RootSkin

From Soil to Soil

bio-inspired design
plant root textile
digital fabrication
circular design
computational design

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Food and architecture have always been intertwined. When humans started to build settlements, we began to dictate where the food would be grown. Simultaneously, natural resources such as water, light and nutrients dictate how a plant grows. When a climbing plant or vines are planted, humans begin to plan the route for the plant to grow, forcing it to take on certain forms. Is it possible to control the plant below the surface of the soil as it is above the soil? Plant roots seek out and grow towards the water source, posing the possibility to control the network of roots that are often hidden deep within the soil.

Today architects are working with nature to create an architecture that is both responsive to and harmonious with nature. As resources, in particular land, become increasingly scarce and our human population continues to grow, we have to find new solutions for both food production and housing. Our cities provide us with new opportunities to reshape the urban fabric while responding to these current issues. While plants provide food, they can also potentially provide other resources that could be used in architectural applications.

Plants already provide us with many benefits such as food, medicine, and cleaning the air, to name but a few. Often, once the fruit or seed is removed and the plant no longer fruits, the plant is removed from the soil and discarded - hopefully composted. This poses the question; is it possible to simultaneously harvest other elements of the plants and make use of them before they biodegrade and end up back in the soil? RootSkin is a research developed to explore the creation of biodegradable textiles made from the roots of plants as well as producing food during the “growth” of the textile. The aim being that these textiles can then form part of architectural installations such as skins for pavilions or buildings, for example. In addition, the natural biodegradation allows for an element of change to be incorporated into design.

INTRODUCTION

According to the Gaia hypothesis by Lovelock and Margulis, living things are part of a self-regulating mechanism on a planetary scale that has preserved habitable conditions for the past three and a half billion years: the oceans, seas, the atmosphere, the earth's crust and all the other geophysical components of planet earth remain in a stable and suitable condition for the existence of life thanks to the behavior and interaction of living organisms, plants and animals (Lovelock, 2009).

Anna Tsing (2015) describes the activities of life-forms as making worlds, stating that we are surrounded by many world-making projects, human and not human. World-making projects emerge from the practical activities of making lives that, in environments populated by multispecies, overlap creating collaborations: for example, bacteria help make the oxygen in our atmosphere, and plants help maintain it; while plants live on land because fungi make soil by digesting rocks. Species that collaborate are called companion species.

Collaborations between living forms maintain the earth in a state of equilibrium, and based on this principle Gaia has worked without foresight or planning on the part of organisms for millions of years, but the evolution of humans is changing that. This change has been described as the starting of a new epoch called the Anthropocene, the epoch in which human disturbance outranks other geological forces endangering the existence of all life forms.

During the last decades we have begun to gain awareness

Fig. 1 - Vision of RootSkin applied to the facade of a building as solar shading.

of the global implications of our actions and as a result, intentional self-regulation — from personal actions to global geoengineering schemes — is either happening or imminently possible. Making such conscious choices to operate within Gaia constitutes a fundamental new state of Gaia, which Timothy M. Lenton and Bruno Latour call Gaia 2.0. Operating within Gaia means emphasizing the agency of life-forms, their ability to set goals and their collaborations, fostering global sustainability (Lenton and Latour, 2020).

Up to now we (humans) have mainly conceived and planned co-existence and collaboration only as a single species environment, some examples are co-housing, co-working, community allotments and ethical purchasing groups (Mancuso S. et al, 2018). Designers can help people realize that we are all participants in complex systems that go beyond our human made constructions, systems that we cannot control, but that we should acknowledge, protect, and learn to live with and within (Antonelli, 2019).

What if we start to develop environments to host and foster multispecies co-existence and collaboration? What if exchange dynamics become the driver of the design of our cities, objects and services? What if we try to restore the environment's state of equilibrium through multispecies cooperation embedded in design?

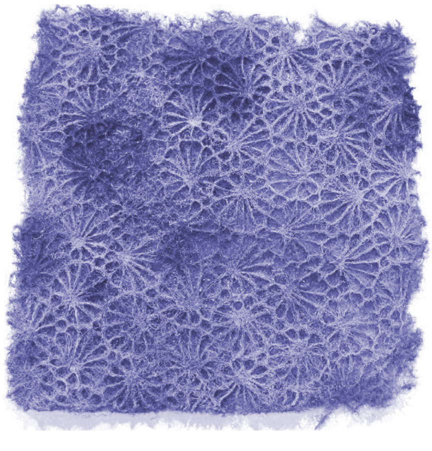

Fig. 2 - RootSkin test1 textile produced.

