefits mentioned earlier apply more to the public, while the implication cost is primarily private. In other words, owners of green roofs bear the risk, whereas all the people benefit from it. Another critical barrier for implementation is the increase in maintenance costs compared to a conventional roof. The green roof application could be improved if the government supports a policy that will, for instance, subsidize part of the application cost (Brudermann and Sangkakool 2017, Zhang, et al. 2012, Blackhurst, Hendrikson and Matthews 2010). But for now, the initial implication and maintenance cost are the primary reasons why the application of green roofs is limited.

Green façades

There are several methods to achieve the greening of building façades, which are classified based on the growing method, into façade greening and living wall system (Köhler 2008, Dunnett and Kingsbury 2004). Façade greening method is the growing of climber plant with direct attachment on the façade surface, which has a growing height limit depending on the grown species and will take years to cover the vertical surface entirely. The cost is relatively low for attaining this type of green façade, however, the maintenance work that comes with the damage due to the direct attachment to the façade should be taken into account as well. The mentioned case is called the direct method since the climber plant attaches directly to the wall. While the indirect way is by using supports such as a mesh to have the climber plant attached to it, instead of adhering to the façade surface material directly (Perini, Ottelé and Haas, et al. 2011).

A living wall system is when nutrients and a watering system are needed to keep the plant healthy, usually from a lack of growing medium for the roots to grow. The choices of plants can vary drastically from the ones that don't grow vertically. The types of living wall systems vary from different growing principles and concepts requiring design with higher complexity and consideration compared to the façade greening method. Living wall system has a higher cost, energy consumption and high maintenance difficulty (Perini, Ottelé and Haas, et al. 2011).

The benefits of green facades are very similar to that of a green roof. Another advantage of green facades could be reducing wind velocity around the building facades (Perini, Ottelé and Fraaij, et al. 2011). Another benefit of adding more vertical green is that they function as a sink for airborne dust particles (Sternberg, et al. 2010, Ottele, van Bohemen and Fraaij 2010), which can be relevant for dense urban areas. Inhaling dust particles smaller than 2.5 micrometers (μm) can impact human health negatively (Powe and Willis 2004); therefore, green facades can serve as an air filter as well. Another research showed that vertical greenery is an auspicious system to reduce urban canyons' temperature (Wong , et al. 2010).

Based on the life cycle analysis, the one with the lowest environmental burden is the direct greening system due to the limited need for material. The living wall system has a higher environmental burden (Ottelé , et al. 2011).

The implication of vertical greenery still faces a similar issue as green roofs. The private investors are solely responsible for the extra investment and additional maintenance costs for adding greenery on the building envelope compared to the conventional method.

1.1 Problem context

Amsterdam faces the problem of collapsing quay walls due to the end of design life and the limited space for greenery due to city densification, while other strategies such as building envelope greening burdens the private building owner. Therefore, instead of promoting the city greening and quay walls renovation separately, the idea of green quay walls can serve as one stone to kill two birds.

In this paper, the focus will be on how the quay walls' renovation can add value to the city itself, where the quay wall should serve more than a structural purpose. Can it be done in a way that adds social and environmental value to the whole city itself? Can it be made into a "sexy topic" when being mentioned? Following are some building envelope greening practices and techniques.

Moss greening idea

Instead of deploying conventional greening methods with different plants, moss greening can be used to cover the building envelope. In Japan, the use of moss mats is widespread. It all starts at indoor cultivation for a year on mats made of organic fabric used as a growing medium. Afterward, the moss mats will be further cultivated outdoor for 3 to 5 years. The moss mats can be directly attached to surfaces such as a vertical wooden panel by stapling it. Or just in modular plastic containers fixed on flat surfaces such as roofs (Pont, et al. 2018).

But why is moss greening a better solution than conventional greening methods?
The problem with conventional greening on building envelopes is that it requires extra investment compared to normal buildings exteriors without greening, followed by regular maintenance to prevent overgrowing and the death of the plants, which can be translated into extra cost for the private building investor. These are the main issues

Mosses are small plants that can extract all the needed nutrition from the environment itself (Glime 2017); therefore, if the growing environment is ideal for a specific moss species, external care is barely required. Secondly, instead of growing it on mats, why not stimulate it to directly develop on the construction material. Moss growing on cementitious material or brick is commonly observable. For this reason, if the mosses grow directly on the construction material, the requirement for a particular growing medium such as soil followed by an attachment system will not be needed. The mosses' roots are mainly for attachment purposes, with a limited penetration depth resulting in less damage. Therefore, by exposing the moss to the ideal growth settings, the maintenance cost will be reduced and if it can grow directly on the construction material such as an exterior brick wall, the initial investment cost can be reduced as well. Moss greening can also filter the air from airborne dust due to it being colonized by bacteria that support oneself by decomposing organic matter collected by the mosses, which includes contaminants that are dangerous to human health (Butcher 2017). Finally, specific moss species can function as biomonitors for anthropogenic air pollution in the city. Which can be considered a more economical and practical bioindicator for monitoring air pollution (Chakrabortty and Paratkar 2006); a change in air pollution can result in the death of the mosses, which serves as an instant visible alert to citizens.

So, the additional advantages of using moss greening methods compared to conventional green roofs and green facades are: low to barely any maintenance effort, low implementation cost, a better air pollution sequestration effect and an economical and practical biomonitor for a fast-changing city.

1.2 Research definition

The promotion of green façade and roof to private owners of buildings, where the private investor takes the burden of the cost while the majority public shares the advantages, will take a while. In the meantime, the Amsterdam municipality should support Amsterdam's greening themselves by investing in green quay walls as the pioneer city greening movement, and then further promote to private parties to increase Amsterdam's greenery. While the construction of quay walls can add environmental and social value to the town, the financial burden will be directly taken by the Amsterdam municipality and the results can be enjoyed by the public they serve.

The two standard façade greening methods are façade greening with climber plants or a living wall system. While either method can be used for the application on quay walls, regular maintenance work primarily due to overgrowing can be substantial, caring of 200 kilometers of green quay walls will be disastrous for the city itself.

Typical quay walls have a finishing material of clay bricks and mortar joints. It is quite possible to promote mosses' growth on the quay walls directly without the need for any other means of support. Since the mosses' roots are mainly for attachment purposes, with a limited penetration depth into the quay wall surface, which should be neglectable. Once mosses species can grow naturally on the quay walls surface, it could extract all the necessary growing nutrients from the atmosphere without an irrigation system, leading to an ideal green quay wall with little to no maintenance effort. Therefore, the focus is placed on redesigning the quay walls to achieve moss greening on it and not a structural calculation of the quay walls themselves.

Research question

How can quay wall elements be designed with improved bio receptivity to stimulate high moss growth coverage that will add social and environmental values to Amsterdam citizens' wellbeing?

Sub questions

1. What is bio receptivity of a material and other crucial fundamental concepts?
2. What are the crucial material properties that contribute to or influences a construction material bio receptivity?
3. What is the crucial fundamental knowledge regarding mosses that are important for in-depth understanding?
4. What crucial environmental conditions need to be considered for the moss growth initiation and stimulation on quay wall elements?
5. How can mosses be cultivated on quay wall building materials and how can the moss growth rate be stimulated to achieve a full surface coverage?
6. How can a common Amsterdam's quay wall element be redesigned with improved bio receptivity to achieve high moss coverage percentage?

Image 1: Example of green roof with moss plants. Left image, moss growth on an asbestos roof. Right image, moss growth on an aging thatch roof, (own image)

2 Methodology

This chapter is dedicated to elaborate on the method and strategy that will be implemented in order to answer the following sub-questions, which will be used to tackle the research question.

2.1 Bio receptivity definitions and concepts

To understand the state of art practices related to bio receptive materials, basic definitions and concepts pertaining to bio receptivity need to be explained first before diving deeper into the topic. For this reason, fundamental definitions and concepts will be described based on literature studies.

2.2 Bio receptive construction materials properties

This section aims to gain knowledge of the state of art practices regarding a material bio receptivity, achieved mainly by conducting a literature review. The literature review scope will be limited to building construction material that can be applied to quay walls, such as clay bricks and cementitious material. In the end, an idea regarding which material properties are crucial or determining for the bio receptivity will be gained.

2.3 Fundamental moss knowledge

In order to understand mosses, fundamental studies should be conducted first. This is achieved by literature study of moss species in general first, followed by careful selection of which information will be crucial in the context of improving moss receptivity on quay walls, specifically in the Netherlands.

2.4 Moss field survey on construction materials

The main goal is to gain information that applies to the Netherlands environmental condition, which can further be used as input information and consideration for the quay wall design in Amsterdam. Based on literature studies, a lot of essential information will be discovered and it is expected to be highly dependent on the moss species, macroclimate and microclimate. For this reason, a field survey will be conducted regarding how moss grows on cementitious and clay material in the Netherlands.

Some site qualifications are required to determine whether the found moss site is suitable or not for more in-depth analysis. The first qualification criteria is a prominent moss growth percentage with a moss coverage percentage above 30 percent. Because this may indicate that the occurring moss growth is exposed to an ideal growing environment instead of moss growth accumulated over a long time. The second qualification criteria are that the moss roots and rhizoids should be directly attached to the construction materials and not to accumulated dust and soil. Because many mosses that grow one construction material surface area are due to accumulated dead organisms and dust, which serves as a growing medium. For this reason, the influence of the construction material properties might not have a direct impact on the moss growth.

The focus of the moss survey will be placed on the occurring moss species and the environmental conditions. The survey will be executed in three simple parts, first is the necessary information regarding the site, such as facing orientation, habitat moisture condition (dry area, moist air, wet area), daylight exposure situation and an estimation of moss coverage percentage. The second part consists of the identification of the moss species collected on site. The third part will consist of a hypothesis why moss growth is prospering in that specific site condition. For example, this might be related to the moisture availability, nutrient source or other reasons that somehow influence the moss growth.

2.5 Moss cultivation experiments on construction materials

After gaining all the knowledge from the earlier studies, the next step would be finding a method to cultivate mosses on construction materials and how this can be further stimulated to increase the moss coverage percentage. This study aims to prove the practicality of moss greening on construction materials. Bio receptivity of materials is usually done by using algae fouling test. Sadly, no widely used moss receptivity test is present. This led to the challenge of finding methods to cultivate moss on construction materials and how this cultivation method can be used on Amsterdam's quay walls element. A literature study on how moss gardeners grow mosses will be conducted first and with this knowledge, trial and error of indoor moss cultivation experiments on quay wall construction materials will be conducted.

2.6 Bio receptive quay walls design and considerations

A literature study on the state of the art quay wall design will serve as the fundamental knowledge for redesigning the quay wall elements. Out of the vast types of quay wall design, a reference prefabricated quay wall element will be chosen for reference purposes for the redesign. Based on earlier research results, a design will be proposed on how the quay wall bio receptivity can be improved, how the quay walls' orientation needs to be taken into consideration during the cultivation and how and which moss species can be cultivated on specific sites. The results will be composed of explanations and drawings regarding the three different parts.

3 Results

3.1 Bio receptivity definitions and concepts

Literature review on the basic definition and fundamental concepts related to bio receptivity

a. Basic bio receptivity terminology

In order to understand bio receptivity, some necessary terminology explanation is needed first. Bio receptivity, defined by Guillitte (1995), is “the aptitude of a material or any other inanimate object to be colonized by one or several groups of living organisms without necessarily undergoing any bio-deterioration”. Based on this research, some bio receptivity influential parameters of stony materials are the chemical composition, moisture content, roughness and porosity of the surface layer.

Other crucial definitions are primary bio receptivity: the material initial potential of colonization. Secondary bio receptivity: material characteristic properties evolve over time due to organism colonization or other factors resulting in a modified colonization potential. Tertiary bio receptivity corresponds to primary or secondary bio receptivity modification by human activities such as biocide coating or surface polishing (Guillitte 1995).

Primary and secondary bio receptivity are considered intrinsic bio receptivity because the colonization potential is based on the material properties. For extrinsic bio receptivity, the colonization potential is caused by other substances or particles that are deposited or accumulated over time instead of being influenced by the material properties itself (Guillitte 1995).

b. Accessibility concept [the right place]

This is defined as the environment’s characteristics that determine the abundance of diaspore sources, proximity and transport capabilities, including the material’s exposure to these sources and vectors (Heimans 1954).

c. Particular environmental condition [the right time]

This is related to the exposed condition such as daylight, shading, water and draft, directly influencing an organism’s growth (Guillitte, Bioreceptivity: a new concept for building ecology studies 1995).

d. Bio receptivity concept [the right material]

The bio receptivity of a material is best expressed under maximum accessibility and environmental conditions that are optimal for the development of organisms (Guillitte, Bioreceptivity: a new concept for building ecology studies 1995).

The three conditions, the right place, the right time and the right material

To have bio colonization by organisms, all of these three are necessary in order to have biological growth. In short, the right bio receptive material, the right timing, which can be season-related and lastly, the right place where diaspore sources are present. If one of these three conditions is missing, no or low biological colonization will occur. Image 2 depicts a graphical representation of all three conditions, the brown rock as the bio receptive material, moss plant as the nearby source of spores and finally, the timing, which is moisture, draft and daylight dependent.

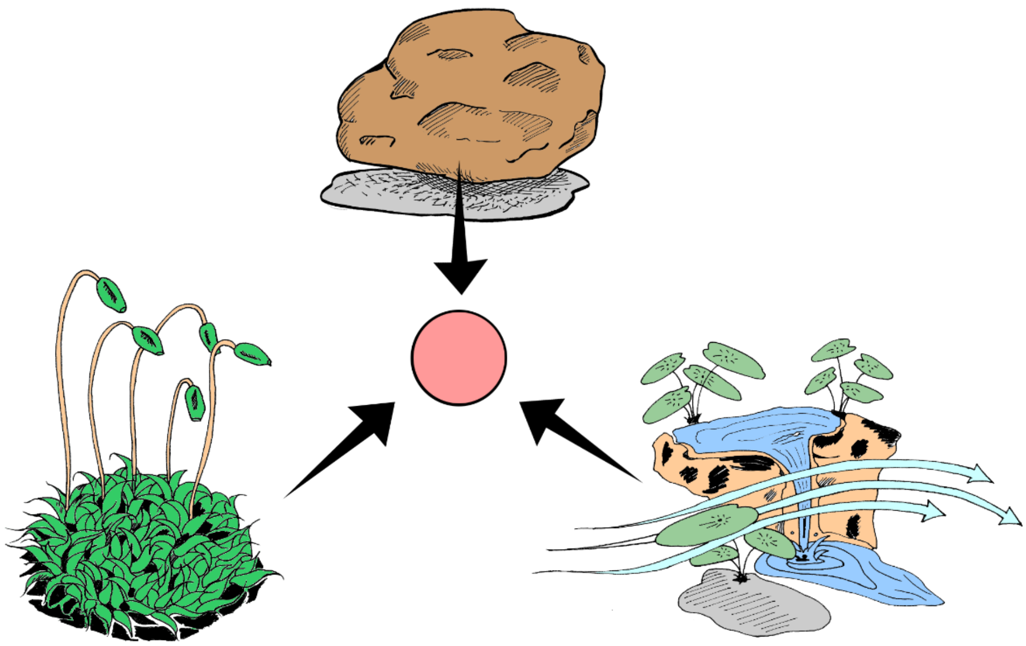


Image 2: The three conditions required for moss growth to be present, own image based on (Guillitte 1995, Heimans 1954).

3.2 Bio receptive construction materials properties

Literature study of construction materials bio receptivity

Since clay and cementitious construction materials are commonly used for quay wall construction, the focus of the literature study scope will be limited to the two materials.

A. Phototrophs receptivity – primary bio receptivity

Based on Gaylarde & Morton (1999) studies, initial colonizers on building materials tend to be phototrophs such as algae and cyanobacteria that grow based on inorganic materials. After the establishment of these phototrophs, then heterotrophic organisms, for instance, mosses, can grow naturally on the initially colonized surface (Cruz and Beckett 2016). That means the growth of mosses is considered as a secondary bio receptive. As it is necessary for the initial colonizers to modify the living condition before mosses can grow on them, the bio receptivity research studies are primarily based on algal growth as the initial colonizer. The research will explore if it is possible to make mosses the initial colonizer instead of other phototrophs and what modification or stimulation will be required.

a. pH value of cementitious material

Some of the findings based on the algal receptivity test are: Ordinary Portland cement with a high pH level resulted in less algal colonization. That is why colonization usually occurs after a pH drop from 13 to 9 due to carbonization (Manso, et al. 2014). The cement paste quantity applications are based on Klein's formula, which is based on the minimum cement paste needed for joining all the aggregate together (Klein, et al. 2012, N. Klein 2012). Therefore, the application of cement paste can also influence the outcome of the material properties. Other crucial variables are water-cement ratio, aggregate size, while the used aggregate types are mainly silica aggregate (Manso, et al. 2014).

b. Porosity and surface roughness

Based on an experiment test, samples with early biofouling were the ones with the highest porosity and surface roughness, but they did not end up with the highest biofouling rate. For this reason, it is concluded that porosity and roughness are crucial for the initial bio receptivity, but the influence for further colonization is limited (Manso, et al. 2014). Another study with similar cementitious material indicated that pore diameter distribution significantly impacted the colonization patterns. The pore diameter distribution influences the water retention and absorption patterns (Manso Blanco 2014). Therefore, these physical properties are crucial for the understanding of a material bio receptivity rate.

A study done by Jamison, McCabe and Warke (2014, 36-40) related to substrate texture influence on early biological growth indicated that surface texture or roughness is vital for pioneering organisms because the spores can settle better and are being protected from being removed by external forces such as wind and rain. But it still differs slightly since a rough surface is more favorable for algal growth while a smooth surface serves as a bright growing place for fungi and cyanobacteria.

Jamison, McCabe and Warke (2014, 36-40) also conducted an on-site investigation of exposing blocks with two different surface roughness. The left side is smooth, while the right side is tooled by hand to create a rougher finish. By using a single block, the mineralogy composition will be the same; therefore, the only difference will be the surface roughness. These blocks are exposed in two different sites, namely a high and a low rainfall area. The moisture content between smooth and rough surfaces is analyzed with a Surveymaster Protimeter.

It turns out, the moisture level between the smooth and rough surface on the wet site has no significant difference. While on the drier area, the moisture level on the tooled side was significantly higher. The difference in moisture level might indicate that the surface roughness is somehow related to moisture retention.

Another study stated that the accumulation of dead organisms and atmospheric particles could function as humus and nutrients to develop liverworts and mosses (Tiano 2002), which points to the importance of surface texture and roughness of the stony materials. Other researchers found that microorganisms: green algae and cyanobacteria have a positive correlation between growth for both roughness and porosity values. Uneven porous surface is the ideal growing condition because it retains more water and the provision of surface area is also larger (Jamison, McCabe and Warke 2014).

c. Microorganism exposure

A bio receptivity outdoor test was conducted on a cementitious material. It was concluded that urban areas might be more suitable for pioneer microorganisms colonization due to aerial microorganisms, air quality, and weather conditions. It also indicated that horizontal surfaces were more comfortable to colonize than vertical surfaces (Manso Blanco 2014). This means that vertical moss greenery will be more difficult to achieve compared to a moss roof garden. Another study states that the rapid colonization rate is due to the air pollution, which serves as a nutrient source (Tanaca, et al. 2011).

d. Capillary absorption

Capillary absorption of liquid by building materials such as gypsum board, particleboard and wood board is the main reason for rapid fungal contamination (Tanaca, et al. 2011).

A study regarding the bio receptivity by phototrophic microorganisms on building limestone materials concluded that rapid and temporary colonization occurs on coarse-grained stones with a high water permeability. In comparison, fine-grained rocks can have a permanent colonization because it can hold moisture for a longer time. In this case, the roughness and capillary coefficient play a more prominent role for colonization than permeability and open porosity (Miller, et al. 2009).

Visual inspection of Ordinary Portland Cement samples' biofouling showed that initial colonization might be located at the parts with a high amount of moisture (Manso, et al. 2014).

B. Moss receptivity – secondary bio receptivity

Mold growth and moss growth were tested on tropical climate exposed walls. The conclusion was that moss growth depends on capillary action and pH value. A moss receptive wall can be achieved by reducing the pH value and increasing the capillary action of the walling material. Cabook is a walling material made of eco-friendly hard soil blocks commonly used in Sri Lanka, which happens to be the one that has the thickest moss growth. Fly ash stabilized block wall was the one with the least moss growth. Other findings were porous spaces and organic matter that have a positive correlation with moss and mold growth. Material composed of high organic matter with a smooth surface reduced the moss and mold growth on it significantly; therefore, surface roughness was crucial. The moss growth only occurred after algae growth was initiated (Udawattha, et al. 2018). The result of the test is displayed in figure 1.

Another research stated that a moss receptive cementitious material could be made with crushed brick while a concrete panel made of fly ash showed the worst results. Even worse than concrete panels made with ordinary Portland cement (Chairunnisa and Susanto 2018).

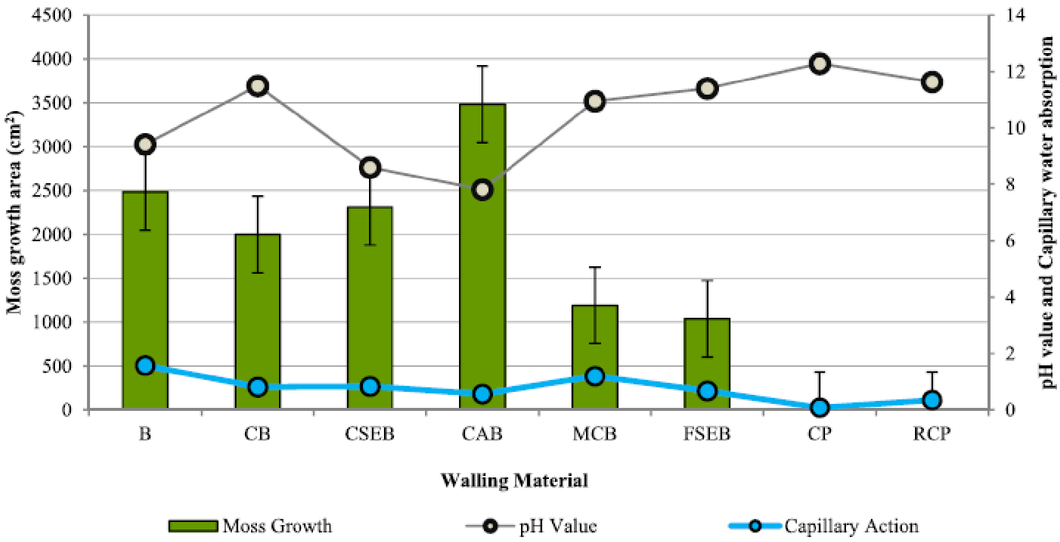


Figure 1: Moss growth vs significant intrinsic properties. B = brick, CB = cement block, CSEB = cement stabilized earth block, CAB = cabook block, MCB = mud concrete block, FSEB =fly ash stabilized earth block, CP = cement plaster, RCP = rough cement paste, figure retrieved from (Udawattha, et al. 2018))

A Study (Baljeu, et al. 2018) conducted in the Netherlands regarding moss growth on concrete structures concluded that there is no direct relation between the age of the construction and moss growth rate. What was very striking is that the same concrete structure had a higher porosity level at a location where moss growth is significant compared to a place where no or barely any moss growth was observable. By analyzing more site locations found with moss growth on concrete structures, no exact boundary value for porosity level was found that might stimulate moss growth. Sadly, more details of the concrete structure information during the construction were missing for a more in-depth analysis. This information is usually registered but seldom shared due to privacy reasons or destroyed ten years after completing the construction. Lastly, 25 out of 28 tested concrete samples had a pH value between 8 and 9 and the other 3 had a pH level higher than 9. This means pH decrease due to carbonization is crucial for moss growth to occur on concrete structures.

3.3 Fundamental moss knowledge

Literature study of mosses

An insurance company building in Munich had a tufa stone wall covered with mosses, stone element shown in Image 3. The tufa stone elements were carefully cultivated by the contractor in a well-controlled environment and later placed on site. Sadly, the carefully cultivated mosses were eventually washed off due to the use of water collected from the roof for irrigation purposes. It turns out that the copper and other metal pollution were the reason for the mosses' death. Another contractor was hired to cultivate mosses on the tufa wall with an improved irrigation system but also failed miserably due to the contractor's lack of understanding of moss ecology or the tufa stone as a growing substrate (Glime 2017, Volume 5,Chapter 5).

Image 3: On the left is tufa stone elements with mosses growth, and on the right side, a close-up view of the mosses grown on the tufa stone. Images retrieved from (Glime 2017, Volume 5,Chapter 5).

It is very important to understand moss ecology if one wants to grow moss on building materials. Since mosses are susceptible plants, the cultivation of mosses can fail miserably if not taking careful consideration. But on the other hand, with more than ten thousand moss species globally, different species grow differently in different living conditions. It is not wise to focus on them in detail yet. Instead, general knowledge of mosses will be studied first and if possible, more in-depth research will be done with a few selected species that apply to the Netherlands quay walls materials.

a. General moss knowledge

Moss is a relatively small green plant capable of performing photosynthesis with the help of sunlight. A certain amount of moss species drift on water without attaching to a substrate. In contrast, most of the moss species are connected to a substrate such as soil, rock, bark with the help of rhizoid, that function only for attachment purpose and not for water and nutrients intake. The intake of water and nutrients is performed by the cell walls that are present in the leaves. Mosses are good bio-indicator because it absorbs moisture without any filtering protection function, therefore, moss growth is susceptible to changes in their growing environment (van Dort, van Gennip and de Bruyn, Basisgids Mosses 2017).

b. *Moss reproduction*

The life cycle of a moss begins when the spore germinates, which only needs little moisture and sunlight to grow. Afterward, it will further develop into male and female components for reproduction purposes. A crucial requirement for the male sperms to be able to swim towards the female reproductive organ is a moist environment. For this reason, mosses cannot reproduce during the dry season. In order to increase the fertilization rate, the distance which the sperm needs to travel should be limited. For this reason, some moss plants consist of both male and female parts, referred to as monoicous moss type. Other kinds of mosses consist of separated male and female sex organs, known as dioicous moss type. After fertilization, the immature sporophyte (spores producing organ) will mature in a quarter to half a year time, where it contains a capsule that will form haploid spores and the spores can disperse with the help of the wind and so does the cycle go on (Moss 2020). Propagation by other means is also possible, for example, brood buds or fragmentation, where torn apart parts can grow to a new moss plant without germinating from spores (van Dort, van Gennip and de Bruyn, Basisgids Mosses 2017).

c. *Moss classification*

Based on the sporophyte characteristics, the moss species is divided into three main categories: liverworts (Marchantiophyta and in dutch “levermossen”), hornworts (Anthocerotophyta and in dutch “hauwmossen”) and bryophyta (in dutch “bladmossen”) (van Dort, van Gennip and de Bruyn, Basisgids Mosses 2017, Moss 2020). Due to the complexity and unnecessary information, no further explanation will be given on the three mentioned moss category characteristics.

d. *Moss growing substrate*

Moss has different substrate type that it naturally grows on and these substrate types are: stony material, dry soil, wet soil, bark, dead wood and no preference, which grows on all the earlier mentioned soil types (van Dort, van Gennip and de Bruyn, Basisgids Mosses 2017). For the quay wall design, it would be wise to limit the study of moss types that grow on stony substrate and without growth preferences. Due to the vast amount of moss species, the moss species searching scope is limited to the ones growing in the Netherlands since this is the location of application, which consist of less than 600 species (van Dort, Buter and Horvers, Fotogids Mossen 2010)

The list of moss species able to grow on all substrate and stony substrate are acquired from the following sources: (van Dort, van Gennip and de Bruyn, Basisgids Mosses 2017, van Dort, Buter and Horvers, Fotogids Mossen 2010, Bijlsma, et al. 2009). Moss species that are able to grow on all substrate type is listed in Table 1 and moss species that are able to grow on a stony substrate is listed in Table 2.

Table 1: Moss growing on both stony and other material substrate list (van Dort, van Gennip and de Bruyn, Basisgids Mosses 2017, van Dort, Buter and Horvers, Fotogids Mossen 2010, Bijlsma, et al. 2009)

	All substrate growth	
	Scientific name	Dutch name
1	Amblystegium serpens	Gewoon pluisdraadmos
2	Brachythecium rutabulum	Gewoon dikkopmos
3	Bryum capillare	Gedraaid knikmos
4	Bryumargenteum	Zilvermos
5	Calliergonella cuspidatum	Gewoon puntmos
6	Campylopus introflexus	Grijs kronkelsteeltje
7	Conocephalum conicum	Kegelmos
8	Dicranum scoparium	Gewoon gaffeltandmos
9	Hypnum cupressiforme	Gesnaveld klauwtjesmos
10	Kindbergia praelonga	Fijn laddermos
11	Leptodictyum riparium	Beekmos
12	Lophocolea heterophylla	Gedrongen kantmos
13	Lunularia cruciate	Halvemaantjesmos
14	Marchantia polymorpha	Paraluutjesmos
15	Mnium hornum	Gewoon sterrenmos
16	Plagiothecium denticulatum	Glanzend platmos
17	Plagiothecium nemorale	Groot platmos

Table 2: Moss growing specifically on stony substrate list (van Dort, van Gennip and de Bruyn, Basisgids Mosses 2017, van Dort, Buter and Horvers, Fotogids Mossen 2010, Bijlsma, et al. 2009)

	Stony substrate growth	
	Scientific name	Dutch name
1	Andreaea rothii	Generfd hunebedmos
2	Andreaea rupestris	Ongenerfd hunebedmos
3	Anomodon viticulosus	Groot touwtjesmos
4	Brachythecium laetum	Rotsdikkopmos
5	Brachythecium populeum	Penseeldikkopmos
6	Bryoerythrophyllum recurvirostre	Oranjesteeltje
7	Bryum donianum	Dikrandmos
8	Bryum radiculosum	Muurknikmos
9	Campylophyllum calcareum	Dwerggoudmos

	Stony substrate growth	
	Scientific name	Dutch name
10	Crateneuron filicinum	Gewoon diknerfmos
11	Ctenidium molluscum	Kammos
12	Cynodontium polycarpon	Gegroefd honstandmos
13	Dicranum fulvum	Steengaffeltandmos
14	Didymodon acutus	Spits dubbeltandmos
15	Didymodon cordatus	Rotsdubbeltandmos
16	Didymodon ferrugineus	Hakig dubbeltandmos
17	Didymodon luridus	Breed dubbeltandmos
18	Didymodon rigidulus	Broeddubbeltandmos
19	Didymodon vinealis	Muurdubbeltandmos
20	Distichium capillaceum	Recht visgraatjesmos
21	Ditrichum flexicaule	Kalksmaltandmos
22	Encalypta streptocarpa	Groot klokhoedje
23	Encalypta vulgaris	Klein klokhoedje
24	Eucladium verticillatum	Tufmos
25	Fissidens dubius	kalkvedermos
26	Fissidens gracilifolius	Steenvedermos
27	Fontinalis antipyretica	Gewoon bronmos
28	Grimmia anodon	Tandloos muisjesmos
29	Grimmia crinita	Krijtmuisjesmos
30	Grimmia hartmanii	Trosmuisjesmos
31	Grimmia laevigata	Dikbladig muisjesmos
32	Grimmia montana	Bergmuisjesmos
33	Grimmia orbicularis	Bolrond muisjesmos
34	Grimmia ovalis	Gezoomd muisjesmos
35	Grimmia pulvinata	Gewoon muisjesmos
36	Grimmia tergestina	Kalkmuisjesmos
37	Grimmia torquata	Schroefmuisjesmos
38	Grimmia trichophylla	Hunebedmuisjesmos
39	Gyroweisia tenuis	Voegenmos
40	Hedwigia ciliata	Recht granietmos
41	Hedwigia stellata	Stergranietmos
42	Homalia trichomanoides	Spatelmos
43	Homalothecium lutescens	Smaragdmos
44	Homalothecium sericeum	Gewoon zijdemos
45	Homalothecium sericeum	Gewoon zijdemos
46	Homomallium incurvatum	Pluchemos
47	Hymenoloma crispulum	Steensikkelsterretje
48	Leptobarbula berica	Steentjesmos
49	Leskea polycarpa	Uiterwaardmos

	Stony substrate growth	
	Scientific name	Dutch name
50	Leucodon sciuroides	Eekhoorntjesmos
51	Lophocolea minor	Klein kantmos
52	Metzgeria furcata	Blaak boomvorkje
53	Mnium marginatum	Rood sterrenmos
54	Mnium stellare	Ongezoomd sterrenmos
55	Neckera complanata	Glad kringmos
56	Neckera crispa	Groot kringmos
57	Orthotrichum anomalum	Gesteelde haarmuts
58	Orthotrichum cupulatum	Bekerhaarmuts
59	Paraleucobryum longifolium	Bezemmos
60	Plagiochila porelloides	Klein varentjesmos
61	Plasteurhynchium striatulum	Geplooid palmjesmos
62	Platydictya jungermannioides	Draadjesmos
63	Pohlia elongata	Lang peermos
64	Pseudocrossicium revolutum	Opgerold smaragdsteeltje
65	Ptychomtrium polyphyllum	Plooimuts
66	Racom. heterostichum alopecurum	Smalnervige bisschopsmuts
67	Racom. heterostichum heterostichum	Borstelige bisschopsmuts
68	Racom. Heterostichum obtusum	Stompe bisschopsmuts
69	Racomitrium fasciculare	Kale bisschipsmuts
70	Racomitrium heterostichum	Hunebedbisschipsmuts
71	Rhynchostegiella murale	Muursnalvemos
72	Rhynchostegiella tenella	Slank snavelmos
73	Rhynchostegium confertum	Boomsnavelmos
74	Rhynchostegium riparioides	Watervalmos
75	Rhynchostegium rotundifolium	Rondbladig snavelmos
76	Schistidium apocarpun	Gebogen achterlichtmos
77	Schistidium crassipilum	Muurachterlichtmos
78	Schistidium elegantulum	Fraai achterlichtmos
79	Schistidium maritimum	Zeeachterlichtmos
80	Syntricia montana	Viool sterretje
81	Syntricia princeps	Steensterretje
82	Syntricia ruralis ruralis	Daksterretje
83	Taxiphyllum wissgrillii	Komkommermos
84	Tortella inclinata	Viltig kronkelbladmos
85	Tortella tortuosa	Gerimpeld kronkelbladmos
86	Tortula marginata	Gerand muursterretje
87	Tortula muralis	Gewoon muursterretje
88	Zygodon viridissimus	Echt iepenmos

e. *Moss growth requirement and life forms*

Not only do mosses need to cope with changing moisture and light regime from changing seasons, but the microclimate of the surrounding also plays a role, such as the growth of neighboring plants. For this reason, the timing is extremely crucial. The timing of the growing organism must be adapted to the growing area climate. When to germinate, to release sperm, to develop the sporophyte and to release the spores (Glime 2017, Volume 1,Chapter 4)

Different factors influence growth, but water availability is the essential factor for mosses. Mosses metabolism will be suspended when water becomes unavailable. Luckily, mosses function like sponges; it absorbs water using capillary spaces and helps maintain moisture in the soil below. If water is still limiting, it can easily survive due to its exceptional desiccation tolerance. On the other hand, when the temperature reaches above 25 degrees Celsius, carbon loss will be higher than the carbon gain, making photosynthesis impossible, then the mosses will go into a dormant state. For this reason, the peak photosynthetic activities of the mosses are occurring during the early morning and late evening when the temperature is low and moisture is available (Glime 2017, Volume 1,Chapter 4, 7 and 9).

Seasonal changes are accompanied by different lighting quality, intensity and duration, which will signal the mosses to prepare for the changes in environmental condition. If the environmental conditions are poor, just like many flowering plants, the mosses will go into a sexual stage as a strategy to survive through their offspring (Glime 2017, Volume 1,Chapter 9).

Winter is the growing season for mosses. Water is often the limiting factor, which can be acquired from fog and dew. Once sufficient moisture is available, light and temperature will be the crucial factor in determining productivity. Productivity will start to decline when the temperature rises above the range of 20 – 25 degrees Celsius, resulting in carbon loss and making carbon dioxide a limiting factor. The optimum growing temperature lies within the scope of 15-25 degrees Celsius, depending on the moss species (Glime 2017, Volume 1,Chapter 10 and 12). Mosses photosynthetic activity can respond quickly depending on moisture and light availability; if one is absent, it will lay dormant until the time is right. For example, shade-grown mosses have a photosynthetic capacity comparable to sun-grown mosses. Once a short amount of sun flecks is available, photosynthetic activity will start immediately, while sun-grown mosses usually lack moisture due to respiration (Glime 2017, Volume 1,Chapter 9 and 11).

Before studying the life forms of mosses, mosses' growth habitats are divided into three parts: aquatic, mesophytic, living in a continually moist environment, and poikilohydric, which is subjected to a wet and dry cycle. Some mosses' life forms can be invariably depending on the moisture conditions; meanwhile, specific life forms occur due to habitat conditions. The abundance of moisture can provide an environment that is optimal for moss growth and development (Glime 2017, Volume 1,Chapter 4 and 7)

The different life forms are classified into: annuals, short turfs, tall turfs, cushions, mats, wefts, pendants, tails, fans, dendroids and streamers; see Image 4 for representation of different life forms (Glime 2017, Volume 1,Chapter 4). The focus of this paper will be mainly on the cushion and mats life forms because these are the commonly observable life forms that occur on clay and stony substrate.

