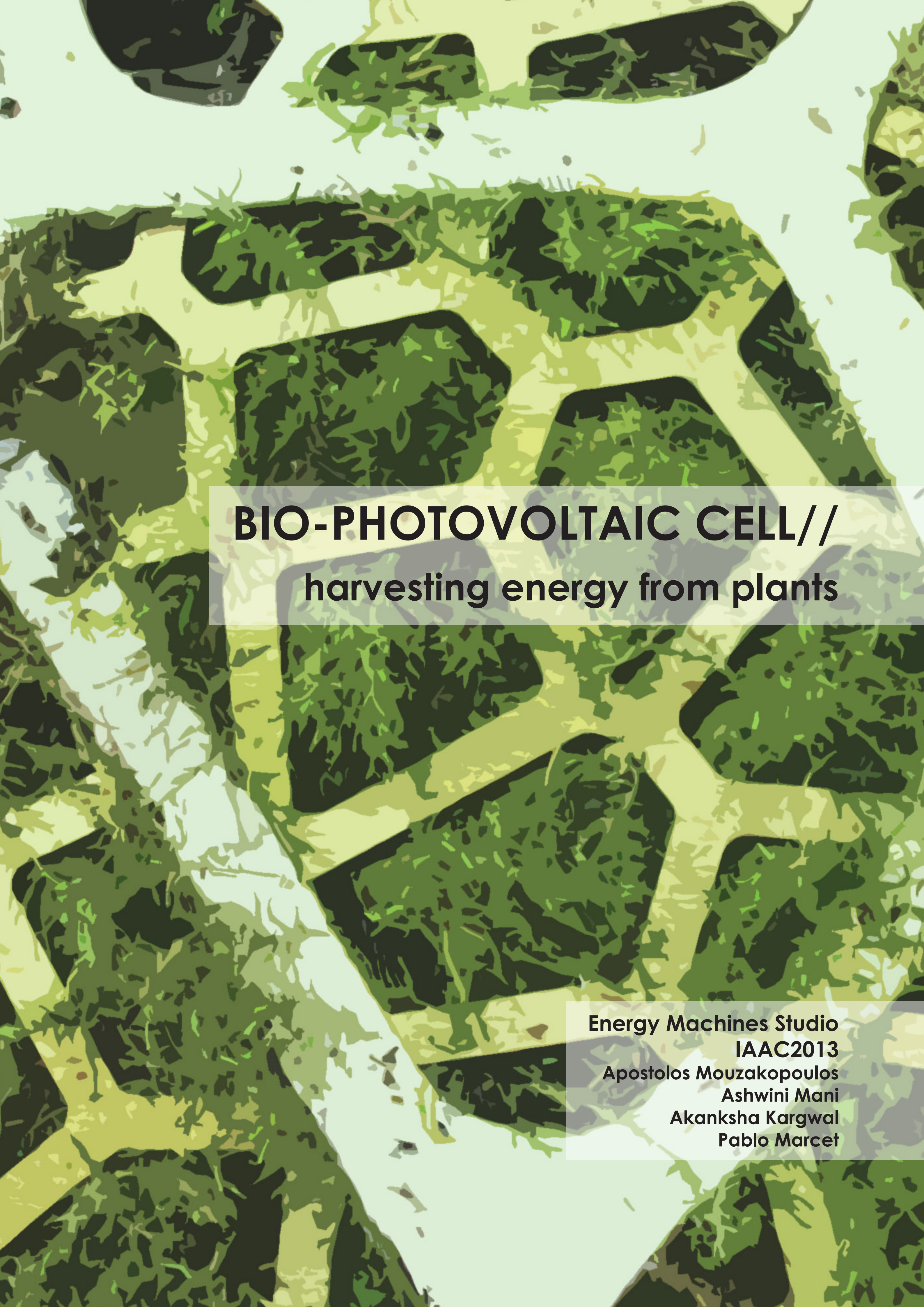


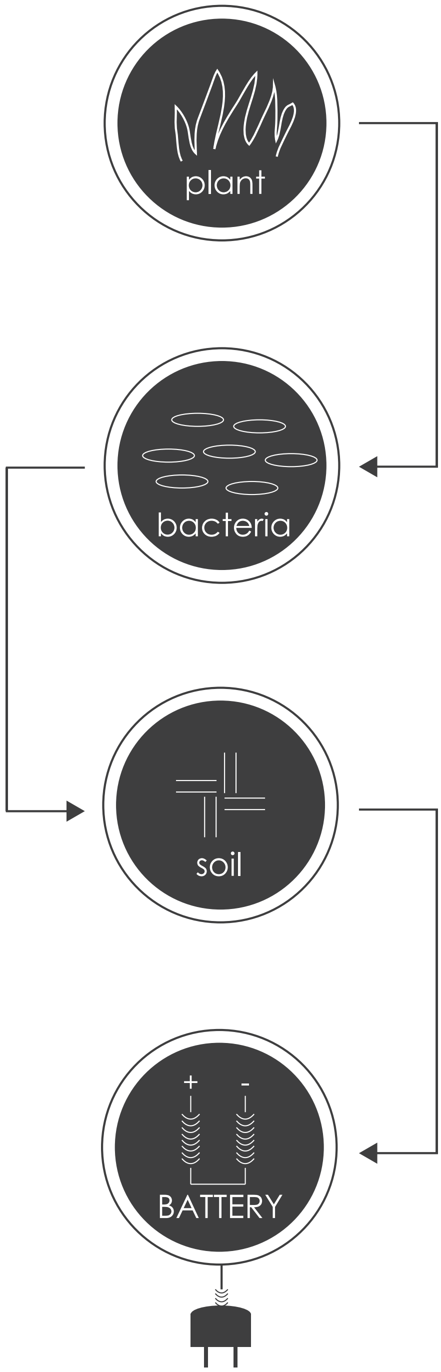
BIO-PHOTOVOLTAIC CELL//

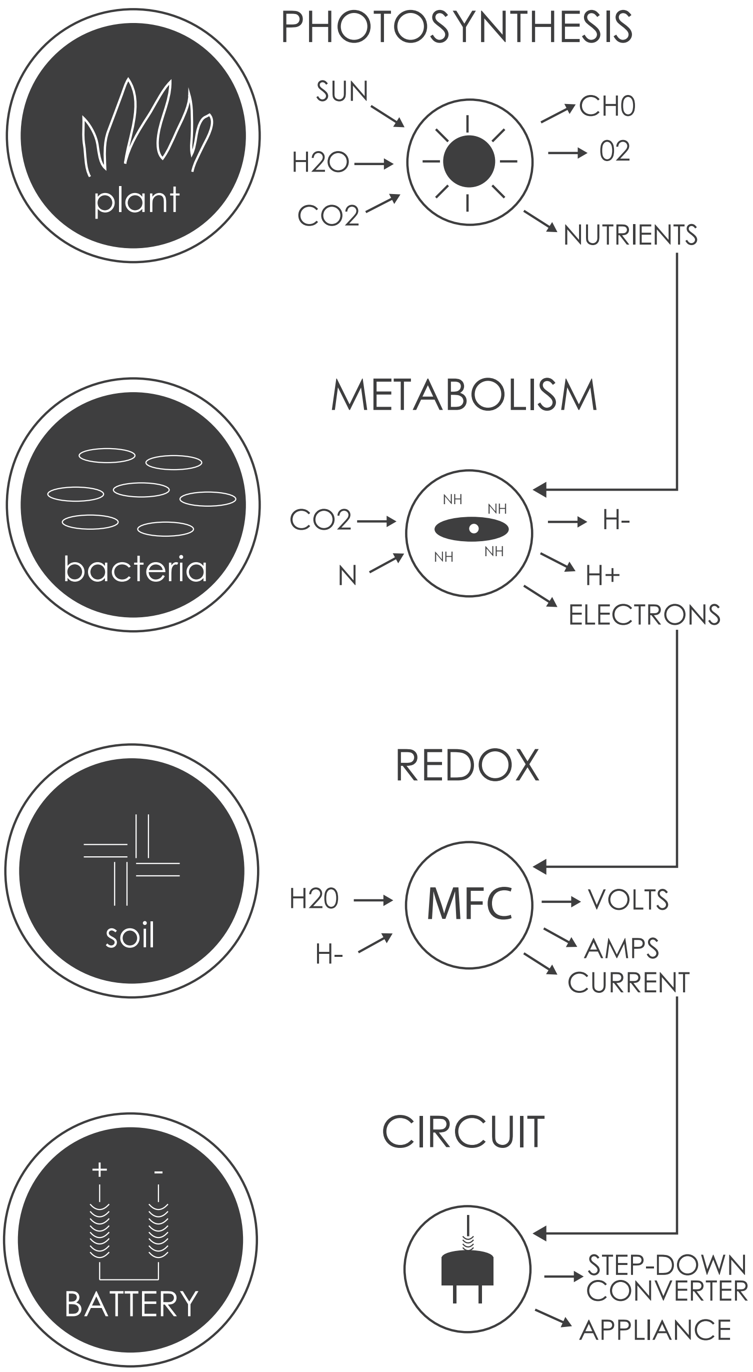
harvesting energy from plants

Energy Machines Studio
IAAC2013
Apostolos Mouzakopoulos
Ashwini Mani
Akanksha Kargwal
Pablo Marcet

Bio-Photovoltaic Cell// **How it works**

Bio-Photovoltaic Cell// How it works.
A Bio-Photovoltaic Cell is a battery in which energy is harvested from bafteria inside the soil that releases electrons. This bacteria are fed by the by-products of the photosynthesis of plants. By introducing an anode and cathode (battery) into the soil, the free electrons may be extracted and put into a circuit.