RootSkin is based on circular principles, created from humans, plants and bacteria collaborations and is taking advantage of robotics and digital fabrication to support the process. It merges activities such as plants and food production with the creation of textiles for the construction industry.

It consists of a network of edible plant (wheat grass) roots, creating a perforated membrane to be used to filter light in buildings. It can be used as a sort of tent behind a window's glass. It can be grown in our cities, for example on buildings' rooftops, on house gardens or applied in agricultural fields. When grown in cities, thanks to the implementation of plants in the urban environment, it brings further ecosystem services as, for example, alleviating the heat island effect, protection from flooding or air quality enhancement.

Rootskin grows on a planar panel covered with a layer of soil or hydrogel to cultivate the plants. The planar panel has a pattern milled into it where the water percolates through the soil deposits, guiding the roots' growth and defining the membrane perforation configuration. This support is integrated into urban surfaces, for example, part of a building's roof. Once the wheat grass, which is a super nutrient food, is grown and harvested, the plants end their lifecycle, and the root network is cut away, resulting in the patterned root membrane. When dried, RootSkin can be integrated into different urban and architectural scenarios providing a skin filtering light. With time the membrane will begin to biodegrade, returning the roots back to the soil to provide, through bacterial decomposition, the nutrients for the next plants to grow. This creates a closed loop cycle whereby no materials are wasted and underutilized.

RootSkin transforms urban morphologies into surfaces for food and biodegradable multispecies collaborations, closing the circle from soil, to roots, food and habitable spaces, and back to soil.

The following describes the steps that have been taken for the development of RootSkin.

INITIAL EXPERIMENTS

Creating the mold for the roots to grow, has been a fundamental part of developing RootSkin. After analysing the works of Diana Scherer (artist working with roots) and Zena Holloway (fashion designer working with roots), a strategy was developed to harvest the roots and to be able to separate them from the various layers of medium. The mold consisted of 4 layers. First, the CNC mold, then a large mesh followed by a more dense tulle, and finally, the seeds and growing medium. The mesh and the tulle were integrated to better help the separation of the roots at the end of the growing process. The initial experimentation was set up with a high quality plywood mold that was coated in a varnish to protect it from moisture. Next a layer of mesh was placed into the mold and a layer of tulle was placed above. On the tulle the seeds were placed with a mixture of hydrogel and vermiculite to retain the moisture and left for 2 weeks to grow indoors as it was too cold outside. For the quick experiments wheat grass seeds were used as the roots grew within 5 to 8 days.

The intricate pattern of the mold was developed using computational design and digital fabrication techniques. Computationally, the patterns were developed and then, using a CNC milling machine, the network for the roots were carved into the medium of the mold. The channels created attract the roots as they go searching for water and thus, are fundamental to the success of the root growth. Key factors to consider in the design include the depth and width of the channels to allow the pattern to be clearly defined.

Furthermore, the design plays a crucial role in the way in which the roots interlock and create the textile. During the first experimentations, patterns that were dense and non-linear were used. This produced good results and the root textile was surprisingly strong as the roots grew in all directions. As the roots dried and shrank slightly, the roots further locked together, making the textile strong as seen in Fig. 2.

As the initial test seemed to work well, the mold was used several times. However, because of this multiple use, problems started to arise. The first issue being that hydrogel was passing through the tulle and blocking the network for the roots to grow but, the most problematic aspect was the fungus. As a result new experiments were set up to understand how to avoid fungus within the roots and on the mold.

PLYWOOD MOLDS

When working with wood, the biggest enemy was fungus. To address the issues of fungus, new small scale experiments were set up to test different coating strategies. Simultaneously, a new linear pattern for RootSkin was under development and therefore, the experiments were set up with the new pattern. Experiments were set up in plywood molds. One was given no coating, a second a natural epoxy resin and the last a sealant paint. However, whatever coating used, eventually the timber and coating began to show signs of fungus.