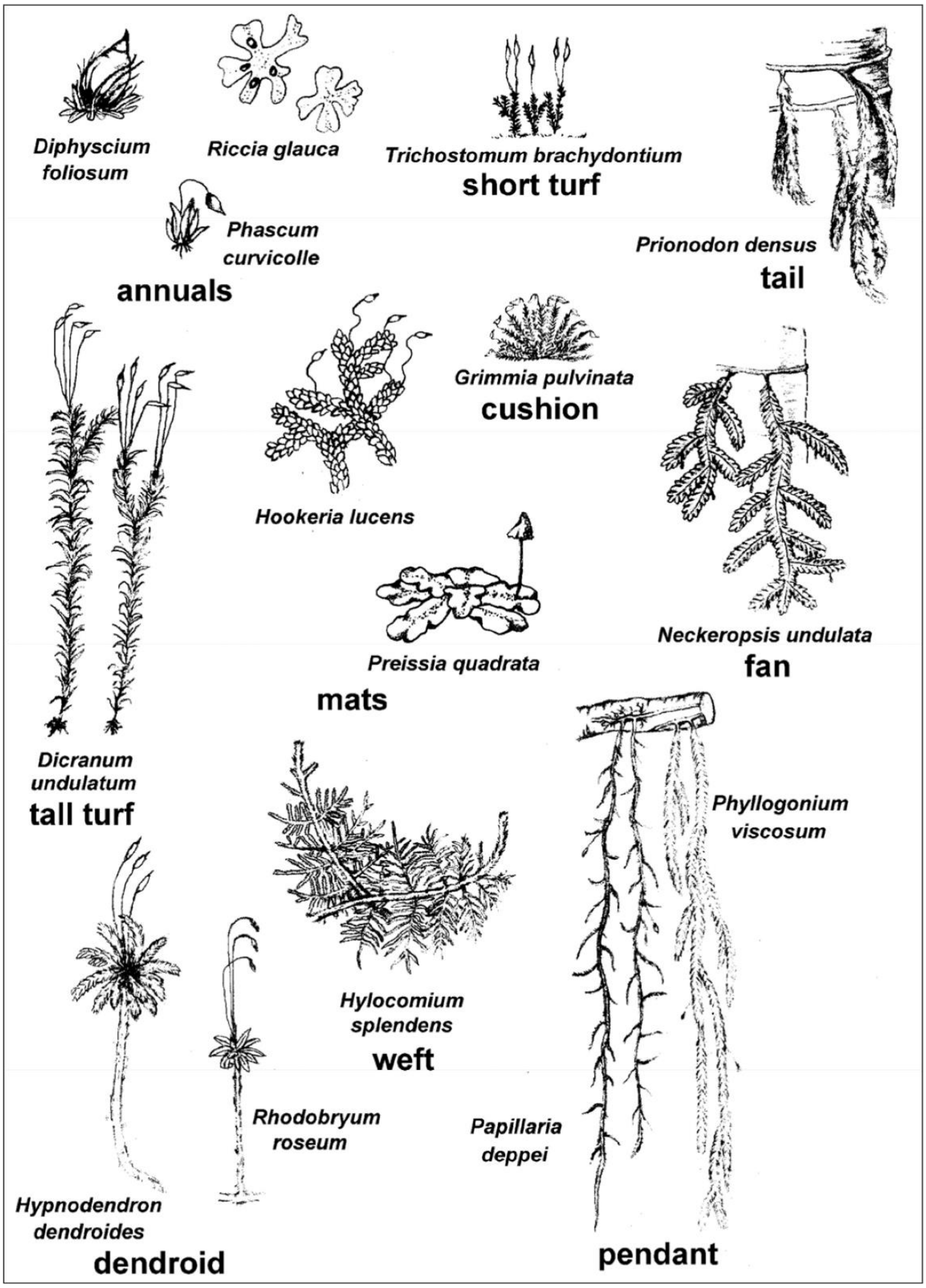


Image 4: Life forms of mosses and liverworts, retrieved from (Mägdefrau 1969, redrawn by Margaret Minahan).

Mats life forms

These usually occur in shady habitats exposed to incredibly moist locations that allow it to grow horizontally to capture more light for photosynthetic activity. Reproduction is more passive for mosses with mats life forms (Glime 2017, Volume 1,Chapter 4 and 9), which is probably because its existence is not being threatened in the growing location.

Cushion life forms

Habitats subjected to high temperature and light are usually dominated by mosses with cushion and short turfs life forms. The cushion life form can reduce the turbulence of the airflow, which will result in reduced water loss due to evaporation. Cushion life forms are formed by exposed shoots broken down by wind force, desiccation and abrasion. Reduced loss of moisture means an extended period of being moist. Therefore, the period of active metabolism is extended (Glime 2017, Volume 1,Chapter 4 and 9).

When cushion mosses are grown in humid habitats, it tends to form looser clump structure compared to dryer habitats. Because of the abundance of moisture, protecting moisture loss due to evaporation is slightly less critical because it can quickly gain moisture from the environment. Some cushion moss has hair points, which reduces moisture loss due to evaporation by creating a diversion for air current and deflecting light (Glime 2017, Volume 1,Chapter 7).

f. Moss nutrients and toxic substances

The five primary nutrient sources for mosses are: precipitation, soil, atmospheric dust, stream water and litter. Mosses likely have the ability to gain nutrients from the soil and rainwater, but litter also plays a crucial role in moss nutrient supply. Litter of woody and herbaceous plants can become nutrient for mosses as long as it doesn't prevent the mosses from gaining light (Glime 2017, Volume 1,Chapter 8).

Mosses are, in general, best grown in habitats with low nutrients. When located in nutrient-rich habitats, fast-growing tracheophytes usually outgrow mosses and limit daylight gain. But the productivity of mosses in high nutrient habitats seems to be equal to those in low nutrient habitats (Glime 2017, Volume 1,Chapter 8).

Many mosses simply cannot survive the high nutrient situation of fertilization. High nutrients supply may cause consternation, which is a common mistake made by bryologists attempting to cultivate bryophytes. Usually, growing mosses lies in acquiring a low nutrient concentration that prevents algae, fungi and bacteria from dominating. The addition of nutrients to the mosses community can last for a long time. The addition of nitrogen fertilization in a moss community did not change back to pre-fertilization after the addition of nitrogen fertilization ceased for 47 years (Glime 2017, Volume 1,Chapter 8).

pH level

The pH level affects the solubility of nutrients. At a high pH level, some nutrients may be unavailable; for this reason, the pH level should be low enough where the minerals are more soluble for moss uptake along with water to be possible. The pH level also affects the toxic substances, at lower pH level, toxic substance becomes soluble and can enter and harm the mosses growth (Glime 2017, Volume 1,Chapter 8).

Nutrients

The macronutrients are: Carbon (C), Hydrogen (H), Oxygen (O), Phosphorus (P), Potassium (K), Nitrogen (N), Sulfur (S), Magnesium (Mg), Calcium (Ca) and Iron (Fe) (Glime 2017, Volume 1,Chapter 8).

The micronutrients are: Zinc (Zn), Manganese (Mn), Copper (Cu), Nickel (Ni), Boron (B), Molybdenum (Mo) and Chlorine (Cl). Micronutrients seem to be essential for mosses but at a lower concentration level. In the end, the required amount still varies within moss species (Glime 2017, Volume 1,Chapter 8).

The nutrient requirement for young shoots are more demanding since the concentration of Nitrogen, Phosphorus and Potassium in young shoots are higher than in the old shoots. For the making of proteins and DNA, Nitrogen and Phosphorous are crucial. Phosphorous is also necessary in ATP to maintain energy (Glime 2017, Volume 1,Chapter 8).

Another finding is that the concentration of the following nutrients, Potassium (K), Iron (Fe), Phosphorus (P) and Nitrogen (N) increased in every part of the plant during summer and autumn, while the concentration dropped during winter. The concentration of the elements is growth cycle-dependent (Glime 2017, Volume 1,Chapter 8). In short, during summer, the dormant period, the mosses collect and store the nutrients. During winter, the nutrients will be used for photosynthetic activity.

The nutrient balance of mosses is very delicate. For example, copper is one of the essential micronutrients. Only a small amount of copper is needed; an immense amount of copper will become toxic for the moss plant. The lack of multiple nutrients can result in retarded growth and when CO_2 is lacking, the addition of nutrients barely has an impact on the development (Glime 2017, Volume 1,Chapter 8).

Lastly, Nitrogen nutrient balance is delicate as well. Nitrogen availability in the form of N_2 gas is abundant, but sadly it cannot be used by the mosses. It needs to be transformed by bacteria or cyanobacteria through a process called nitrogen fixation into a form that plants can absorb it through their root systems. A high concentration of nitrogen can influence the germination rate and early development of spores negatively. While the interaction between Nitrogen and Phosphorous is strange as well. The addition of the two nutrients separately will result in moss coverage gain. But adding both, will lead to a decrease in moss coverage (Glime 2017, Volume 1,Chapter 6 and 8).

3.4 Moss field survey on construction materials

For the field survey, the form of the site questionnaire can be found in Appendix i and the complete results of the conducted field survey can be found in Appendix ii. The field survey results will be described here, and a short overview of the results is presented in Table 3.

a. Field survey moss species findings

Based on the twelve sites field survey done, the mosses that are able to grow on quay wall construction materials are:

- **"Grimmia torquata" (Schroefmuisjesmos)** with a cushion life form, Image 5,
- **"Orthotrichum anomalum" (Gesteelde haarmuts)** with a cushion life form, see Image 6,
- **"Schistidium crassipilum" (Muurachterlichtmos)** with a cushion life form, see Image 7,
- **"Syntrichia montana" (Vioolsterretje)** with a cushion life form, see Image 8,
- **"Hypnum cupressiforme" (Gesnaveld klauwtjesmos)** with a mats life form, see Image 9,
- **"Brachithecium rutabulum" (Gewoon dikkopmos)** with a mats life form,see Image 10,
- **"Bryum capillare" (Gedraaid knikmos)** with a cushion or turf life forms, see Image 11,
- **"Kindbergia praelonga" (Fijn laddermos)** with a mats life form, see Image 12,
- **"Riccardia latifrons" (Breed moerasvorkje)** with a mats life form, see Image 13,
- **"Grimmia pulvinata" (Gewoon muisjesmos)** with cushion life form, see Image 14,
- **"Leptodontium flexifolium" (Rietdakmos)** with turf life form, see Image 15,
- **"Schistidium trichodon" (Zeeachterlichtmos)** with a cushion life form, see Image 16.

Moss identification is made based on description and photo comparison from the following books: (van Dort, Buter and Horvers, Fotogids Mossen 2010, van Dort, van Gennip and de Bruyn, Basisgids Mosses 2017) and the website: https://waarneming.nl/. Due to many similarities with other moss species, the possibility of wrong identification is not zero. For this reason, images of the identified mosses are displayed for confirmation purpose whether the identification is done correctly.

Table 3: results of the field survey done in Appendix ii

Field survey results		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12
Mosses	Grimmia torquata	✔				✔							
	Orthotridium anomalum		✔	✔		✔							✔
	Schistidium crassipilum		✔										
	Syntrichia montana		✔										
	Hypnum cupressiforme		✔			✔							✔
	Brachithecium rutabulum			✔				✔	✔		✔		
	Bryum capillare			✔				✔	✔	✔			
	Kindbergia praelonga				✔								
	Riccardia latifrons				✔			✔		✔	✔		
	Grimmia pulvinata					✔	✔		✔			✔	✔
	Leptodontium flexifolium						✔		✔	✔	✔		
	Schistidium trichodon							✔		✔	✔		
Direct sunlight exposure	0 hours		✔		✔								
	0-2 hours	✔		✔					✔	✔	✔	✔	
	2-4 hours						✔	✔					
	4-6 hours					✔							
	6> hours												✔
	Shaded - gain sunflecks	✔	✔	✔		✔	✔	✔	✔	✔		✔	✗
	Shaded - no sunflecks				✔						✔		✗
Moisture condition	Water body nearby	✗	✔	✔	✔	✗	✔	✔	✔	✔	✔	✗	✔
	Dry	✔				✔						✔	✔
	Moist		✔	✔			✔	✔	✔	✔	✔		
	Wet				✔								
Material	Cementitious mat.	✔	✔	✔	✔			✔	✔	✔	✔	✔	✔
	Clay bricks							✔	✔	✔	✔		
	Bitumen shingles					✔	✔						

b. Field survey results

The conducted field survey focused more on the environmental aspect instead of materials properties due to the lack of equipment and usage experience. Secondly, with extensive varying ecological conditions, material properties comparison might result in findings where data are present but hard to draw a firm conclusion. Therefore, it is not a wise thing to do. Instead, more accurate environmental conditions measurement can be done to understand what the construction material undergoes throughout a yearly cycle.

From the literature study regarding mosses, 105 moss species can grow on stony substrate, which is further limited to 12 moss species that can grow on quay wall construction material found during the field surveys. Therefore, the mosses to test for cultivation purposes will be limited to these 12 species instead of 105 species.

Based on the field survey, it was concluded that direct sunlight exposure is the most crucial factor for mosses to prosper well. The lack of direct sunlight in a permanently shaded corner in a wet environment resulted in only two moss species able to grow well, which is **Kindbergia praelonga" (Fijn laddermos)** and **Riccardia latifrons" (Breed moerasvorkje)** (Field survey site 4). So, these two might be used on north-facing surface quay walls that do not receive direct sunlight. Another extreme case of where concrete is permanently exposed to direct sunlight. Where only mosses with cushion life forms can grow (Field survey site 12). Based on observation, reaching a high moss coverage percentage using only mosses with cushion life forms is very hard and probably time-consuming. With the help of mosses with mats life forms, more extensive surface area coverage can be achieved. Results from the survey sites with high moss coverage percentage, limited direct sunlight exposure is crucial. Instead, gaining more sunlight through sun flecks was better. Sunlight is necessary for photosynthetic purpose, but at the same time, it can result in increased temperature, which makes metabolism activity impossible and secondly increase the carbon and moisture loss which also hinder photosynthetic activity. Most sites with successful moss growth have limited exposure to direct sunlight from zero to two hours and some permanently shaded by trees where the utilization of sun flecks is sufficient for proper growth.

At the end of the field survey study, only the influence of the amount of direct sunlight hours is understood, directly affecting the moisture condition of the mosses. The impact of a nearby water body and the nutrient sources in the form of decaying biomass is not entirely known. Thus, a more in-depth analysis of the site conditions can help gain more detailed information regarding the mosses' growing condition. Finally, the twelve found mosses species should also be studied more in-depth. For example, what nutrients does each species need, the non-lethal amount of nutrients supply, the ideal growing pH level and which moss species can coexist?

Image 5: Left shows an on-site collected Grimmia torquata moss in cushion life forms that covers an area of 100 x 100 square millimeter and on the right is a close-up image during hydrated stage (own image)

Image 6: Shows Orthotrichum anomalum in a cushion life form on the left side and the right side is a close-up view of a single branch (own image)

Image 7: shows Schistidium crassipilum in natural habitat before collection on the left side and the right side is close up view (own image)

Image 8: shows Syntrichia montana in a dry state on the left side and a hydrated state on the right side (own image)

Image 9: shows Hypnum cupressiforme with sporophyte; on the left side, it is situated on-site and the right side is a clearer view when moist (own image)

Image 10: shows Brachithecium rutabulum both with sporophyte, on the left side the mats life form appearance and on the right side a closer view (own image)

Image 11: shows Bryum capillare, on the left side the cushion life form appearance and on the right side a closer view (own image)

Image 12: shows Kindbergia praelonga, the left side its mats life form appearance and on the right side a close-up view of the sporophyte (own image)

Image 13: shows Riccardia latifrons on the left its mats life form appearance and on the right a closer view (own image)

Image 14: shows Grimmia pulvinata as a cushion from in its natural habitat on the left and the right a close-up view with sporophyte (own image)

Image 15: shows Leptodontium flexifolium with turf life forms in dry condition on the left side and moist condition on the right side (own image)

Image 16: shows Schistidium trichodon in cushion form on the left side and a close-up view on the right side (own image)

3.5 Moss cultivation experiments on construction materials

This part aims to find a method to cultivate mosses in an indoor environment to assess the bio receptivity of a material and later use this method to grow mosses on quay wall elements materials. First, the chosen method for moss cultivation will be described, with accompanying issues that will be solved to improve the technique based on moss growth test on quay wall construction materials. In the end, some ideas of how to assess the efficiency of the testing method and how to measure moss growth rate will be described.

a. Indoor moss cultivation method

As concluded in Objective 1, three conditions need to be present to have moss growth, which are: ***Accessibility concept***, ***Particular environmental condition*** and ***Bio receptive material***. Therefore, in order to test the quay wall construction material for bio receptivity, the other two conditions should be present.

Accessibility concept idea

This is defined as the environment's characteristics that determine the abundance of diaspore sources, proximity, and transport capabilities, including the material's exposure to these sources and vectors (Heimans 1954).

For the accessibility concept, to expose the test material to the spore of specific moss plants. A commonly used moss gardening technique is to collect the moss plant you want to propagate. Add it in a blender with either buttermilk, yogurt or beer, which serves as a liquid nutrient source. Lastly, the blended "moss shake" should be applied directly to the test material using a brush, as shown in Image 17 (Moran 2019, Maslowski n.d.). This method will be used to fulfill the accessibility requirement for the testing of a material moss receptivity.

Image 17: Example of the moss cultivation method, left shows the used mosses, center shows how it is supposed to be after blending and the right side is the leftover moss fractions after application (own images)

Particular environmental condition

This is related to the exposed condition such as daylight, shading, water, and draft, directly influencing an organism's growth (Guillitte 1995).

For this reason, the testing strategy is being studied to assess the bio receptivity of a material exposed to a particular environmental condition and the accessibility concept. Some general knowledge to start with creating the ideal growing environment for mosses are full sunlight intensity between 70000 – 100000 lux, exposure temperature of 15°C to 25°C (Richards 1984), substrate pH value between 5 to 5.5 and around 60% relative humidity or more (Udawattha, et al. 2018).

Based on mosses' growing conditions, two possible testing methods can create a moss particular environmental condition. The first method is the use of a terrarium, where a simple "mini-environment" is made with plants' help. The plants will absorb water from the soil as it grows, followed by the leaves' transpiration resulting in water being released to the environment. The released water will condensate on the container surfaces and return to the soil. The water cycle will continue (Steil 2002) with a permanently moist environment without draft, which could be considered an ideal growing habitat for the moss species. The second strategy would be the indoor cultivation of mosses technique developed by Haughian & Lundholm (2020). Below will describe both methods more in-depth.

Test option 1 – "the Terrarium"

Suitability of a terrarium

A terrarium is usually a sealable glass container containing soil and plants and can be opened for maintenance to access the plants inside. The main idea of a terrarium is to create a close water cycle in a sealed container. Transpiration and evaporation will occur due to external light and heat sources. The humidity level will keep rising until condensation on the container surface starts appearing. The transpired and evaporated water on the container surface will fall back to the soil, basic principles of a terrarium shown in Image 18. This is how a humid environment can be created, stimulating moss growth (Terrarium n.d.).

Advantage of using a terrarium

- Humid environment
- No draft, which might hinder the initial moss growth
- Affordable and easy to set up
- Easy to operate, which has a self-operating water cycle

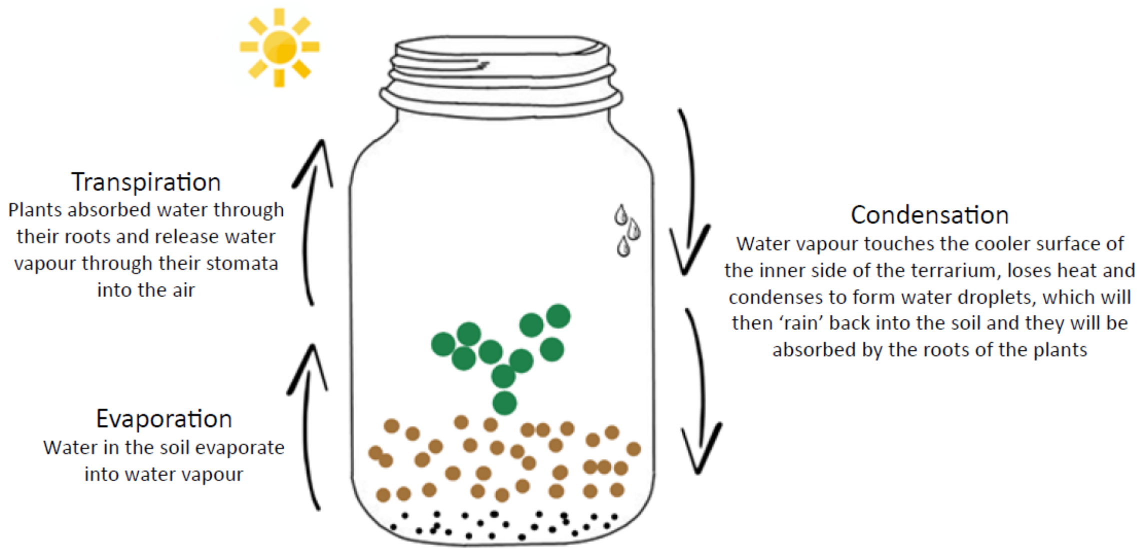


Image 18:Basic terrarium water cycle principle (image retrieved from https://www.lushglassdoor.com/blogs/news/what-is-terrarium-ecosystem

Test option 2 – "the moss machine"

This testing option is taken from a study done by Haughian and Lundholm (2020), where the primary purpose of this experiment is to come up with a low-cost method for indoor moss cultivation.

The setup

The idea of using a stack tray for different layering moss growth tests, with a misting system for regular spraying intervals, which are commonly used by Japanese moss nurseries and LED grow lighting systems to supply the needed lighting for moss growth with as little heat generation as possible.

To prevent the misting system from wetting the adjacent laboratory operations, plastic wrapping has been put around, followed by ventilation gaps on the top corner to avoid overheating. A drainage system is needed to prevent leakage from the accumulated water on the bottom, shown in Image 19.

The lights are set on a 12 hour on/off cycle per day while the misting spray activates once every 20 minutes during the 24 hours per day.

The rejection

- Although the moss machine is affordable in the range of € 600, the setup is complicated. It is composed of a misting and lighting system where a fixed testing location is needed with a water drainage pipe.
- Another study (Pont, et al. 2018) concluded that using the moss cultivation technique and a water misting system on smooth surfaces prove to be quite tricky because the water misting system will wash the moss fragments and nutrients away. For this reason, the results of the material with a rough surface might be slightly better due to the removal of the moss fractions on materials with smooth surfaces.
- Regular direct moisture supply, in this case, water, might not be entirely testing the material's intrinsic bio receptivity. For example, the water retention through capillary absorption might be less critical due to regular water supply (Guillitte and Dreesen 1995).
- This method works well growing on layers of organic fabric and the applied moss plants were outdoor collected mature moss plants, which will differ from initial spore germination growth.

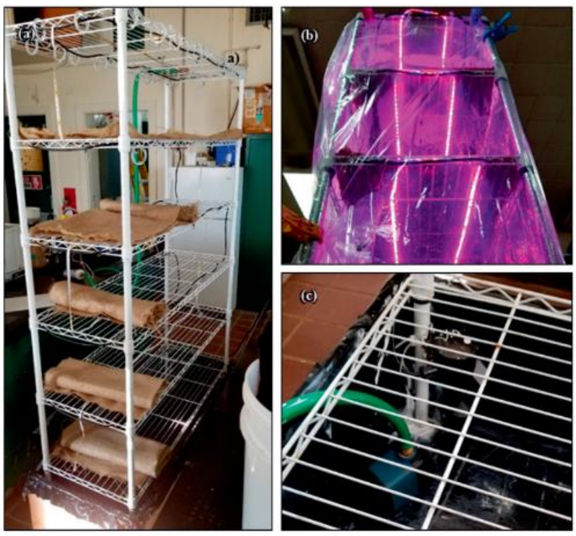


Image 19: The moss machine setup, a: the overall system, b: the covering and LED lighting setup and c: the pump and drainage basin, image retrieved from (Haughian and Lundholm 2020)

b. Terrarium test findings

In theory, the terrarium as a testing strategy sounds promising, but the only way to know whether it truly works or not is by testing it. For this reason, a rough terrarium setup has been made with the primary purpose of assessing the possibility of moss growth in a terrarium. Therefore, the tested material should have a high bio receptivity to show moss growth possibility. In case the method works, but if the chosen material simply has a low bio receptivity, which will result in barely any bio colonization, then the technique might be discarded based on poor results of low bio receptivity of the tested material. So, the chosen test material is clay bricks, which are commonly colonized by mosses. The used clay bricks for testing are acquired from the GAMMA store.

The findings are summarized below and more detailed information regarding the testings can be found in Appendices iii, iv, v, vi, and vii.

Nutrient source for the moss cultivation technique

The choice of nutrient source was between organic buttermilk and yogurt. Image 20 shows two different samples after six weeks of growth in the terrarium; on the left side, the yogurt sample is shown and on the right side, the buttermilk sample is shown. Based on the comparison of samples with two different nutrient sources, it is concluded that buttermilk serves as a better nutrient source for the moss cultivation technique.

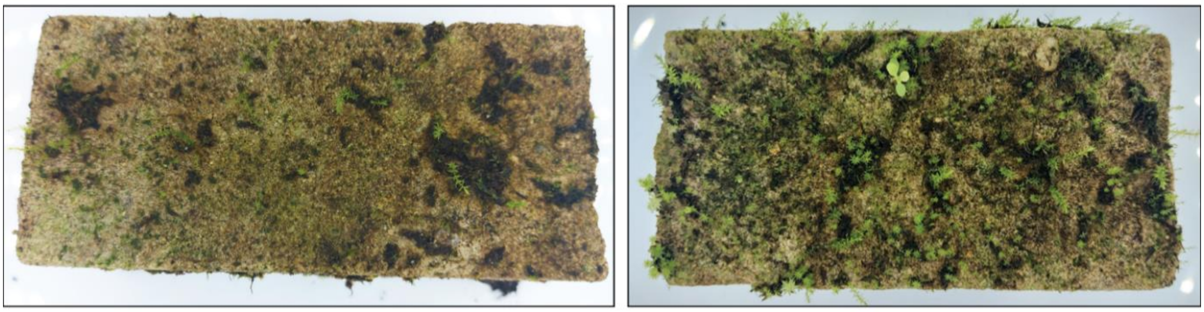


Image 20: Sixth-week results of the initial terrarium test; on the left is the yogurt test sample and on the right is the buttermilk test sample (own image)

Figure 2 below shows the content of both buttermilk and yogurt per 100 ml. Phosphorous is one of the crucial ingredients in plant fertilizer. But sadly, the phosphorous content for the yogurt was not indicated, therefore hard to draw a conclusion based on these numbers. Based on nutrient studies for mosses, three crucial nutrients are phosphorous, nitrogen and carbon. In this case, the sugar content may serve as a carbon source for the growth of mosses. But, buttermilk with lower sugar content still performs better than yogurt.

	Buttermilk (per 100 ml)	Yoghurt (per 100 ml)
Energie	154 kJ	263 kJ
Vetten	0.5 gr	3.18 gr
Koolhydraten (suikers)	0.4 gr	4.54 gr
Eiwit (proteine)	3.7 gr	4.1 gr
Zout	3.6 gr	0.2 gr
Calcium	120 mg	109 mg
Fosfor	89 mg	-
Vitamine B2	0.17 mg	-

Figure 2: Organic buttermilk and yogurt content comparison

Based on the experiment results, it is concluded that there's insufficient testing data and studies have been done to be able to draw a firm conclusion. Secondly, moss growth is very complicated. For example, adding nitrogen or phosphorous alone can boost the most growth but adding both together will not. It might also be moss species-dependent since mosses can grow on low nutrition availability. But the reason why buttermilk performs better might be related to getting the nutrition level low enough so that other organisms cannot thrive and consume all the nutrition since this is a common mistake made by moss gardeners (Glime 2017). Based on observation during the moss growth on bricks sample with the moss cultivation technique, mold grows initiated in the first three days and the development of mosses started after the mold growth ceased. The yogurt may have a higher nutrition content, which is consumed by other organisms during the mold growth period, resulting in less moss growth afterward.

Terrarium temperature influence

The temperature of the testing chamber is exceptionally crucial. Once it rises above 25 degrees Celsius, the germination and growth of mosses will be impossible. Since carbon loss will be greater than carbon gain making photosynthetic activity impossible. The temperature will also influence the test samples' moisture availability; nothing can be done without moisture. The second terrarium test done in Appendix v had no moss growth on all the tested samples, which led to the study of the closed terrarium temperature in Appendix vi. Image 21 showed one of the red brick samples, the wrapping around the brick was meant for naming purposes only to keep all the samples organized. The top of the sample was dry, while the wrapping trapped the moisture on the sides of the sample. After the removal of the sample plastic wrapping, there was observable moss growth on the sides. The trapped moisture might have reduced the temperature and prolonged the moist period, making it possible for mosses to germinate on the sides of the bricks.

Image 21: Red brick sample 1 of the second terrarium test. The brick sample is depicted before and after the removal of plastic naming wrapping (own image)

Glass terrarium design

The glass terrarium design is meant to create a similar condition as the plastic terrarium, with a reduction of temperature, shown in Image 22. This is achieved by using artificial growth LED lighting instead of direct sunlight. A moisturizer/ humidifier has been added to increase the moss growth rate, which is on a timer control to schedule on/off cycle as the artificial lighting. The occurring peak temperature dropped to 30 degrees Celsius based on temperature measurement, while the plastic terrarium peaked at 40 degrees Celsius. Based on two different tests conducted in the glass terrarium, which is shown in Appendices vi and vii. It turns out, the temperature at which the moss samples are exposed should be below 25 degrees Celsius the whole time because the first test in the glass terrarium had a temperature peak of 30 degrees Celsius, which resulted in zero moss growth.

While the second test had a delay in moss growth caused by the temperature that is higher than 25 degrees Celsius in the beginning stage. Later, visible moss growth was observable because the temperature was below 25 degrees Celsius. See Image 23 for the second test's temperature profile during the first day of the first, fourth and eighth week of testing.

Image 22: Glass terrarium with waterfall design made of EPS foam (own image)

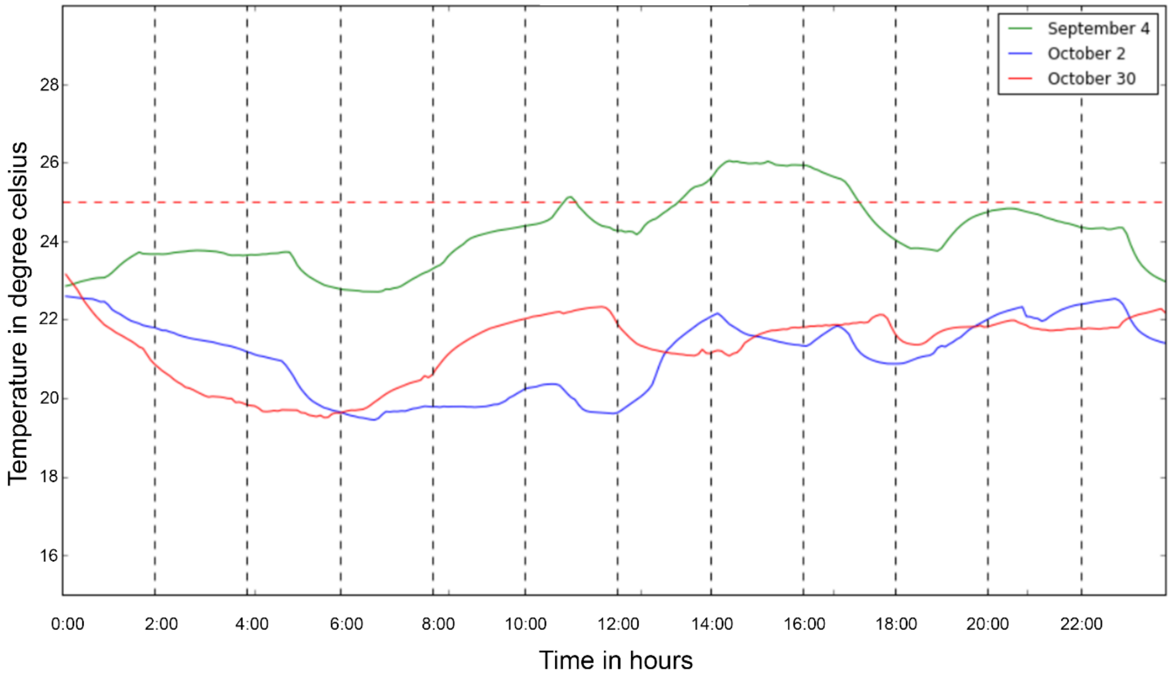


Image 23: shows the temperature profile of the glass terrarium second test; September 4 is the first day of testing, October 2 is the day after four weeks of testing and October 30 is the last day of testing. (own graph)

In the second terrarium test, three different test materials used are red brick, brown brick, and aerated concrete. Three different moss species are used separately for the moss cultivation technique, two consists of moss with mats life forms and one with cushion life forms. On both the red and brown bricks samples, the mosses with mats life forms were able to grow well, as shown in Image 24. Simultaneously, the moss with cushion life form was unable to produce on the brick samples. On the other hand, all of the three different moss species were able to grow on the aerated concrete even though it was very slow, where the growing pace might be related to the material properties itself. Because the aerated concrete losses its moisture fast, resulting in a suspended metabolism state, while the bricks samples continue their metabolism activity. Therefore, the results of the glass terrarium test are influenced by the material properties as well.

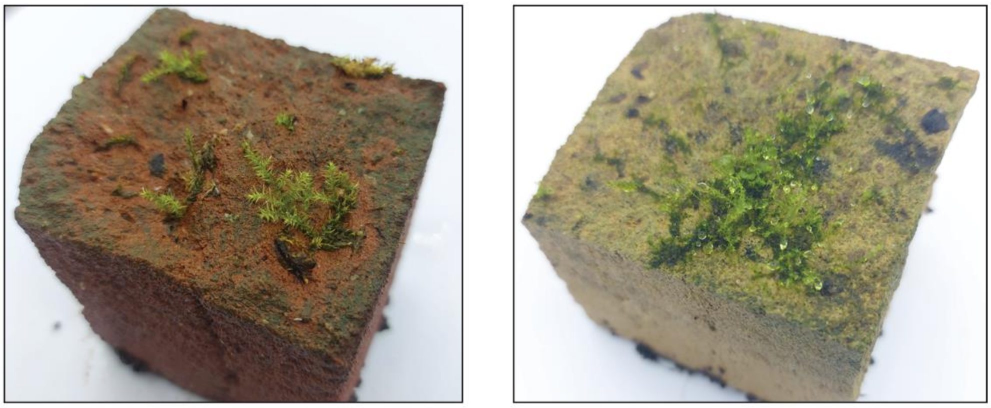


Image 24: shows the red and brown brick test sample with mats life form mosses growing on it (own image)

At the end of the indoor terrarium tests, it is concluded that the terrarium testing method does work if the temperature can be manipulated to be below 25 degrees Celsius at all times. The results collected from the indoor terrarium test needs to be carefully considered which material properties are being tested, especially when moisture is being supplied regularly with the help of a moisturizer. Since the terrarium has a stagnant airflow, testing for material roughness effects might be impossible with a terrarium. The chemical composition of the material does somehow influence the moss growth rate and finally, the use of artificial lighting might be insufficient due to the occurring moss etiolation. For this reason, if the temperature can be controlled well, the use of natural daylight is better than artificial growth lighting.

Glass terrarium design improvement

The second test in the glass terrarium had positive results because of the temperature decreased due to the winter season. Therefore, a way to improve the design is by adding the possibility to reduce the temperature during the other season. The waterfall redesign with clay pots does not only serve as a means to increase the humidity of the glass terrarium but provides a means to control the terrarium temperature, as shown in Image 25. The addition of an aquarium water chiller is possible, where the water pump is needed to extract water from the terrarium to the water chiller. The water chiller will lower the water temperature that goes back to the terrarium via the waterfall as a means to reduce the temperature.

Image 25: shows the terrarium with clay pots waterfall design (own image)

c. Simultaneous outdoor testing idea

In order to understand the indoor moss terrarium growth efficiency, similar testing samples can be put outdoor, in locations where moss growth is prominent. By comparing the indoor-grown sample with the outdoor-grown sample, the effectiveness of the terrarium can be assessed. The terrarium testing effectiveness can be evaluated by using similar test samples, where one will be cultivated with the indoor terrarium and the other ones put in an outdoor location. For the indoor sample, a weekly photo record can be taken, but the outdoor ones will be collected at the end of the testing period. So only the end result of the outdoor sample will be available for comparison.

The sample tested outside should be placed into a transparent plastic container for daylight to reach. Holes should be drilled on the bottom of the container to prevent water accumulation resulting from rain. The test sample can then be put inside after applying the moss cultivation technique and finally cover with carbon-fiber mesh or transparent cloth where water and light can penetrate and prevent animals from reaching the test samples, depicted in Image 26.

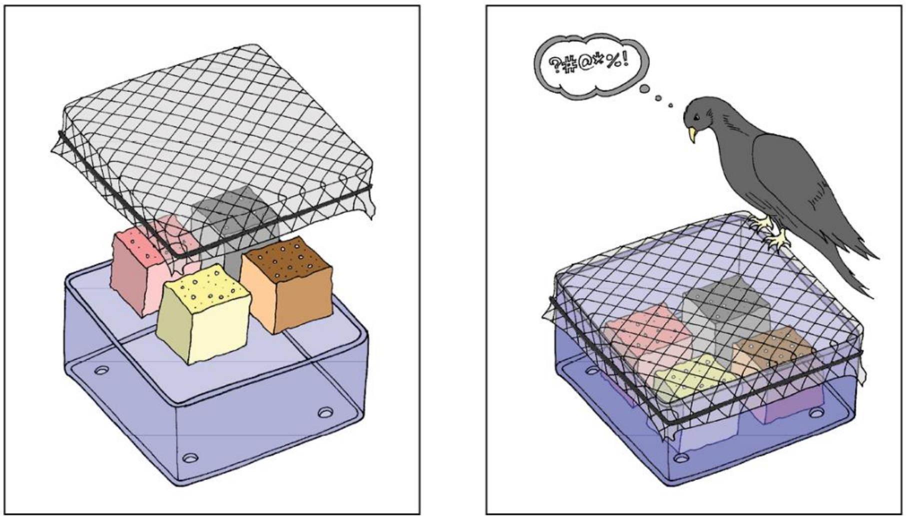


Image 26: Outdoor testing unit composition (own image)

The test sample container can be placed on trees, secured in a way that it will not cause danger from falling down and hard to reach for passerby. Place on-site where water is present in the form of a creek and near concrete structure with abundant moss growth. Both of the last-mentioned methods can be slightly buried to make it harder to notice by a passerby. See Image 27 for outdoor testing unit placement ideas.