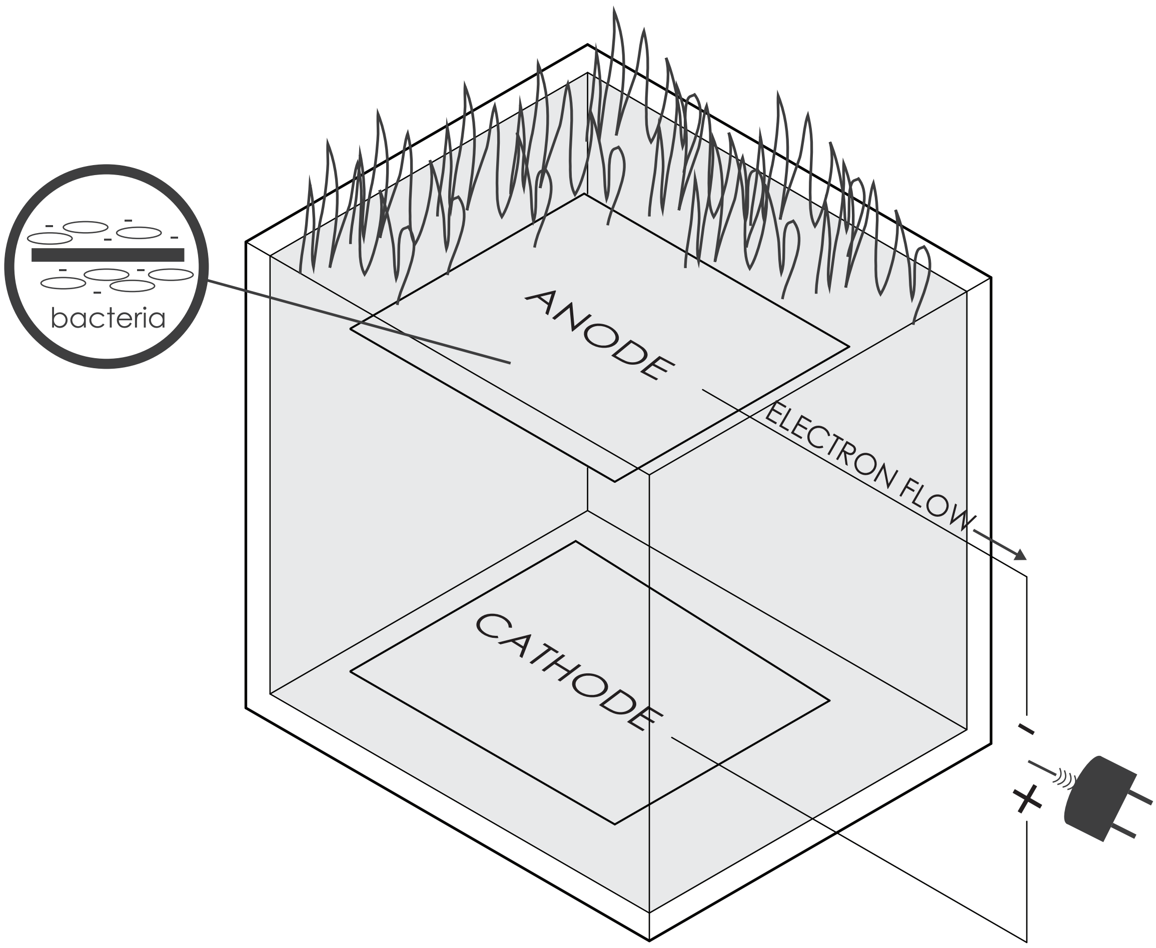


Bio-Photovoltaic Cell/ Processes.

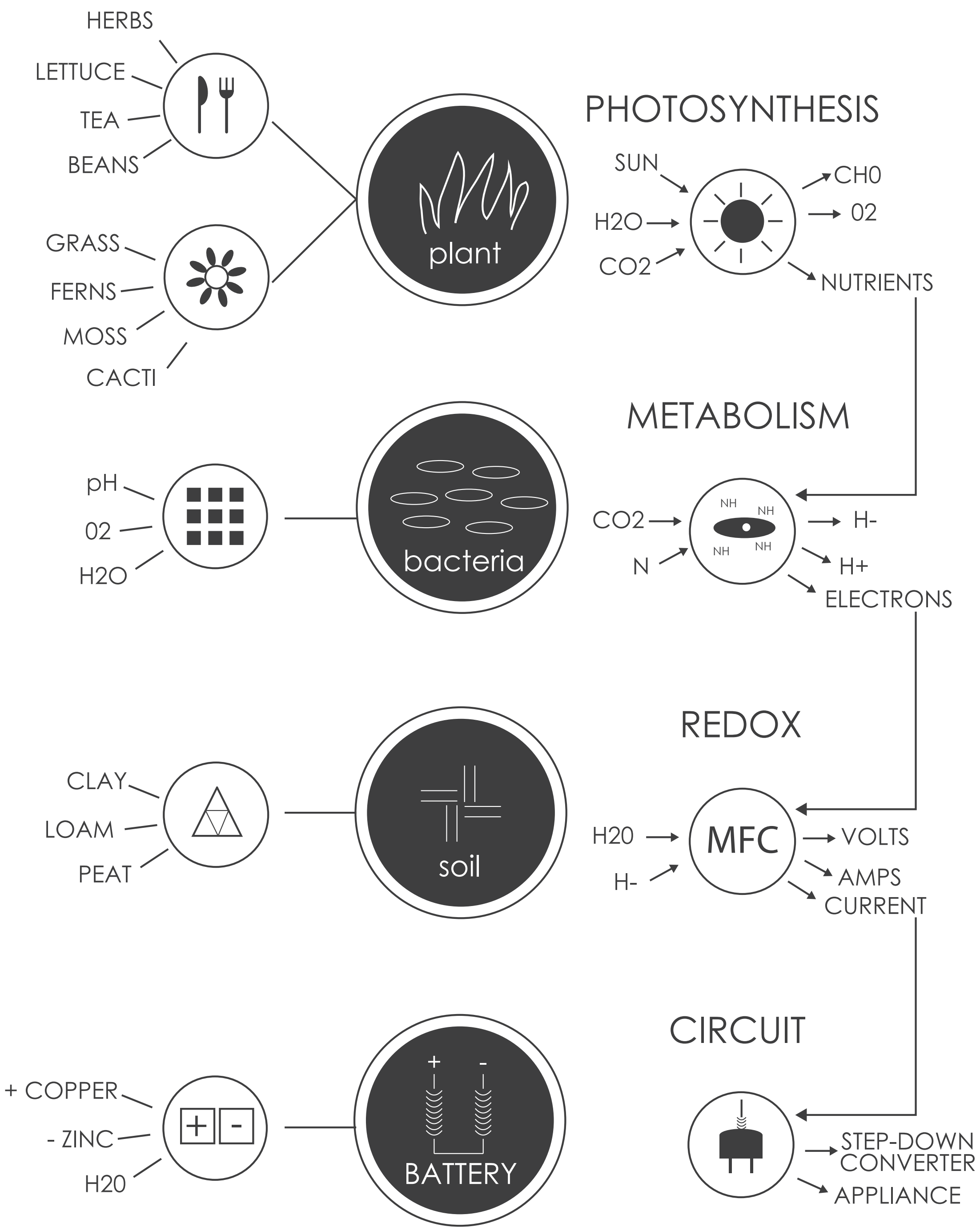
Several processes take place to be able to produce the energy. First, the plants feed themselves by photosynthesis out of which by-products, nutrients, are released to the soil. Bacteria living in the soil take this nutrients and metabolize it releasing hidrogen protons and electrons into the soil medium. If a microbial fuel cell, anode and cathode are introduced to the soil and a redox process occurs, transfering the free electons in the soil from anode to cathode. By connecting a circuit with a capacitor or step-down converter into the fuel cell it uses the electron flow to power appliances or any other electrical device.

Bio-Photovoltaic Cell// Parameters

Each of the components that compose the BPV have certain parameters that may be changed to control the processes and efficiency of the output. The type of plant that grows, be it edible or decorative, the soil characterístics that enable microbial growth, the type of soil that controls the electron transfer, and the battery's materials and composition that controls the efficiency with which the electrons are gathered and transfered.



Bio-Photovoltaic Cel Illustration


HERBS
LETTUCE
TEA
BEANS
GRASS
FERNS
MOSS
CACTI
plant
PHOTOSYNTHESIS
SUN
H2O
CO2
CH0
02
NUTRIENTS
pH
02
H2O
bacteria
METABOLISM
NH
NH
NH
NH
CO2
N
H-
H+
ELECTRONS
CLAY
LOAM
PEAT
soil
REDOX
H20
H-
MFC
VOLTS
AMPS
CURRENT
+ COPPER
- ZINC
H20
+
-
BATTERY
CIRCUIT
STEP-DOWN
CONVERTER
APPLIANCE

Prototype 1

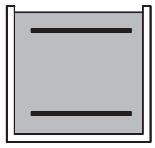
Experimenting on the parameters of the bio-photovoltaic cell is essential to optimize it's size and performance. A series of experiments have been conducted by changinig one of a series of parameters and observing it's effect on it's performance (volts).
The parameters and independent variables are the following:
- Saturation (0%, 50%, 100%)
- Anode distance (25, 50, 75, and 100 mm)
- Soil volume (125, 250, 500, 750 cm3)
- Container shape (cube, hexagon, triangle)
- Anode type (sheet, coil, mesh)