The seeds were planted in the molds and they were left for two weeks as the roots seemed to grow very slowly. This time they were placed in the courtyard as the temperature had increased and allowed access to maximum natural light. After two weeks the roots were removed, but the roots had barely grown and produced a lot of fungi. The first hypothesis was that there was too much moisture being retained and therefore, the tests that followed included adding drainage holes. To reduce the moisture build up, holes were drilled into the base of the molds to allow the overflowing water to escape. Again the experiments were left for 2 weeks, and still the same issues arose. In some cases there was even more mold than before. Upon further discussions with experts it was found that at certain times of the year there are a higher number of fungus spores in the air. It happened to be that RootSkin was being developed and grown during the period of the year with the highest number of fungus spores in the air. Instead of aiding, the drainage holes were further contributing to the fungi problem by exposing the roots directly to the air. At this point, the decision was taken to only grow indoors and new tests were completed at a larger scale.

In addition to the material used for the mold, it was noticed that the layering of meshes was also proving to be problematic. In some experiments, the roots were barely passing through the tulle and in other cases they were. As the experiments developed, this layering strategy was varied to find the optimal solution that promotes growth. Finding the balance between root growth and ease of harvesting became a key challenge while developing RootSkin.

Indoors, the decision was taken to test the plywood mold with the natural epoxy resin coating as out of three options at the smaller scale, this proved to be the best solution. The original layering system was used in a last

Fig. 3 - RootSkin test 2 plywood mold.