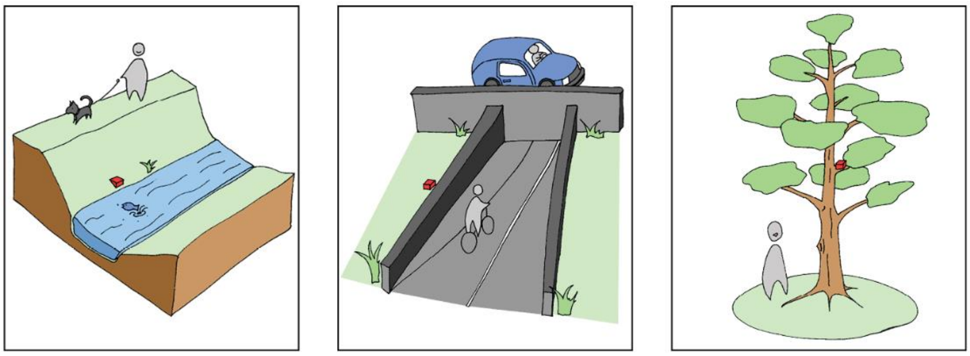


Image 27: Possible test unit placement (own image)

d. Biomass measuring technique idea

The biomass measuring technique is required as a method to analyze test samples' moss receptivity on a time basis. Because different moss species can either have a linear or exponential growth rate (Glime 2017, Volume 1, Chapter 7). Therefore, the sample with the earliest observable moss growth might not be the one that gains the highest moss colonization rate. Since the indoor experiment barely resulted in moss colonization to test this method, the technique will be described only as a conceptual idea.

1.Image analysis for coverage area measurement

By using image analysis to assess the moss growth on test sample is a good idea. The problem is that some mosses grow upwards while others grow sideways. For example, mosses with cushion and turf life forms will grow upwards, while mosses with mats life forms will grow sidewards, covering more surface area. Therefore, mats life forms mosses will reach a higher coverage percentage but not necessarily more biomass. A possible solution is to measure the height and use this data together with the results from image analysis to estimate the volume of the grown mosses, which might serve as a more reliable method.

Another strategy is to only use one type of moss species during the moss cultivation method, which means the growth life forms and density will be similar. But in real life, this might be atypical since one moss species seldom occurs alone. Therefore, this idea is limited to measuring small test samples cultivated in a controlled environment.

2.Depth gauge to measure growth height

The depth gauge can be used to measure the mosses' growth height on the test samples and during the field survey. Which should be combined with image analysis to estimated the volume of the mosses. If not used together, the height measurement of mosses is practically useless.

3.Sample weighing strategy to monitor growth

By weighing the sample weekly can work as a method to assess the moss test sample's biomass growth. This method's problem is that the measurement does not tell much because the weight gain or loss can vary dramatically due to the test sample's moisture content. For example, if the test sample's first measurement is fully saturated while the second measurement is only 80 percent saturated. The moisture difference will result in mass differences, which will be hard to distinguish from the biomass gain. Secondly, mosses can absorb and lose moisture and soil can stick to the bottom of the test sample as well. Thirdly, the moss cultivation technique adds moss fractions directly on top of the sample, which either grows new sprouts or is dead. The addition of moss fractions increases the mass slightly even without occurring moss growth.

Conclusion

At the end of the test, it is possible to dry the sample with moss-grown on it and subtract the sample's dry mass to attain the sample's amount of biomass gain to confirm the image analysis results. Sadly, there is insufficient moss growth on the samples to test the mentioned biomass measuring techniques. In the end, the mentioned technique will still be questionable due to the fact that the increase of biomass can occur without an increase in height and vice versa (Glime 2017, Volume 1, Chapter 4). So, the main concern will be whether more growth or more coverage is preferred. For a greening system aesthetics, full coverage would be preferred and the density can increase slowly afterward.

3.6 Bio receptive quay walls design and considerations

The Amsterdam municipality is responsible for 1800 bridges and 600 kilometer quay walls. Based on surveys, 850 bridges and 200 kilometer quay walls has renovation priority. Sadly, the renovation pace of quay walls in Amsterdam is around 500 meters and one bridge yearly. The goal for 2024, is to increase it to 2000 meters quay walls and 6 to 8 bridges per year to reduce the backlog work. That means that the renovation of bridges and quay walls will take a tremendous amount of time to complete. Due to the large-scale renovation of quay walls, the integration of other functions to add value to the city is one of the renovation goals as well, where greening of the city is also included (Actieplan bruggen en kademuren 2019).

Why should mosses be considered for the greening of quay walls instead of traditional greening methods? Imagine the use of climber plants to achieve quay wall greening. If the roots can gain water directly from the canal, then watering the plants is not needed. What if the climber plants growth gets out of control, covering the canal water body and reaching the pavement? This will result in regular maintenance of the climber plants and another issue is the roots growing in diameter over time, which can damage the quay walls. With mosses, its growth rate is very slow with limited growth expansion on material surfaces over time; the mosses used for quay wall greening purposes can not grow on the water body as well. Lastly, the roots (rhizoids) do not grow in diameter since they are mainly for attachment purposes. Based on a field study (Baljeu, et al. 2018) the penetration of rhizoids is less than twelve millimeters but does increase moisture compared to areas without moss growth.

a. Amsterdam's quay wall element design

Based on the three winning parties for the renovation of Amsterdam's quay walls, each of them has different innovative quay wall renovation methods. Therefore, studying standard quay wall construction methods might be irrelevant due to the fact that the modular quay wall element is custom-made by the following winning parties G-Kracht, Kade2020 and Koningsgracht, simplified quay wall design of the three winning parties have been redrawn, shown on Image 28 and 29 (Kade 2020 XXX 2020, G Kracht 2021, Royal Haskoning DHV 2021).

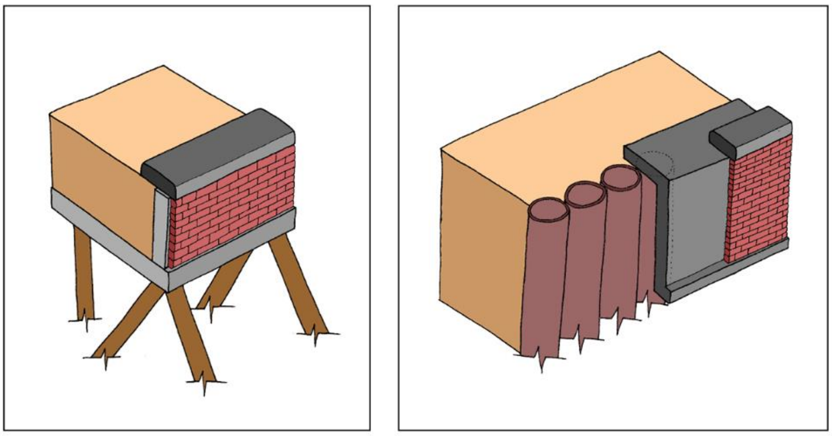
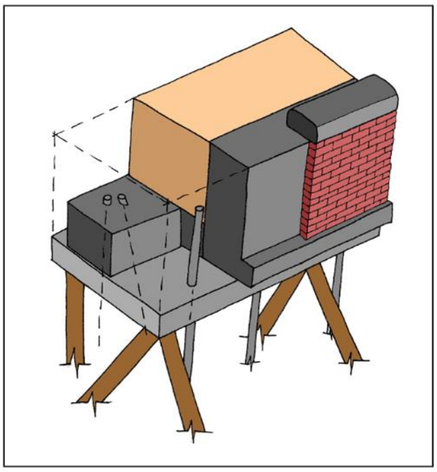


Image 28: on the left typical Amsterdam's quay wall and the right shows the quay wall design by G-Kracht, redrawn based on (G Kracht 2021)



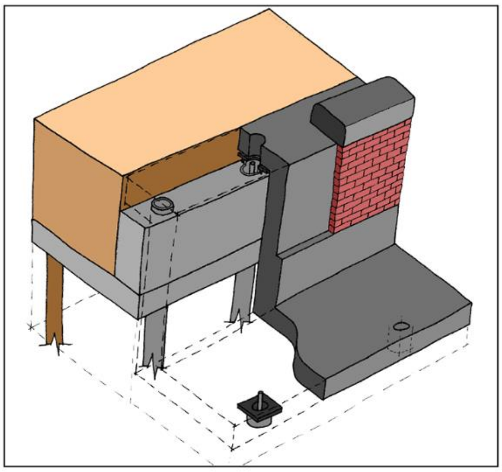


Image 29: on the left shows quay wall design by Koningsgracht and on the right shows the quay wall design by Kade2020, redrawn based on (Kade 2020 XXX 2020, Royal Haskoning DHV 2021)

This thesis focuses on improving the quay walls bio receptivity and not designing a whole different quay wall system in terms of construction practicality and calculation wise. For this reason, no structural calculation will be performed to check the strength and stability of a quay wall element. All three designs consist of a modular prefabricated concrete quay wall with brick finishing. An ideal case would be to choose one of the modular prefabricated elements and redesign it to improve bio receptivity. Sadly, technical drawings and calculations are not available due to privacy reasons and the project's ongoing development. Instead, a reference quay wall renovation design for Rechtboomsloot in Amsterdam will be used, where the requirements, technical drawing and calculation are provided by Dr. ir. Marc Ottele, redrawn of the quay wall design is shown in Image 30.

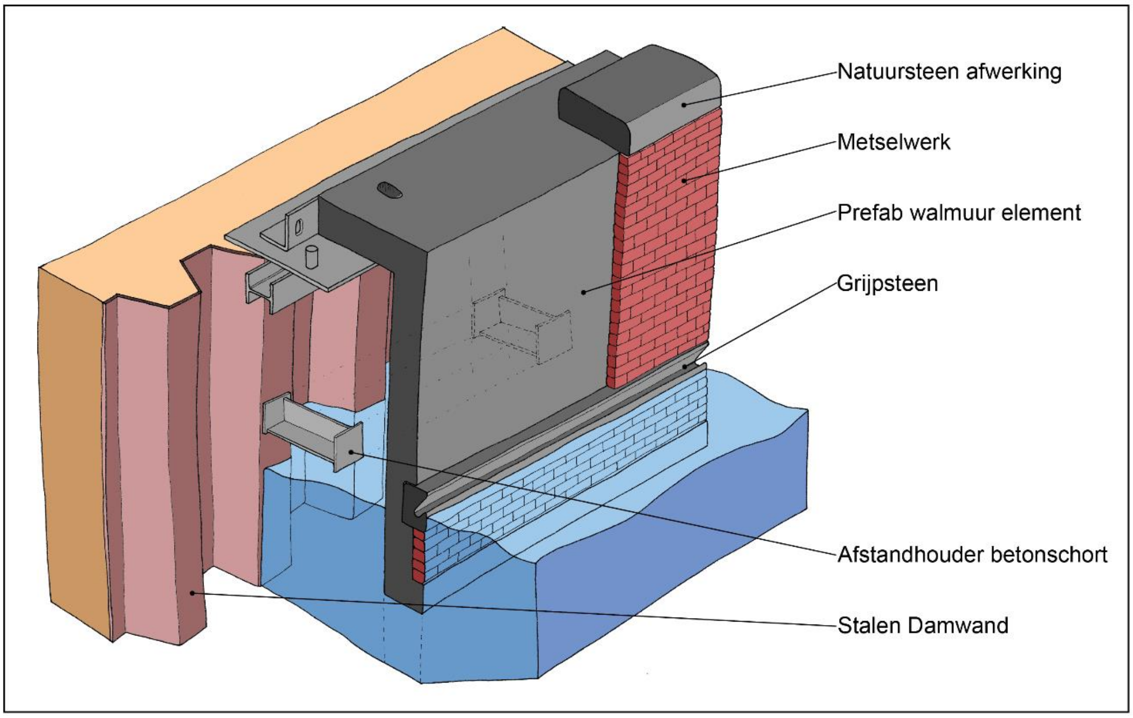


Image 30: Quay wall renovation for Rechtboomsloot in Amsterdam, redrawn image not on scale

The stated requirement for the prefabricated quay wall design are:
-Consequent class CC2
-Prefabricated concrete strength class C35/45
-Reinforcing steel quality B500B
-Cement type CEM iii/B LH HS 42,5 (XC4 quality)

The stated requirement for the masonry work are:
-Brick bond: English bond (kruisverband)
-Average compression strength: minimum 30 N/mm^2
-Freeze and thaw resistant class (Vorstdooiweerheid) : F2
-Waterabsorbance (Wateropneming): < 12%
-Initial rate of absorption (Initiele wateropzuiging): <4 kg/m^2*min
-Usage class (Gebruiksklasse): B5 (according to NEN 2489)
-Brick size: Standaard waalformaat (L: 210 mm, W: 100 mm, D: 50 mm)
-Size class: II (L: 206-213 mm, W: 97-102 mm, D: 48-51 mm)
-Thickness of mortar joint: 10 mm
-Bedding mortar: Portland cement (NEN-EN 197-1: 2000)

Design parameter

To improve the bio receptivity of the quay walls, design parameters that play a role need to be taken into consideration. During the field survey, it is found that the amount of direct sunlight plays a crucial role; the moisture condition affects the growth of mosses directly and the nutrient source in the form of degrading biomass. The amount of direct sunlight exposure can be manipulated with the shape of bricks, but for this paper, a study site location will be chosen and explain how the orientation should be taken into consideration to promote moss growth without modifying the brick shape. The design will focus on improving the moisture condition of the quay walls to stimulate moss growth. Followed by a suggestion on how nutrients can be supplied in a natural way.

Moisture improvement design idea

To improve the quay walls' moisture condition, first, the possible moisture sources need to be determined. Potential moisture sources can be rain, fog, mist and dew. But how reliable can these sources of moisture be for moss growth initiation? For example, if one entirely relies on the raining frequency as the primary moisture source. The moss growth initiation will be complicated since the frequency is random, resulting in a dry and wet cycle of the quay walls surface. To promote moss growth initiation, a continuous moist surface followed by low temperature is preferred instead of a wet and dry cycle. For this reason, rainfall cannot be relied on as the primary moisture source. Another option would be extracting water from the canal through capillary action. In this case, there are two possible ways to achieve this feature. First is utilizing a fiber/cloth layer located behind the masonry work to extract water upwards. The second is to promote bricks and mortar capillary action, a simple concept depiction shown in Image 31. Both ideas will be examined to understand better what kind of obstacles would render it impossible and how this can be solved.

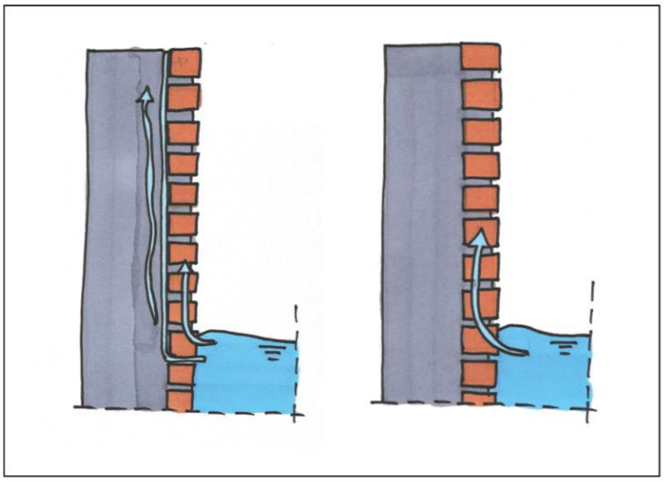


Image 31: On the left shows fiber/ cloth layer solution and the on the right promoting bricks and mortar capillary action (own image)

Capillary action through fiber/cloth layer

The idea behind this is to sandwich a fiber/ cloth layer between the prefabricated concrete element and the masonry wall. An opening on the masonry wall allows direct water contact to the fiber/ cloth layer to pull the water upwards through capillary action to moisturize the bricks from one side. While one side is moist and the other exposed side is dry, a horizontal moisture movement will take place, causing the exposed side to be moist as well. Since the masonry wall is not directly attached to the prefabricated concrete unit, horizontal stability support will be needed to achieve a safe structure. This can be done with the help of adding an anchor railing for the wall ties. An anchor railing is chosen instead of regular cavity masonry wall ties because, with the traditional wall ties, an approximation of the bedding mortar height is needed for the wall ties advanced placement. Therefore, the construction tolerance on the masonry wall is limited, but with an anchor railing, the wall ties height can easily be adjusted.

Whether the masonry wall can be prefabricated with the concrete unit together during the casting is questionable due to the presence of a fiber/ cloth layer in between. Thus, the masonry might need to be build afterward, making it labor-intensive for each prefabricated unit. A second issue would be the wall ties corrosion over the years, resulting in a large-scale renovation again. Finally, the masonry wall might not be horizontal force impact tolerant because the masonry wall is not in direct contact with the prefabricated concrete unit. For this reason, horizontal impact force will be transferred through the supporting bottom and ties, where the created moment/shear force can cause the masonry wall to crack. Therefore, this design idea is discarded due to a high complexity level compared to a normal prefabricated masonry element and no further study has been conducted regarding the fiber/cloth layer properties to achieve sufficient capillary action to lift the water upwards, see Image 32 simple representation of the design idea.

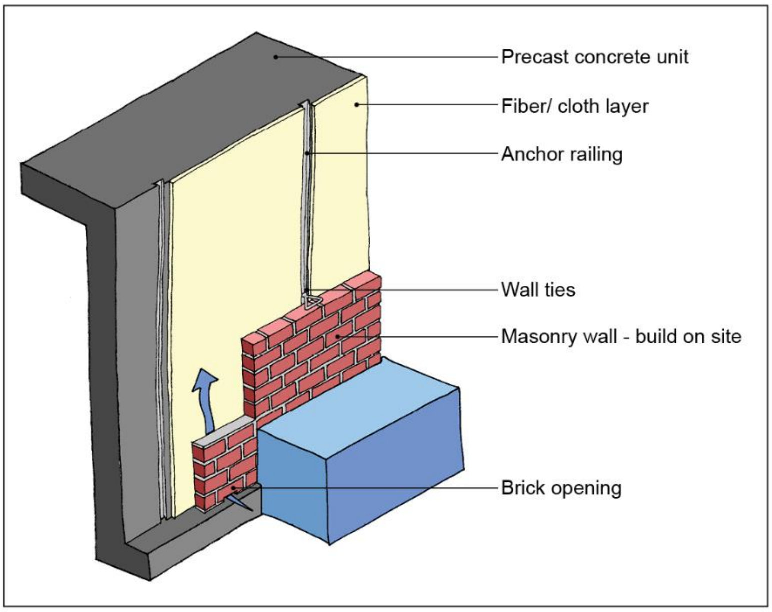


Image 32: shows the capillary action through fiber/ cloth design idea practicalities (own image)

Capillary action through brick and mortar

Compared to capillary action through a fiber/ cloth layer, capillary action through masonry is much simpler if this can indeed improve the moisture condition of the exposed masonry wall surfaces, see Image 33. Another issue would be whether this can be fully prefabricated in the factory instead of on-site labor or laying bricks after prefabricated concrete elements harden.

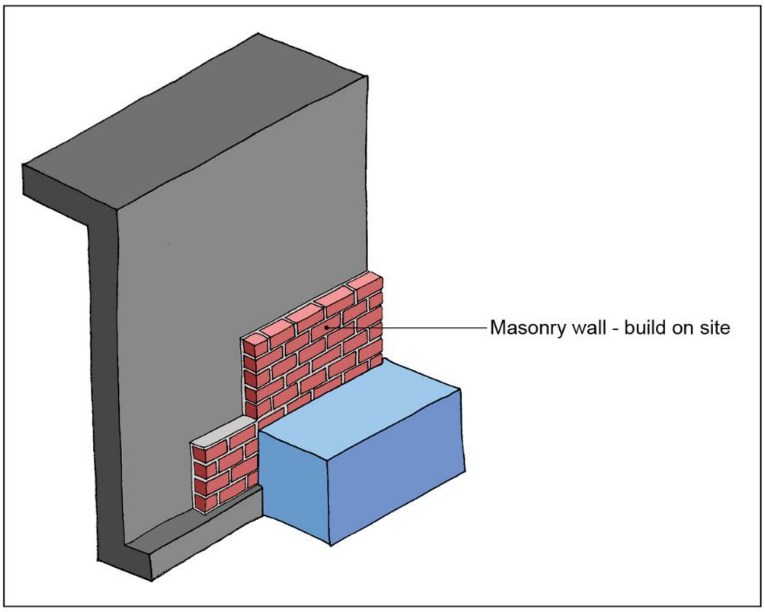


Image 33: shows quay wall design idea of promoting capillary action of the masonry itself (own image)

To have moisture transport upwards through capillary action on the masonry walls, the used bricks properties and the bedding mortar plays an important role. The brick property that indicates the initial rate of absorption (IRA) is called "initiele wateropzuiging" (IW) in Dutch, which is divided into four different classes based on the amount of water absorbed in kilograms per square meter during a minute, see Table 4 for the specific values. For this reason, if bricks with properties of IW4 (IRA4) are used for the quay walls, the stronger capillary action will result in a higher moisture level. The capillary action is from within one brick; for the moisture to reach the other bricks above, it needs to penetrate through a bedding mortar layer connecting the bricks. The bedding mortar properties will decide whether it serves as a moisture barrier or allowing the moisture to travel upwards (van Hunen, et al. 2012).

Table 4: Classes of initial rate of absorption, information retrieved from NEN-EN 771-1

	Water opzuiging (kg/m2*minuut)	Gedrag
IW1	0 - 0.5	Slecht zuigend
IW2	0.5 - 1.5	Matig zuigend
IW3	1.5 - 4.0	Normaal zuigend
IW4	> 4.0	Sterk zuigend

Based on an experimental test carried out by Van Hunen and colleagues (2012), where a small sample of masonry blocks are used. All samples were made of similar bricks with an IRA value of 3.5 kg/m^2*minute and four different mortar.

- Mortar A : "schelpkalkmortel" (lime : sand ratio = 1 : 2) **(shell lime mortar)**
- Mortar B : "licht hydraulische kalkmortel" (lime : sand = 1 : 2) **(hydraulic lime mortar)**
- Mortar C : "steenkalk-trasmortel" (lime : trass : sand = 5 : 1 : 12) **(trass lime mortar)**
- Mortar X : "metselcementmortel MC10" (MC : sand = 1 : 3)

The four test samples are fully submerged in water for 24 hours and the increase in mass in percentage is measured and afterward allowed to dry on only one surface to represent the drying behavior in real masonry walls; the results are shown in Figure 3. This experiment concludes that mortar samples B and X function as a barrier effect in the masonry walls. While mortar samples A and C barely have a barrier effect in the masonry walls. A similar test was done with the same four mortar samples but with bricks with an IRA value of 2.3 kg/m^2*minute. The barrier effect of samples B and X is less compared to samples A and C. However, samples with B and X mortars are dryer compared to samples with A and C mortars (van Hunen, et al. 2012). For this reason, using either mortar A or C to improve the moisture condition of the quay walls would be recommended.

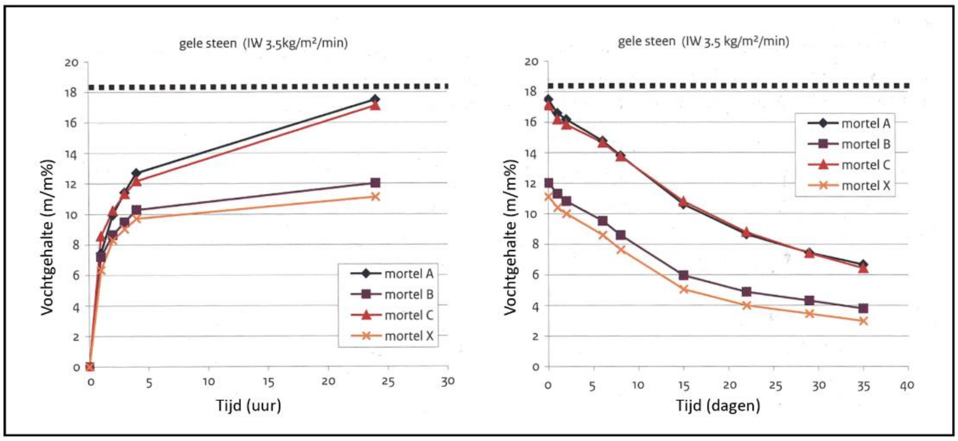


Figure 3: Shows the wetting and drying experimental test results of using different mortars, retrieved from (van Hunen, et al. 2012)

In another experimental research done by Lubelli and colleagues (2020) on the impact of mortar and brick properties on masonry bio receptivity, two different bricks are used, named B2 and B8. One crucial criterion is that the used bricks should be frost resistant, satisfying the F2 class according to EN771-1 (CEN 2015). Different physical and chemical properties have been acquired, but in my opinion, one significant difference is the Initial rate of absorbance value between the B2 and B8 bricks. B2 with an IRA value of 3.91 kg/m^2*minute and B8 with an IRA value of 0.20 kg/m^2*minute. In the end, it turns out samples with B2 bricks acquired better results for plant growth. It was concluded that the bricks work as a water reservoir for the mortar, which can extract water by capillary action to prolong the moist period for plant growth. Mortars with higher porosity and capillary action have a positive effect on bio receptivity. In this case, mortars with trass lime gained the best growth results, followed by natural hydraulic lime binder.

Based on this information, bricks with an IRW value above 3.0 kg/m^2*minute should be used in addition to either trass lime or lime mortar to ensure that the bedding mortar does not serve as a moisture barrier but stimulate moisture through capillary absorption. This will cause the masonry to be moist most of the time. Masonry that is dry is less subjected to damage (van Hunen, et al. 2012); for this reason, the chosen bricks need to suffice the F2 frost resistant class, which is meant for masonry that is permanently in contact with water.

After acquiring information on what bricks parameter and bedding mortar to consider for the quay wall finishing, another issue would be how this should be incorporated in the quay walls prefabrication process. If the masonry walls are simply built after the prefabricated concrete element hardens, this might be labor-intensive. Image 34 shows how prefabricated masonry façade elements are made. A mold is used to lay bricks with an offset to create a raked joint before applying concrete with steel reinforcement.

Image 34: shows how prefabricated masonry facade element is made, images provided by Dr. Roel Schipper (Source: wall elements for Maasstad Ziekenhuis Rotterdam fabricated by Loveld, www.loveld.com)

By prefabricating the quay wall element shown in Image 34, the bedding mortar connecting the bricks is actually concrete that will serve as a moisture barrier against capillary action. That means the wanted capillary action will be blocked. Therefore, the challenge will be how to make it possible to prefabricate the quay wall elements efficiently and still keep the capillary absorption quality. This can be achieved by creating a deeper raked joint, around twice the joint thickness for adequate cohesion, while the joint thickness must be 10 mm. The created raked joint of 20 mm, will be pointed with either lime or trass lime mortar that will serve as the bridge for capillary action to continue from brick to brick. This mortar layer might be subjected to damage over some time and might need repointing in the future. But the goal of this mortar layer is mainly to create a moist quay wall for a certain period to promote moss growth. Once this is achieved, the damaged mortar layer should not be repointed anymore. The repointing will be labor-intensive and this also requires the cleaning of the green quay walls. For this reason, if the pointing mortar falls off some time in the future after the moss greening is achieved, for material degradation study, only the bedding structural concrete needs to be checked for damage, see Image 35 for a concept illustration.

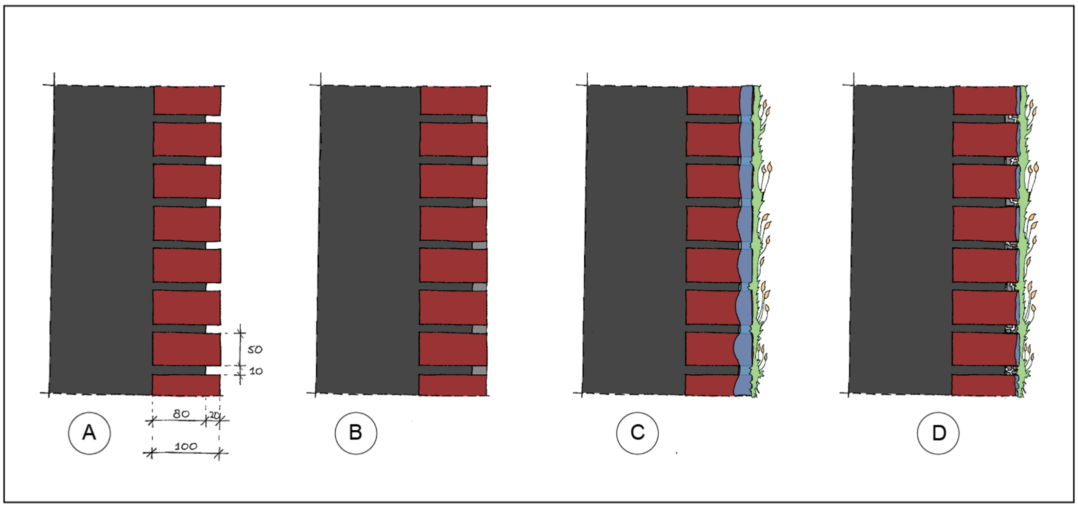


Image 35: A. how a section of the prefabricated quay wall element before pointing, B. prefabricated quay wall element after pointing, C. shows the moisture in the quay wall element and the moss growth and D. shows how the moisture reduces in the quay wall element after the pointing are damaged (own image)

Nutrient supply idea

Based on a literature study done earlier, the influence of nutrients is essential for moss growth. However, this is not simple to understand. For example, if an inappropriate concentration of nutrients is added, it might become toxic or stimulate other organisms to prosper, resulting in the decline of moss growth. Therefore, the correct nutrient contents are needed and the concentration level should be low enough so that other organisms cannot take advantage of it. The required nutrient concentration is low, which means less fertilizer will be required. But, if more than 100 kilometers of green moss quay walls need to be fertilized once a year. This might be problematic, resulting in a high maintenance cost due to labor-intensive work. Based on the field survey, most of the sites gain nutrients in the form of degrading biomass. The slow degradation process serves as a low nutrient concentration supply. Therefore, taking advantage of degrading biomass in the forms of falling leaves and branches would be a great idea. But how can this be supplied to the quay walls vertical surfaces?

The idea is to use pervious concrete blocks instead of natural stones for the quay wall edge finishing. Pervious concrete is similar to conventional concrete, composed of water, cement and coarse aggregates. The only difference is that less or no sand is added, which allows water to pass through easily due to the created porous open-cell structure (ConcreteNetwork n.d.).

The pervious concrete block profile will be shaped in a way that prevents the biomass from falling directly into the canals. When it rains, the rainwater on the street level will pass through the degraded biomass and leak down the quay wall vertical surface to reach the canals waterbody; see Image 36 to depict the design idea. In the end, the addition of pervious concrete blocks is not mandatory since not all quay walls edge has natural stones as finishing elements; some are just a continuous masonry bond. But it is highly recommended to promote moss growth and can also serve as a secondary moisture source for the mosses.

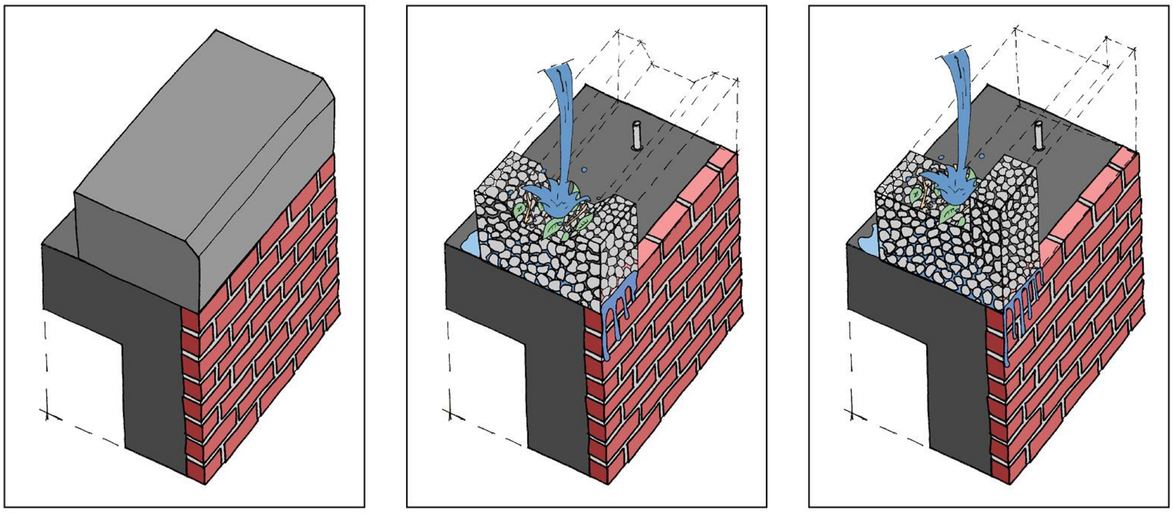


Image 36: On the left shows the standard quay wall edge finishing with natural stone; on the center and right, both depict similar idea with pervious concrete blocks with slightly different profile (own image)

b. Quay wall design site selection and study

Based on the field survey done, the direct sunlight availability during the growing season is essential and careful consideration needs to be taken into account which moss species to cultivate there. The selection of a study site can be broad; the main goal is to get an idea of the quay walls exposure to direct sunlight taking the surrounding buildings and orientation into consideration. The chosen site is the canal intersection between "Rechtboomssloot" and "Kromboomssloot". The intersection is selected due to a broader range of quay wall orientation than only one running straight. The reference calculation and technical drawings used are meant for the selected site as well. See Image 37 for the location of the chosen site in Amsterdam.

Image 37: The chosen study site location, intersection of Rechtboomssloot and Kromboomssloot (google maps)

In order to have an approximation of the daylight amount on the quay walls surfaces with the surrounding building, a 3D model of the chosen site is made with Revit to analyze the daylight condition on the winter solstice, December 21st, 2020. Only one day is chosen to simplify the work and one month before and after the winter solstice has approximately the same direct daylight exposure amount. The summer solstice is not needed because, during this period of the year, the temperature surpasses 25 degrees Celsius, resulting in a dormant period for the mosses. The surrounding trees have been omitted to simplify the analysis as well, that means some location will benefit from sun flecks instead of direct daylight exposure. Based on the investigation, the direct sunlight exposure on the quay walls is divided into four time periods: no direct sunlight, one hour, one and a half hour and two hours of continuous exposure; see Image 41 for the exact exposure time.