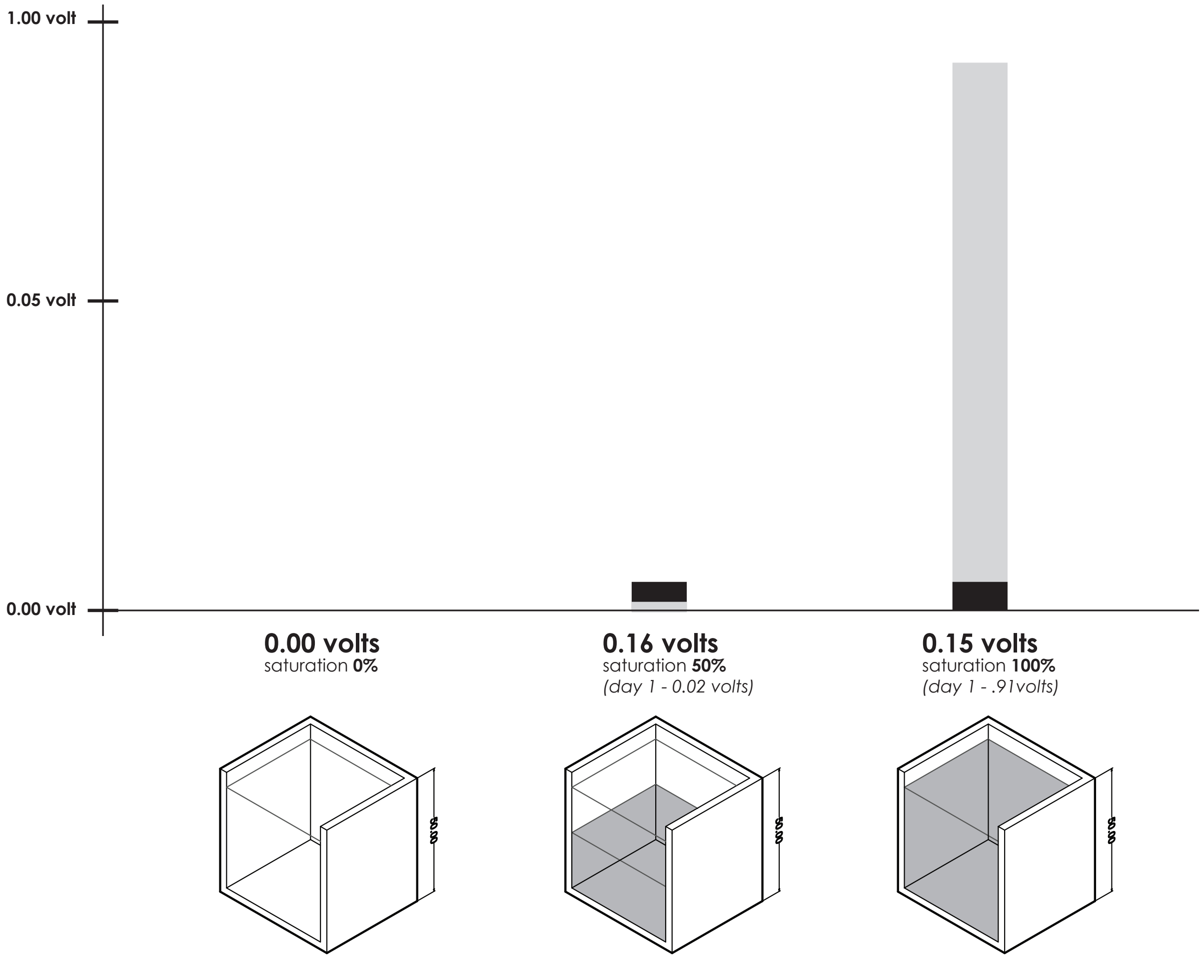
All tests where conducted with 100% saturation, sheet cathode (copper anode and zinc cathode), and commercial soil, except for those which tested upon the related parameters.
The containers were laser cut on 3mm plywood and put toguether with fast drying glue. Insulated copper wire was used for all circuit components and meassured with a multimeter with a 2 volt range.
The moss was not added to the experimentation considering that what is being meassured is the bacterial electron discharge and not their lifespan.

Saturation Experiment:
Three experiments where done with, 0%, 50%, and 100% saturation. The soil was dried out in the sun and water was added accordingly with the experiment being done. The results where as follows:

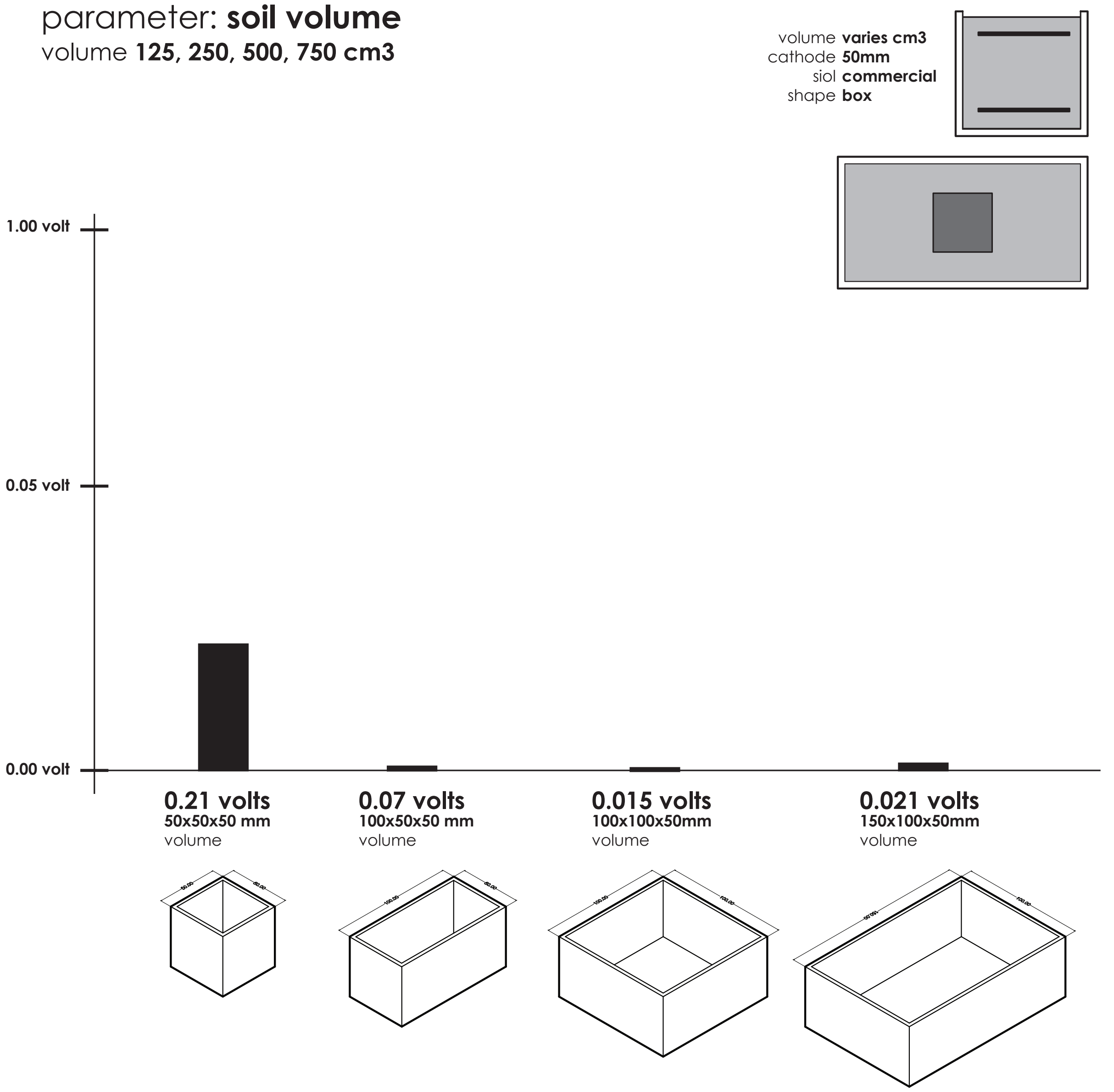
parameter: **saturation**
saturation **0%, 50%, 100%**