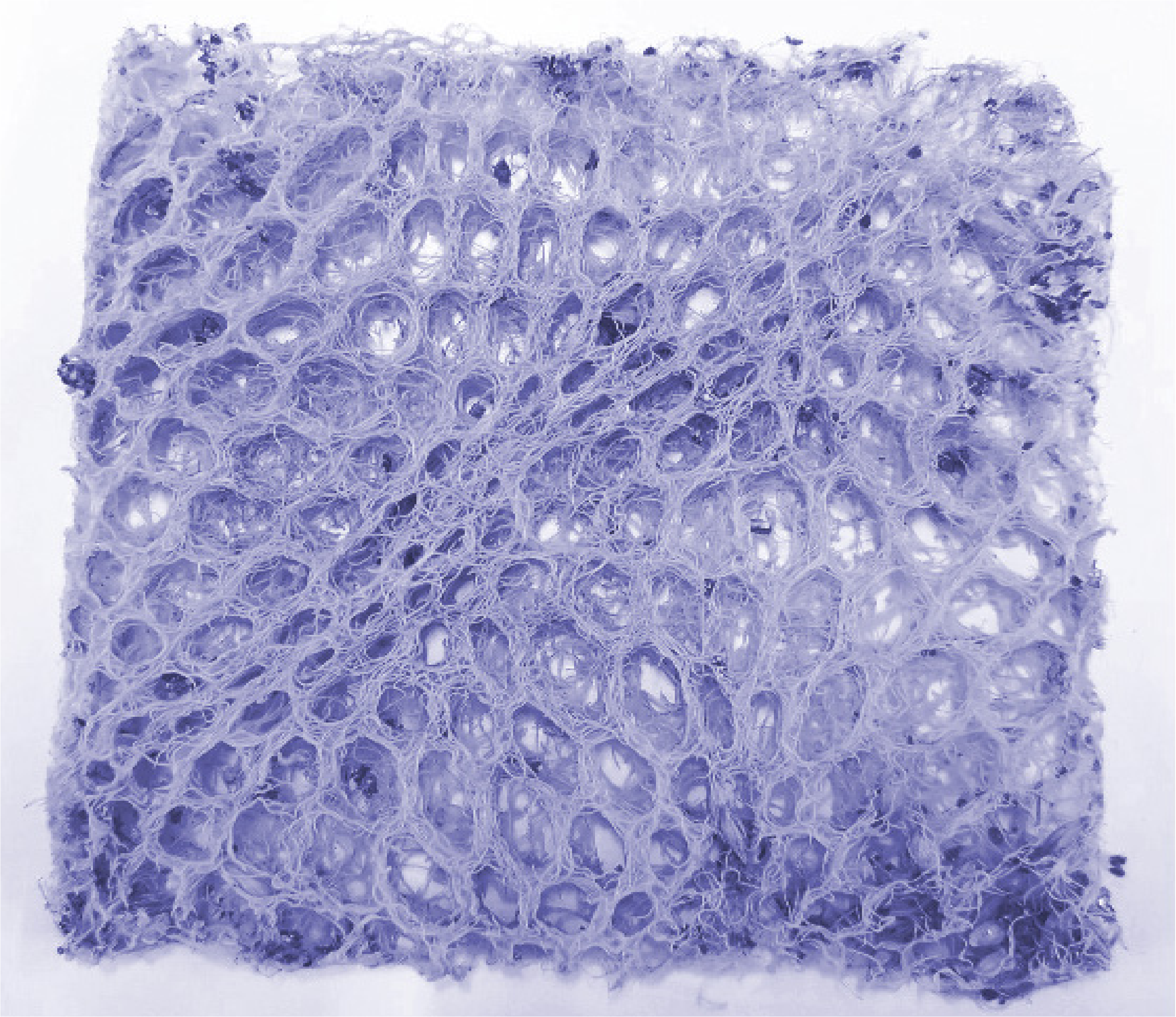

Fig. 4 - Rootskin Test 3 plastic 3D printed mold.

attempt to make the separation process easier. Similar to the small scale experiments, the roots took a very long time to grow and were not interlocking in a way that would allow for a textile to be extracted, Fig.3. While testing this large scale prototype, leftover seeds had been left in their plastic packaging container to germinate. Surprisingly, these roots had grown in four days, had intertwined and had produced a textile of roots. It was deduced from this that there was an issue with the mold material. While one might believe that roots would prefer natural materials, it turned out that they were thriving in plastic, an inert material.

3D PRINTED MOLDS

With this new knowledge, two small 3D printed molds were used to run quick tests. The results of these textiles were unlike what was achieved in the plywood molds, see Fig.4. The roots were very happy and grew within five to six days. The patterns of these molds were also denser, more defined, and allowed the roots to intertwine a great deal. The success of these textiles demonstrated that understanding the optimal material was key to the success of producing the root textile. While it was believed that the roots would prefer more natural materials such as timber, this proved not to be the case.

POLYCARBONATE MOLDS

RootSkin was developed to create facade panels and therefore achieving a scaled-up panel was fundamental. With the new knowledge that inert materials were proving to be the most successful, one last attempt was made using leftover 6mm polycarbonate. Thus, the pattern was milled into the polycarbonate and against our natural instincts, this proved to foster the best root growth. The roots thrived in the polycarbonate molds, an inert material, and grew much faster than they had done in previous tests. As a result, it was deduced