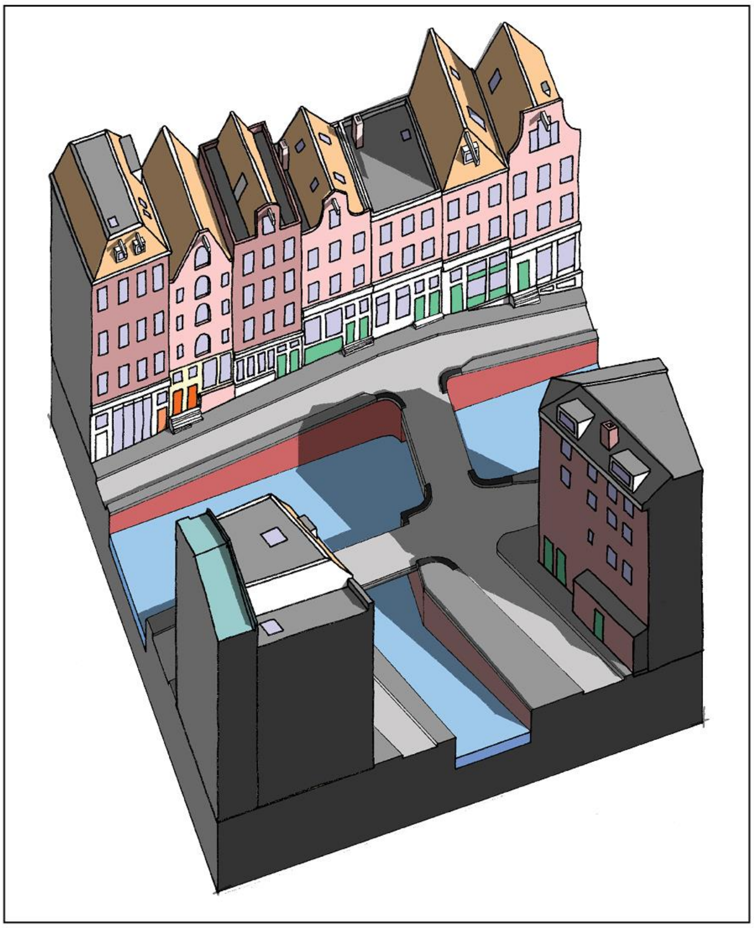


Image 38: shows the chosen site with adjacent buildings (own image)

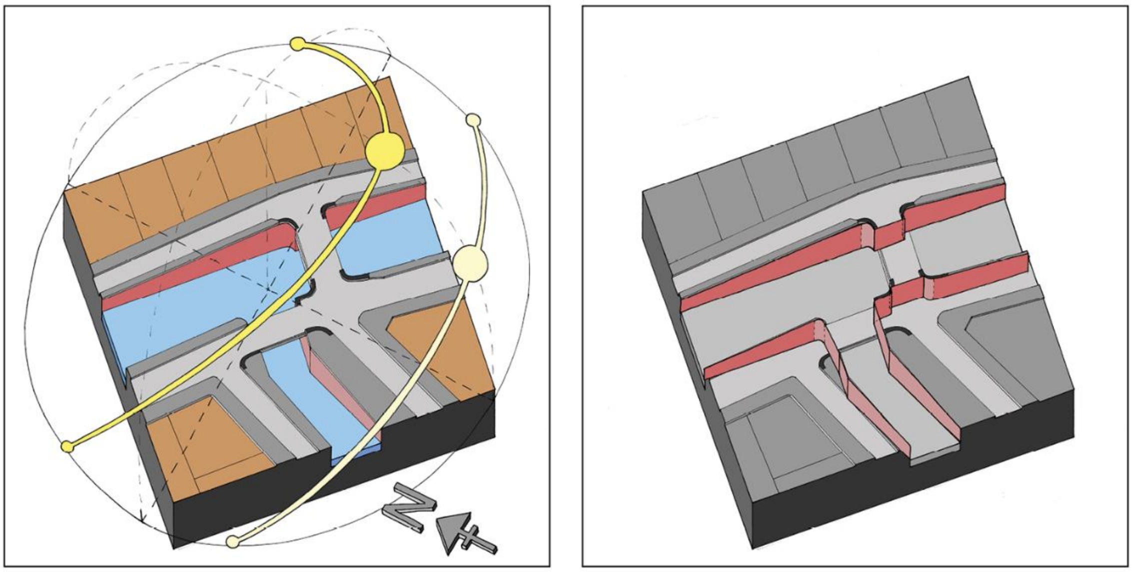


Image 39: on the left is the winter and summer solstice of the chosen site and on the right side is the highlighted quay walls surfaces (own image)

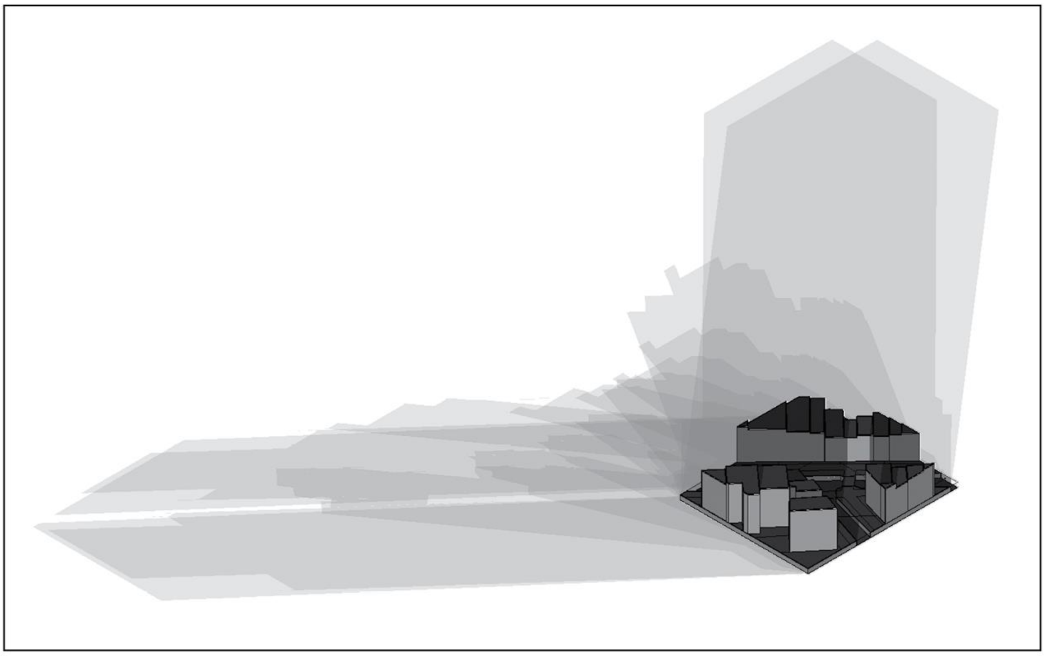


Image 40: shows the 3D model in Revit with varying shadows during winter solstice (own image)

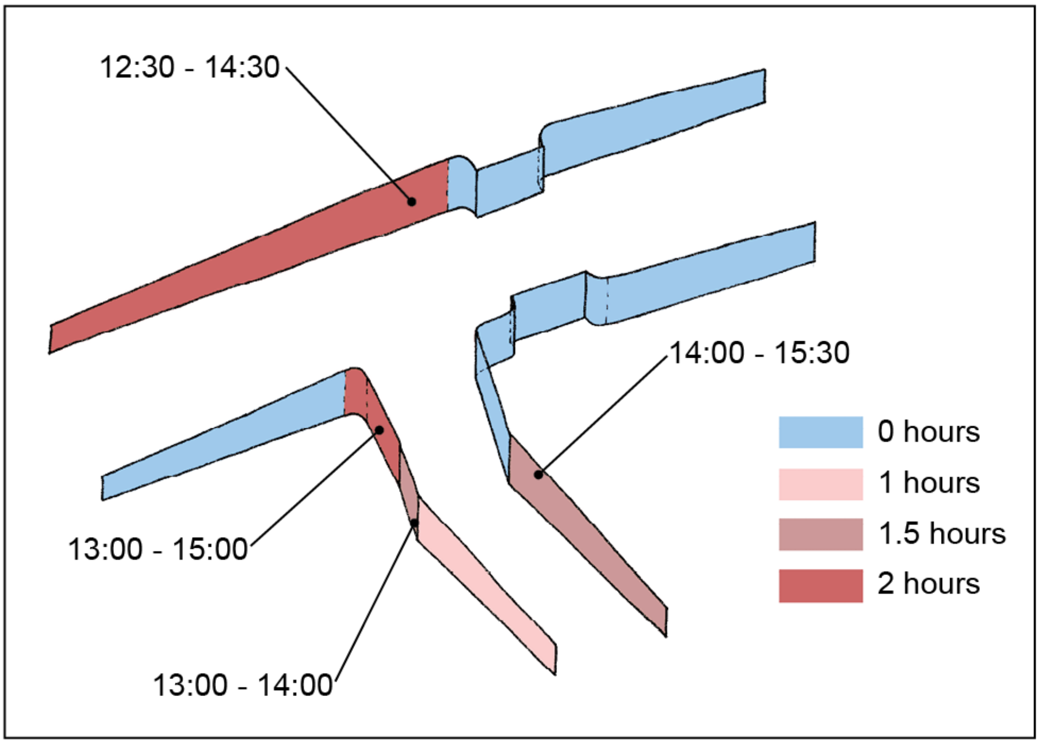


Image 41: shows the different hours of direct daylight exposure of the quay walls on the reference site (own image)

Based on the direct sunlight exposure results shown in Image 41, the different direct sunlight exposure varies between zero and two hours. Since the difference between one or two hours of direct sunlight is more or less the same, it will be approximately similar moisture conditions caused by the sunlight. With the field survey findings, the following moss species are recommended for the moss cultivation technique. Some of the chosen species were growing on quay walls located in Delft with no direct sunlight exposure. While the side with direct sunlight exposure is limited to the moss with cushion life forms, two other moss species are added to the list for cultivation on these exposure surface (Hypnum cupressiforme and Orthotrichum anomalum) because they were able to prosper on a site with the same range of direct sunlight exposure and limited moisture source.

No direct sunlight exposure on quay wall surfaces

Possible mosses to use for the moss cultivation technique are:
-Schistidium trichodon (Zeeachterlichtmos) (quay wall surface – no daylight side)
-Riccardia latifrons (Breed moerasvorkje) (quay wall surface – no daylight side)
-Brachithecium rutabulum (Gewoon dikkopmos) (quay wall surface – no daylight side)
-Leptodontium flexifolium (Rietdakmos) (quay wall surface – no daylight side)

One to Two hours of direct sunlight exposure on quay wall surfaces

Possible mosses to use for the moss cultivation technique are:
-Bryum capillare (Gedraaid knikmos) (found on quay wall surface – dry side)
-Grimmia pulvinate (Gewoon muisjesmos) (found on quay wall surface – dry side)
-Hypnum cupressiforme (Gesnaveld klauwtjesmos) (found on cementitious material – dry area)
-Orthotrichum anomalum (Gesteelde haarmuts) (found on cementitious material – dry area)

c. On-site moss cultivation idea

Moss growth on newly placed quay walls is difficult mainly because mosses are not primary colonizers; they are secondary colonizing organisms. The primary colonizers such as algae and cyanobacteria usually make the material surface ideal for moss growth after a certain amount of time. However, waiting for the natural organisms colonizing sequence will be time-consuming and hard to control since the primary focus is to have moss greening. For this reason, an improved moss colonization pace in a controlled method is required. Based on the indoor moss growth test done, the moss cultivation technique can be applied on the quay walls and then sealed with transparent plastic wrapping to reduce evaporative moisture loss, see Image 42. The plastic wrapping helps retain moisture on the masonry surface and protects the surface from external forces; once the moss germination occurred, the wrapping can be removed, which will probably take 2 to 3 months. Then the mosses can absorb moisture from the environment by themselves. A two-step sequence is illustrated in Image 43; first, apply the chosen moss species for the cultivation mixture on the quay walls. Afterward, apply a transparent plastic cover to prevent moisture loss through evaporation while letting direct sunlight reach the quay wall surface. The plastic wrapping needs to be secured on the quay walls to prevent removal caused by high wind pressure.

Image 42: One of the experimental brick sample, where the naming plastic trapped the moisture and resulted in moss growth on the sides (own image)

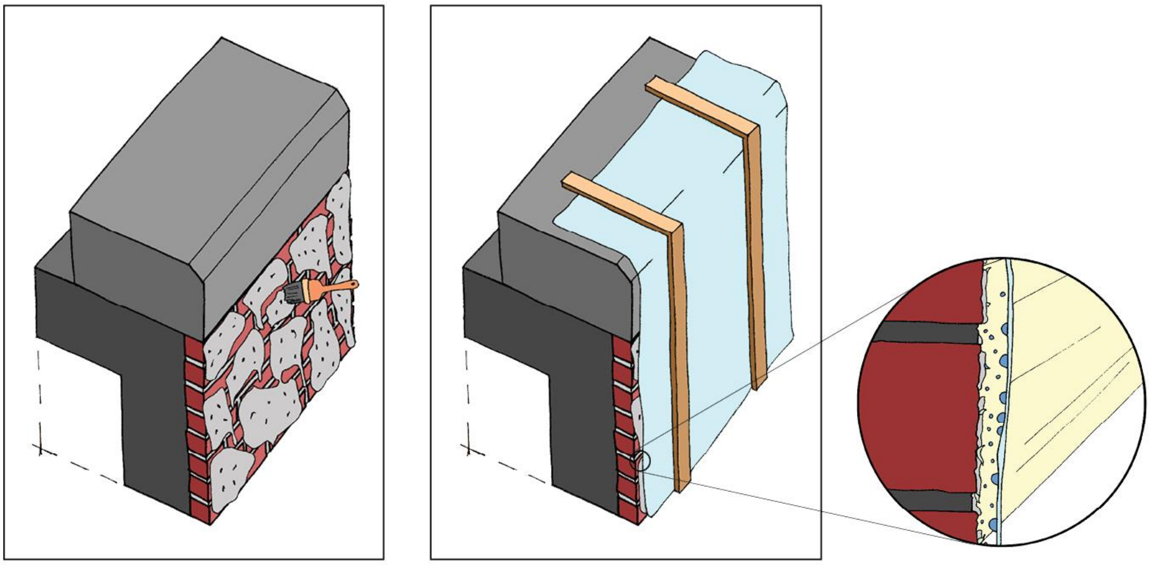


Image 43: on the left side, it shows how the moss cultivation technique is being applied to the quay walls and on the right side how it should be covered with transparent plastic to prevent moisture loss and gain direct sunlight (own image)

4 Discussion

In this chapter, unexpected results findings during different stages of this research paper will be discussed. The first part will discuss the importance of moisture for moss growth in different colonized material surfaces, which can be influenced by external factors that are site-dependent and internal factors such as material properties. The second part will describe the limit and careful consideration of the results of using a terrarium to stimulate moss growth on building materials. The third part describes the limited findings of the field survey. The fourth part would discuss the feasibility of pre-vegetated moss panels. The last part will discuss why moss greening should be preferred over conventional greening methods.

4.1 The importance of moisture

Moisture is the most crucial requirement for moss growth

Many studies have been done regarding moss growth on different construction materials, where vital chemical and physical parameters are mentioned that influence a material's primary bio receptivity, such as surface roughness, material pH level, porosity, capillary action or toxic substance.

Based on these studies conducted in different settings, a broad range of other parameters is given, which does not clarify why moss growth appears.

For moss to grow, the most crucial requirement is water or moisture. Other essential factors such as daylight, nitrogen and phosphorous are essential as well. But usually, mosses can adapt in a way to grow under low daylight or nutrition availability. For example, the same moss species shaded by trees and exposed to direct sunlight will still have a similar photosynthetic ability. The difference is that the shaded moss will need to utilize sun flecks so that the photosynthetic capacity will peak during the short amount of direct sunlight. Moss can easily attain the required nutrition from air dust, storing it until it can be used. Moss typically collects food during spring and summer when growth is impossible due to high temperature or lack of daylight.

Without moisture, the moss plant will lay dormant and dry out until water will be available again. For the primary bio receptivity of material, the moisture retention ability is particularly crucial for the setting and germination phase. The more prolonged the material can retain moisture, the longer the period for spore germination. Colonized material roughness serves as an attachment surface for dust, spore and nutritional particles. In the case of high wind velocity, the rough surface will retain less dust and this also accounts for smooth surfaces, which makes it impossible to stay. Morning dew, mist or rain serves as the most common moisture source for the material, where the material will get saturated and take a while to dry. Image 44, the left side shows how dust can be trapped and protected from the wind by the rougher surface; the right side shows how the material gets saturated by either rain or morning mist or dew.

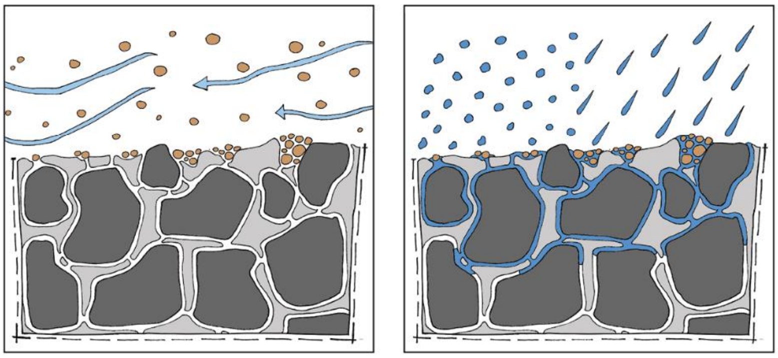


Image 44: Surface roughness and dust accumulation through wind shown on the left side and the right side depicts moisture acquirement of the material from the environment (own image)

When the material is exposed to high wind velocity or direct sunlight, the material's moisture will evaporate faster, resulting in a faster drying rate, shown in Image 45. For this reason, material that is directly exposed to sunlight or high wind velocity has a growth limit due to lack of moisture. Therefore, spore germination might be challenging and further development limited by moisture availability before the moss plant can retain/absorb sufficient moisture itself.

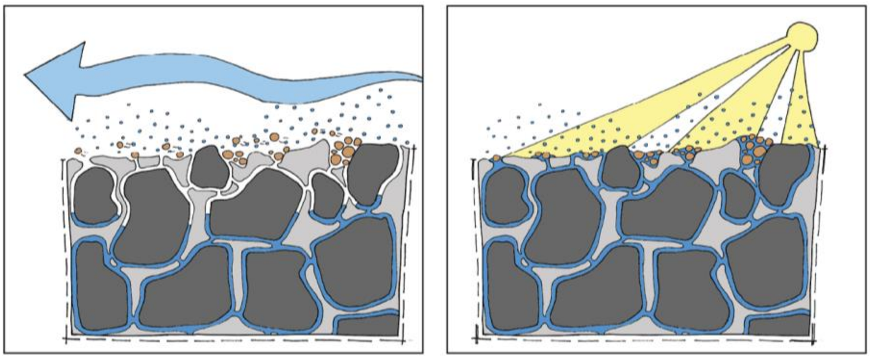


Image 45: Moisture evaporation caused by high wind velocity and direct sunlight (own image)

The idea behind this is that the material can retain moisture longer and be utilized by moss spore to germinate to the degree that the material's moisture gets resupplied by either rain, morning dew or fog before it gets entirely dried out. If this occurs, that means that the spore will gain sufficient time to germinate, which can take weeks. Image 46 shows moisture for moss growth extracted from the saturated material, where lack of moisture will hinder moss germination until moisture gets resupplied through external moisture sources. For this reason, no exact porosity level of cementitious materials can determine whether moss growth occurs or not since the moisture balance is also dependent on external factors. Another critical issue would be the influence depth of the material to supply moisture to the exposed surface. Based on observation during the field survey, different colonized material, bricks and cementitious material does have a certain influence depth. However, the colonized bitumen shingles are so thin that they can not retain moisture for a long time. The influence depth of the material is again dependent on the material surface drying behavior. Whether it is moisture transport or vapor transport during the drying process plays a crucial role, since a brick of 100 mm thick, drying on one surface can take a few weeks to dry completely due to the vapor transport mechanism. At the same time, the mortar dries faster than bricks due to moisture transport in the continuous microstructure of the mortar network (van Hunen, et al. 2012). Thus, the influence depth of bricks is less than the mortar. Therefore, the influence depth depends on the material properties.

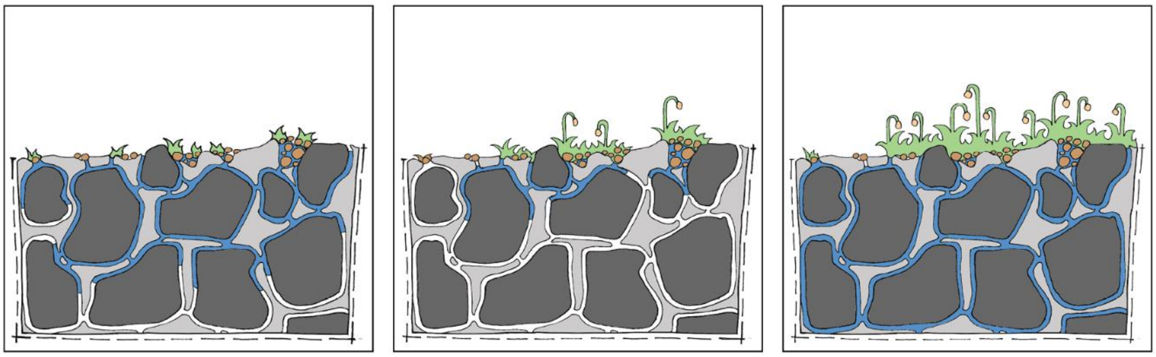


Image 46: Initial moss growth stimulated by material moisture content and get refilled by a moisture source to enhance the moss growth further (own image)

Does this mean that every moist area is suitable for growing mosses? Based on the field survey, the importance of moisture followed by limited direct daylight is crucial for moss growth. But not much could be told from the nutrient sources of the location it prosper. The moss nutrient requirement is very low and its nature to compete for nutrients is non-existent. Moss can thrive on-sites where other organisms cannot grow, either due to low nutrient level or substrate type. A typical mistake made by moss gardeners is failing to achieve a low nutrient level so that it is insufficient for other organisms to grow (Glime 2017). The substrate type is also limiting other organisms' growth. Therefore the nutrient level plays a crucial role when cultivating moss on quay wall materials.

4.2 Terrarium used for moss receptivity testing method

Currently, algae fouling test is widely done to assess a material's bio receptivity. No standardized testing method is available to assess a materials moss receptivity. Based on the few terrarium test done, it does show potential as an indoor moss cultivation testing method. Control of temperature, humidity and daylight is crucial. A change in one of these three parameters might yield a different result.

Another critical question is what properties of the material are being tested in this cultivation method? In this case, moisturizer is being used regularly to resupply moisture, so the material moisture retention ability is not thoroughly tested. Secondly, there are no external forces such as wind that hinder the moss growth. Therefore, the material roughness is not entirely being tested as well. But based on the difference in moss growth ability on bricks and aerated concrete, it can be concluded that moss growth is influenced by either or both chemical and physical properties. But the exact properties influencing moss growth are unknown since no data for comparison is available.

4.3 Field survey findings

The conducted field surveys showed that moisture condition influenced by direct sunlight exposure is crucial. Limited exposure to direct sunlight is ideal for moss growth. But this does not necessarily mean that shaded areas are ideal for moss growth. What could not be taken into consideration were the influence of different forms of nutrient supply and a nearby water body. Lastly, very little is known of the found mosses, the ideal pH level, nutrient requirements and the appropriate concentration level. With the availability of this information, a more tailored design can be made to grow specific mosses. For example, a possible design is to make mortar that serves as a nutrient source for the mosses. But due to the lack of this detailed information, it would be wise to gain more knowledge. Therefore, a more refined field survey can yield better results and be converted into design input.

4.4 Pre-vegetated moss versus growth in situ moss

Ideal outdoor moss growing condition is more or less limited to winter in the Netherlands. So, is it wiser to use a pre-vegetated moss panel instead of growing in situ? The mosses that are grown indoors on the construction material under ideal condition and later moved to the construction site. This concept is possible but does come with its own risk. Growing it indoors under perfect condition and suddenly changed to the real site location may cause a shock to the young mosses since they are less heat tolerant than mature mosses, which takes three to five years of growing in outdoor conditions. The real growing condition might not even be ideal for the pre-vegetated mosses, which can easily result in the hard cultivated mosses' death. For this reason, growing mosses on-site should be better and it will be observable whether it manages to germinate or not. If not, another approach can be taken to cultivate mosses there.

4.5 Moss greening versus conventional greening methods

Why should the moss greening method be used instead of the conventional greening method? Advantages of using moss for greening purposes on building materials such as concrete or masonry wall are: first is the direct attachment on the building material; therefore, no soil or attachment mechanisms are needed. Second, the penetration depth of the mosses roots (rhizoids) is limited and does not grow in diameter compared to climber plants. Therefore, building materials damage caused by roots is limited or very little when using mosses (Baljeu, et al. 2018). Third, mosses can acquire all the necessary growth requirements and nutrition from the environment. For this reason, barely or no external moisture or nutrient supply is needed to maintain the moss growth (Glime 2017). Fourth, moss greening might serve as a better airborne dust filter due to the presence of colonizing bacteria that supports oneself by decomposing organic matter collected by the mosses (Butcher 2017). Lastly, mosses can be used as biomonitors for anthropogenic air pollution in the city. It is proven to be an economical and practical bioindicator for monitoring air pollution (Chakrabortty and Paratkar 2006).

Moss greening also comes with disadvantages, especially since it is not a commonly used greening method and very limited practical examples are present. For this reason, some possible disadvantages compared to conventional greening methods are listed. First, not much is known about moss growth on construction materials; therefore, cultivating mosses on building materials will not be easy. Different organisms' growth is inevitable, which might not be aesthetically pleasing for everyone. Second, mosses are loosely attached to the building materials due to the roots' limited penetration depth (rhizoids). So, external protection might be needed to prevent mosses from being removed accidentally by people. Moss gardens in Japan are strictly prohibited from walking and touching the grown mosses. Third, during Spring and Summer seasons, the mosses will be in a dormant state due to the high temperature, which is brown colored. This might be controversial since it is supposed to be a green wall and if the application expands to the building façade, will it stimulate external fire spread since it will be in a dry and flammable state. Finally, biodeterioration on statues cause by biocolonization is very common and prevention studied in depth. For this reason, the penetration depth of the roots might be limited, but the occurrence of biodeterioration on building materials can be problematic in the future.

5 Conclusion and Recommendations

In this part, the conclusion and recommendations of the research are presented. The conclusions serve as an answer for the research questions formulated in Chapter 1 and the main research findings will be mentioned as well. The recommendations serve as a sign of what can be done for future research in the moss receptivity testing and quay wall greening methods.

5.1 Conclusion

This research aims to promote quay wall greening sustainably for Amsterdam, sustainable in the perspective of low maintenance of the quay walls over a long period. For this reason, moss greening is chosen since it has more or less similar advantages to other greening methods. However, it does not cause overgrowing hindrance covering nearby areas; the root system is mainly for attachment purposes and will not grow in diameter, so it will not damage the quay walls. Finally, if the moss's growth on the quay walls environment can occur naturally, a greening method that barely needs any care since the mosses can acquire all the required nutrients and resources without external help.

It is concluded that available moisture is crucial for moss growth, which can be influenced by the surrounding conditions such as rain, direct sunlight and wind. Only limited moss species are able to grow on building materials; therefore, careful consideration of which species to cultivate on the quay walls is needed. Improving the moisture condition of the quay walls to promote moss growth can be achieved, but some practical issues should be taken into consideration, such as the quay wall orientation and how to cultivate the moss on the quay walls followed by sufficient protection.

The main research question is:

"How can quay wall elements be designed with improved bio receptivity to stimulate high moss growth coverage that will add social and environmental values to Amsterdam citizens' wellbeing ?"

To break the research question into manageable parts that can be studied individually and later be used to answer the main research question, six sub-questions were formed that are responded to separately below.

Q1. What is bio receptivity of a material and other crucial fundamental concepts?

Bio receptivity, defined by Guillitte (1995), is "the aptitude of a material or any other inanimate object to be colonized by one or several groups of living organisms without necessarily undergoing any bio-deterioration".

Accessibility concept: This is defined as the environment's characteristics that determine the abundance of diaspore sources, proximity and transport capabilities, including the material's exposure to these sources and vectors (Heimans 1954).
Particular environmental condition: This is related to the exposed condition such as daylight, shading, water and draft, directly influencing an organism's growth (Guillitte, Bioreceptivity: a new concept for building ecology studies 1995).
Bio receptivity concept: The bio receptivity of a material is best expressed under maximum accessibility and environmental conditions that are optimal for the development of organisms (Guillitte, Bioreceptivity: a new concept for building ecology studies 1995).

Therefore, to have bio colonization by organisms, all these three concepts should be satisfied to a certain amount of degree to have biological growth.

Q2. What are the crucial material properties that contribute to or influences a construction material bio receptivity?

Based on literature research, physical and chemical properties affect a material bio receptivity, such as pH level, porosity, surface roughness, capillary action, and chemical composition. Due to the inconsistent testing settings of different research papers, it is hard to draw a firm conclusion. Some materials might yield better results in a tropical climate that favors other moss species, while in a temperate climate, moss growth might not occur. For this reason, the five mentioned parameter serves a site-specific function for the moss growth.

pH level: All moss species have a specific pH level range that they can grow on, typically in the range of pH level 6. At the same time, the pH level can influence the nutrients and toxic substance solubility.
Surface roughness: a rough surface can serve as a firm attachment surface for spores and dust against high wind velocity and at the same time, it also affects moisture retention.
Porosity: in this case, it serves as a water reservoir of colonized material.
Capillary action: with the porosity as the material's water reservoir, the capillary action serves as the supply of water to the colonized surface.
Chemical composition: The chemical composition of a material can be used by the mosses as either nutrients or toxic substances. For this reason, a material with toxic substances for mosses will not gain any moss colonization at all.

Q3. What is the crucial fundamental knowledge regarding mosses that are important for in-depth understanding?

Mosses are plants extremely sensitive to changes in the growing environment; thus, they can be used as bioindicators in large cities. On the other hand, moss greenery can easily be influenced negatively by small changes. For example, if a metal railing is installed near a green moss quay walls. That specific metal concentration will increase and this might cause the growth to decline since mosses are very sensitive to nutrients and toxic substances. Unlike vascular plants, mosses' growing season is during autumn and winter because the temperature is below 25 degrees Celsius, which means that carbon gain is higher than carbon loss. If the temperature is too high or insufficient moisture is available for photosynthetic activity, the mosses will just lay dormant and wait patiently when the time is right.

Q4. What crucial environmental conditions need to be considered for the moss growth initiation and stimulation on quay wall elements?

Based on the field survey done from August to December 2020, twelve sites were chosen to be analyzed. The moss growth should be around thirty percent so that sites with prominent cushion life forms mosses can be included in the selection criteria. Only twelve different moss species are found and identified that are able to grow on cementitious material, bricks and bitumen shingles. It was concluded that the influence of the duration of direct sunlight was prominent. Site with limited direct sunlight or in the form of sun flecks had a higher moss coverage percentage due to the presence of mosses with mats life forms. For this reason, the amount of sunlight a quay wall surface receives needs to be taken into account when choosing which moss species to apply. A more extensive field survey should be done since the influence of nearby water bodies and nutrient sources in decaying biomass forms is barely understood.

Q5. How can mosses be cultivated on quay wall building materials and how can the moss growth rate be stimulated to achieve a full surface coverage?

Terrariums have been used to cultivate mosses on building material. This method does create a humid environment promoting moss growth. Still, one major problem is that the exposure to sunlight might result in temperatures above 25 degrees Celsius which prevents moss fractions and spore germination. Based on the moss cultivation test, it turns out wrapping a sample with transparent plastic can prevent evaporative moisture loss. Which will stimulate the moss germination and might be possible to apply directly on a material surface exposed to the outdoor environment instead of being in a terrarium.

A moss cultivation technique from moss gardeners is used, where moss fractions from a specific moss species are taken and blended with a nutrient source to form a moss fraction mixture. This mixture should be applied to the construction material with a brush at least twice and then hope for moss germination. In this research, organic buttermilk was successfully used as the nutrient source since it gave better results compared to organic yogurt.

Lastly, the used of terrariums to create an ideal growing condition for mosses is possible. This can promote laboratory moss growth test to assess a material moss receptivity instead of using algae fouling test. Based on the conducted test, the use of sunlight was better than artificial lighting. The problem that came with it is an increase in temperature that is not favorable for moss growth. For this reason, if the terrarium temperature can be controlled well, this might even yield better results. Artificial growth lighting usage during the terrarium is very limited. Using specific light spectrum ranges might be better and create a stable lighting condition for moss growth because not every day will be equally sunny, which can directly influence the moss growth.

Q6. How can a common Amsterdam's quay wall element be redesigned with improved bio receptivity to achieve high moss coverage percentage?

Based on the field survey and indoor tests, the construction material's moisture condition is extremely important for moss germination and growth. Therefore, improving the moisture condition of the quay wall can lead to improved bio colonization. Based on a literature study, masonry moisture uptake caused by capillary action is a commonly encountered problem in old historic buildings. Where solutions to prevent capillary action are researched, a wet masonry wall is more prone to damages than dry conditions. But to improve the quay walls bio receptivity, the opposite should be done. Bricks with a high Initial rate of absorbance (IRA) should be used, followed by either lime or trass lime mortar to stimulate the upward water movement. To limit the masonry work's damage due to being constantly moist, the used bricks should be chosen in a way that suffices the F2 frost resistance class. A solution to how the quay wall elements can be prefabricated with a raked joint for further pointing with mortar supports the upwards moisture movement is given. Once the pointing is damaged, no repointing should be done. This is to limit the repair work and prevent the removal of the achieved moss greening since the pointing is only meant for moisture stimulation for moss growth. Once this is achieved, the mosses can attain and store moisture and nutrients from the atmosphere.

The use of pervious concrete block on the quay wall edge is proposed but not mandatory. The purpose is to retain biomass in the forms of leaves and branches. It will deteriorate slowly and when it rains, the accumulated water will take these nutrients and drip down the moss-grown quay walls as a form of natural nutrient supply to increase the colonization pace.

What needs to be taken into consideration is the orientation and the surroundings of the quay walls. The orientation and the surrounding will decide the duration of direct sunlight exposure, influencing the quay walls' moisture condition. Based on the natural lighting condition, a decision can be made of which mosses grow on a specific quay wall surface. Recommendations are given based on mosses that were grown on quay walls in Delft. Once certain moss species are selected to grow on a specific quay wall surface, the moss cultivation technique can be used on the quay walls, followed by a transparent plastic cover to protect them from external forces' removal. It is also preventing the loss of moisture through evaporation while allowing sunlight to penetrate for germination.

Research Question: "How can quay wall elements be designed with improved bio receptivity to stimulate high moss growth coverage that will add social and environmental values to Amsterdam citizens' wellbeing ?"

Now the quay walls can be designed to improve moisture conditions that can stimulate moss growth. With the moss cultivation technique's help, mosses can be cultivated on the quay walls and hopefully, within one year or two winters, a high moss coverage percentage can be achieved. The increase in greenery by moss quay walls greenery can add social and environmental values to the Amsterdam citizens' wellbeing.

One crucial concern will be the aesthetics that green moss quay walls will bring to Amsterdam. The colonized quay walls will not be only composed of mosses; there will be other organisms on it as well, such as bacteria, lichen, algae, cyanobacteria or other microorganisms. Image 47 shows the cushion mosses during their dormant season in August and their growing season in December. So during summer, it will be **black moss quay walls** instead of green moss quay walls. But during winter, when most vascular plants lost all their leaves, creating a gloomy scenery, the quay walls will be green. Therefore, it will not be an evergreen quay wall. But it does have similar advantages to an ordinary green façade. Additionally, it might serve as a bioindicator for the city. Since mosses serve as food for many insects, which will be eaten by the fishes and then birds, Amsterdam's biodiversity will improve in the long run.

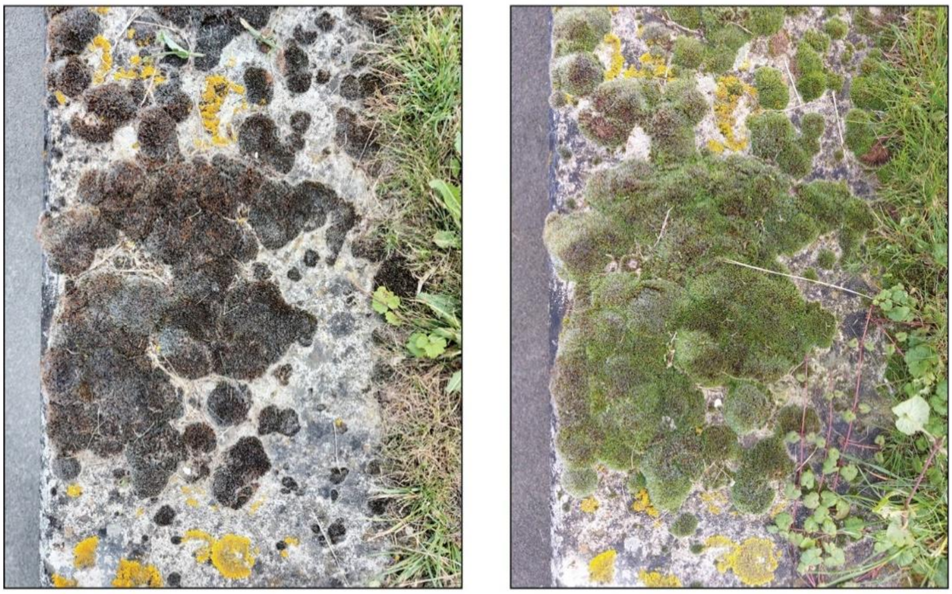


Image 47: moss state during the dormant season in August on the left and growth season during December on the right (own image)

5.2 Recommendations

Based on the research findings, recommendations are presented for future research on both experimental testing and moss greening practicality.

1.Field survey improvement

The field survey findings are too general, mainly limited by time and equipment availability. Instead of just looking at the colonized material, the colonizing environment is advised to study in-depth, ideally for one year, to go through four different seasons.

2. In-depth moss study/experiment

Not much is understood of the found mosses during the field survey. For this reason, the mosses can be studied more in-depth to understand their specific needs, such as daylight amount, pH level, moisture condition, macro and micronutrients requirement. These findings can be used as design input for moss greening in the Netherlands, where the growing substrate can be further expanded to other building construction materials.

3. Moss receptivity laboratory test

The terrarium method is still rough since it gives inconsistent testing results, which is influenced by many factors. For this reason, this testing method can be further improved for laboratory use, where samples can be tested for moss receptivity within a limited time under a controlled environment.

4. Green moss quay walls feasibility

Based on the proposed design, it might sound promising, but in the end, the only way to know whether it truly works or not is by testing it. For this reason, a real scale test on-site needs to be done to assess its practicality. There are already organizations working in Breda to achieve green quay walls, “GreenQuays”. It supports the greening of quay walls with trees, vascular plants and mosses. Careful consideration needs to be taken into account so that the quay walls' durability is not traded for greenery. The proposed quay wall design with bricks having an Initial rate of absorption above 3.0 kg/m^2*minute and pointing either from lime or trass lime mortar needs to be further tested to achieve the wanted moisture level on quay walls through capillary action. Based on a consult with professor Caspar Groot, the use of shell lime mortar will not work due to a long hardening time and the used of brick with a high Initial rate of absorption might not result in a high moisture capillary action height. Because a high Initial rate of absorption is caused by rough pores that have a high impact on water absorption within one minute; but the fine pores can result in higher capillary water absorption height in a longer time span. For this reason, it is recommended to do more lab experiments to improve the quay walls moisture condition through capillary action.

5. Deterioration of building materials

Based on a literature study, using moss for greenery purposes on construction material may sound less damaging on the construction material because the roots (rhizoids) do not grow in diameter and mainly for attachment purposes. But, mosses occur with other biological colonization too. The addition of other microorganisms can cause biodeterioration. Therefore this aspect should be considered to reduce the material damage and prolong its service life. The frost-thaw cycle on the building materials with high moisture content will be detrimental as well. Therefore, it is suggested to do further research on the biological and mechanical deterioration of the moss colonized building materials.

6. Moss greening method application

The focus of this paper is mainly on green moss quay walls. The application of moss greening can be further expanded to different materials and surface types. For example, with a more in-depth understanding of mosses, it is suggested to do future research on different building envelope surfaces. Such as exterior wall surfaces made of masonry work or concrete that are self-sufficient in the colonized location. More moss green roofs in an urban environment. Expanding to indoor moss walls followed by many different benefits such as improved indoor air quality, reduced airborne dust, stabilized moisture levels and reduced carbon levels (Butcher 2017).

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Appendix i: Field survey site study form

Field survey location selection and practices

The field survey will be documented so that readers will be able to find the location with ease, unless the mosses grown area has been removed/cleaned as a result of regular maintenance.

Before documenting these survey spots, how should one decide whether it can be used for reference purposes or not since moss growth is widespread on cementitious material and bricks such as pavement tiles. The moss growth might be initiated by humus accumulation instead of directly grown on the cementitious material and some areas where mosses are grown on non-cementitious material can be an insightful learning source. For this reason, the survey areas need to fulfill a set of requirements to be taken into consideration.

First qualification

The first requirement for survey area selection is the presence of prominent moss growth with a surface coverage percentage of around 30 percent or more. Thirty percent coverage is chosen because the moss coverage percentage is related to the selected location being examined, which might vary drastically from ten to ninety percent depending on the moss life forms and the chosen location. Therefore, by choosing thirty percent moss coverage and above, more moss sites can be included. For example, cushion life forms seldom reached above fifty percent coverage while mats life forms quickly reached eighty percent coverage. Thirty percent coverage above can indicate that the chosen area has a high moss growth stimulation instead of low maintenance and has grown slowly over the years. The studied surface area should be at least 200-millimeter times 200 millimeter or more extensive. The purpose of this minimum area requirement is to result in a better moss surface coverage estimation. By choosing a smaller area, the coverage percentage might be larger based on the selected location.