volume **125cm3**
cathode **50mm**
siol **commercial**
shape **cube**

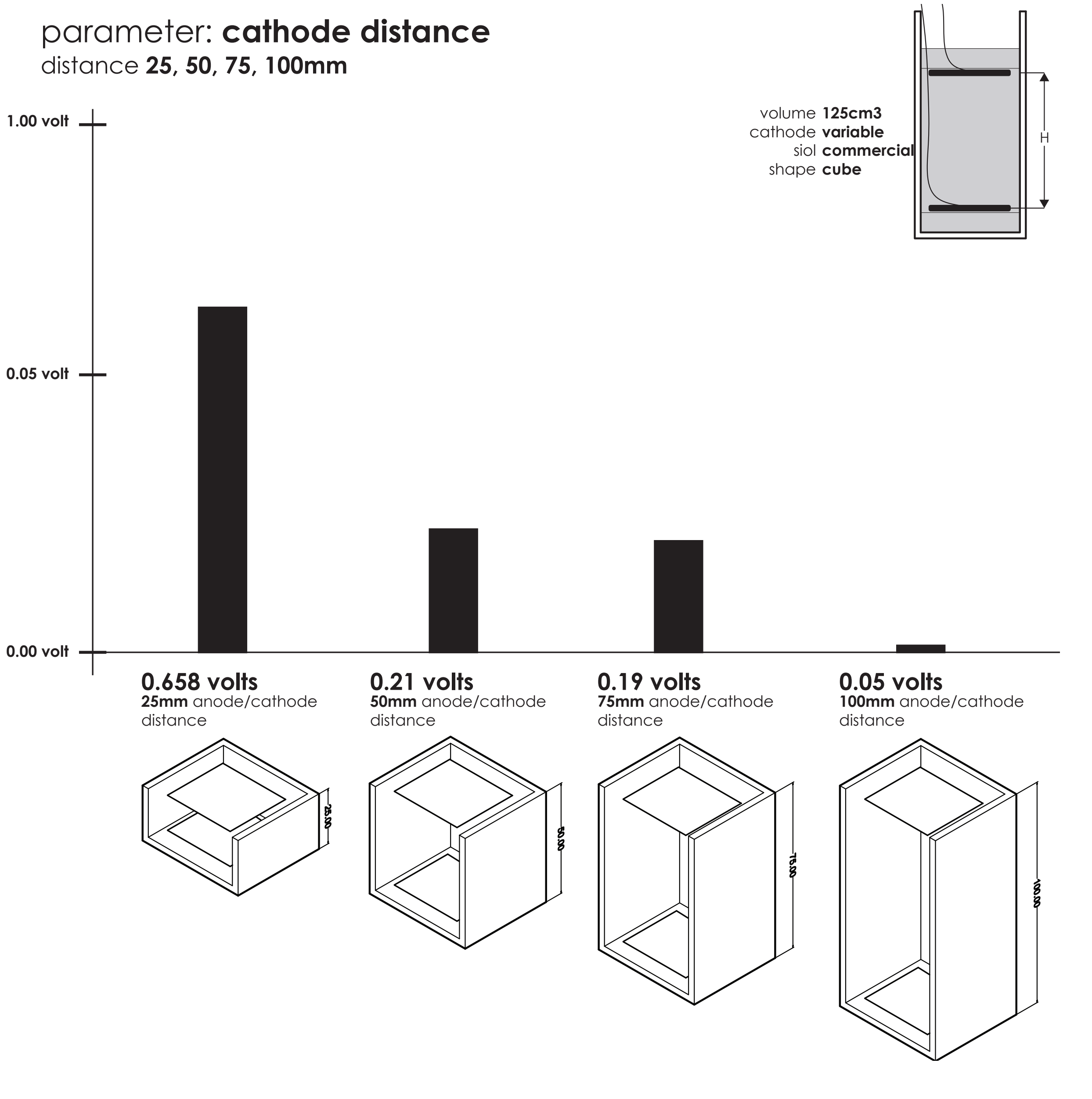




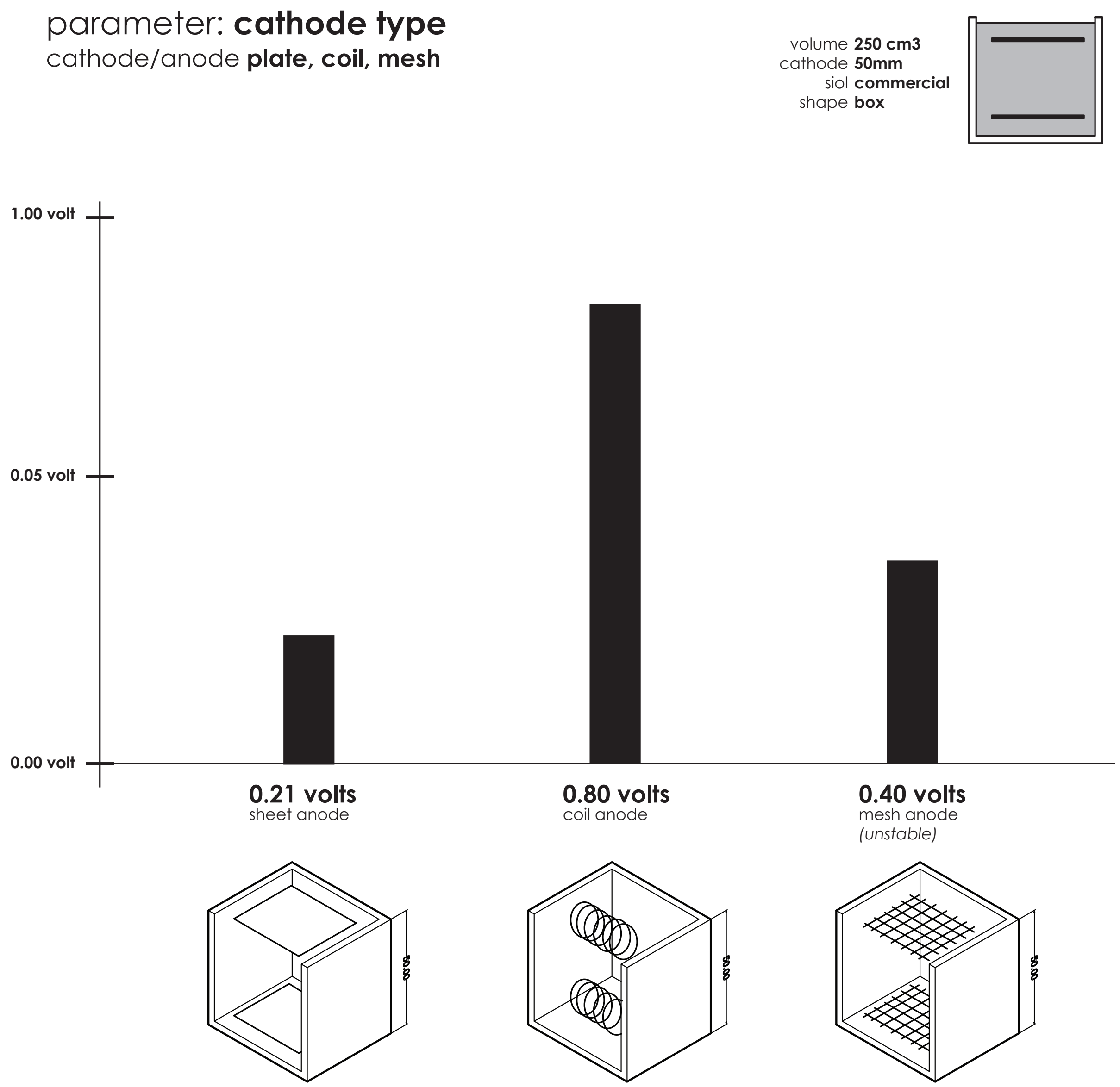
Soil Volume Experiment:
To analyse the volume of soil in relation to the cathode area, four different volumes where tested, 125, 250, 500, and 750 cubic centimeters. The anode, soil, and saturation where kept constant. The results are as follows:



Cathode Distance Experiment:
To analyse the difference in voltage considering the distance between cathode and anode four experiments where done. With the same cathode and anode components, they where separated 25mm, 50mm, 75mm, and a 100mm. The results where as follows:



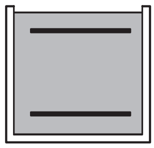
Cathode type experiment:
Since the bacteria gather around the anode and cathode, this experiments try out the relation between the cathode surface and the way it is in contact with the soil. A plate, a coil, and a mesh were tried and their effects recorded. The results are as follows:

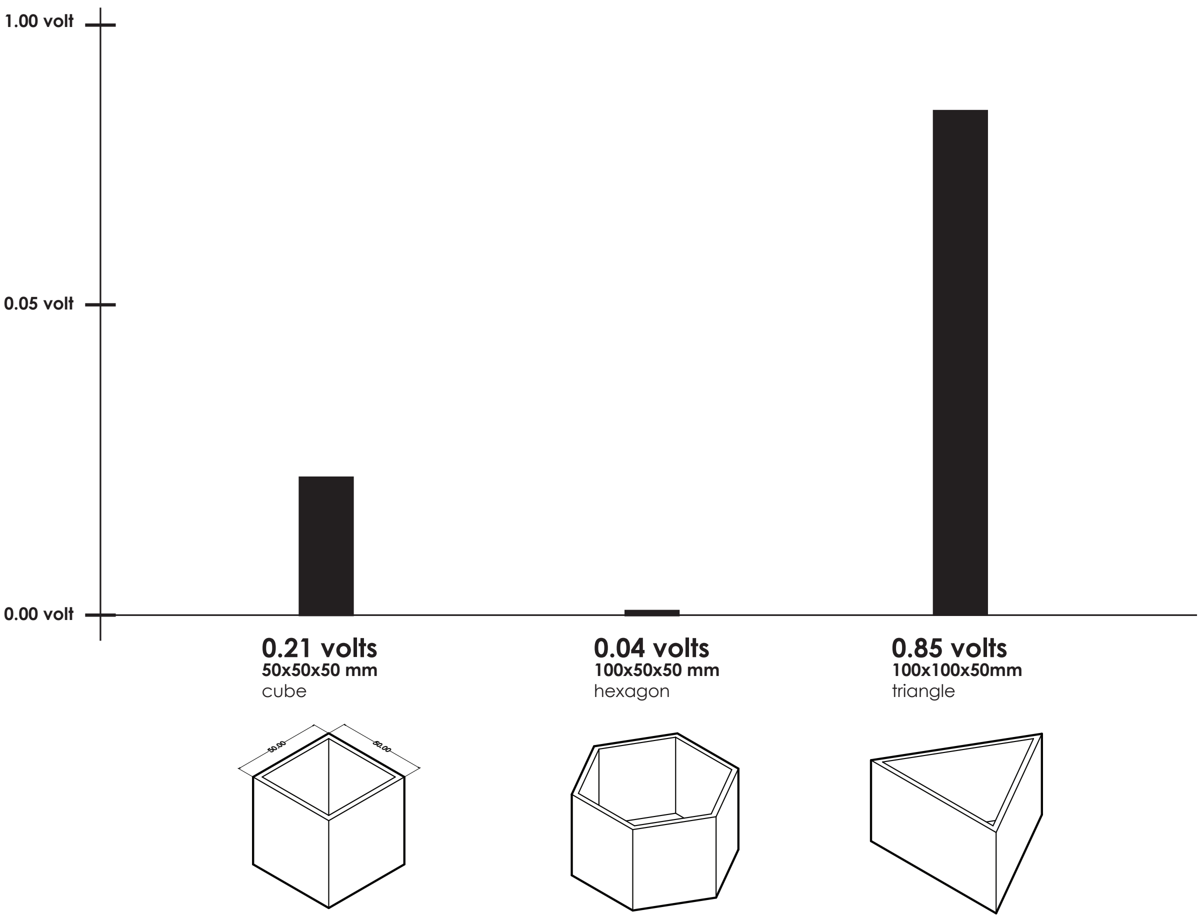


Container Shape Experiment:
To see the influence of the shape of the container on the battery's performance three shapes where tried out. A cube, an hexagon, and a triangle, all containing 250cm3 of soil and plate cathodes in commercial saturated soil. The results where the following:

parameter: **container shape**
volume **cube, hexagon, triangle**

volume **250 cm3**
cathode **50mm**
siol **commercial**
shape **varies**

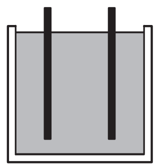


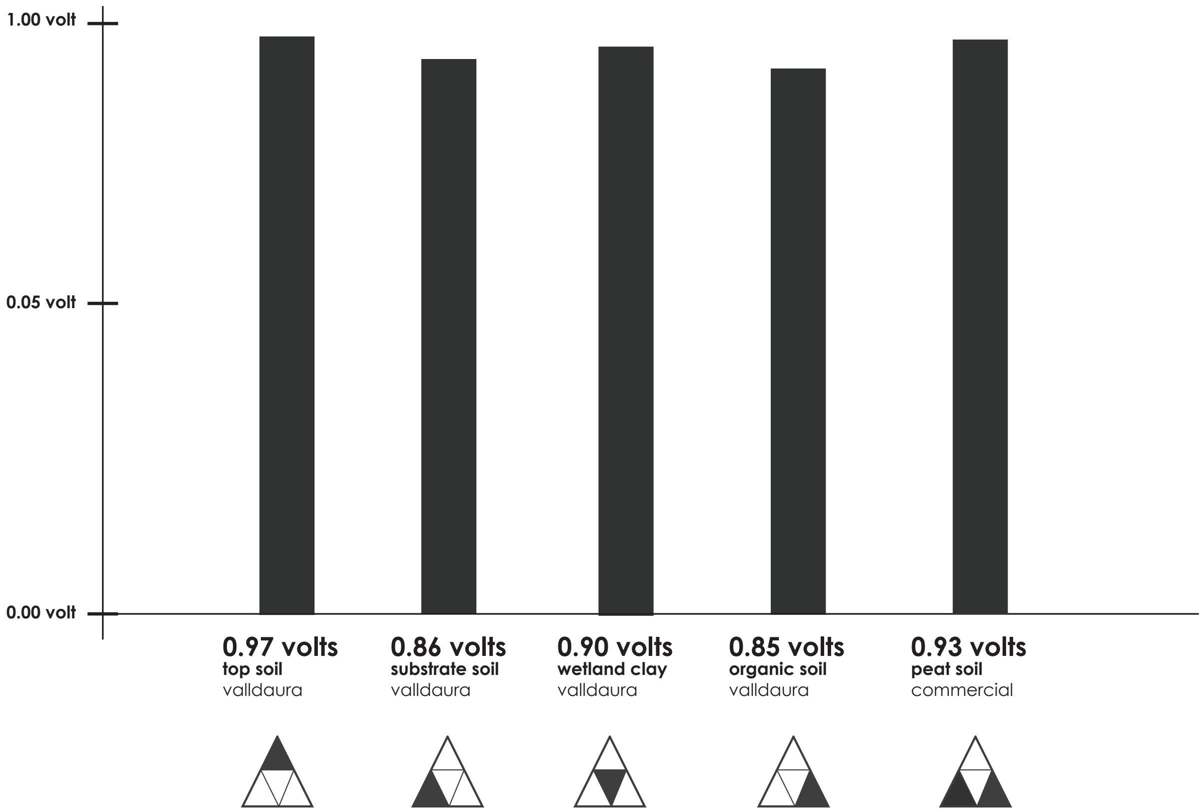


Soil type experiment:
To see which soil type contained more bacteria, hence more energy, five soil types where tested. Four or them are soils found in the Valldaura forests, top soil, substrate soil, wetland soil, and dark organic soil. The fifth is commercial soil which is a mix of peat and organic soil. The results are as follows:

parameter: **soil type**
volume **top, clay, organic, substrate, peat**

volume **cm3**
cathode **20mm**
siol **varies**
shape **box**

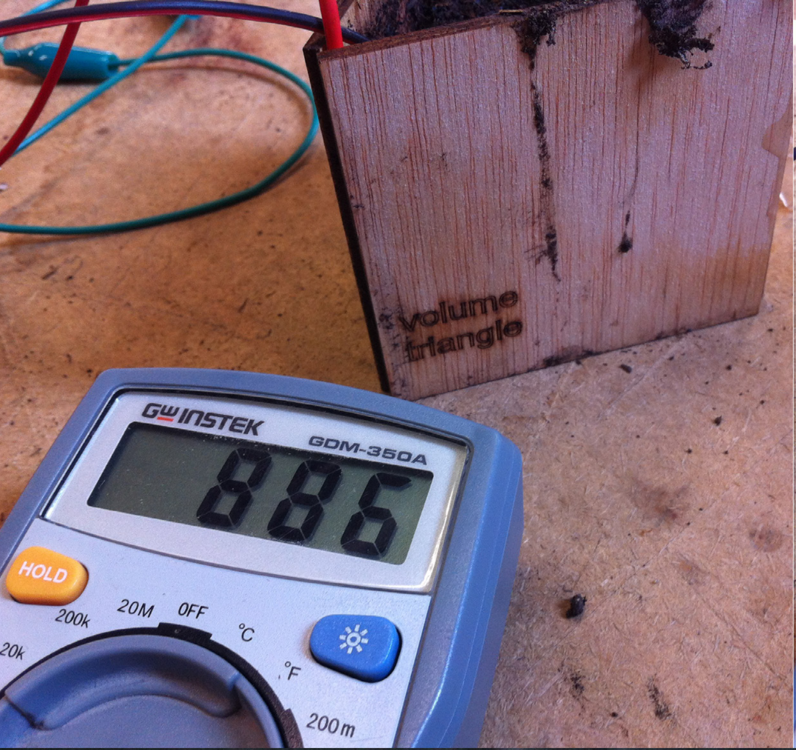




Conclusions

Based on the results of the experiment, the following relationships where found:
1. 100% saturated soil produces the best results since the water in the medium promotes electrolisis within the soil.
2. The closer the anode and cathode are placed the more efficient the electron transfer is.
3. The relationsip between the soil volume and the cathode's area does not grow as volume grows.
4. A triangle container is more efficient.
5. The coil cathode maximizes the surface for the bacteria to gather around, hence it is the most efficient electron collector.
6. All soil types yeild similar results, hence have similar bacteria count.

Out of all the experiments undertaken voltage and amperage were meassured, and even though voltage was always present, no amperes were observed. All containers were connected in series to increase the voltage and still there was no amperage. To get amperage, the batteries must be connected to a capacitor or step down converter.


volume
triangle
GW INSTEK
GDM-350A
886
HOLD
200k
20M
OFF
°C
°F
200m


height
2.5cm
GW INSTEK
GDM-350A
658
HOLD
20M
OFF

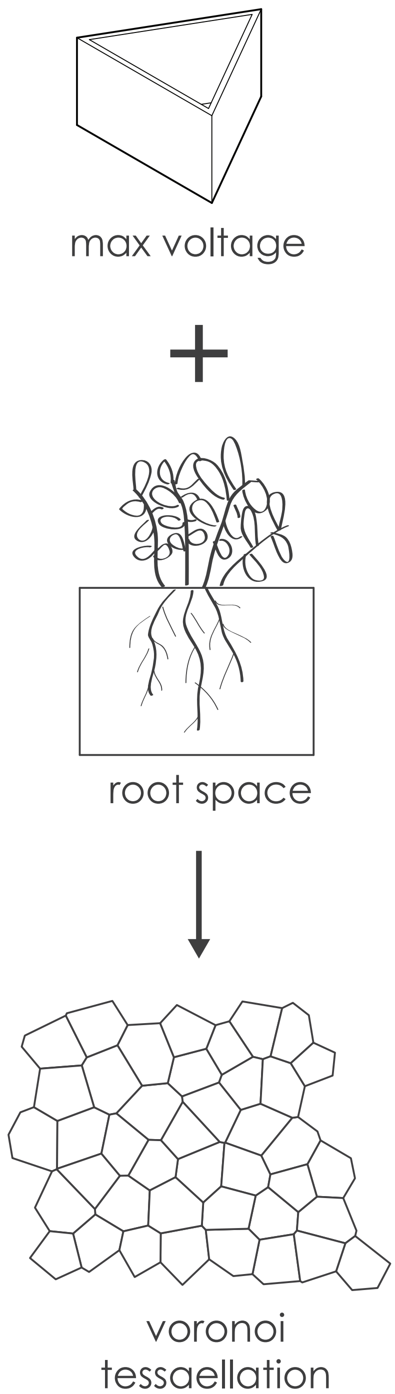

volume
hexagon

Prototype 2

After gathering the conclusions of the first prototype they were applied to a new design which aimed to create a panel that contained 100 batteries. The parameters taken were the shape of the container (triangle), the soil type (commercial), anode and cathode type (zinc and copper), cathode distance (25mm), 100% saturation, and a volume of 50x50x50mm.

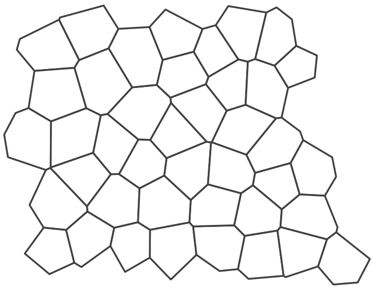
The parameters were applied as follows:
- The container shape was modified to ensure enough space for the plant's roots.
- A permanent water bed through managing water levels between cells.
- Vertical coil cathodes placed 25mm appart.
- Zinc anode and copper cathode.
- Commercial soil.
- Cell area 50x50mm, height 50mm.

The fabrication procedure consisted of laser cutting the walls and base and then glueing them to place. A coat of impermeabilazer. Sheet zinc and copper twisted to a coil connected in series. Commercial peat soil and moss.