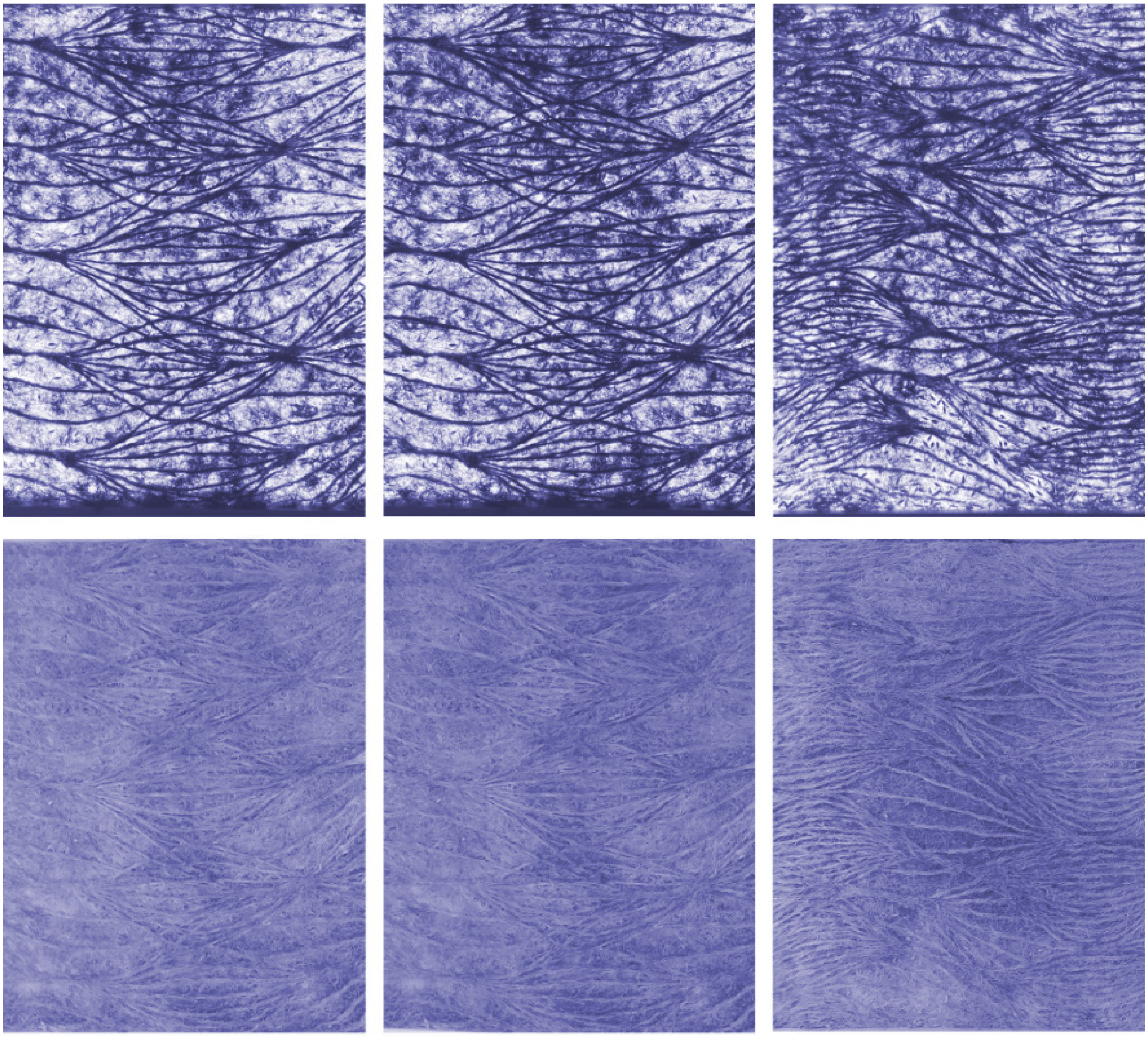

Fig. 5 - Rootskin Test 4 polycarbonate mold (upper level retro illuminated).

that the pH or glue used in the plywood was most likely affecting the growth of the roots.

In the initial experiment done with the polycarbonate, two layers of mesh were utilized. There were still doubts whether the fine tulle was hindering the growth of the roots. The next experiment was one with both meshes and one with no meshes. This meant the seeds sat directly on the mold. After just five days the roots without the mesh were ready to be harvested while the roots with the mesh had not grown as much but were already showing signs of degradation as seen in Fig.5. It was clear that the meshes were definitely impacting the root growth and would require further investigation. Therefore, for the final RootSkin panels it was decided to grow the panels without the mesh. While this proved to be successful in terms of root development, separating the layers took a lot of hours and was quite complex.

While contending with the issues of material use, another issue arose related to the linear pattern. At the small scale this was not noticeable, but at the larger scale this proved to be more problematic. The linear pattern meant there were less opportunities for the roots to cross and interlock. Instead, the roots were growing parallel to each other. Once the textile was removed from the mold, the roots began to react to the humidity resulting in a decrease in the definition of the pattern of the roots. To overcome these issues, the roots had to be cut and separated from the plant as quickly as possible and dried. When it took longer to separate the roots from the grass, fungi would begin to grow in the roots. The sun proved to be the best way to dry the roots in an even manner, Fig. 5.