Second qualification

The second qualification, the moss roots, rhizoids, should be directly attached to the construction material and not have a soil layer in between. This is done because many mosses are growing due to dust/soil accumulation, which might mean that the material it grew on top has barely impacted the moss growth. This can be confirmed by removing the moss and see whether a thick layer of soil is attached to the roots. However, this qualification will be less strict for moss growth on quay walls; typical quay wall sites have soil accumulated over a period attached to it. Therefore, some mosses are grown directly on the soil, while others are connected to the quay wall element.

Categorization idea

After several survey spots suffices the first qualification, it can be further separated by the type of moss species grown there. Location with similar moss species can be put together as a grouping because a specific moss species already indicates that the site condition is ideal for its growth. Thus, it would be suitable for comparing sites with similar moss species growing and further looking into the details. Mosses can survive extreme weather, where the same moss species can attain different grown forms based on the site condition. Therefore, similar moss species will not necessarily indicate the same environmental condition are present.

On-site recordings

On-site inspection will be conducted here, where it is separated into three parts, first site location and condition. Site location is meant to make it possible for other people to confirm the findings' site condition and validity. The second part is the identification of the site inspection moss species. The identification of moss species will be made based on careful photographic inspection and comparison with literature studies photos and descriptions. In the end, the possibility of being identified incorrectly is still present; this is due to the difficulty for proper identification due to how similar moss looks like and done by a nonprofessional. Lastly, the final part will hypothesize why moss growth is prospering in that specific site condition. For example, this might be related to the moisture availability, nutrient source or other reasons that somehow influence the moss growth.

1.Site location and condition

Date of visit: this will be crucial because the moss condition's taken picture is season dependent; for example, during fall and winter, where the temperature is low enough for moss growth, while spring and summer, the moss will be in a dormant state.

Date of visit: **[ ]**
Location: **[ ]**
City: **[ ]**
Street name with closes house number if possible: **[ ]**
Construction type and function: **[ ]**
Moss colonized material: **[ ]**

Site condition

Surface exposure: **[vertical/ horizontal/ angled]**
Exposure orientation in case of horizontal/angled surface: **[North/ East/ South/ West]**
Surface coverage percentage: **[ ]**
Living/ moisture condition: **[dry / moist air / wet]**
Daylight condition: **[ ]**
Water source: **[ ]**

2.Moss species identification

Mosses of the specific site will be collected for identification purposes, any minor study of life forms. Close-up images will be taken and presented for the reader to be able to identify the collected moss themselves in case of doubt. The life forms could also be described a bit if possible.

3.Moss growth stimulation hypothesis

A hypothesis will be formed regarding why moss growth is prospering in this specific site but not proven. Which might be a site-specific source of nutrients, a nearby water source, shaded from sunlight by the surrounding, resulting in lower temperature and less moisture evaporation, protected from wind/draft, resulting in less moisture evaporation as well, animal feces or decaying biomass as a nutrient source when positioned to nearby trees or plants or other reasons that influence the moss growth positively.

Appendix ii: Field survey results

Site 1, located in Delft

Picture 1: Location of site 1, underneath the steel slope bridge (own picture)

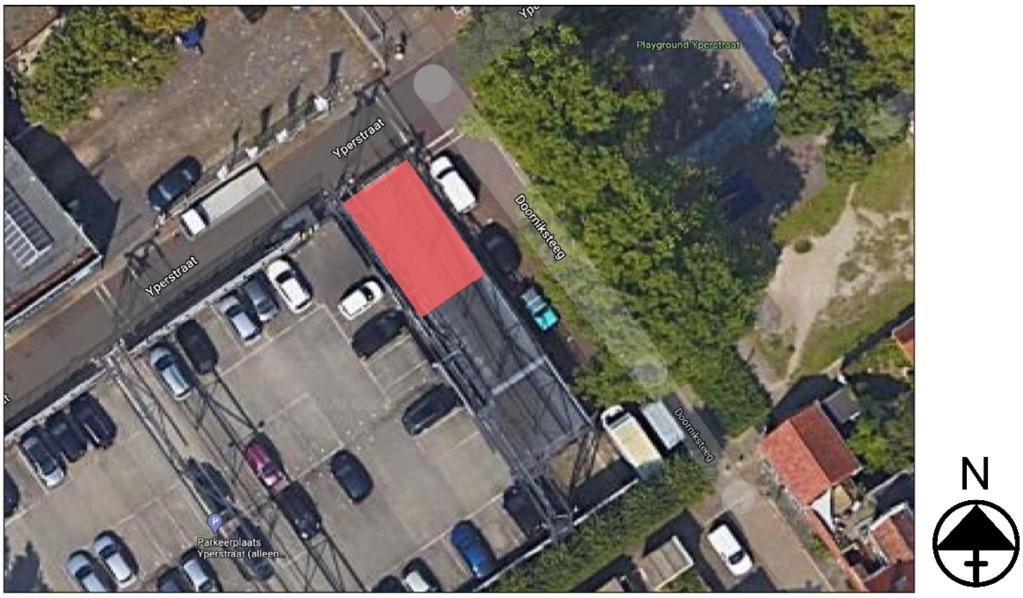
This survey spot is located underneath the slope to the upper parking space. This survey spot might be a bit questionable because the cushion moss growth is mainly attached to the soil, which is accumulated on top or on the edge of the concrete paving units. But the concentration is so dense that one can conclude that it suffices specific conditions to be able to grow so well. Another point is that only one type of moss can prosper under this condition. Therefore, it is concluded that this survey site may indicate some environmental factors that can influence moss growth positively.

Picture 2: Mosses growing underneath the steel slope bridge (own picture)

Results

The moss growth coverage percentage is over 50 percent; sadly, the rhizoids are not directly attached to the cementitious material but still chosen as a field survey location because the moss growth is so dominant that it may indicate an ideal growing condition which useful information can be gained from this analysis.

1.Site location and condition



Picture 3: Moss grown location indicated in red (google maps)

Date of visit: 9 October 2020
Location: Parking lot slope on the corner of "Yperstraat" and "Doorniksteeg"
City: Delft
Street name with closes house number: "Yperstraat 46
Construction type and function: Steel structure construction, car park function
Moss colonized material: mortar pavement tiles

Site condition

Surface exposure: [~~vertical~~/ horizontal/ ~~angled]~~
Exposure orientation in case of ~~vertical/angled surface~~: [~~North/ East/ South/ West~~]
Surface coverage percentage: 80 percent from the first 4 meters underneath the slope, declining to the range of 20 – 30 percent of the 12 meter underneath the slope. After 12 meters, barely any moss growth visible on the mortar pavement tiles.
Living/moisture condition: [dry / ~~moist air / wet~~]
Daylight condition: Only receive direct sunlight during sunrise till 11 am; afterward, the steel slope structure will block out direct sunlight
Water source: there is no nearby water source that fuel the moss-grown area directly; the primary moisture source is rainfall, fog and dew.

2.Moss identification

Moss species identification: "Grimmia torquata" (Schroefmuisjesmos) with a cushion life form, pictures 4 and 5.

Picture 4:Left shows an on-site collected cushion sample that covers an area of 100 x 100 mm^2 and on the right is a close-up image during hydrated stage (own picture)

Picture 5: shows the close up image of Grimmia torquata in two different scale (own picture)

3.Moss growth stimulation hypothesis

Mosses rhizoids were adequately attached to the accumulated dust/humus on the joints of the tiles, but mosses attachment to the cementitious tiles were poor. It was mainly attached to the accumulated dust/humus, which could be easily removed. Due to this reason, some moss cushions were flipped upside down. The high wind velocity might have caused this. No sporophyte production was present, which means the species is not exposed to extreme conditions that threaten its existence.

The location underneath the slope might have an environment with a reduced wind velocity due to surrounding dust, dirt, leaves and branches accumulation. Secondly, the site is only exposed to the morning sun, starting from sunrise until 11 am. This might result in less moisture evaporation due to limited direct sunlight exposure and reduced wind velocity underneath the slope, while the accumulated dust and biomass may serve as nutrients for the mosses.

Site 2, located in Delft

Picture 6: Location of site 2, the cementitious roof of the powerhouse (own picture)

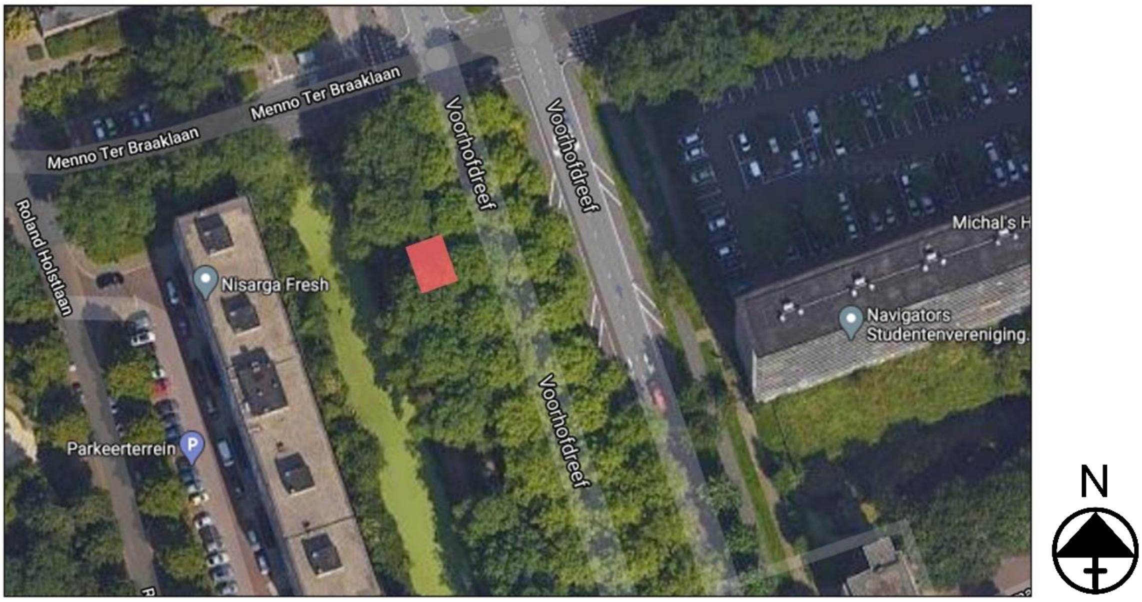
The roof of a powerhouse in Delft, shaded by trees followed by a high moss coverage percentage, is an excellent study sample of being shaded by trees and the supply of nutrients in the forms of bird feces and biomass decomposition. The shading of trees and nutrient supply may be crucial for the prospering mosses and how it affects the moisture condition is unknown.

Picture 7: site location close up view, biomass and bird feces are noticeable (own picture)

Results

The moss percentage is around 60 to 70 percent, where the rhizoids are well attached to the cementitious roof. Trees entirely shade the powerhouse; for this reason, sun flecks occur occasionally and after 3 pm, it is entirely shaded by the neighboring building.

1.Site location and condition



Picture 8: Moss grown location indicated in red (google maps)

Date of visit: 14 October 2020
Location: close to the Crossing of Menno Ter Braaklaan and Voorhofdreef
City: Delft
Street name with closes house number: Voorhofdreef
Construction type and function: Concrete roof for small electrical unit
Moss colonized material: concrete slope roof

Site condition

Surface exposure:[~~ vertical~~/ horizontal/ ~~angled]~~(small slope angle, considered horizontal orientation)
Exposure orientation in case of ~~vertical/angled surface~~: [~~North/ East/ South/ West~~]
Surface coverage percentage: 60 to 70 percent moss coverage.
Living/moisture condition: [~~dry~~ / moist air /~~ wet~~]
Daylight condition: Entirely shaded by trees and buildings, only receive sun flecks from sunrise till 3 pm, blocked by building afterward.
Water source: located close to a canal resulting in moist air; other than that, the usual source of moisture is rain, fog and dew.

2.Moss identification

Moss species identification: "Orthotrichum anomalum" (Gesteelde haarmuts) with a cushion life form, see **picture 9, 10 and 11**, "**Schistidium crassipilum" (Muurachterlichtmos)** with a cushion life form, see **picture 12 and 13**, **"Syntrichia montana" (Vioolsterretje)** with a cushion life form, see **picture 14, 15 and 16** and **"Hypnum cupressiforme" (Gesnaveld klauwtjesmos)** with a mats life form, see **picture 17 and 18**.

Picture 9: Shows Orthotrichum anomalum in dry state on the left side and hydrated state on the right side (own picture)

Picture 10: Shows Orthotrichum anomalum in a cushion life form on the left side and the right side is a close-up view of a single branch (own picture)

Picture 11: Both sides are a close-up view of Orthotrichum anomalum with sporophyte from two different habitat (own picture)

Picture 12: shows Schistidium crassipilum in dry state on the left side and the hydrated state on the right side (own picture)

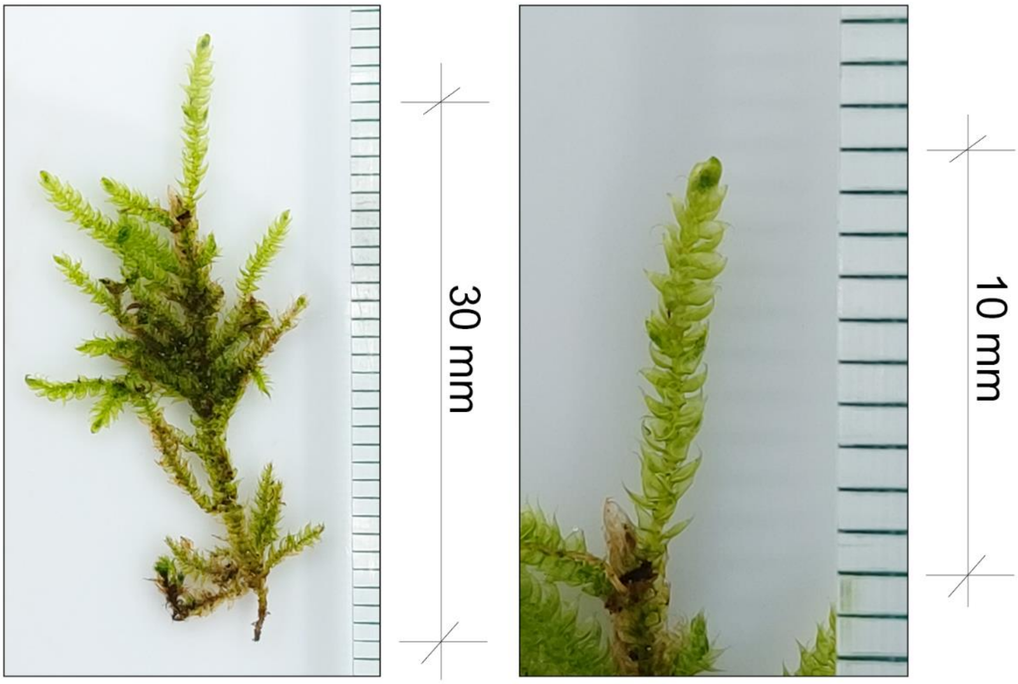
Picture 13: shows Schistidium crassipilum in natural state before collection on the left side and the right side is close up view (own picture)

Picture 14: shows Syntrichia montana in its natural state on-site, left side without sporophyte and right side with sporophyte (own picture)

Picture 15: shows Syntrichia montana in a dry state on the left side and a hydrated state on the right side (own picture)

Picture 16: shows Syntrichia montana close up view; on the left side is a young shoot while the right side is a mature shoot (own picture)

Picture 17: shows Hypnum cupressiforme with sporophyte; on the left side, it is situated on-site and the right side is a more precise view when moist (own picture)



Picture 18: shows a close-up view of Hypnum cupressiforme in two different scales (own picture)

3.Moss growth stimulation hypothesis

Mosses rhizoids were adequately attached to the concrete roof. Trees branches, leaves and bird feces were abundant on top of the mosses. This may serve as a primary nutrient source for the mosses. The mosses are shaded by trees from direct sunlight in all directions and around 3 pm onwards the western sun is blocked entirely by the neighboring building. For this reason, the mosses are dependent on limited sun flecks, but on the other hand, moisture evaporation is limited due to limited direct sunlight, making the mosses moist for a more extended period of time. Nothing concrete can be said about wind velocity, but it might be reduced due to the surrounding trees and the fact that biomass can quickly accumulate on top of the roof without being blown away. There is a canal nearby, which results in moist air and probably serves as a stable primary source of moisture throughout the year. Moss with mats life form grew on top meant that the moisture condition is good enough, but it did produce sporophyte, meaning that its existence is threatened, so moisture might still be lacking.

Site 3, located in Delft

Picture 19: site location 3, concrete sewer unit underneath a student housing (own picture)

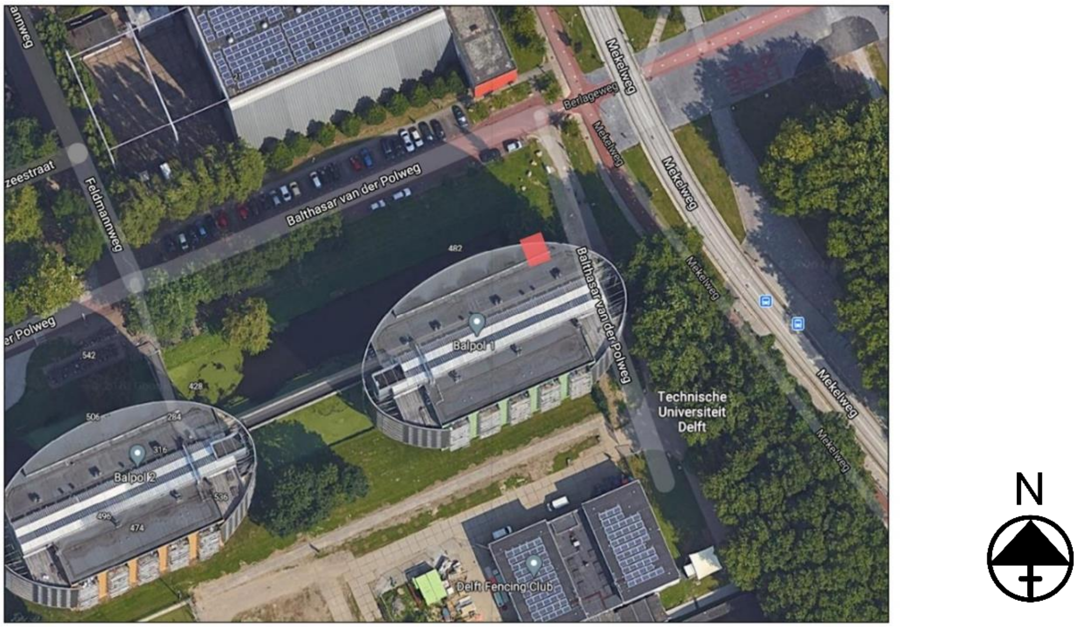
This is located close to a canal in the TU Delft campus, where mosses with mats life forms cover the concrete surface a lot. Mat forming moss usually grows well due to the abundance of resources, so this site serves as an informative site study to determine possible resources and it also has limited sunlight exposure throughout the day, which makes this site a tremendous environment to gain knowledge.

Picture 20: close up view of the occurring moss, where one moss species dominates while other moss species occurs less (own picture)

Results

This location has a moss coverage percentage of 80, where a combination of site conditions is present. Limited direct sunlight and abundance of moisture conditions are present, which resulted in a high coverage percentage with barely any sporophyte production from the mosses. Surrounding trees branches and leaves do accumulate a bit, serving as a nutrient source for the mosses.

1.Site location and condition



Picture 21: Moss grown location indicated in red (google maps)

Date of visit: 6 December 2020
Location: Corner of the Balthasar van der Polweg
City: Delft
Street name with closes house number: Balthasar van der Polweg, Balpol 1 (student housing)
Construction type and function: Concrete cap for sewer unit
Moss colonized material: concrete

Site condition

Surface exposure: [~~vertical~~/ horizontal/ ~~angled]~~
Exposure orientation in case of ~~vertical/angled surface~~: [~~North/ East/ South/ West~~]
Surface coverage percentage: 80 percent moss coverage.
Living/moisture condition: [~~dry~~ / moist air / ~~wet~~]
Daylight condition: Mostly shaded by trees and buildings, receives sun flecks from sunrise till 10 am, afterward a small amount of sunlight during sunset. Most of the direct sunlight path is blocked by "Balpol 1" building itself.
Water source: located close to a canal resulting in moist air, it is also situated directly under the student housing façade, which means the repelled rainwater from the façade will be dropped directly to the mosses grown spot, other sources are fog and dew.

2.Moss identification

Moss species identification: "Brachithecium rutabulum" (Gewoon dikkopmos) with a mats life form, see **picture 22**, **"Bryum capillare" (Gedraaid knikmos)** with a cushion or turf life forms, see **picture 23** and **"Orthotrichum anomalum" (Gesteelde haarmuts)** with a cushion life form, see **picture 9, 10 and 11**.

Picture 22: shows Brachithecium rutabulum both with sporophyte, on the left side the mats life form appearance and on the right side a closer view (own picture)

Picture 23: shows Bryum capillare, on the left side the cushion life form appearance and on the right side a closer view (own picture)

3.Moss growth stimulation hypothesis

Mosses rhizoids were adequately attached to the concrete cap. The moss species diversity is quite large since it is located next to the nearby plants' soil. But the dominating moss species is **Brachithecium rutabulum**, which has mats life forms, while other occurring species have a lower coverage percentage. The abundance of moisture might be the critical factor for successful moss growth. The concrete cap can also be moist from underneath from water evaporation while the mosses grow on top of it, extending the humid period of the concrete cap itself. Another point is the limited amount of direct sunlight exposure. This might help increase the moisture condition of the mosses due to reduced moisture evaporation. It is also situated near the canal, where the mosses can gain moisture from the moist air directly. Barely any sporophytes production was visible, which means that the mosses' existence is not threatened. Minor tree leaves are accumulated on the mosses and not much can be said about the wind.

Site 4, located in Delft

Picture 24: shows the corner where site 4 is situated (own picture)

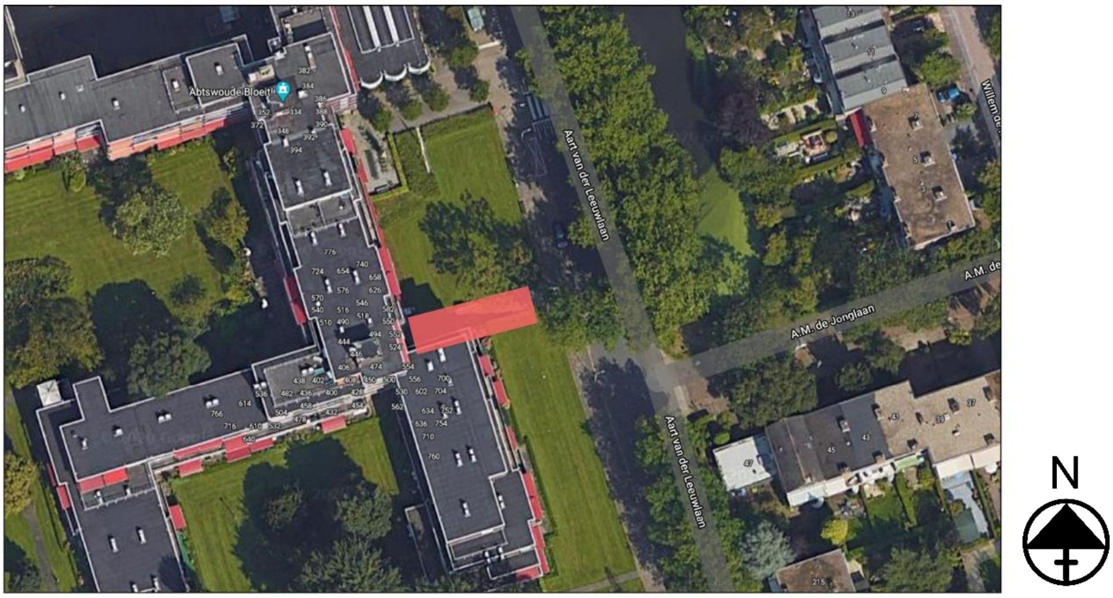
This site is unique due to the presence of flowing water from a drainage pipe in a shaded corner accompanied by low maintenance, so the type of mosses that prosper from this setting is different again. Here it has an expanding/mats life form, where the water resource is abundant.

Picture 25: shows the observable moss growth in different area on the site (own picture)

Results

The moss coverage percentage is around forty percent concentrated on one spot and lower coverage percentage away from the water source. The location is permanently shaded by the neighboring building and protected from draft from surrounding walls.

1.Site location and condition



Picture 26: Moss grown location indicated in red (google maps)

Date of visit: 6 December 2020
Location: Aart van der Leeuwlaan 332 – 778
City: Delft
Street name with closes house number: Aart van der Leeuwlaan 332 – 778 (Abtswoude bloeit!)
Construction type and function: Cementitious pavement tiles
Moss colonized material: cementitious blocks

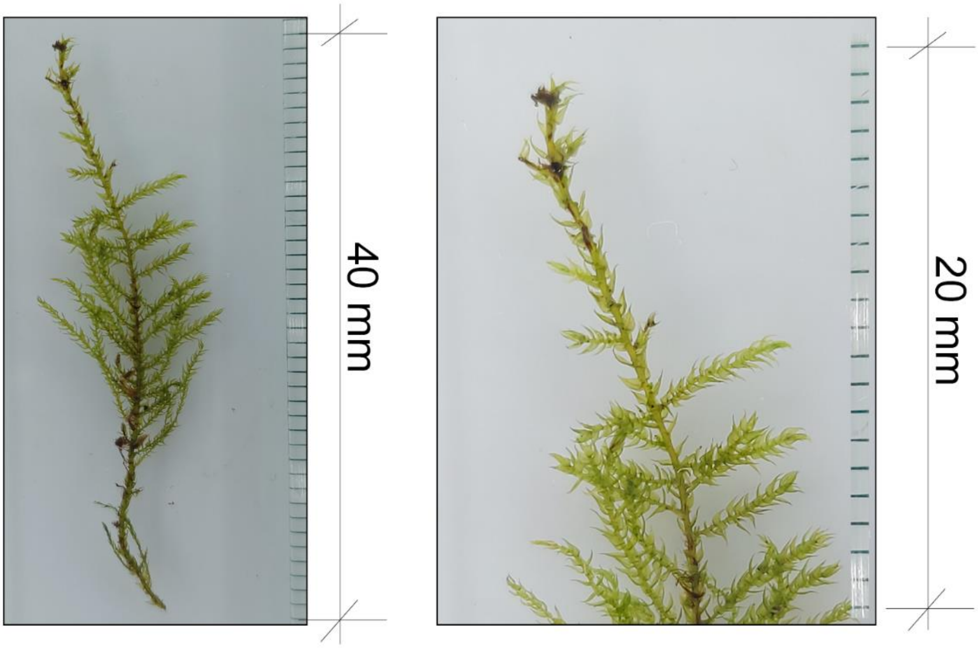
Site condition

Surface exposure: [~~ vertical~~/ horizontal/ ~~angled]~~
Exposure orientation in case of ~~vertical/angled surface~~: [~~North/ East/ South/ West~~]
Surface coverage percentage: 40 percent above moss coverage.
Living/moisture condition: [~~dry~~ / moist air / wet] (both wet and moist air)
Daylight condition: Entirely shaded by the building, does not receive any direct sunlight
Water source: primary source of moisture is from a running drainage pipe resulting in a wet environment and creates moist air for farther away mosses.

2.Moss identification

Moss species identification: "Kindbergia praelonga" (Fijn laddermos) with a mats life form, see **pictures 27 and 28** and **"Riccardia latifrons" (Breed moerasvorkje)** with a mats life form and it usually grows in forest, see **picture 29**.

Picture 27: shows Kindbergia praelonga, the left side its mats life form appearance and on the right side a close-up view of the sporophyte (own picture)



Picture 28: shows Kindbergia praelonga at two different scales (own picture)

Picture 29: shows Riccardia latifrons on the right its mats life form appearance and on the right a closer view (own picture)

3.Moss growth stimulation hypothesis

This survey spot is quite extreme, where no direct daylight is present and a permanent running water source from a drainage pipe is present. Two moss species are found; both have mats life forms and prosper in shaded condition with permanent moist condition. Minor leaves and branches accumulated on the spot and the wind velocity was relatively low. Serves as a site protected from draft and barely any sporophyte production was present at all. The rhizoids are directly attached to the cementitious pavement tiles. The moss growth is the highest around the water source and declines a bit with increasing distance. Somehow, this site shows two entirely different moss species from other sites which is exposed to indirect or direct sunlight. The found moss species, **Riccardia latifrons,** typically grows in forests, so the abundance of moisture might make it possible to prosper here.

Site 5, located in Delft

Picture 30: shows the south-facing side on the left half and east-facing side on the right of site 5 location (own picture)

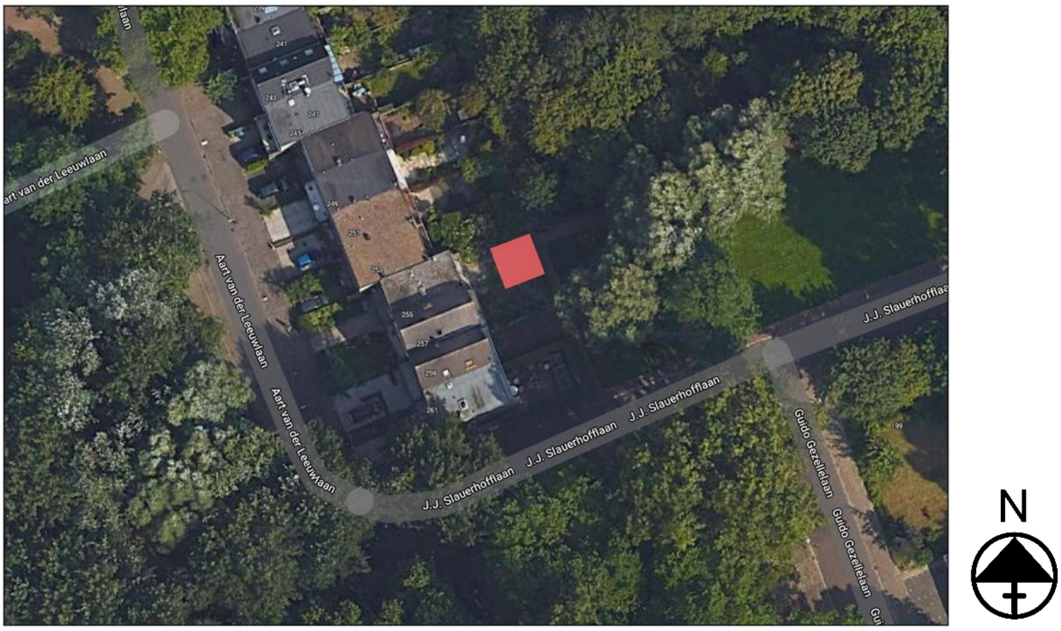
This storage house is located in Delft behind a residential building. The beauty of it is moss coverage on two sides of the sloping roof is high while the two other sides have far less moss growth, which might be related to sunlight exposure. More prolonged exposure due to orientation or shaded by nearby trees might be the cause.

Picture 31: left side is a close-up view of the cushion moss and the right side shows the east and north-facing direction of the roof slope (own picture)

Results

Although it is not made of construction material that can be applied to a quay wall design, this site is still chosen. It can serve as a good source of information regarding moss habitats. The small storage house roof is made of bitumen shingles, which usually has a ceramic granules finish. For this reason, it might be somehow related to clay. This site is unique because the gabled roof has four facing sides, a bit rotated, but will still be considered the four following orientations: North, East, South and West. The fascinating aspect is that the moss growth is present in all four facing side, but the sides facing North and East has the highest percentage of moss growth while the other two has a moss coverage percentage of less than five percent.

1.Site location and condition



Picture 32: Moss grown location indicated in red (google maps)

Date of visit: 14 October 2020
Location: Aart van der Leeuwlaan
City: Delft
Street name with closes house number: Aart van der Leeuwlaan no 255 backyard
Construction type and function: Bitumen roof shingles for storage house
Moss colonized material: Bitumen shingles (assume with ceramic granules finish)

Site condition

Surface exposure: [~~ vertical/ horizontal~~/ angled]
Exposure orientation in case of vertical/angled surface: [North/ East/ South/ West] **(all four)**
Surface coverage percentage:North facing: 40%, East facing: 70%, South facing: 2%, West facing: 5%.
Living/moisture condition: [dry / ~~moist air / wet~~]
Daylight condition: Gabled roof, North and East facing slope gets shaded by the trees from sunrise till 11 am. Afterward, all four sides are subjected to direct sunlight from 11 am till 5 pm. After 5 pm, during the sunset, the building will shade the storage house from direct sunlight. Still, from 11 am to 5 pm, you can argue that the North and East facing side receives less sun due to the sloping angle, which results in less surface exposure.
Water source: No nearby water body, primary sources of moisture are rain, fog and dew.

Picture 33: West facing roof slope on the left side and South facing roof slope on the right side (own picture)

Picture 34: East-facing roof slope on the left side and North facing roof slope on the right side (own picture)

2.Moss identification

Moss species identification: "Hypnum cupressiforme" (Gesnaveld klauwtjesmos) with a mats life form, see **picture 17 and 18**, **"Grimmia pulvinata" (Gewoon muisjesmos)** with cushion life form, see **picture 35 and 36**, **"Grimmia torquata" (Schroefmuisjesmos)** with cushion life form, see **picture 4 and 5** and **"Orthotrichum anomalum" (Gesteelde haarmuts)** with cushion life form, see **picture 9, 10 and 11**.

Picture 35: shows Grimmia pulvinata as a cushion form in its natural habitat on the left and the right a close-up view with sporophyte (own picture)

Picture 36: shows a close-up view of Grimmia pulvinata in two different scales with sporophyte (own picture)

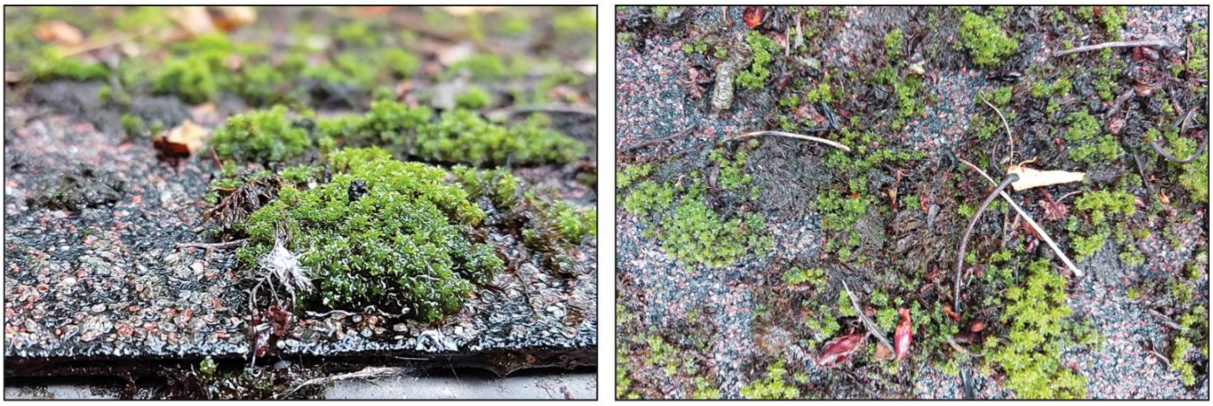
3.Moss growth stimulation hypothesis

Mosses rhizoids were adequately attached to the bitumen shingles of the roof. Some leaves were present in the east-facing direction, while all the other three sides are free of leaves. This might indicate that the wind velocity is a bit high; therefore, leaves are usually blown away from the roof. No direct source of moisture is present, which concludes that these mosses only gain moisture from rainfall, fog and dew. Lastly, the significant difference is the amount of direct sunlight exposure on all four sides. There are trees positioned to the east and north side of the roof. No branches are directly above the storage house roof. The north side trees barely have any effect since the sun doesn't come from the north at all. The east side positioned trees are shading the North and Eastern roof side from direct sunlight during sunrise till 11 am, which can be translated in reduce temperature and prolonged moist period. Once it passes 11 am, the roof is not being shaded by any object, but the roof angling reduces the exposed surface area of the North and East facing side of the roof. After 5 pm, the storage house roof is shaded by the buildings located on its west. So, it is concluded that the significant difference is the sun exposure period and amount, which can be translated into reduced temperature and moisture evaporation resulting in a prolonged moist period. The production of sporophyte is plenty, which might indicate that the existence of the mosses is threatened.

Site 6, located in Delft

Picture 37: shows the location of site 6, the storage house roof (own picture)

The found moss growth medium is similar to location 5, but the type of moss that is able to grow here is entirely different. It is located close to a canal with floating boathouses, which should have a more humid setting and is also shaded by trees. Although the moss attachment to the roof tile material is loose, the environmental condition can result in some exciting findings to help understand the moss ideal growing environment.



Picture 38: shows a close-up view of the colonizing mosses on site 6 (own picture)

Results

Around sixty percent moss coverage is present. This site is shaded by the surrounding tree, depending on the time of the day. Since it is not entirely shaded, but surrounding trees significantly reduce the exposure to direct sunlight. Tree branches and leaves do accumulate on the roof, while the boathouse with the same roofing material but not shaded at all only has little cushion mosses grown on it.

1.Site location and condition

Picture 39: Moss grown location indicated in red (google maps)

Date of visit: 9 October 2020
Location: Zuidergracht 9
City: Delft
Street name with closes house number: Zuidergracht 9
Construction type and function: Bitumen roof shingles for storage house
Moss colonized material: Bitumen shingles (assume with ceramic granules finish)

Site condition

Surface exposure: [~~vertical~~/ horizontal/ ~~angled]~~ (small angle considered horizontal orientation)
Exposure orientation in case of ~~vertical/angled surface~~: [~~North/ East/ South/ West~~]
Surface coverage percentage: 60 percent moss coverage.
Living/moisture condition: [~~dry~~ / moist air / ~~wet~~]
Daylight condition: From sunrise till 12 pm, it is shaded by surrounding trees and after 12 pm till sunset, it is more exposed to direct sunlight, but there are still branches covering the mosses.
Water source: located close to a canal resulting in moist air; other than that, the usual source of water is rain, fog and dew.

2.Moss identification

Moss species identification: "Leptodontium flexifolium" (Rietdakmos) with turf life form, see **picture 40 and 41** and **"Grimmia pulvinata" (Gewoon muisjesmos)** with a cushion life form, see **picture 35 and 36**.