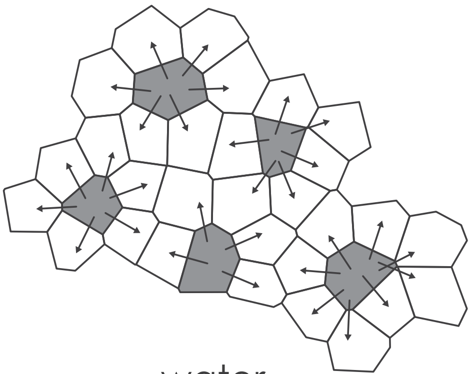


Tessellation//
Maximum voltage had to be conserved and at the same time enough space for the plant's roots to have enough space to grow.
To achieve both results, a voronoi tessellation was applied. This allowed for the cells that would contain the batteries to keep the triangular proportion while giving the plant more soil volume to spread it's roots.

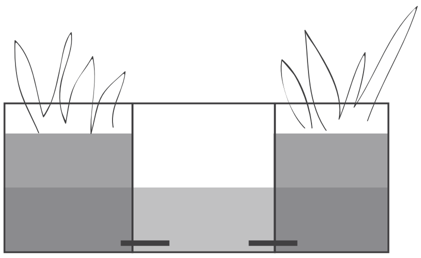
Irrigation System//
By tessellating with voronoi, it was possible to reach more plant cells (batteries) with only once cell of water. To ensure that all cells were kept at a 100% saturation a water base was created by connecting the plant cells with the water cells via a tube. This would keep the water bed height constant throughout all the cells.



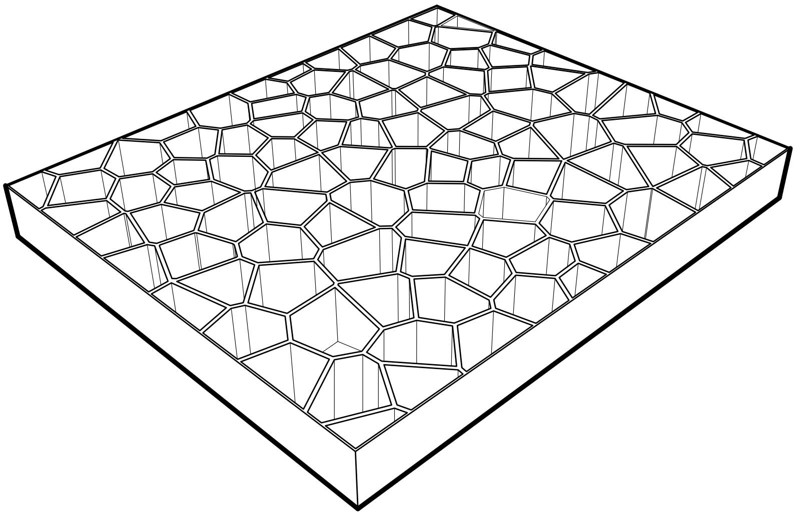
voronoi
tessaellation



water
distribution



section



Prototype//Fabrication

A 500mm by 600mm box with a height of 60mm was laser cut and glued together to create a panel that could be used in any horizontal surface.

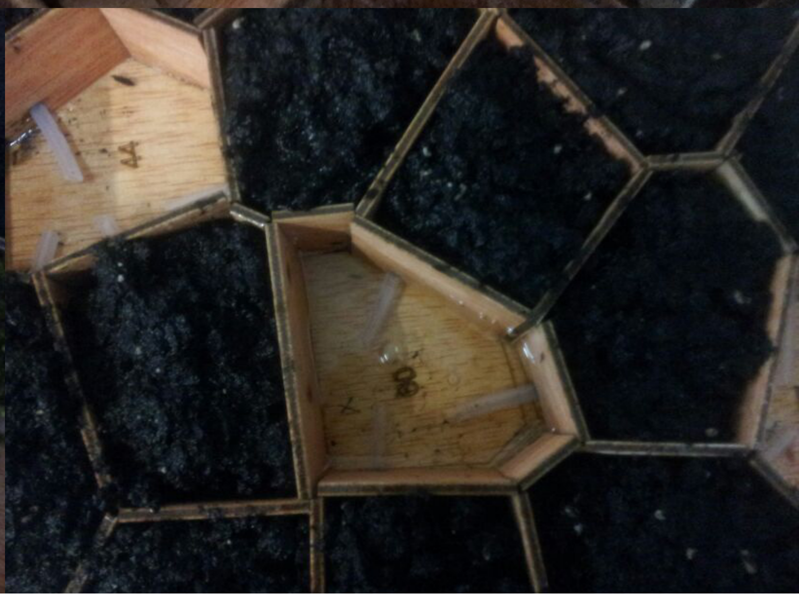
A coat of impermeable resin was applied to prevent the wood from bending.

Zinc anode and copper cathode was twisted to a coil and connected to wires.

Holes were drilled for the anode and cathode wires which were connected in series.

holes were also drilled in the vertical walls to connect the plant cells to the water cells and create the water bed.

Finally soil, water, and moss were placed.

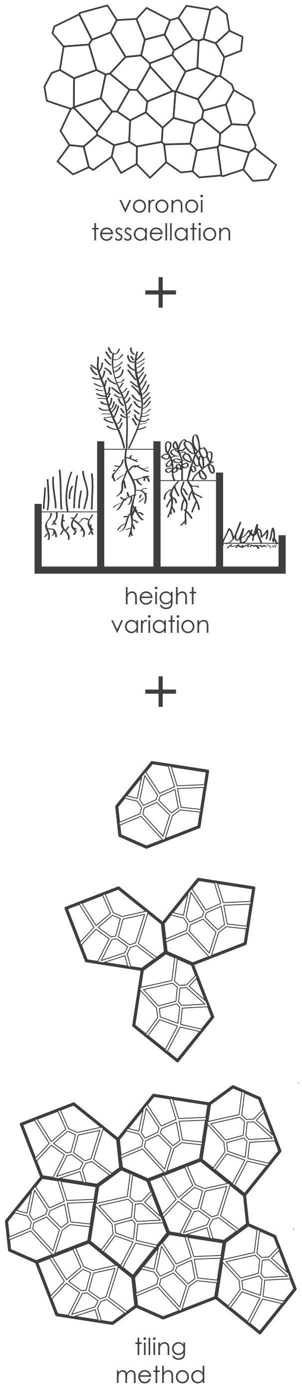


Prototype 3

Having tested "prototype 2" several thing were deleted from it and others added for "prototype 3". For the new prototype the a tiling system that would allow several prototypes to piece together along with height variations to allow for different plants to grow on the same tile. Vertical positioning aswell as horizontal positioning was going to be explored so mesh was added to contain the soil inside the cells. From the second prototype the irrigation system based on a constant water level was removed since it was not useful for vertical placement. The anode and cathode were changed to sheets of 25x25mm since twisting the sheet was inacurate.

Since tiling is possible only with one or two shapes, doing a tiling system of individual voronoi cells was unfeaseble. So a tile was designed to blur into the voronoi pattern. The height is varied as a surface that ondulates from 100mm to 25mm in height.

To fabricate it, the model was cut in layers which were then laser cut and glued together . On the base, a hole was cut in the bottom to place the cathode so it would have contact with the air and get water from the oxidation of hidrogen ions.



Prototype//

Taking the voronoi cells from the previous prototype and adding different cell height to accomodate different types of plants.

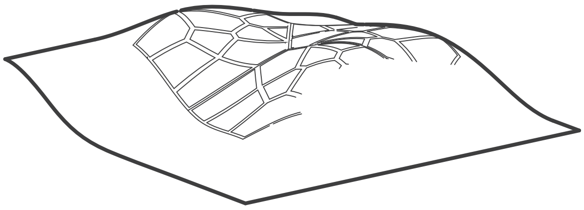
At the same time developing a tile that can be replicated and joined to blend into the voronoi pattern of the cells.

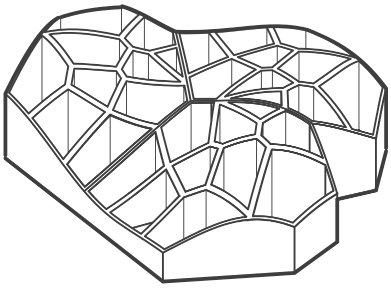
Height Variation//

To get the different heights for different plants within a group of tiles a surface is draped around the three tiles and trimmed to imprint it in the tiles.

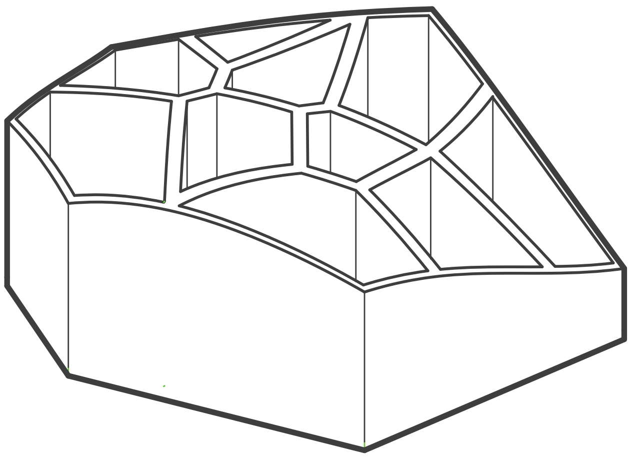
This makes each of the tiles unique and able to grow different combinations of plants.

The single cell example illustrates how the wall vary height within the tile itself.