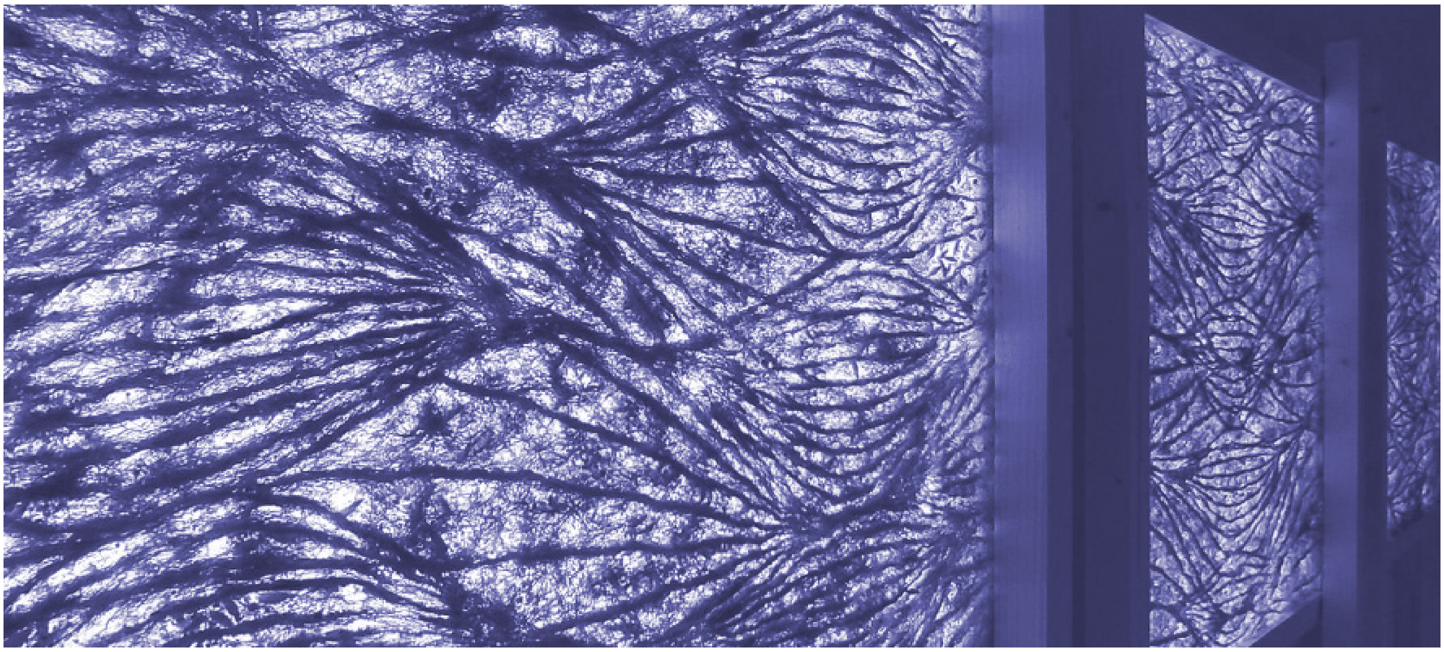

Fig. 6 - Rootskin presented in Tallinn Architecture Biennale 2022.

ARCHITECTURAL APPLICATION

Utilizing biodegradable materials in real life architectural applications poses several challenges. When working with plants there is always a level of unpredictability; whether it is will the plant produce its fruit, or will the roots be dense enough to create a strong textile. The goal of RootSkin was to develop a strategy that would make it possible to harvest the fruits above the soil for food and harvest the roots below the ground level to create a textile. Due to the nature of the textile and its translucency and biodegradability, it lends itself to becoming a skin that could be applied to buildings. As the density of roots can be controlled, this poses beautiful opportunities to play with translucency, Fig.6.

Furthermore, the biodegradable nature of the textile poses new challenges and/or opportunities. After a certain amount of time the textile will biodegrade, especially if it is exposed to the elements. This will create opportunities to renew or evolve the design of the skin overtime, creating an ever changing urban fabric. On the other hand, if the skin is to last a long period of time, coating strategies would need to be developed that also do not hinder the biodegradable nature of the textile.

CONCLUSION AND FUTURE PERSPECTIVES

Through the tests, we demonstrated how to develop a textile for the construction industry. The product is currently at a Technology Readiness Level (TRL) between 3 and 4. In order to rise its TRL and establish that it could be viable for the market the following research steps are required and foreseen in the near future:

(1) Further tests on the mold bottom panel material: at the moment we managed to grow it on plastic material; more natural and ecological materials need to be tested in order to enhance the product’s sustainability.

(2) Further tests on the patterns: the textile pattern defines on one side the transparency and on the other side the structural resistance of the textile; further tests with different patterns will be useful in order to raise the structural resistance and make it possible to produce larger panels.

(3) Further tests on the plants used: wheatgrass has the advantage of being a superfood and being fast in growing; however, further tests with other plant species could make it possible to extend the range of plants from which RootSkin can be produced.

(4) Development of composite materials from rootskin: at the moment RootSkin degrades rapidly when coming in contact with water and consequently is mainly applicable to interior environments. Tests on creating composite materials from RootSkin that might resist water would allow for its use in the exterior environment.

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