Picture 40: shows Leptodontium flexifolium in dry condition on the left side and moist condition on the right side (own picture)

Picture 41: shows Leptodontium flexifolium in its natural habitat on the left side and a close-up view on the right side (own picture)

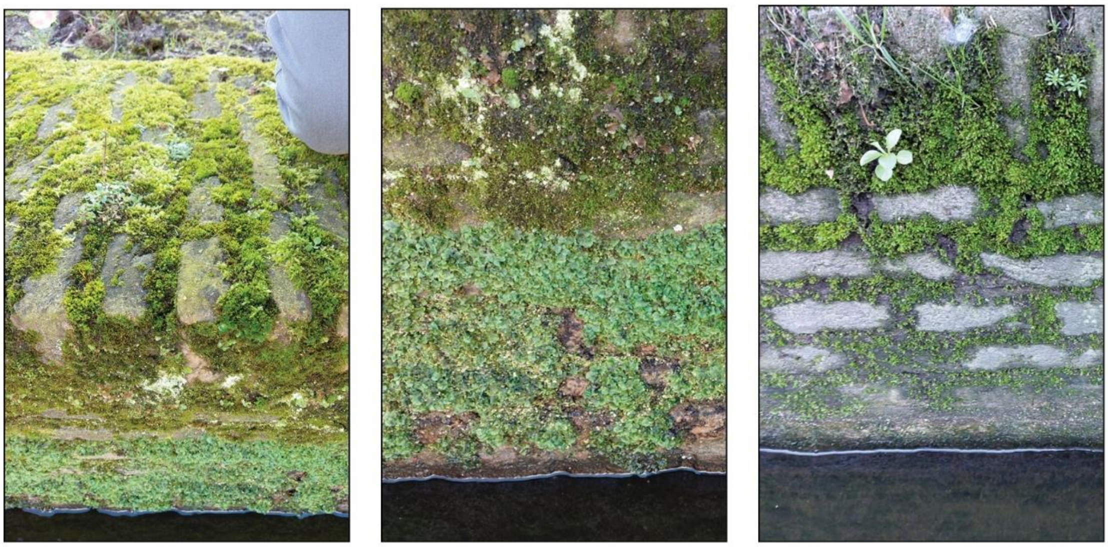
3.Moss growth stimulation hypothesis

Mosses rhizoids were loosely attached to the bitumen shingles roof. This might be due to the accumulation of biomass from the trees above, which might serve as a significant source of nutrients and growing medium. This site is quite shaded by the surrounding trees; from morning till 12 pm, it is entirely shaded by trees and from 12 pm onwards, it becomes more exposed to direct sunlight but still shaded to some degree. The shade provided by the surrounding and the accumulation of biomass plays a significant role in the prospering moss growth because the floating boathouse roof is made of similar bitumen shingles but not shaded at all resulted in a moss coverage percentage of less than one percent. Lastly, **Leptodontium flexifolium** is a moss species that grows on dry sand, which is made possible by the dust and biomass accumulation.

Site 7, located in Delft

Picture 42: shows the location quay wall shaded by buildings (own picture)

This site location is chosen due to the high coverage percentage and the canal's orientation, which has a North-West facing alignment. This alignment is essential because the quay walls are on both sides of the canal, but the amount of direct sunlight on each quay wall surface is unequal due to this alignment. The surrounding buildings also serve as a permanent shading, unlike deciduous trees that lose all their leaves during fall.

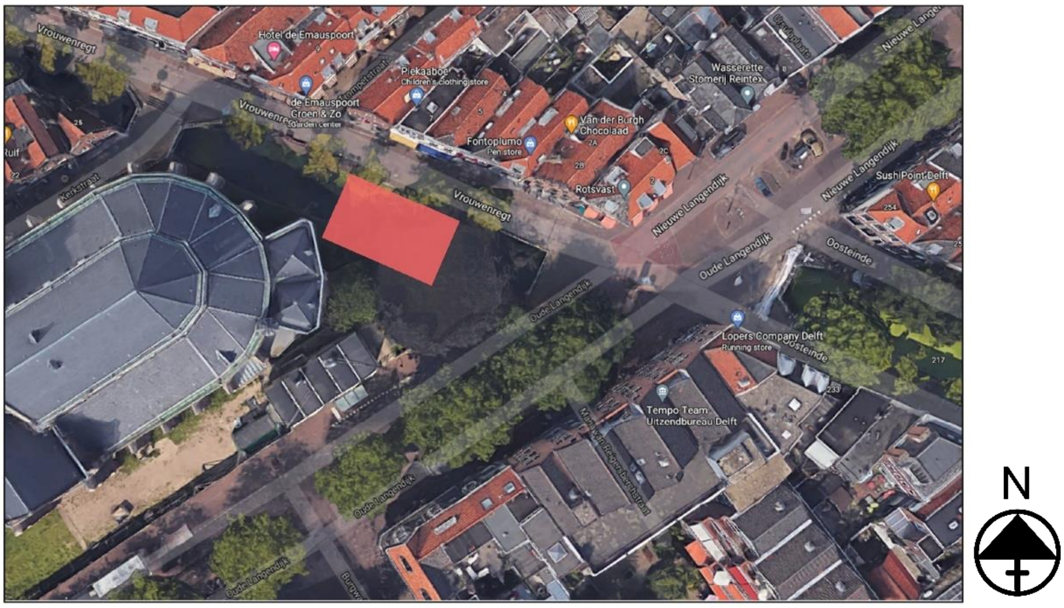


Picture 43: Shows the different colonizing patterns that are influenced by the exposed environment (own picture)

Results

The quay walls survey's focus is on the vertical surface instead of the horizontal part, because the vertical surface is usually harder to colonized since it has to battle gravity and usually covers more surface area. The quay walls along a canal have two sides, opposite each other, where both sides will be considered compared to each other. For this case, it will be referred to the East and West quay wall side. For example, the West side one is located on the left side based on Picture 42 with a North-East facing surface direction, while the other side has a South-West facing surface direction.

1.Site location and condition



Picture 44: Moss grown location indicated in red (google maps)

Date of visit: 10 December 2020
Location: Behind the "Nieuwe Kerk"
City: Delft
Street name with closes house number: Vrouwenregt 6
Construction type and function: quay wall
Moss colonized material: bricks and mortar joints

Site condition

Surface exposure: [vertical~~/ horizontal~~/ ~~angled]~~
Exposure orientation align with: [North-West direction]
Surface coverage percentage: (West) 70 and (East) 20 percent moss coverage.
Living/moisture condition: [~~dry~~ / moist air /~~ wet~~]
Daylight condition: The west quay wall side only receives direct sunlight during sunrise in the early morning, which is slightly shaded by trees, while the east quay wall side receives more direct sunlight starting from 11 am till sunset.
Water source: located close to a canal resulting in moist air; other than that, the usual source of water is rain, fog and dew.

2.Moss identification

Moss species identification: “Riccardia latifrons” (Breed moerasvorkje) with a mats life form and it usually grows in the forest, see **picture 29, “Bryum capillare” (Gedraaid knikmos)** with a cushion or turf life forms, see **picture 23, “Brachithecium rutabulum” (Gewoon dikkopmos)** with a mats life form, see **picture 22** and **“Schistidium trichodon” (Zeeachterlichtmos)** with a cushion life form, see **picture 45**.

Picture 45: shows Schistidium trichodon in cushion form on the left side and a close-up view on the right side (own picture)

3.Moss growth stimulation hypothesis

The moss rhizoid attachment was directly attached to the quay wall construction material and attached to accumulated soil on the quay walls. The exact relation of how moss growth is initiated is unknown. Based on observation, the west side has a much higher moss coverage percentage, by mosses with mats life forms grown on it, while the east side has a lower moss coverage percentage and is mostly composed of moss with cushion life forms. This difference is possibly caused by the difference in direct sunlight exposure in the west and east directions. The west direction with less direct sunlight has a higher moss growth percentage and barely any sporophyte production was visible.

Site 8, located in Delft

Picture 46: shows the location of the quay walls of site 8 (own picture)

This site location is chosen due to the high coverage percentage and the canal's orientation, which has a North-East facing alignment. This alignment is essential because the quay walls are on both sides of the canal, but the amount of direct sunlight on each quay wall surface is unequal due to this alignment. The surrounding buildings also serve as a permanent shading, unlike deciduous trees that lose all their leaves during fall.

Picture 47: shows the colonized surface of the two opposite facing quay walls (own picture)

Results

The quay walls survey's focus is on the vertical surface instead of the horizontal part, because the vertical surface is usually harder to colonized since it has to battle gravity and usually covers more surface area. The quay walls along a canal have two sides, opposite each other, where both sides will be considered compared to each other. For this case, it will be referred to the North and South quay wall side. For example, the South side one is located on the bottom side based on Picture 46 with a North-West facing surface direction, while the other side has a South-East facing surface direction.

1.Site location and condition

Picture 48: Moss grown location indicated in red (google maps)

Date of visit: 10 December 2020
Location: Kolk
City: Delft
Street name with closes house number: Kolk 6
Construction type and function: quay wall
Moss colonized material: bricks and mortar joints

Site condition

Surface exposure: [vertical/ ~~horizontal/ angled~~]
Exposure orientation align with: [North-East direction]
Surface coverage percentage: (South) 90 and (North) 15 percent moss coverage.
Living/moisture condition: [~~dry~~ / moist air / ~~wet~~]
Daylight condition: The South side barely receives any direct sunlight due to the north-facing direction, while the North side gets the full range of direct sunlight throughout the whole day with scarcely any shading from nearby trees.
Water source: located close to a canal resulting in moist air; other than that, the usual source of water is rain, fog and dew.

2.Moss identification

Moss species identification: “Leptodontium flexifolium” (Rietdakmos) with turf life form, see **picture 40 and 41, “Bryum capillare” (Gedraaid knikmos)** with a cushion or turf life forms, see **picture 23, “Brachithecium rutabulum” (Gewoon dikkopmos)** with a mats life form, see **picture 22** and **“Grimmia pulvinata” (Gewoon muisjesmos)** with a cushion life form, see **picture 35 and 36**.

Picture 49: shows the colonized quay wall taken from site 8 (own picture)

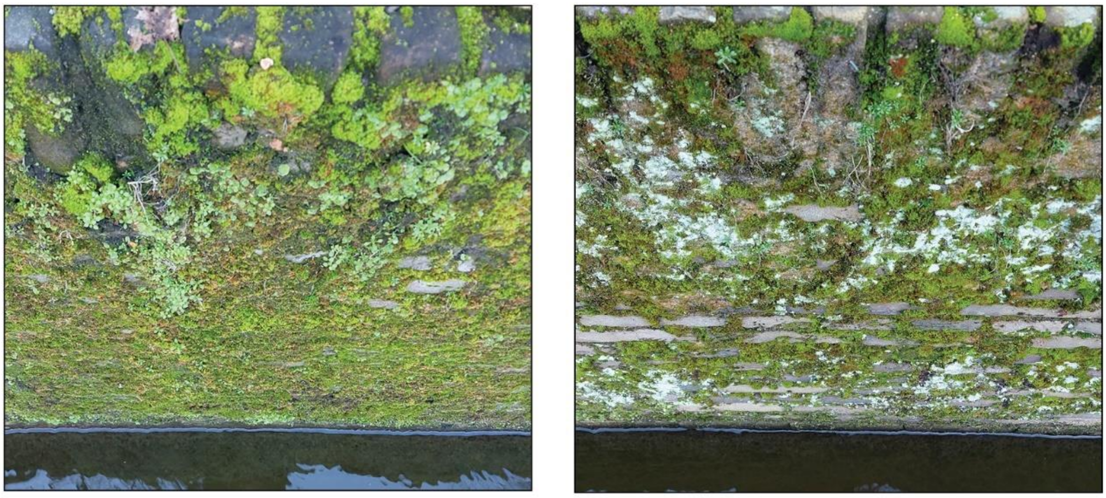
3.Moss growth stimulation hypothesis

The moss rhizoid attachment was directly attached to the quay wall construction material and attached to accumulated soil on the quay walls. The exact relation of how moss growth is initiated is unknown. Based on observation, the south side has a much higher moss coverage percentage, with mosses with mats life forms grown on it, while the north side has a lower moss coverage percentage and is mostly composed of moss with cushion life forms. The significant difference between these two sides is the exposure to direct sunlight. With no direct sunlight, the south side experiences an optimal growth condition for an immense moss species diversity, while the opposite direction is mainly composed of cushion moss. Another point to mention is that soil does accumulate on the quay walls and serves as a growing medium for mosses and some plants. Barely any sporophyte production was observable.

Site 9, located in Delft

Picture 50: Shows the location of site 9, with the two opposing quay walls visible (own picture)

This site location is chosen due to the high coverage percentage and the canal's orientation, which has a North-West facing alignment, getting close to a North-South facing alignment. This alignment is essential because the quay walls are on both sides of the canal, but due to this alignment, the amount of direct sunlight varies on each quay wall; however, this case has more the less equal direct sunlight on both sides. The surrounding buildings also serve as a permanent shading, unlike deciduous trees that lose all their leaves during fall.



Picture 51: shows the colonized surface of both sides (own picture)

Results

The quay walls survey's focus is on the vertical surface instead of the horizontal part, because the vertical surface is usually harder to colonized since it has to battle gravity and usually covers more surface area. The quay walls along a canal have two sides, opposite each other, where both sides will be considered compared to each other. For this case, it will be referred to the West and East quay wall side. For example, the West side one is located on the left side based on Picture 52 with a North-East facing surface direction, while the other side has a South-West facing surface direction.

1.Site location and condition

Picture 52: Moss grown location indicated in red (google maps)

Date of visit: 10 December 2020
Location: Breestraat bridge, near Hotel Grand Canal
City: Delft
Street name with closes house number: Oude Delft 2
Construction type and function: quay wall
Moss colonized material: bricks and mortar joints

Site condition

Surface exposure: [vertical/ ~~horizontal/ angled~~]
Exposure orientation align with: [North-West direction]
Surface coverage percentage: (West) 70 and (East) 40 percent moss coverage.
Living/moisture condition: [~~dry~~ / moist air / ~~wet~~]
Daylight condition: The west side is exposed to direct sunlight from sunrise till around 12 pm, while the east side is exposed to direct sunlight from 12 pm till sunset. Low angle sun is partially blocked by the neighboring buildings, which accounts for both the west and the east side.
Water source: located close to a canal resulting in moist air; other than that, the usual source of water is rain, fog and dew.

2.Moss identification

Moss species identification: "Leptodontium flexifolium" (Rietdakmos) with turf life form, see **picture 40 and 41, "Bryum capillare" (Gedraaid knikmos)** with a cushion or turf life forms, see **picture 23, "Riccardia latifrons" (Breed moerasvorkje)** with a mats life form and it usually grows in forest, see **picture 29,** and **"Schistidium trichodon" (Zeeachterlichtmos)** with a cushion life form, see **picture 45.**

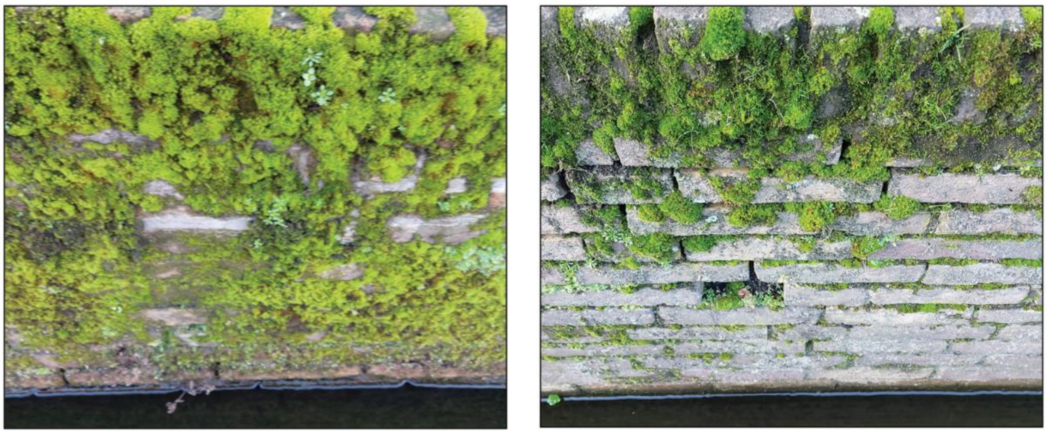
3.Moss growth stimulation hypothesis

The moss rhizoid attachment was directly attached to the quay wall construction material and attached to accumulated soil on the quay walls. The exact relation of how moss growth is initiated is unknown. Based on observation, the west side has a higher moss coverage percentage, but the occurrence of mosses with mats life forms is not that high. On both sides of the quay walls, the moss colonization occurs on the mortar joints more than the brick surfaces. This might be related to the porosity or surface roughness of the bricks. Sadly no measurement data are available for further understanding. It is also possible that dust and soil can quickly accumulate on the mortar joint, serving as a better attachment surface and growing medium for the mosses. The amount of direct sunlight might be considered equal on both sides, but the west side still has a higher colonization percentage. This may be related to the availability of moisture, assuming the mosses gain moisture during the night. During sunrise, where only the west side gain direct sunlight, can perform photosynthetic activity. In the meantime, the east side needs to wait till the afternoon to gain direct sunlight to perform photosynthetic activity. Therefore, from morning till afternoon, the east side may be losing moisture to the surroundings due to increasing temperature and decreasing humidity level. By the time it reaches afternoon, the amount of moisture retained for photosynthetic activity is reduced.

Site 10, located in Delft

Picture 53: shows both side of the quay walls of site 10 (own picture)

This site location is chosen due to the high coverage percentage and the canal's orientation, which has a North-East facing alignment. This alignment is essential because the quay walls are on both sides of the canal, but the amount of direct sunlight varies on each quay wall's side due to this alignment. The surrounding buildings also serve as a permanent shading, unlike deciduous trees that lose all their leaves during fall.

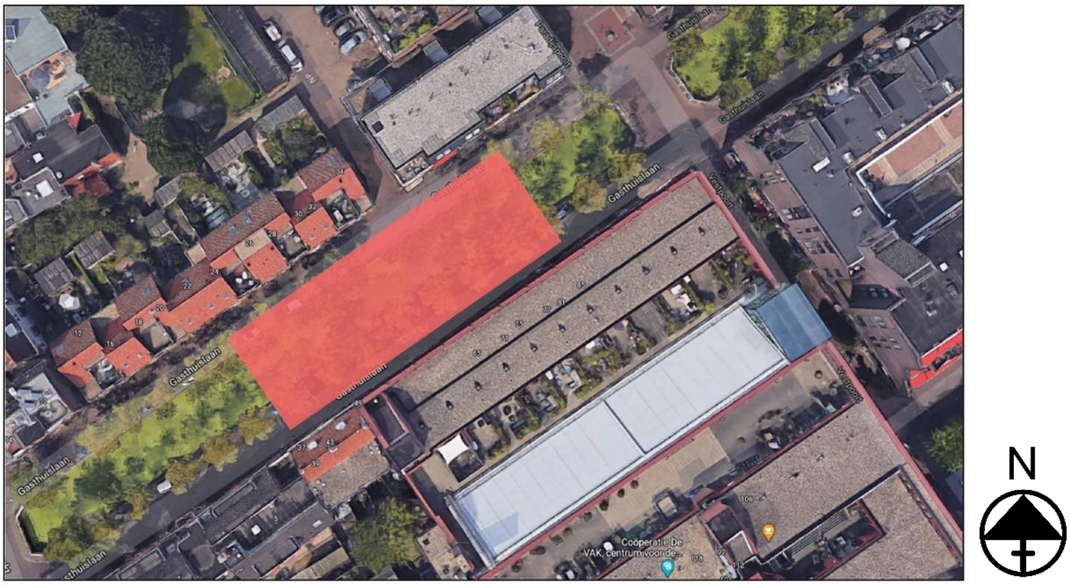


Picture 54: shows the difference between opposite quay walls colonization (own picture)

Results

The quay walls survey's focus is on the vertical surface instead of the horizontal part because the vertical surface is usually harder to colonized since it has to battle gravity and usually covers more surface area. The quay walls along a canal have two sides, opposite each other, where both sides will be considered compared to each other. For this case, it will be referred to the South and North quay wall side. For example, the South side one is located on the bottom side based on **Picture 55** with a North-West facing surface direction, while the other side has a South-East facing surface direction.

1.Site location and condition



Picture 55: Moss grown location indicated in red (google maps)

Date of visit: 10 December 2020
Location: Gasthuislaan 65
City: Delft
Street name with closes house number: Gasthuislaan 65
Construction type and function: quay wall
Moss colonized material: bricks and mortar joints

Site condition

Surface exposure: [vertical/ ~~horizontal/ angled~~]
Exposure orientation align with: [North-East direction]
Surface coverage percentage: (South) 70 and (North) 40 percent moss coverage.
Living/moisture condition: [~~dry~~ / moist air / ~~wet~~]
Daylight condition: The south side is shaded throughout most of the days; only during sunset, direct sunlight can reach the quay wall surface. In comparison, the north side is exposed to direct sunlight throughout the day except for sunset.
Water source: located close to a canal resulting in moist air; other than that, the usual source of water is rain, fog and dew.

2.Moss identification

Moss species identification: “Leptodontium flexifolium” (Rietdakmos) with turf life form, see **picture 40 and 41, “Riccardia latifrons” (Breed moerasvorkje)** with a mats life form and it usually grows in forest, see **picture 29, “Brachithecium rutabulum” (Gewoon dikkopmos)** with a mats life form, see **picture 22** and **“Schistidium trichodon” (Zeeachterlichtmos)** with a cushion life form, see **picture 45.**

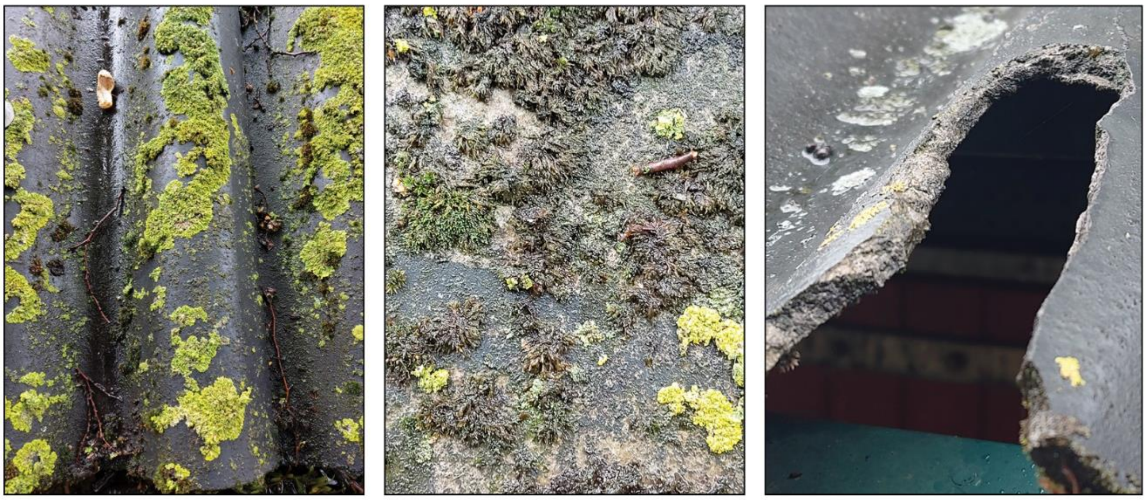
3.Moss growth stimulation hypothesis

The moss rhizoid attachment was attached directly to the quay wall construction material and attached to accumulated soil on the quay walls. The exact relation of how moss growth is initiated is unknown. Based on observation, the south side has a higher moss coverage percentage with the presence of mosses with mats life forms. While the north side mainly has mosses with cushion life forms. The amount of direct sunlight is the significant difference between these two sides, where the one with barely any direct sunlight prosper in moss growth and the one with more direct sunlight exposure is limited to cushion life forms mosses. Minor sporophyte production was observable on the south side.

Site 11, located in Amsterdam

Picture 56: shows the location of site 11, where the exposed roof is partially colonized by living organisms (own picture)

This site is a storage building belonging to a small farm, where part of the roof is shaded by the tree resulting in lichen and moss growth, while the non-shaded part has nothing growing on it. It is possible that the tree above the roof function as a nutrient source for the growing lichen and moss. Another possibility is that the tree reduces the amount of direct sunlight reaching the roof material, resulting in less moisture evaporation. Lastly, the roof tile is a prefab concrete panel, which suffices the material qualification.

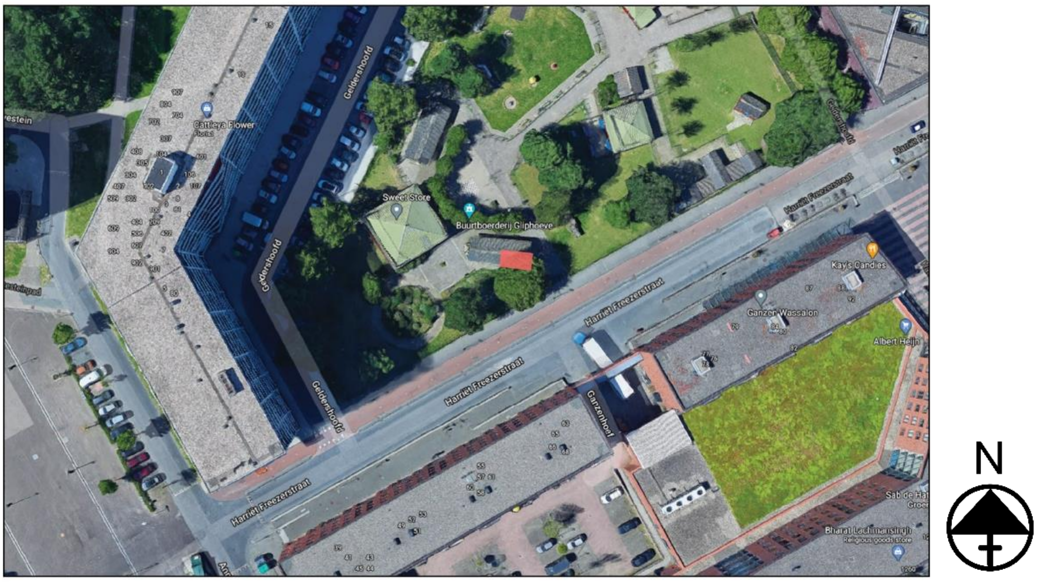


Picture 57: close up picture of the colonizing organisms and the roofing material (own picture)

Results

Although the moss coverage percentage is lower than 30 percent, this site serves as an obvious example of the impact of tree shading. Due to the tree located south of the building, part of the roof is shaded while the other part is exposed to direct sunlight and it may also serve as a nutrient source in the form of decaying biomass.

1.Site location and condition



Picture 58: Moss grown location indicated in red (google maps)

Date of visit: 9 July 2020
Location: Buurtboerderij Gliphoeve
City: Amsterdam
Street name with closes house number: Harriet Freezerstraat 65
Construction type and function: Prefabricated concrete roof panel unit
Moss colonized material: Concrete

Site condition

Surface exposure: [~~vertical/ horizontal/~~ angled]
Exposure orientation in case of vertical/angled surface: [~~North/ East/~~ South~~/ West~~]
Surface coverage percentage: 20 percent moss coverage.
Living/moisture condition: [~~dry~~ / moist air /~~ wet~~]
Daylight condition: The tree located south of the roof blocks most of the direct sunlight path throughout the day; low angle sun from sunrise and sunset can reach the colonized surface.
Water source: the only source of water is rain, fog and dew.

2.Moss identification

Moss species identification: "Grimmia pulvinata" (Gewoon muisjesmos) with cushion life form, see **pictures 35 and 36.** The other one is left unidentified since it is a lichen species and not a moss species.

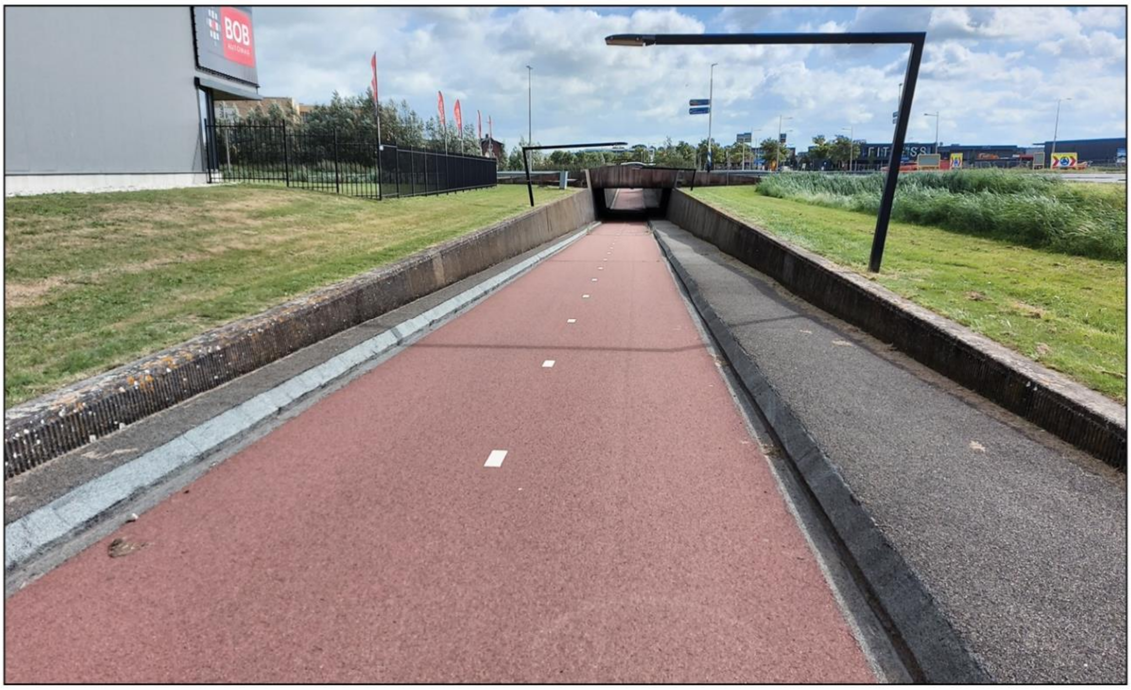
 

Picture 59: On the left shows the colonizing lichen and the right the colonizing moss species (own picture)

3.Moss growth stimulation hypothesis

Mosses rhizoids were attached adequately to the concrete roofing unit but in a low coverage percentage. The other colonizing organism is left unidentified because it is not a moss species. (the lack of tools). This site study shows the impact of shading by trees and maybe also functioning as a source of nutrients in the form of biomass decomposition. No sporophyte production was visible, and the wind velocity might be a bit high because only a cushion moss species can grow on it.

Site 12, located in Berkel en Rodenrijs



Picture 60: shows the location of the retaining wall in site 12 (own picture)

Concrete retaining wall for biking lane tunnel, the moss coverage percentage is around forty percent or more. Based on observation, the maintenance of the concrete surface is not that frequent. So, this might indicate the amount of time needed to attain this moss coverage percentage. It is possible to tell the number of growing cycles a cushion moss went through by inspecting the layering. Sadly, it was not observable. Lastly, this site is directly exposed to sunlight, which has a different range of moss species growing on it with tiny direct sources of nutrients or protection.

Picture 61: shows the colonizing organisms, picture taken in the month of August (own picture)

Results

As the only site that is permanently exposed to sunlight, only moss species with cushion life forms can grow in such a dry environment. It is located near a canal, but the canal's impact on the moss growth is unknown.

1.Site location and condition

Picture 62: Moss grown location indicated in red (google maps)

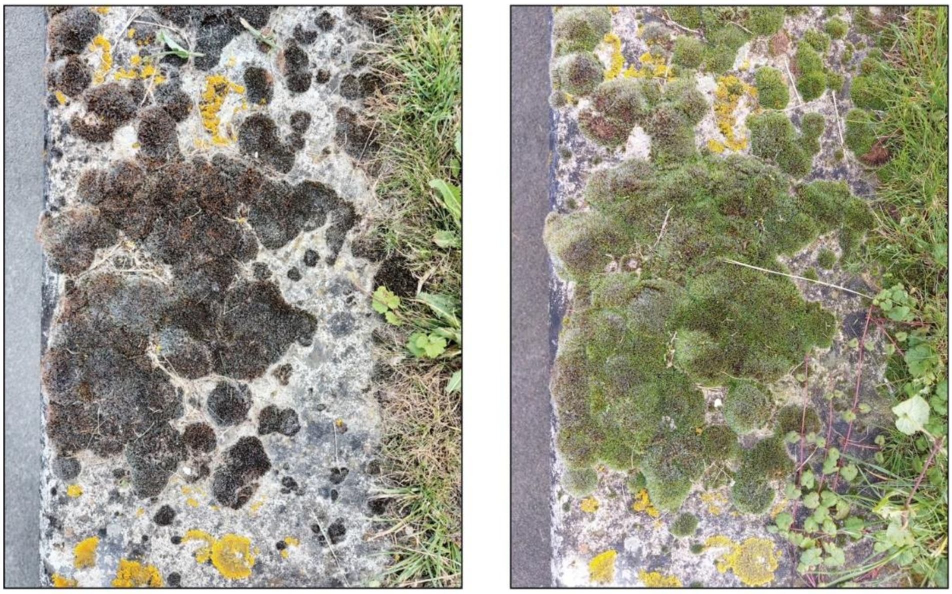
Date of visit: 22 August 2020
Location: Nearby Bob Autowas
City: Berkel en Rodenrijs
Street name with closes house number: Nobelsingel
Construction type and function: Concrete retaining wall
Moss colonized material: Concrete

Site condition

Surface exposure: [~~vertical~~/ horizontal/ ~~angled]~~
Exposure orientation in case of ~~vertical/angled surface~~: [~~North/ East/ South/ West~~]
Surface coverage percentage: 40 percent moss coverage. (location dependent)
Living/moisture condition: [dry / ~~moist air / wet~~]
Daylight condition: Exposed to direct sunlight permanently.
Water source: located close to a canal; therefore, air might be in moist condition. Other than that, the usual source of water is rain, fog and dew.

2.Moss identification

Moss species identification: "Grimmia pulvinata" (Gewoon muisjesmos) with cushion life form, see **picture 35 and 36, "Orthotrichum anomalum" (Gesteelde haarmuts)** with a cushion life form, see **picture 9, 10 and 11, "Hypnum cupressiforme" (Gesnaveld klauwtjesmos)** with a mats life form, see **picture 17 and 18** and the other one is left unidentified since it is a lichen specie and not moss specie.



Picture 63: Closer view of the colonized material in two different months, on the left taken in August and the right was taken in December (own picture)

3.Moss growth stimulation hypothesis

Mosses rhizoids were adequately attached to the concrete. The mosses are directly exposed to sunlight without shading, limiting mosses with cushion life forms to prosper at a slow growth rate, assuming that the maintenance frequency is extremely low. Although there is a canal close to it, the living condition is still considered dry due to the high moisture evaporation rate. Minor mats life forms mosses were observable, but it was growing on the nearby soil instead of the concrete surface, for this reason, not taken into consideration in the moss identification part.

Appendix iii: Initial terrarium test

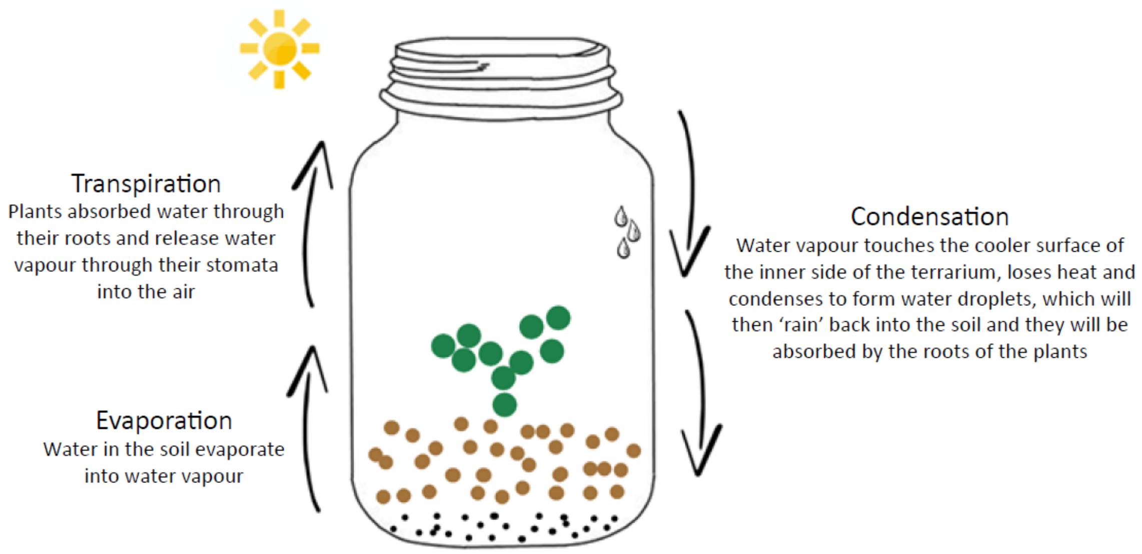
"the Terrarium test method"

Suitability of a terrarium

A terrarium is usually a sealable glass container containing soil and plants and can be opened for maintenance to access the plants inside. The main idea of a terrarium is to create a close water cycle in a sealed container. Transpiration and evaporation will occur due to external light and heat sources. The humidity level will keep rising until condensation on the container surface starts appearing. The transpired and evaporated water on the container surface will drop back to the soil. This is how a humid environment can be created, stimulating moss growth (Moss 2020).