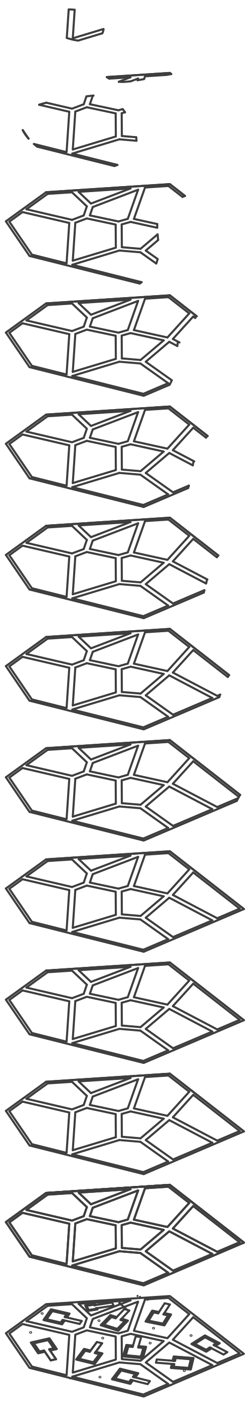


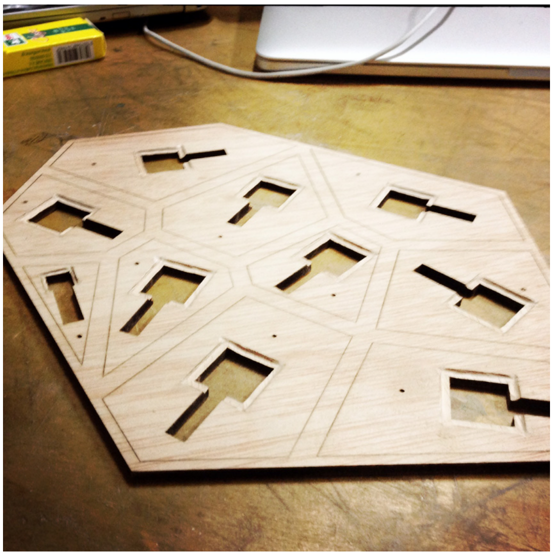


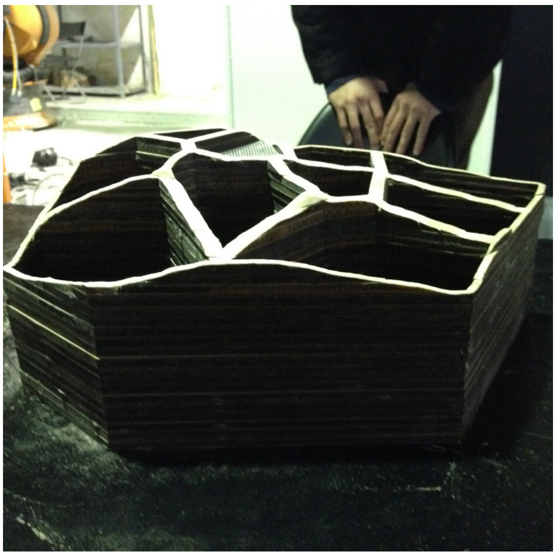
cell height
variation



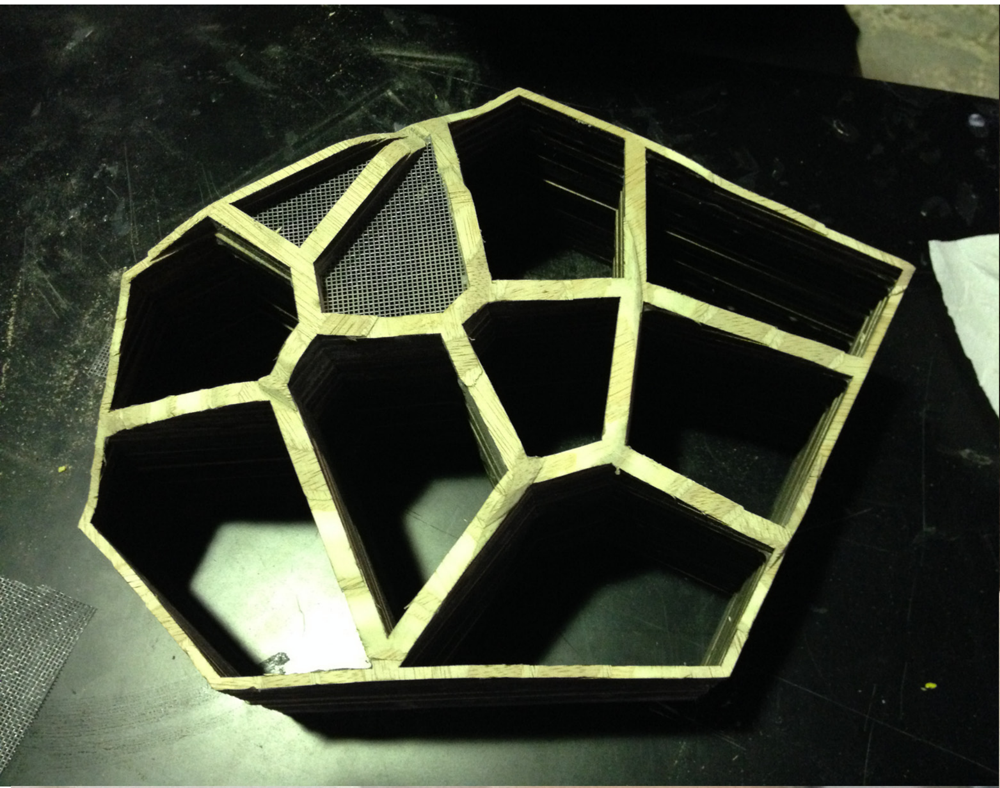
single tile
example

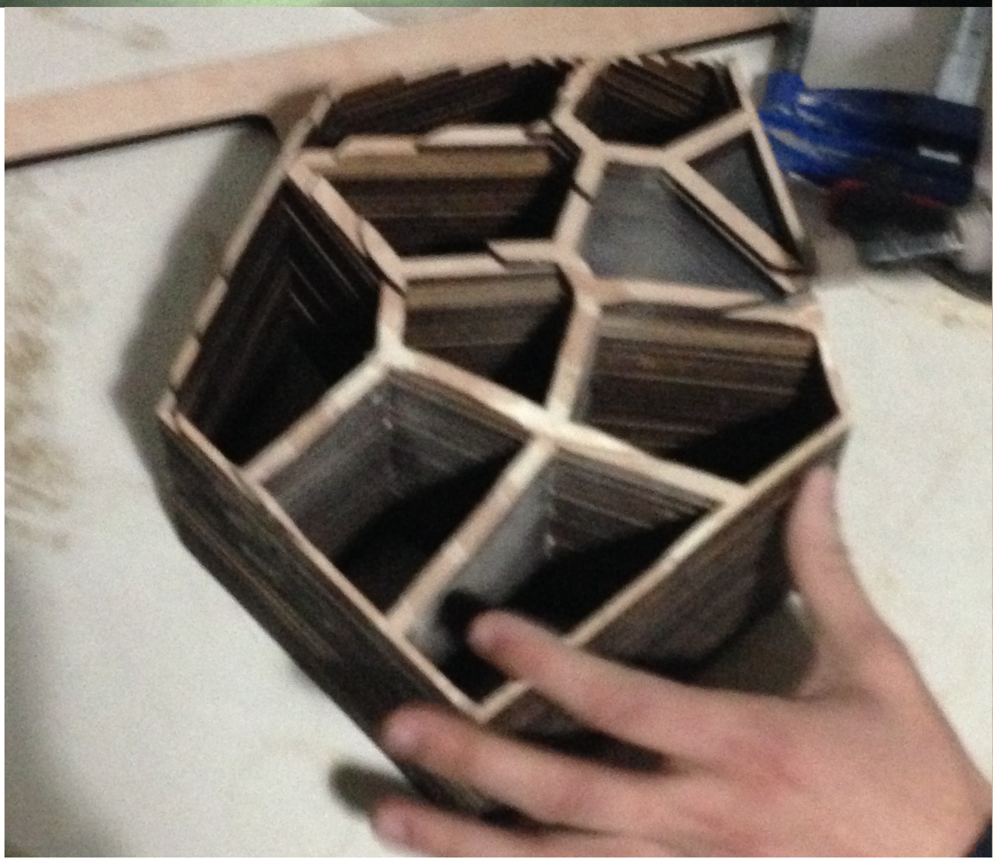






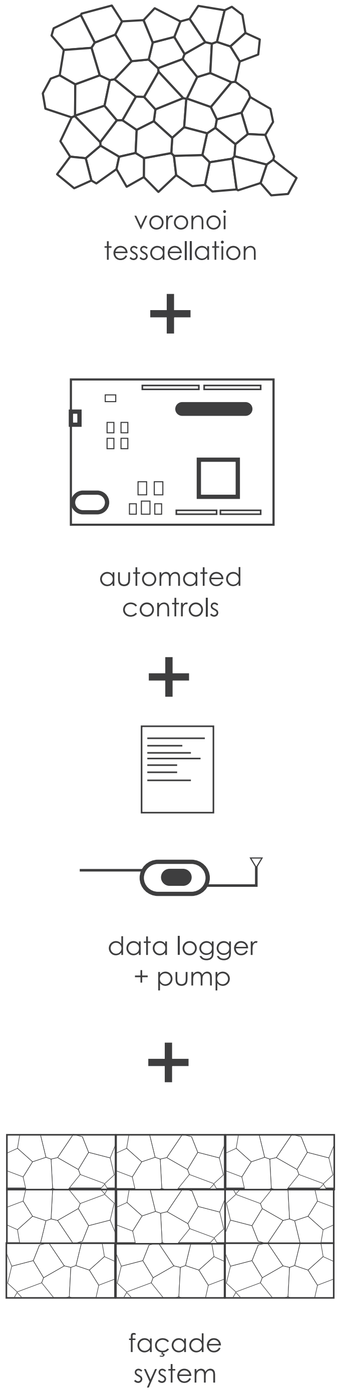
Fabrication//
The fabrication process consisted of the layering of laser cut 5mm plywood sheets glued together to make the body of the tile.
In between the layers, were each single cell ends, a mesh is added to keep the soil in place when placed vertically.
The first of the layers has holes for the wiring as well as for the placement of the copper cathode sheet.
Afterwards a coating of impermeable resin is added inside the cells to protect the wood from bending.
Finally the saturated soil and moss is placed.