Advantage of using a terrarium

- Humid environment
- No draft, which might hinder the initial moss growth
- Affordable and easy to set up
- Easy to operate, which has a self-operation water cycle



Drawing 1: Basic terrarium water cycle principle, drawing retrieved from: (https://www.lushglassdoor.com/blogs/news/what-is-terrarium-ecosystem)

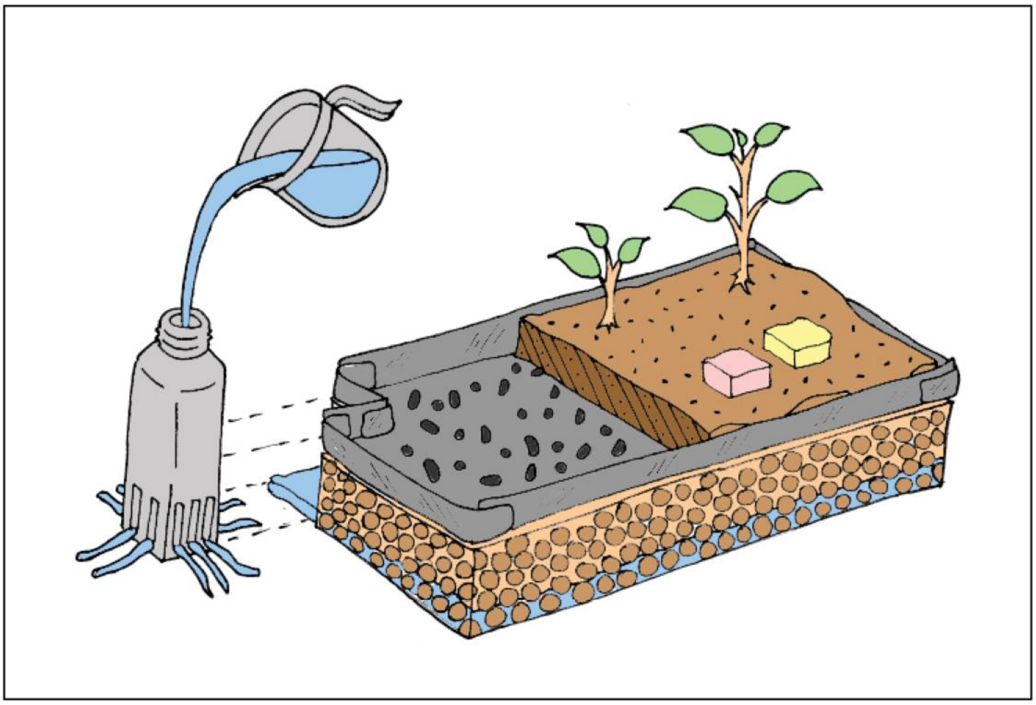
Initial terrarium testing material

In theory, the terrarium as a testing strategy sounds promising, but the only way to know whether it truly works or not is by testing it. For this reason, a rough terrarium setup has been made with the primary purpose of accessing the possibility of moss growth in a terrarium. Therefore, the tested material should have a high bio receptivity to show moss growth possibility. In case the method works, but if the chosen material simply has a low bio receptivity, it will barely have bio colonization. The technique might be discarded due to poor results regarding low bio receptivity of the tested material bio colonization. So, the chosen test material is clay bricks, which are commonly colonized by mosses. The used red and white clay bricks for testing are acquired from the store GAMMA (https://www.gamma.nl/). **Picture 64** shows how the samples are soaked in water for one hour before applying the moss cultivation technique.

Picture 64: shows the used bricks samples for initial terrarium testing, soaked in water (own picture)

1.Terrarium setup

The terrarium is made of different layers that serve various functions. The layers are composed of plants, growing soil/humus, graphite, cloth/carbon fiber mesh and expanded clay. Expanded clay on the bottom is to regulate the water cycle and prevent the soil above from getting too soggy from exposure to water. Cloth/ carbon fiber mesh serves as a barrier to separate the soil/ humus from the expanded clay. Simply place the mesh above the expanded clay. For purification purposes, active carbon is used and prevent mold build-up. The substrate soil layer doesn't matter what substrate you use; the thickness can be limited because mosses need a shallow layer to grow on top (SerpaDesign 2017). Some plants will be added to ensure that transpiration does occur when the mosses are still absent. The chosen used plants are randomly selected and small enough to fit in the container.



Drawing 2: The basic depiction of the used terrarium design (own drawing)

Terrarium water refill design

The water level in the plastic terrarium will reduce overtime. Thus, water needs to be added to maintain the water cycle, which will result in a moist environment. Water can be poured directly into the soil itself, but this would create a slight soil disturbance and some dirt will pass through the separation mesh layer to the expanded clay layer. In general, this is a minor problem, but it can also be easily solved when laying the soil layers, where one can make it easy to add water directly to the expanded clay filter layer. This is achieved by using a bottle with holes on the bottom to bridge the top and filter layers.

2.Initial testing [January 31, 2020– March 13, 2020, 6 weeks test]

Moss species selection

Moss species selection was made randomly based on local outdoor growing mosses growing on either cementitious material or brick. For this reason, the collected mosses name and species are not studied thoroughly yet.

Picture 65: Location of collected mosses for initial terrarium test (own picture)

Picture 66: The used mosses for initial cultivation trial (own picture)

Nutrient source usage for moss cultivation technique

For the moss cultivation technique, a form of nutrient needs to be blended with mosses into a liquid mixture of moss fragments. Based on different sources, buttermilk, yogurt and beer are commonly used. Beer has been discarded because the liquid is too thin, which might easily drip away. In the end, thick liquids such as buttermilk and yogurt are used, not knowing which one functions better. The decision of which exact brand to use is entirely random, but both chosen ones were organic because of the fear of added chemicals that will prevent the moss growth process.

Picture 67: the used organic yogurt and buttermilk for the moss cultivation technique (own picture)

3.Testing results

After exposing the terrarium made of plastic containers to the sunlight, it was observable that condensation did occur on the plastic container surfaces, which indicated a humid environment on the inside.

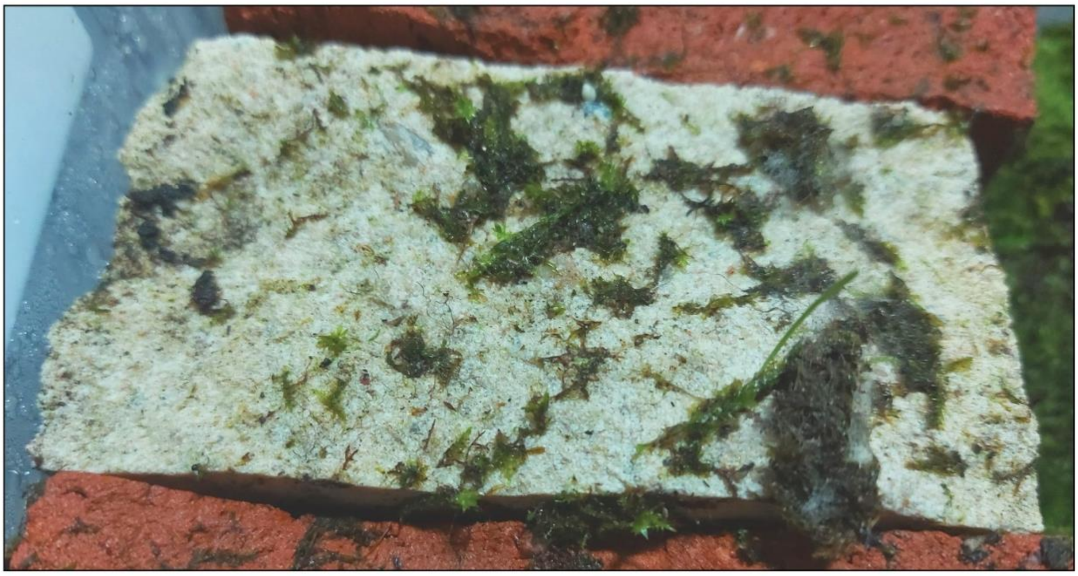
Picture 68: shows the condensation on the plastic terrarium surface (own picture)

First-week results

Picture 69: First-week results, on the left, is the terrarium with yogurt nutrient source and the right is the terrarium with buttermilk nutrient source (own picture)

After the first week, mold growth is slightly reducing compared to the early three days and on the buttermilk terrarium, some small moss germination is observable.

Second-week results

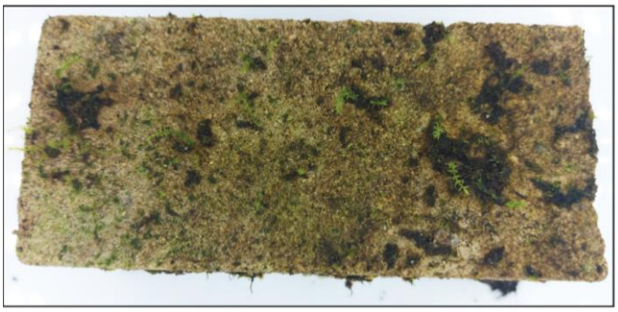
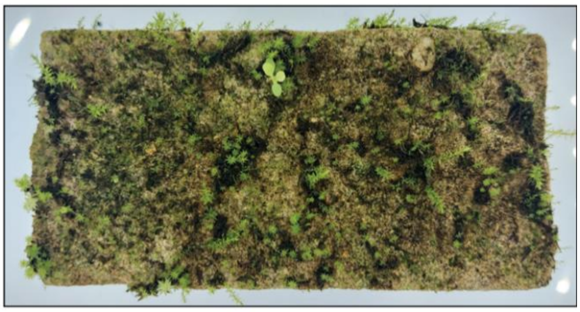


Picture 70: shows the results after two weeks of the buttermilk sample (own picture)

After two weeks of testing, moss growth on the buttermilk sample was apparent. Moss germination occurred from both moss spores and moss fractions.

Sixth-week results

Picture 71: First-week results, on the left, is the terrarium with yogurt nutrient source and the right is the terrarium with buttermilk nutrient source (own picture)

Picture 72: Sixth-week results, on the left, is the yogurt test sample and the right is the buttermilk test sample (own picture)

So, based on the two terrariums, it is concluded that the moss cultivation technique works for growing mosses. Secondly, buttermilk serves as a better nutrient source to grow mosses with the moss cultivation technique.

Yogurt and Buttermilk content study

	Buttermilk (per 100 ml)	Yoghurt (per 100 ml)
Energie	154 kJ	263 kJ
Vetten	0.5 gr	3.18 gr
Koolhydraten (suikers)	0.4 gr	4.54 gr
Eiwit (proteine)	3.7 gr	4.1 gr
Zout	3.6 gr	0.2 gr
Calcium	120 mg	109 mg
Fosfor	89 mg	-
Vitamine B2	0.17 mg	-

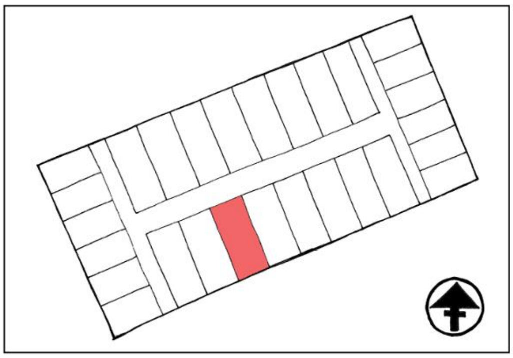
The table above shows the content of both buttermilk and yogurt per 100 ml. Phosphorous is one of the crucial ingredients in plant fertilizer. But sadly, the phosphorous content for the yogurt was not indicated, therefore harder to draw a conclusion based on these numbers. Based on nutrient studies for mosses, three crucial nutrients are phosphorous, nitrogen and carbon. In this case, the sugar content may serve as a carbon source for the growth of mosses. But, buttermilk with lower sugar content still performs better than yogurt.

In the end, it is concluded that insufficient testing and study with different nutrient sources have been done to be able to draw a firm conclusion. Secondly, moss growth is very complicated. For example, adding nitrogen or phosphorous alone can boost the most growth but adding both together will not. It might also be moss species-dependent since mosses can grow on low nutrition availability. But the reason why buttermilk performs better might be related to getting the nutrition level low enough so that other organisms cannot thrive and consume all the nutrition since this is a common mistake made by moss gardeners (Glime 2017).

Appendix iv: Terrarium test sunlight exposure condition/orientation

Testing orientation

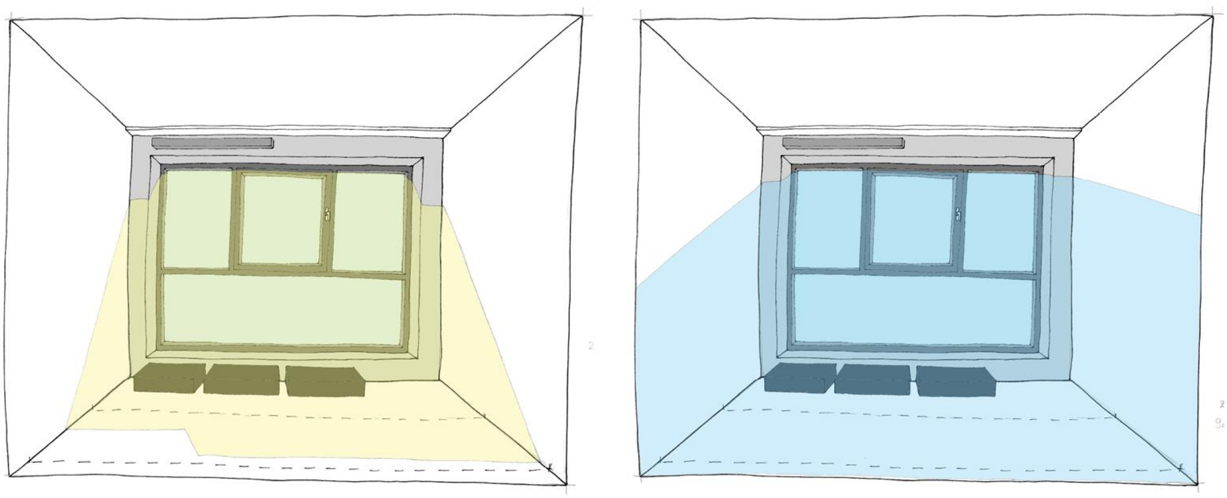
The indoor plastic terrarium test is conducted in a studio apartment in the Stieltjesweg student complex on the twentieth floor. The window faces the southeast orientation, which will have morning sunlight starting around 7 am and afternoon sun till 4 pm



Drawing 3: shows the room facing orientation, South-East (own drawing)

The natural lighting condition differs slightly between summer (June 21) and winter (December 21). During summer, the sunlight penetration is less than 2 meters, while winter has a deeper penetration depth, which is around 4-5 meters.

Based on the sketch below, the plastic terrariums are placed above the black boxes to gain equal sunlight since the glazing is slightly elevated above the floor level. It is assumed that all the terrariums are exposed to the same amount of direct sunlight resulting in a similar testing environment, for instance, the humidity level, temperature and daylight/shading amount.



Drawing 4: On the left, direct sunlight penetration during summer and on the right, direct sunlight penetration during winter (own drawing)

The glass terrarium is placed with an offset of two meters from the window to avoid summer direct sunlight exposure and gain winter direct sunlight exposure. It is placed on top of a closet, with a height of one meter above the floor.

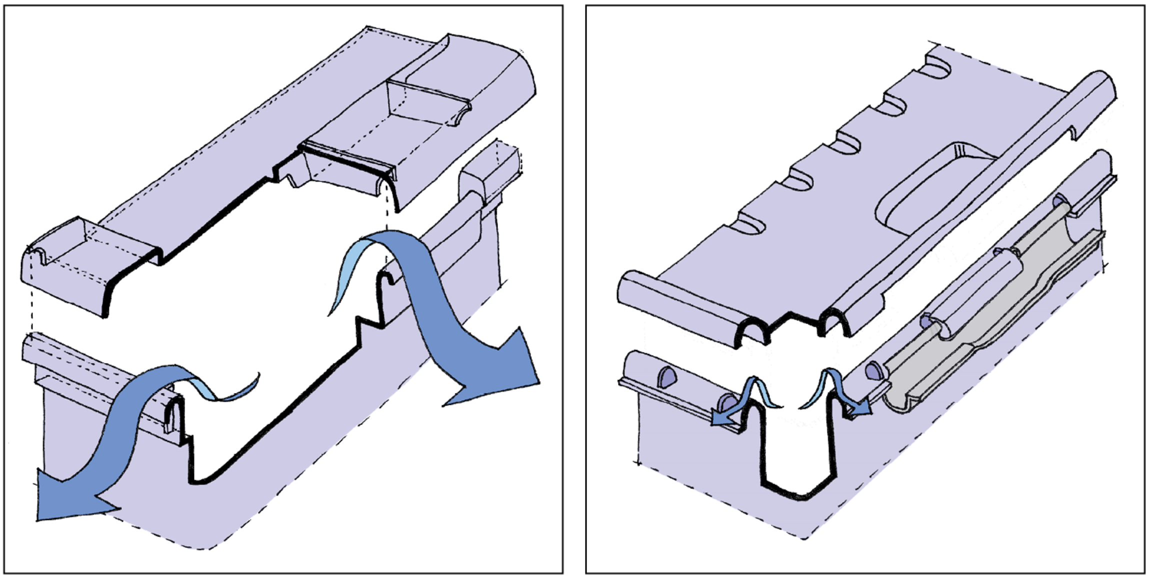
Appendix v: Second terrarium test

Large terrarium design

To be able to test more samples at the same time, larger terrariums are needed. Here some of the design choices and mistakes will be explained during the making of these terrariums first and then move on to the testing results.

The plastic container closure

Initially, plastic containers are being searched based on the size to accommodate more samples. Sadly, it turns out the plastic container's closure (cap) is crucial in trapping the water vapor, which will result in condensation on the plastic surfaces. Due to this reason, the first few large terrariums had fewer and unequal condensation droplets on the covers on the plastic container surfaces, which can result in different growing conditions. Therefore, another plastic container is used for the testing, where equal condensation is observable on the plastic covers. Picture 73 below will demonstrate how to distinguish between a good and poor plastic container closure. On the left, the plastic container has a loose clip closure where airtightness is hard to attain, while on the right, the sample has an interlocking edge profile followed by a clipping closure on two sides to keep it locked.



Picture 73: On the left is the poor closure example and on the right side is the container with better closure (own picture)

Terrariums design without plants

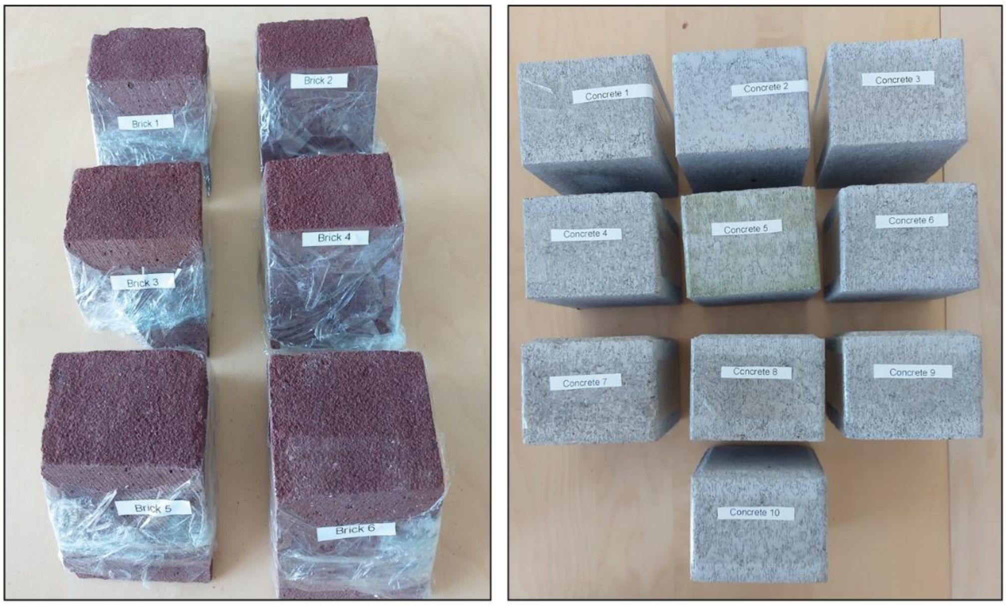
Are plants necessary in the terrariums to secure the water cycle? For this reason, a terrarium with very few plants is made. Initially, there are only green onions and coriander sprouts grown from seeds. After a while, soil greening starts occurring, which is followed by an unpleasant odor. For this reason, patches of collected mosses have been added to cover the soil. The amount of condensation on the container surface was more the less similar to terrariums with more plants in it. Another point to mention is that there were more dead fruit flies in the terrarium without plants. Therefore terrariums without plants are fine to use for the moss cultivation technique.

Picture 74: shows the terrarium without plans idea (own picture)

Second terrarium test [May 5, 2020 – June 9, 2020- 5 weeks test]

With the results based on the initial terrarium test, it is proven that indoor moss cultivation on a given material surface is possible with the moss cultivation technique.

A second test will be conducted, and weekly images will be taken of the test sample to evaluate the technique. If a proper moss growth within a certain amount of time can be achieved, the terrarium testing time can be set as a fixed parameter for comparison. For the testing sample, red bricks and concrete pavement tiles are used. The test material is taken from a disposal site to recycle some material and reduce costs. A printing device is used for the naming of the sample to prevent wrong references and it is chosen so that it can withstand a moist environment.



Picture 75: shows the used test samples for the second terrarium test (own picture)

Picture 76: Top view of the three large plastic terrarium with all testing samples in place before applying the mixture from the moss cultivation technique (own picture)

Picture 77: shows the used moss species for the moss cultivation technique, how the liquid moss mixture looks like and the leftover moss fractions at the end of the application (own picture)

Results

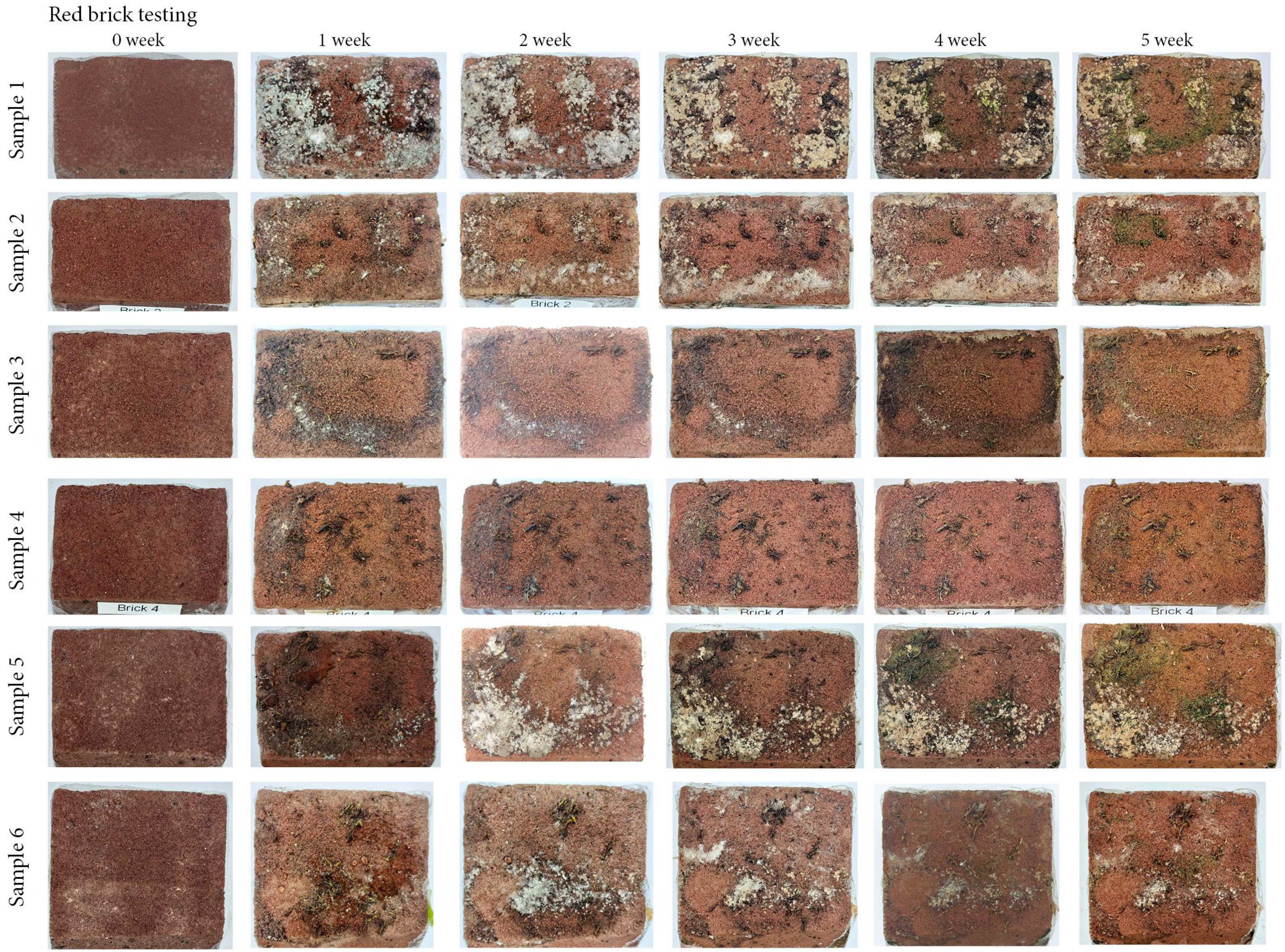
Based on the five-week testing, there were no observable most growth on the top surface, which led to the question of why it did not grow this time, not even on the brick samples.

A possible reason is that the terrarium temperature was too high, making the environmental condition impossible for moss germination and growth. Based on observation, the test samples exposed surface was seldom moist/wet. Did the exposure to direct sunlight lead to faster moisture evaporation? The direct sunlight exposure might have caused the lack of moisture. Without moisture, moss growth becomes impossible.

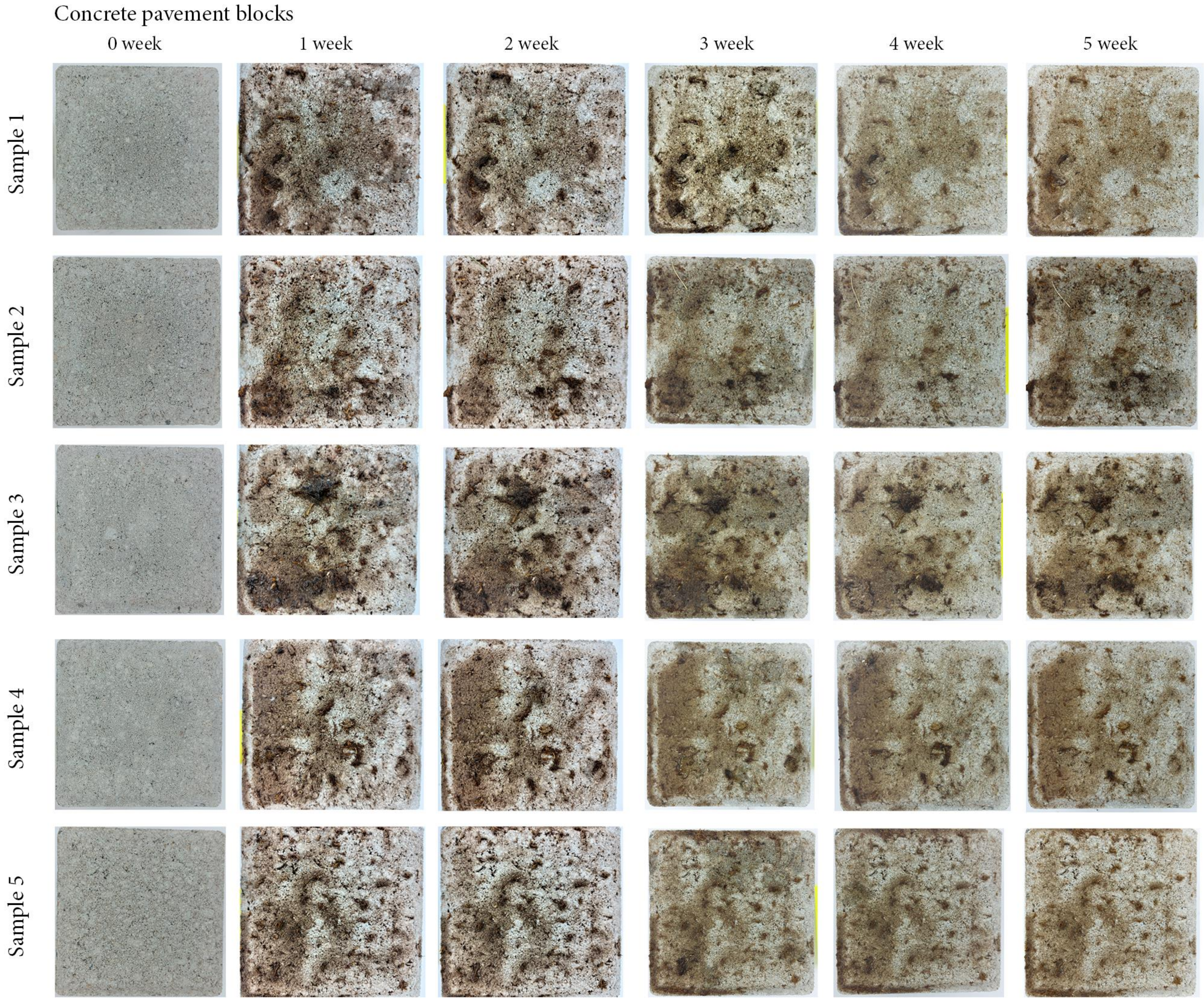
After removing the naming plastic wrapping around the brick sample for a final inspection, moss grew on the sides. Due to the plastic wrapping being fixed loosely around the brick, moisture was trapped in between. The plastic wrapping created a different micro-environment that is ideal for moss germination. The sample's tested top surface was dry, and the surface area covered by the tape turns out to be moist. Therefore, the lack of moisture is definitely one reason why moss growth on the top surface was impossible and how temperature influenced the development is unknown. The weekly photo recording of the samples can be seen on **pictures 79, 80 and 81**.

This failure led to the study of the plastic terrarium's temperature and moisture level to gain better insight and understanding of how the plastic terrarium can be adjusted to stimulate moss growth.

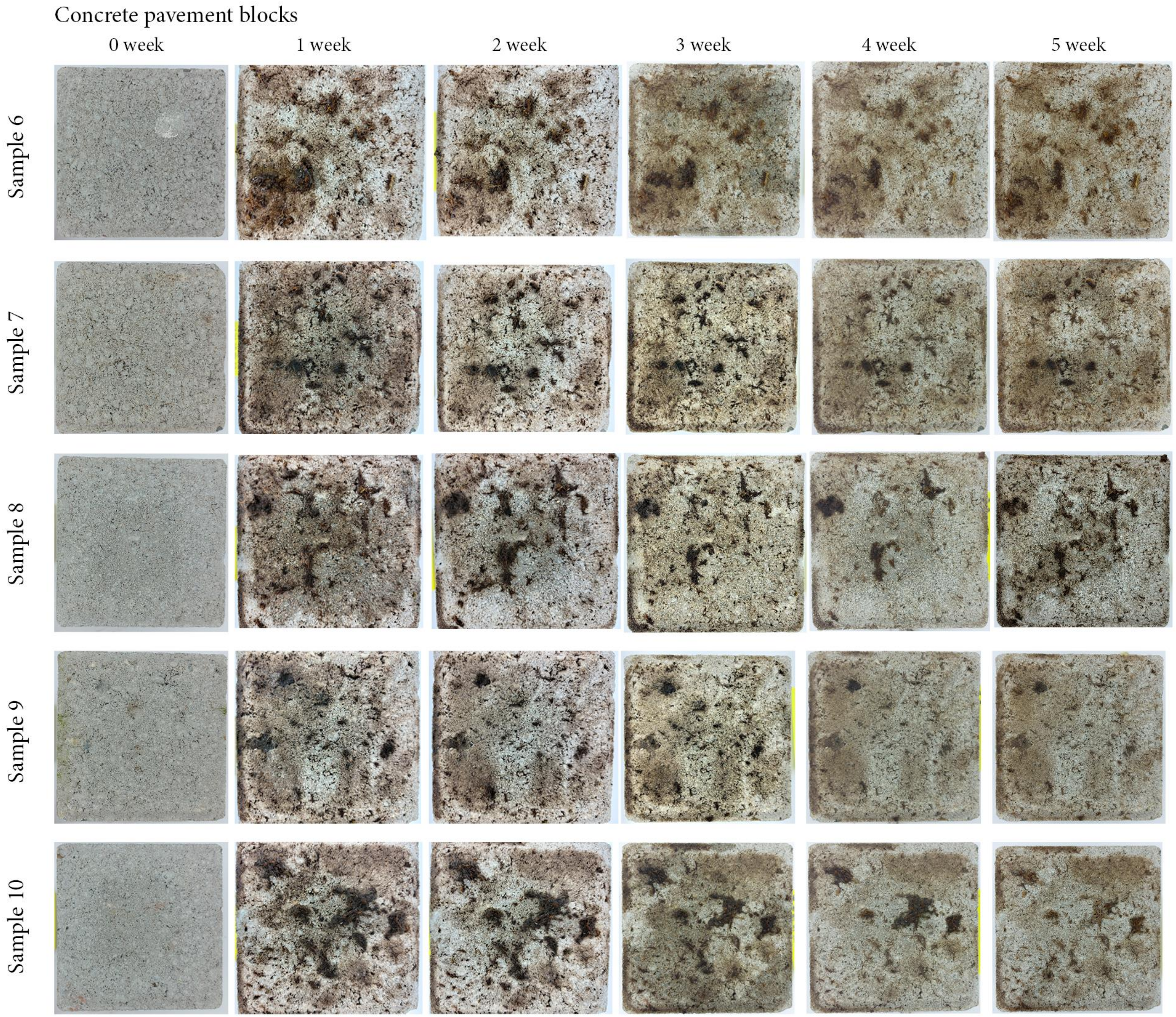
Picture 78: Redbrick sample one, before and after the removal of the plastic wrapping (own picture)



Picture 79: weekly photo recording of redbrick sample 1 to 6 (own picture)



Picture 80:weekly photo recording of concrete pavement tiles sample 1 to 5 (own picture)



Picture 81: weekly photo recording of concrete pavement tiles sample 6 to 10 (own picture)

Appendix vi: Temperature and Humidity study of the terrarium

Temperature and Humidity study of the terrarium

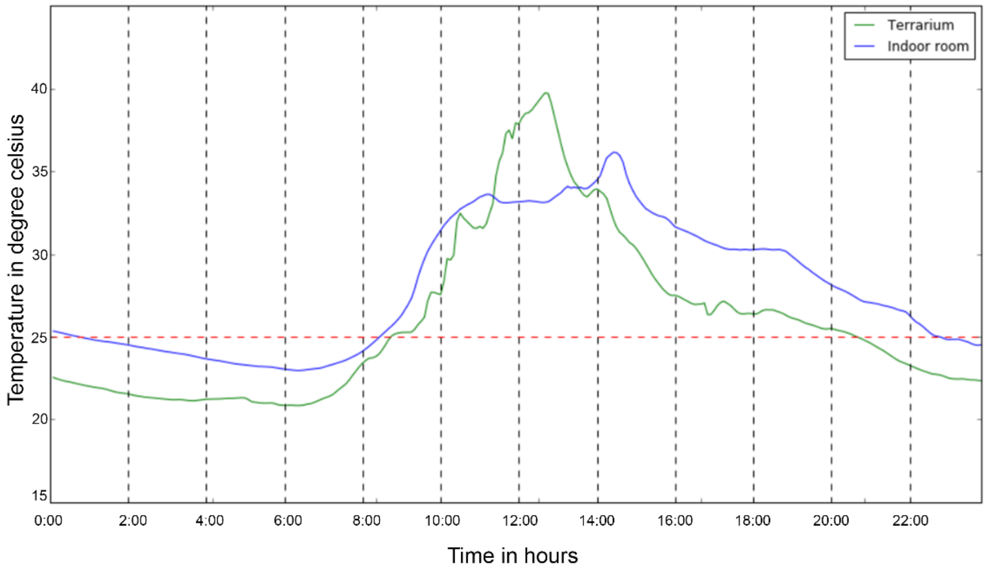
Use of Thermo hygrometer to understand the terrarium growing environment to measure the humidity/ temperature pattern and compare it to typical room values. The combometer and indoor house thermo-hygrometer shown in **picture 82** are initially used to measure the temperature and humidity to understand the plastic container terrarium environmental conditions better. In the end, it turns out that these measuring devices are inaccurate. For example, the combometer always indicates 99% humidity even when it is not humid. Based on the **picture 82** below, the indoor house thermo-hygrometer with three more sensors placed next to each other still shows slightly different temperature and humidity measurements. Therefore, it is decided that these two devices' measured values are not reliable and will not be used at all.

Picture 82: shows the combometer on the left and indoor house thermo hygrometer on the right side (own picture)

Finally, it is decided to use a Hoboware MX1104, as shown in **picture 83**, which is more expensive, but the measured data is more reliable and light intensity in lux can also be measure. The measured data can easily be acquired instead of measuring on a daily or hourly basis.

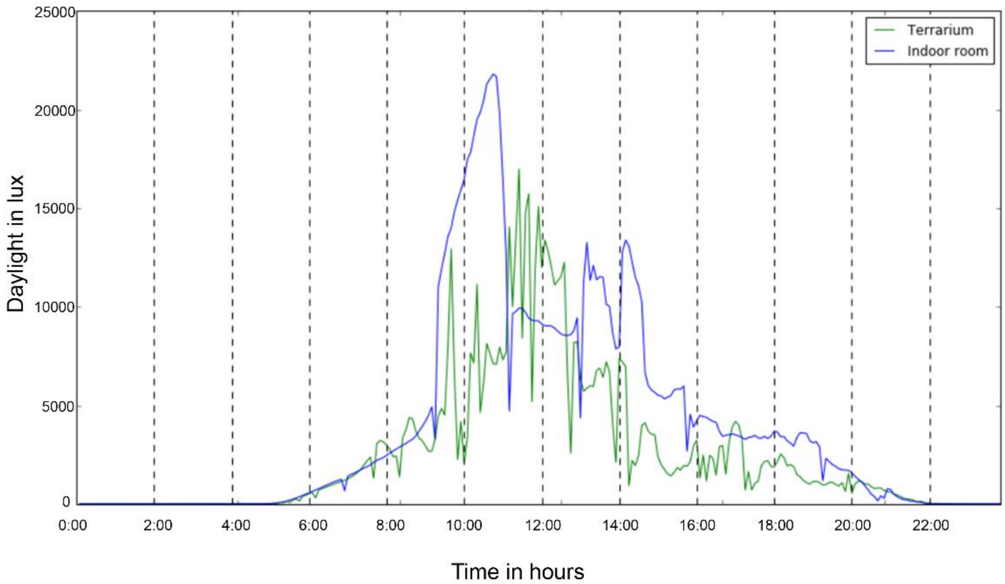
Picture 83: Hoboware MX1104 measuring device (own picture)

A full-day measurement for the indoor room environment and plastic terrarium is taken with the Hoboware MX1104 device. The results will be compared to give an idea of what the plastic container terrarium temperature and humidity conditions are. The plastic terrarium data is collected on June 21, 2020, while the indoor room data is collected on June 26, 2020. The measurement time interval is 5 minutes, which means 288 data measurements for 24 hours, starting at 12 am.



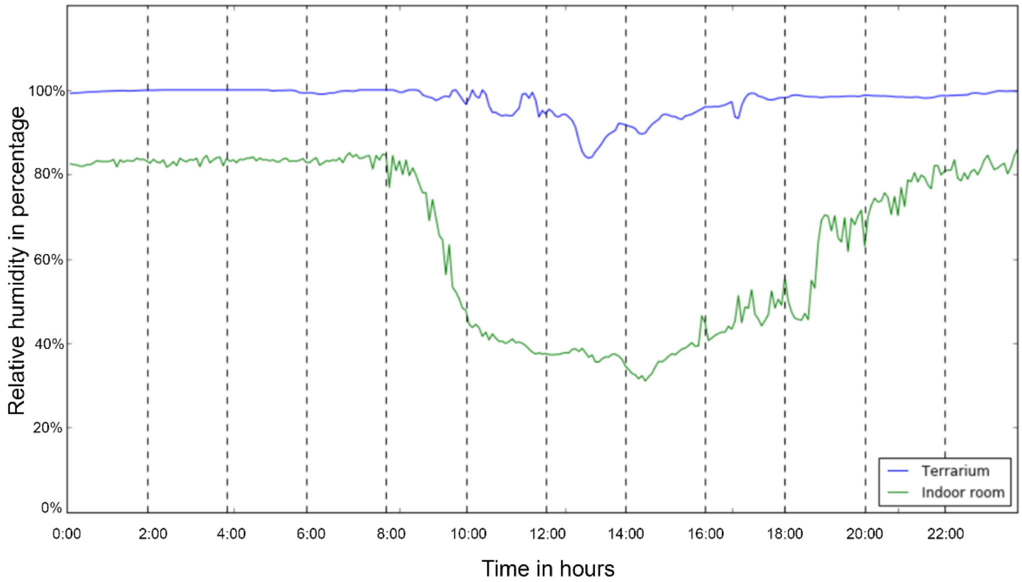
Picture 84: Temperature measurement for terrarium and indoor room of two different days (own graph)

The optimum growing temperature for mosses should not exceed 25 degrees Celsius, but based on the data shown in **picture 84**. It turns out approximately half of the day. The temperature exceeds 25 degrees Celsius. There will be a high-temperature peak in the terrarium, which reaches close to 40 degrees Celsius. The high-temperature peak can be lethal for the mosses since high temperatures accompanied by moist conditions can damage the moss cell structure (Glime 2017).



Picture 85: Daylight in lux measurement for terrarium and indoor room of two different days (own graph)

The temperature pattern follows the daylight exposure. Sadly, the terrarium and indoor room daylight pattern should not be compared with each other because the terrarium measurement has an envelope layer from the plastic container, which might reflect part of the direct sunlight resulting in strange patterns. For this reason, it cannot be used to conclude that June 26 is warmer than June 21 or vice versa, but only assume that it should be approximately the same.



Picture 86: Relative humidity measurement for terrarium and indoor room of two different days (own graph)

Lastly, the humidity level in the plastic terrarium is indeed high, which has a humidity level above 80 percent all the time. Meanwhile, the indoor humidity reached a maximum that is slightly above 80 percent and drops when the temperature increase.

So, based on the high temperature during summer, it is concluded that it causes an increase in temperature in the terrarium, making it impossible for moss to grow. Based on the reading (Glime 2017), it is also stated that during spring and summer, where the temperature reaches above 25 degrees Celsius, it is a dormant period for mosses to collect nutrients and wait till fall and winter to grow.

P**icture 87** below is taken from the initial terrarium brick test sample in the month of June. The grown moss was dying due to the high temperature combined with a moist environment. Mature mosses can withstand temperature fluctuations better, which are at least three years old. Japanese moss nurseries grow mosses indoor for two years and let them mature outdoor for 3 to 5 years to improve the survival rate when applying moss mats to different settings.

Picture 87: Brick sample from initial terrarium test, moss browning due to high temperature in the terrarium (own picture)

Appendix vii: Third terrarium test

Glass terrarium design

Terrariums are also used to house reptiles, where arid or humid environments can be created artificially to house different types of reptiles. Due to the high temperature in the plastic terrariums, it is concluded that it prevents mosses' growth and germination. So, another method is needed for the indoor cultivation of the mosses.

The main idea is to use a terrarium that is not exposed to direct sunlight to reduce the temperature. Instead of using direct sunlight, artificial lighting will be used to stimulate moss growth shown on the right side of **picture 90**, followed by a ventilation opening on the top part that allows the heat to escape in order to lower the temperature. But this also results in a reduction in the humidity level. To compensate for this loss of humidity/moisture, a waterfall design made of EPS foam and a moisturizer device is used.

Picture 88: Glass terrarium with waterfall design made of EPS foam (own picture)

Picture 89: The test sample placed on a wooden stance and functioning moisturizer on the right side (own picture)

For the testing, it is decided to use a wooden table to elevate the test sample from the soil so that capillary action from the earth can be ruled out as a moisture source. But due to organism growth on the wooden stance, it is decided to discard it and put it directly on the soil instead. The soil attached to the test sample will directly affect its weight balance, influencing the weight balance of the testing sample if one plans on measuring weight gain to assess the grown mosses' biomass gain.

Picture 90: Left: microorganism growth on the wooden table (own picture) and right: the used growth lamp for the glass terrarium test, picture retrieved from: http://www.exo-terra.com/nl/products/natural_light.php

Testing run 1 [July 24, 2020 – August 21, 2020 – 4 weeks test]

The used lighting and moisturizer are on an on/off cycle to imitate regular day lighting time and night moisture gain from dew. The moisturizer functions from 12 am to 7 am, while the artificial lighting function from 8 am to 4 pm. The waterfall made of EPS foam is running the whole time, but in the end, it turns out that the EPS foam waterfall is not a good idea due to water leakage throughout the material itself. For this reason, the designed water circulation does not reach the designated destination. The humidity level influence by the waterfall is unknown, the humidity level is already close to 90 percent above. Therefore, measuring the humidity level with and without the waterfall functioning might not give an accurate result of the humidity influenced by the waterfall.

The six different moss species used for the moss cultivation technique are: **“Grimmia pulvinata” (Gewoon muisjesmos), “Orthotrichum anomalum” (Gesteelde haarmuts)**, **“Hypnum cupressiforme” (Gesnaveld klauwtjesmos)**, **“Bryum capillare” (Gedraaid knikmos)**, **Syntrichia montana (Vioolsterretje)** and **“Grimmia torquata” (Schroefmuisjesmos),** shown in **picture 91**. These six moss species are chosen for the moss cultivation technique because they are collected during the field survey, which were growing well on concrete structures. Secondly, all six moss species are added together, knowing that not all will be able to grow well in the created glass terrarium environment. Therefore, it is added together as an experiment to tell which one can grow. However, based on the first terrarium test, the growing mosses are hard to recognize due to the young shoots' age and size. Therefore, if two out of the six moss species grow, it will be challenging to differentiate them from the other four that do not grow.

The used testing samples are red bricks, yellow bricks and aerated concrete blocks. The choice of material is limited to what can be acquired from the GAMMA store. Aerated concrete is very light with high porosity. Some research paper stated that this material has a high bio-receptivity. That is why it is added to the testing as well, assuming that it is oxidized in order to have a lower pH level.

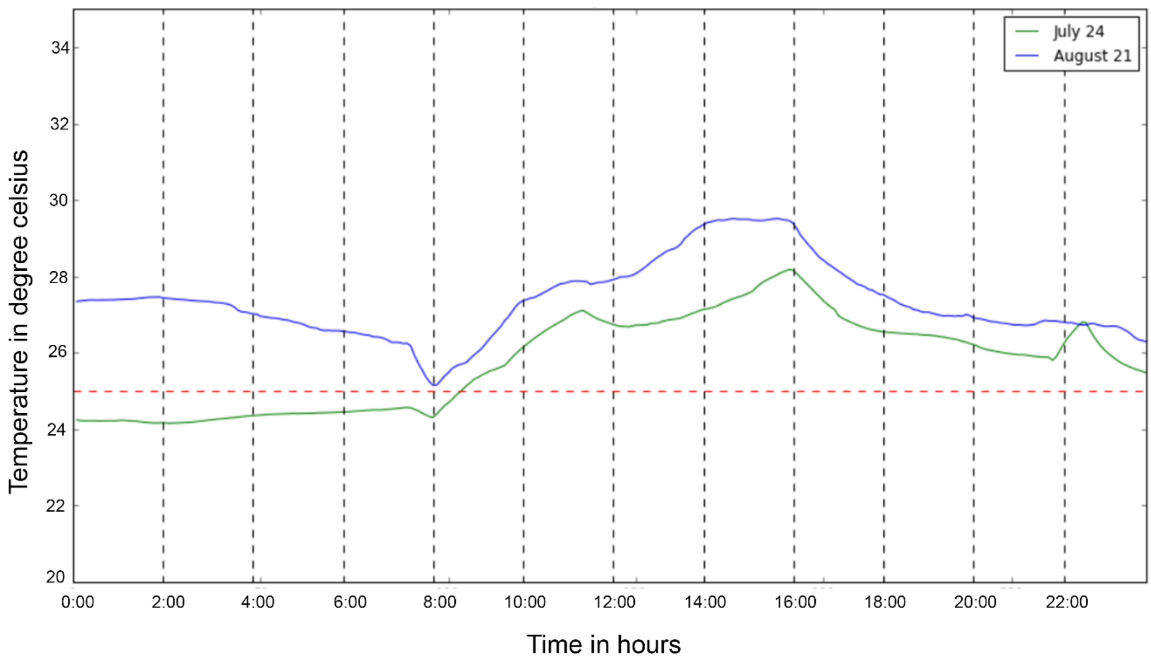
Since bricks cover more surface area compared to mortar joints in a quay wall element, this is considered a mandatory testing material.

Picture 91: The six different moss species used for the moss cultivation technique (own picture)

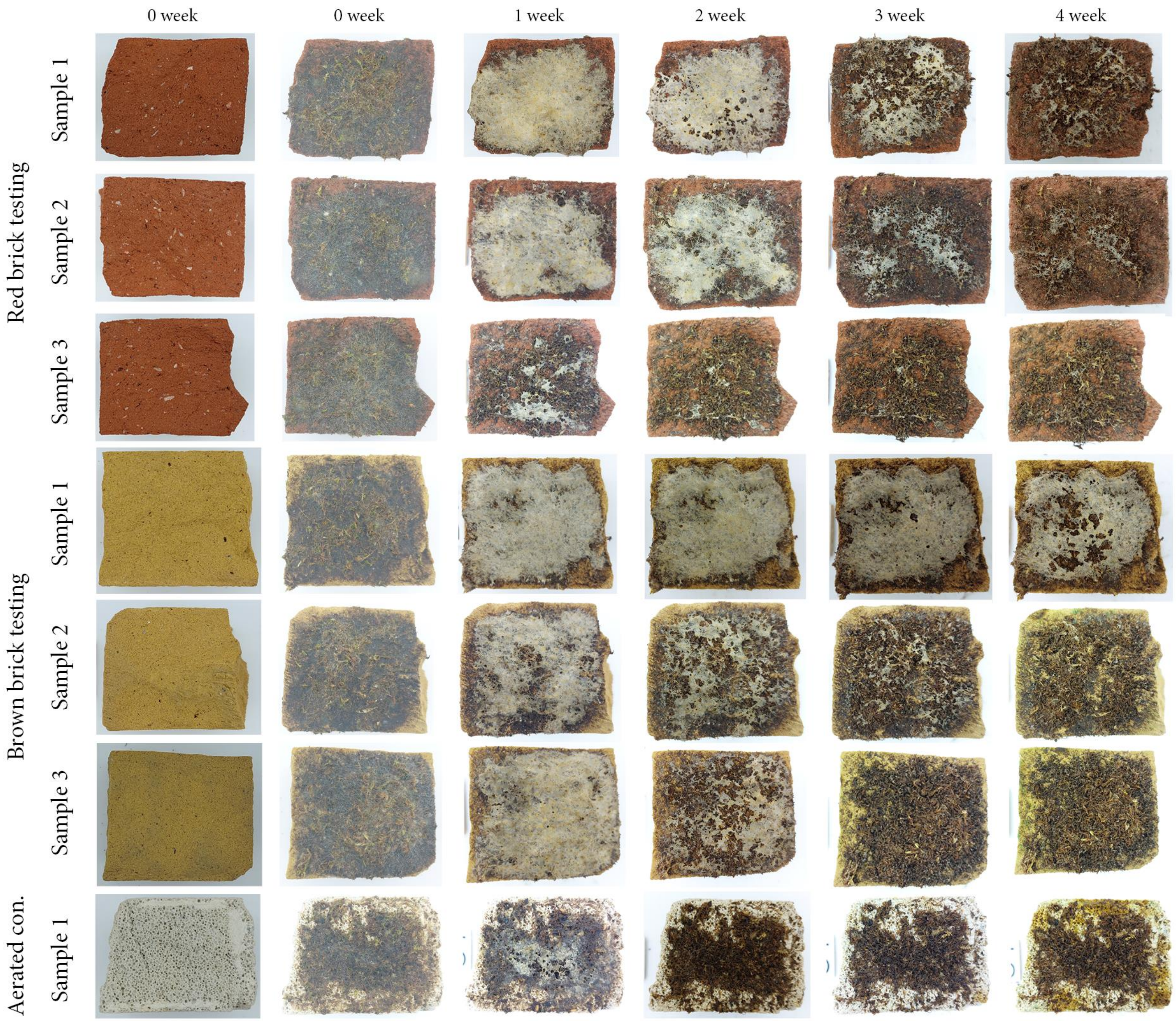
Test results

Based on observation and comparison of weekly picture recording, as shown in **picture 92**, there was no moss growth in all the test samples. The initial thought was that by adding more moss fractions on top of the test samples, the moss growth would be faster. Sadly, it only stimulated fruit flies' development, laying eggs on the samples and later growing into larvae. Initially, there were three aerated concrete samples; sadly, two were removed for hygienic reasons. The porosity of the aerated concrete serves as a better location due to protection for fruit flies eggs and on the brick samples, fewer eggs were present. After the test's failure, the first and last day of the test's temperature was analyzed, as shown in **picture 93**. The average temperature of both days did not exceed 30 degrees Celsius, which resulted in a decrease in temperature compared to the plastic terrarium exposed to direct sunlight reaching a peak temperature of 40 degrees Celsius. Sadly, the average temperature is still above 25 degrees Celsius, the margin where moss productivity declines and becomes dormant. Therefore, the glass terrarium resulted in a decrease in temperature but not low enough for moss germination to occur. Weekly photo recording of the samples can be found on **picture 94**.

Picture 92: Fruit fly egg on the aerated concrete on the left side and the ride side is a close-up view of a fruit fly (own picture)



Picture 93: shows the temperature profile on the first and the last day of testing, July 24 and August 21, 2020 (own graph)



Picture 94: weekly photo recording of the tested samples (own picture)

Testing run 2: done simultaneously with plastic terrarium [September 4, 2020 – October 30, 2020 – 8 weeks test]

In order to be able to stimulate moss growth, some time has been spent on how to utilize natural daylight while keeping the temperature low. One idea was to use a water chiller to reduce the water temperature, which will be circulated with the waterfall's help. Secondly, since the EPS waterfall does not function well due to water leakage through the foam itself, it will be replaced with clay pots shown in **picture 95**. To increase the humidity of the glass terrarium, a water splash is preferred. Sadly, the redesign is not complete, so that the second test will be conducted without this improvement.

Picture 95: clay pots made for the new waterfall design to be used in the glass terrarium as a replacement for the EPS foam waterfall (own picture)

Since fall is coming, accompanied by a temperature decrease, it is decided to simultaneously do another test run with both the glass and plastic terrarium. The previous test sample is being used again after being cleaned using a toothbrush and water. Using soap might not be a good idea because it might add chemicals to the test sample surface, negatively influencing the moss growth.

Adjustment of test run 2, instead of using different moss species together in the moss cultivation technique, it is decided to use one single moss species on one test sample each. There are, in total, 15 test samples, 5 of red clay brick, 5 of brown clay brick and 5 of aerated concrete. There are five samples for each of the three different materials; sample 1, sample 2 and sample 3 of each material are tested in the glass terrarium, while sample 4 and sample 5 of each material are tested in the plastic terrarium.

The moisturizer and lighting on/off cycle are changed as well. Initially, the idea is to imitate daylight's natural occurrence from morning to afternoon and moisture gain through dew in the evening. Instead, it is changed to a 6 hours cycle, first 2 hours of moisturizer to wet the sample followed by 4 hours of artificial lighting. The idea behind this adjustment is assuming that moisture is needed for photosynthetic activity first and then followed by artificial lighting for it to perform photosynthesis. After four hours of lighting, the sample's moisture loss may prevent it from continuing growth; therefore, the moisturizer will be activated for two hours and followed by 4 hours of artificial lighting again. One day consists of four cycles with a time span of six hours divided into two hours of moisturizing and four lighting hours. Moisturizer starts at 5:30 am till 7:30 am, artificial lighting is turned on from 7:30 am to 11:30 am, and this scheme repeats every 6 hours.

Moss cultivation technique mixture for test samples 1 and 4 is made of **"Grimmia pulvinata" (Gewoon muisjesmos)**. For test samples 2 and 5, **"Brachithecium rutabulum" (Gewoon dikkopmos)** is used for the moss cultivation mixture. These two moss species are chosen because, based on careful observation, they might be the ones growing in the plastic terrarium during the initial test. Finally, for sample 3, **"Kindbergia praelonga" (Fijn laddermos)** is used because, as one of the collected moss samples from the field survey, it grows well in the glass terrarium, see **picture 96**. Therefore, the glass terrarium may have an ideal growing environment for it to germinate.

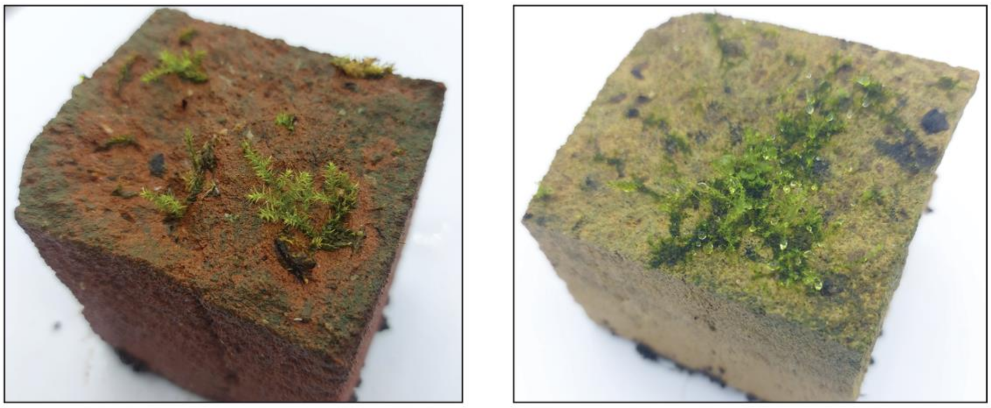
Picture 96: Kindbergia praelonga growth in the glass terrarium, both on soil and EPS foam (own picture)

Test results

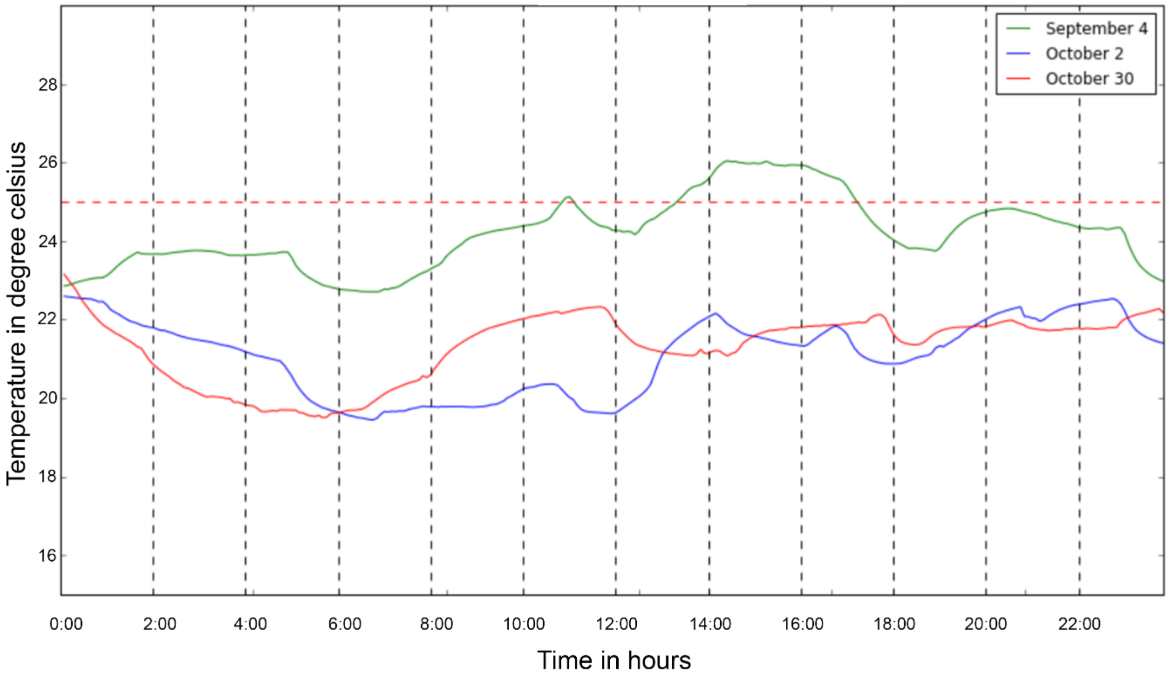
This test took place from September 4, 2020, till October 30, 2020, eight weeks testing period. Sample 2 and sample 3 of the red and brown clay bricks started to show visible moss growth after the third week, while all other samples barely had any moss growth. The aerated concrete started to have visible moss growth around the fourth week of testing, sample 1, 2 and 3 has moss growth on it. Moss growth of samples 2 and 3 of the aerated concrete compared to the red and brown bricks sample was that the aerated samples have moss growth with insufficient moisture due to observed drying. This might somehow be related to the aerated concrete properties, which resulted in losing moisture fast. Sample 1 used **Grimmia pulvinata** for the moss cultivation technique, which has a cushion life form and grows in dry condition. Only on the aerated concrete in the glass terrarium, **Grimmia pulvinata** can grow. On the red and brown bricks, **Grimmia pulvinata** is not showing any signs of growth. By the end of the testing period, in the plastic terrarium, only minor moss growth was visible on the aerated concrete sample 4, which also showed growth of **Grimmia pulvinata**. Therefore, it was concluded that aerated concrete has a slightly drier growing condition, which is more advantageous for moss with cushion life forms.

Meanwhile, both red and brown bricks can retain the moisture for a more extended period, making it possible for mosses with mats life forms to grow. On the other hand, this testing method does somehow test the material properties for bio receptivity. Because one may argue that moisturizing the sample every now and then makes it ideal for mosses to grow. But based on the difference between the bricks and aerated concrete results, it can be concluded that the material properties do influence the rate of moss growth in the glass and plastic terrarium test.

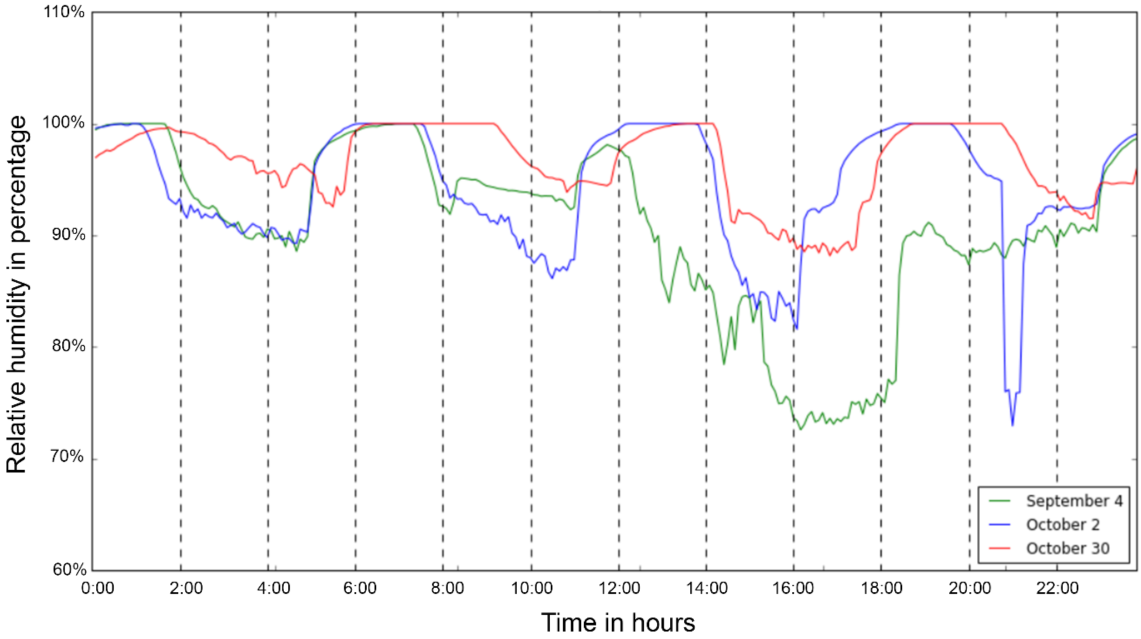
Finally, why observable moss growth in the glass terrarium started in the third week while the initial terrarium test has visible moss growth in the first week will be reasoned. The difference in germination time might be related to the temperature during the testing period. The temperature profile for three different days is presented in **picture 98**; the chosen dates are the first testing date, September 4th. The middle of the testing, which is four weeks after the first day, October 2nd. The last chosen date is the last day of testing, which is eight weeks after the first day, October 30th. By comparing the temperature profile of these three selected days, during September 4th, the glass terrarium temperature has a period above 25 degrees Celsius, while the two other dates in October showed that the temperature is entirely below 25 degrees Celsius. Therefore, the delay in observable moss growth might be related to the first few week's temperature.



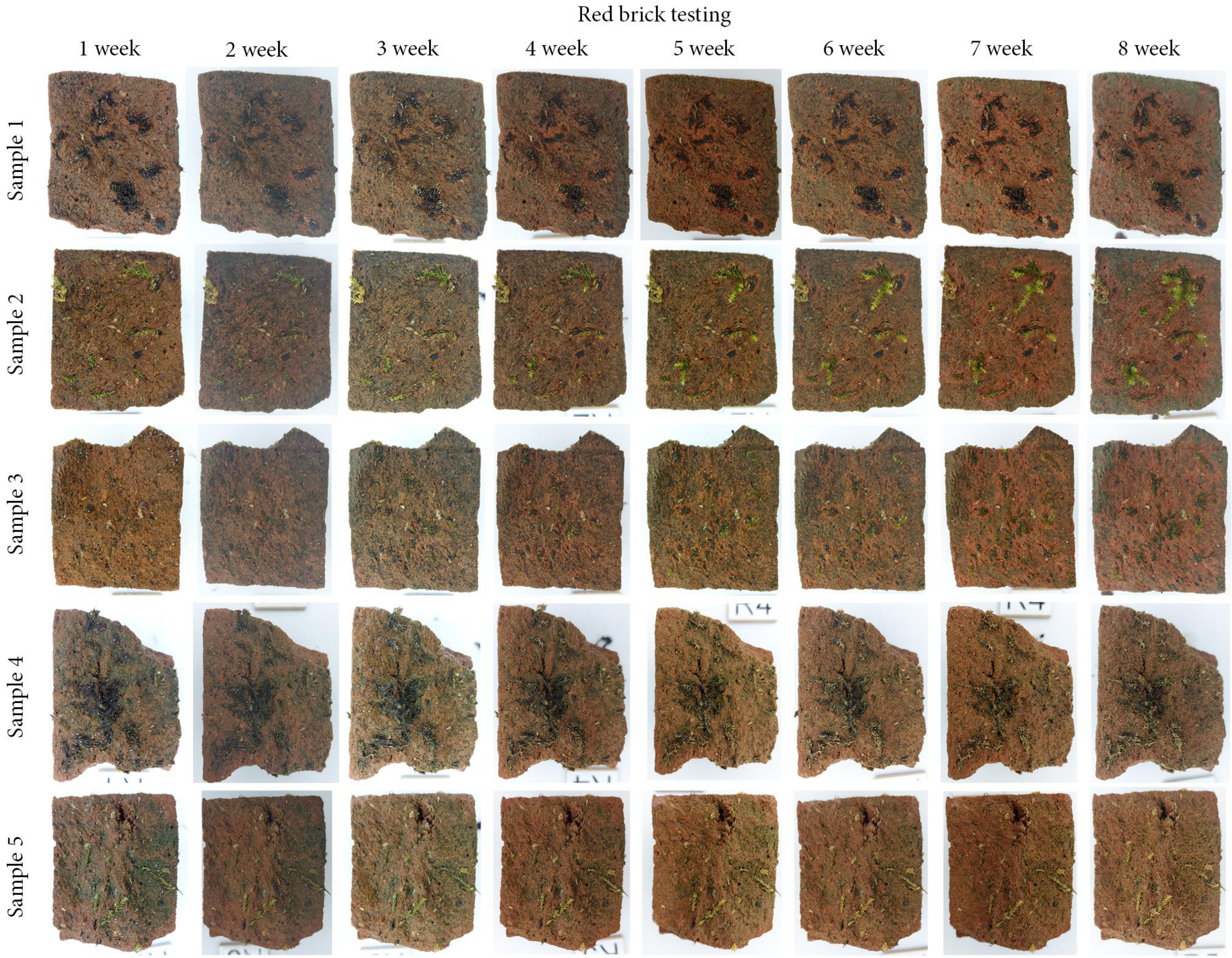
Picture 97: Moss growth after 8 weeks, on the left red brick sample 2 and on the right, yellow brick sample 3 (own picture)



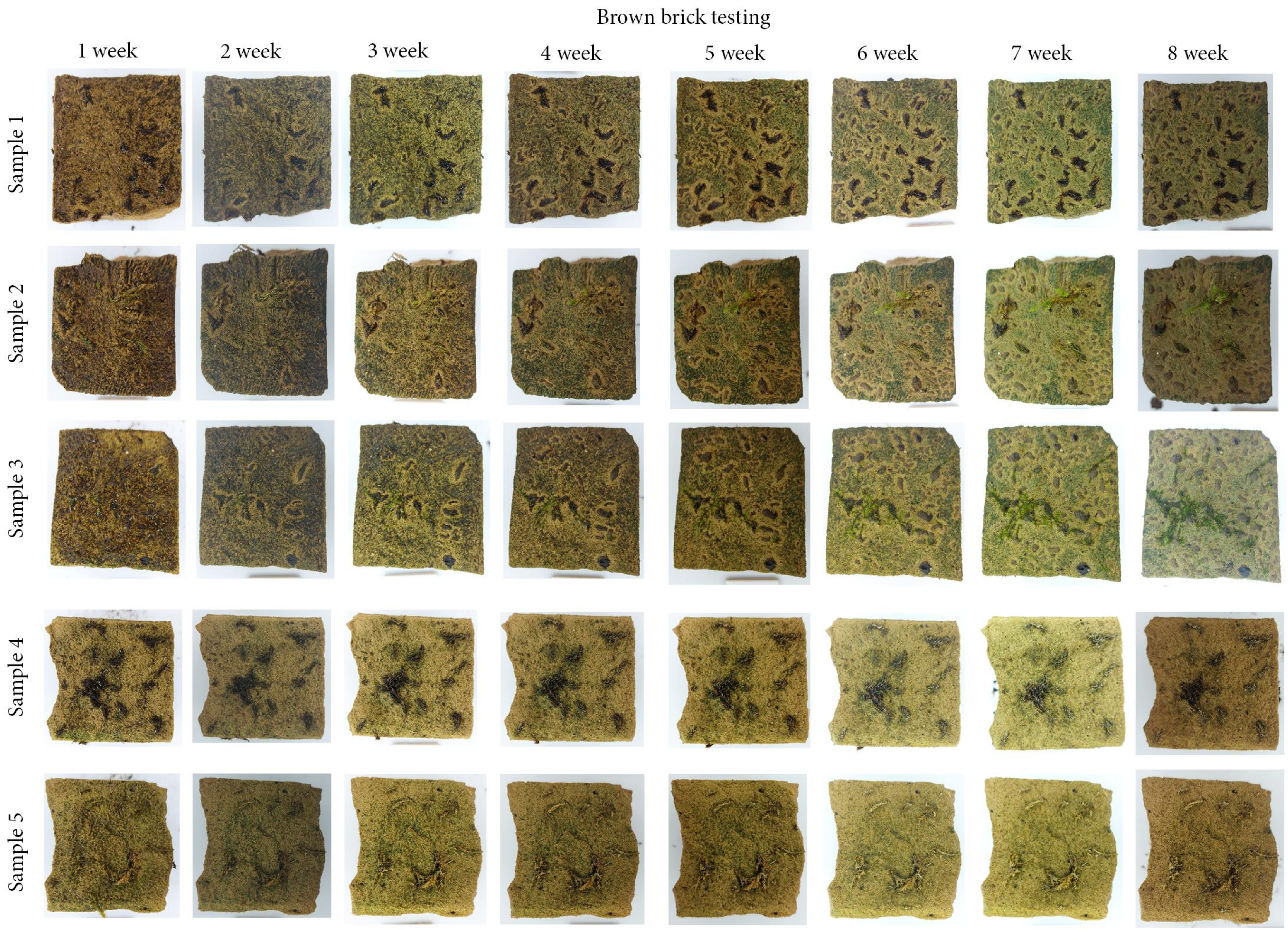
Picture 98: shows the temperature profile on the first, fifth and eight weeks of the second test run (own graph)



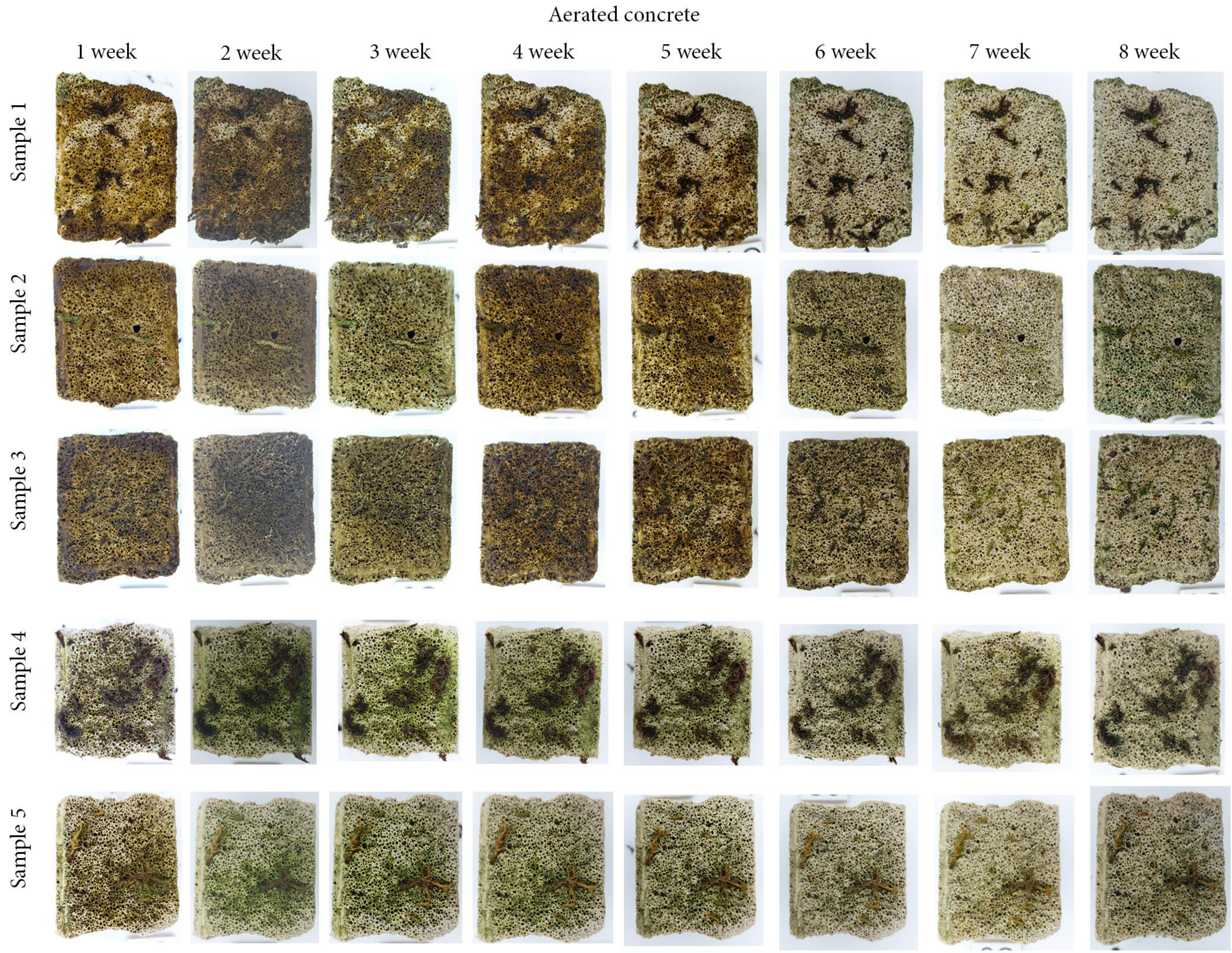
Picture 99: shows the humidity profile on the first, fifth and eighth week of the second test run (own graph)



Picture 100: Red brick testing sample (own picture)



Picture 101: Yellow brick testing sample (own picture)



Picture 102: aerated concrete testing sample (own picture)