Prototype 4

Having tested the different components and systems in previous prototypes, “prototype 4” incorporates the best of them. Adding to this, the prototype also incorporates a automation system that controls the irrigations system and a data logger to monitor the variables that affect the plant’s growth.
From “prototype 3” the idea of tiling was kept, but in this case it tiled in 2x1m panels that are to be mounted on a curtain wall system to create a vertical garden. The height variation to accomodate different plants was removed since they require different conditions to thrive and the irrigation system works only for one condition for each panel.
A customized design system was also developed. In this system the user can create his/her own panel design and send it to be fabricated to the Fablab.
The fabrication procedure consists of milling the panel in polysteryne and applying coats of ruber and epoxy resin to stiffen and waterproof it. Afterwards the wiring and electronics are assembled and the soil and moss placed. Finally, the finishing is laser cut and glued to the exposed surfaces.



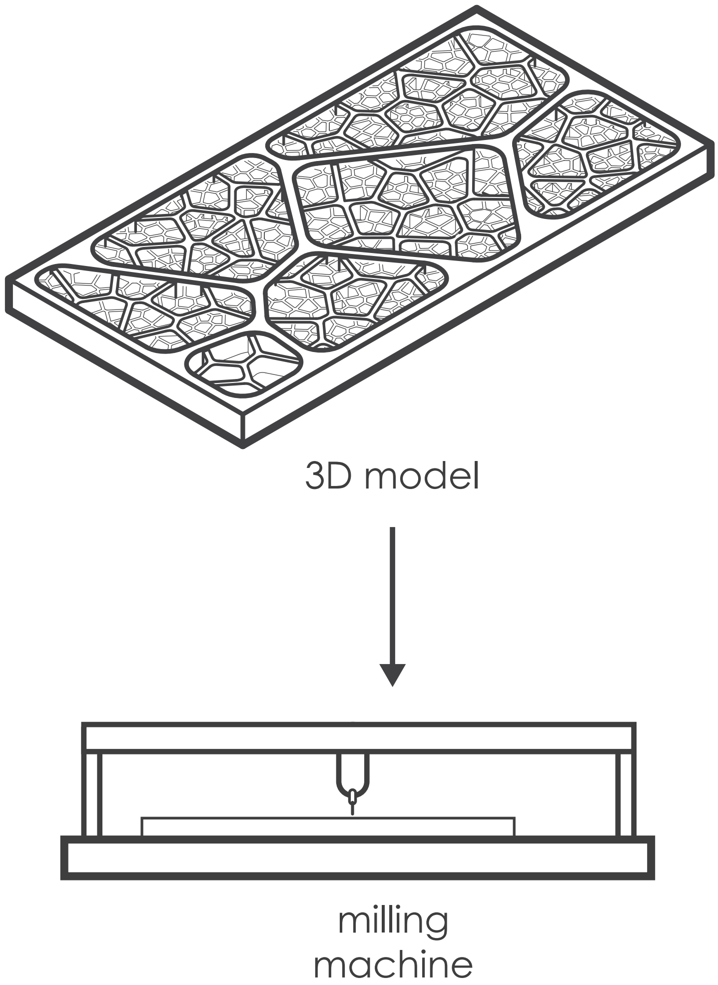
Prototype 4//

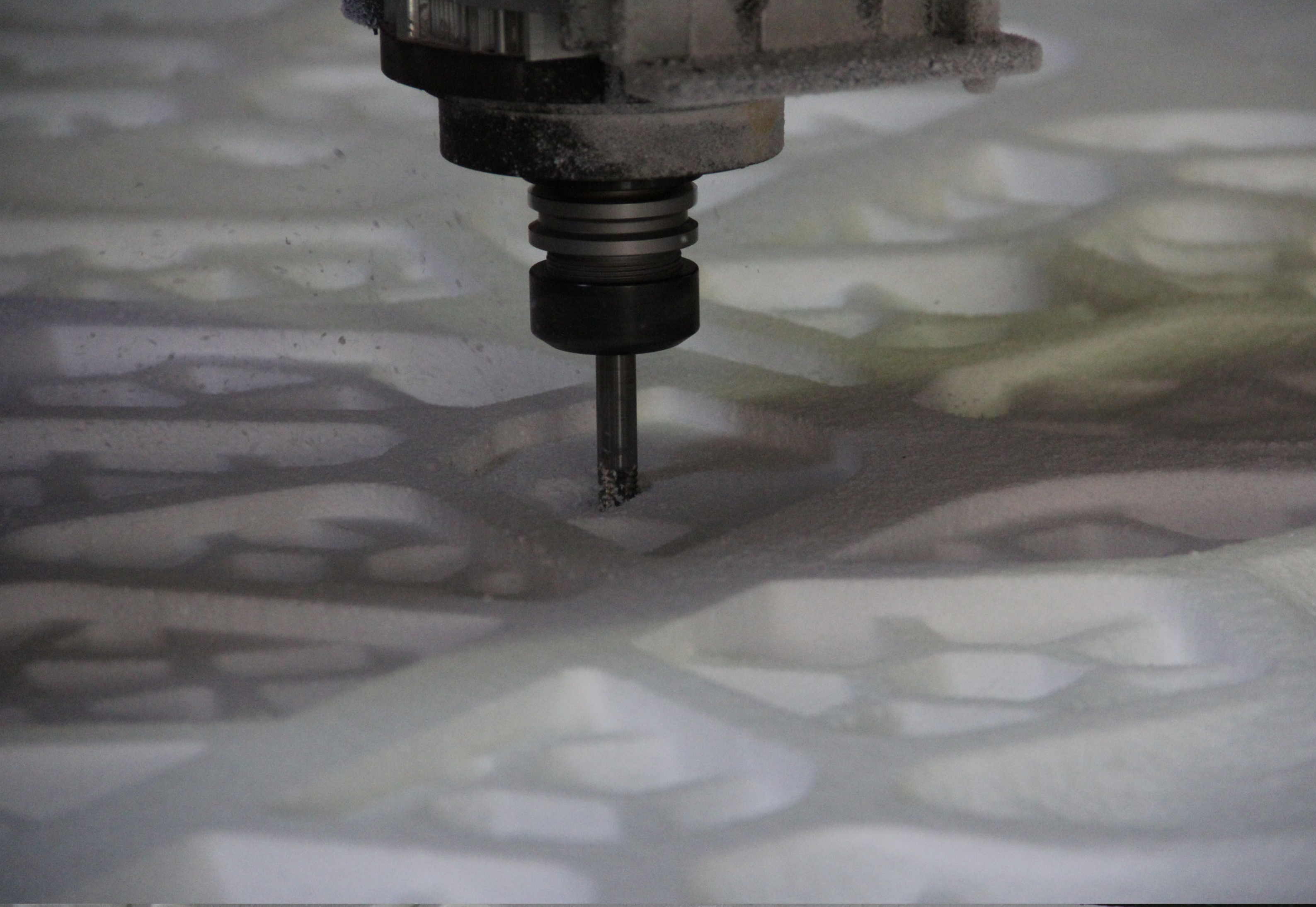
The prototype incorporates the voronoi pattern in three different levels mimetizing a leaf. Each of the levels vary in size, the first, bigger, gives rigidity to the piece, the second subdivides the different battery clusters, and the third, smallest, contains the battery cells.

An Arduino is powered by the batteries and controls the sensors for the data and water pump of the irrigation system.

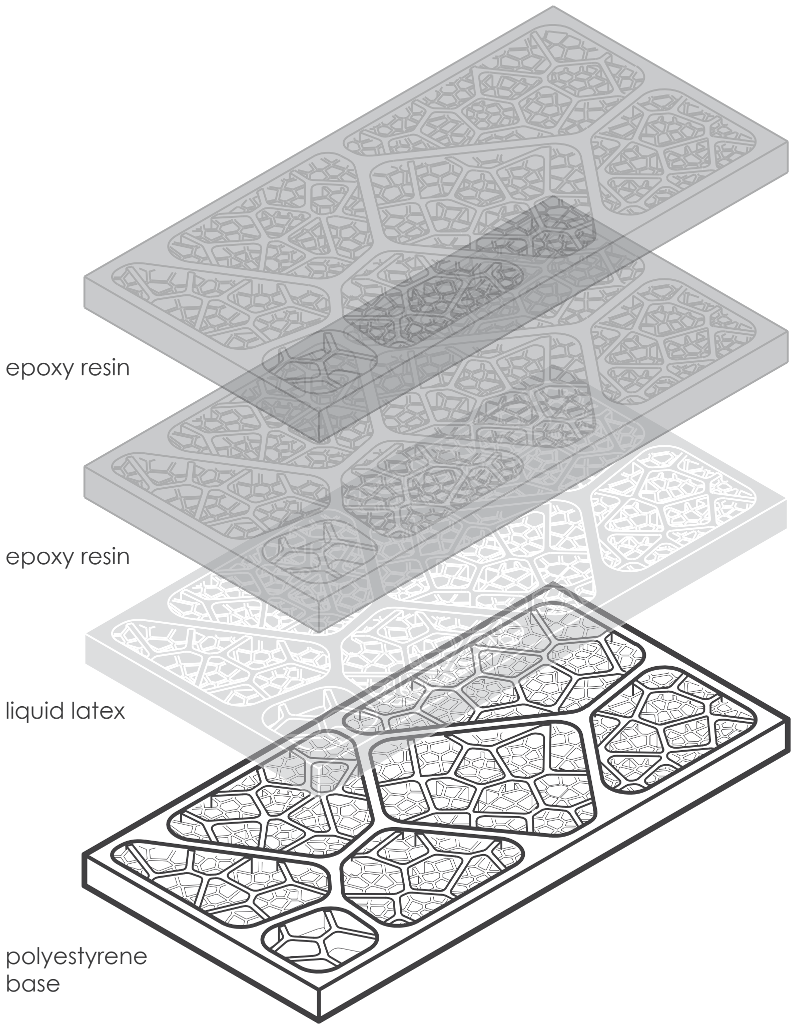
Each panel is 2x1m and 10cm thick made of polystyrene coated in epoxy resin. A wood finishing is applied to give coherence and rigidity to the whole.

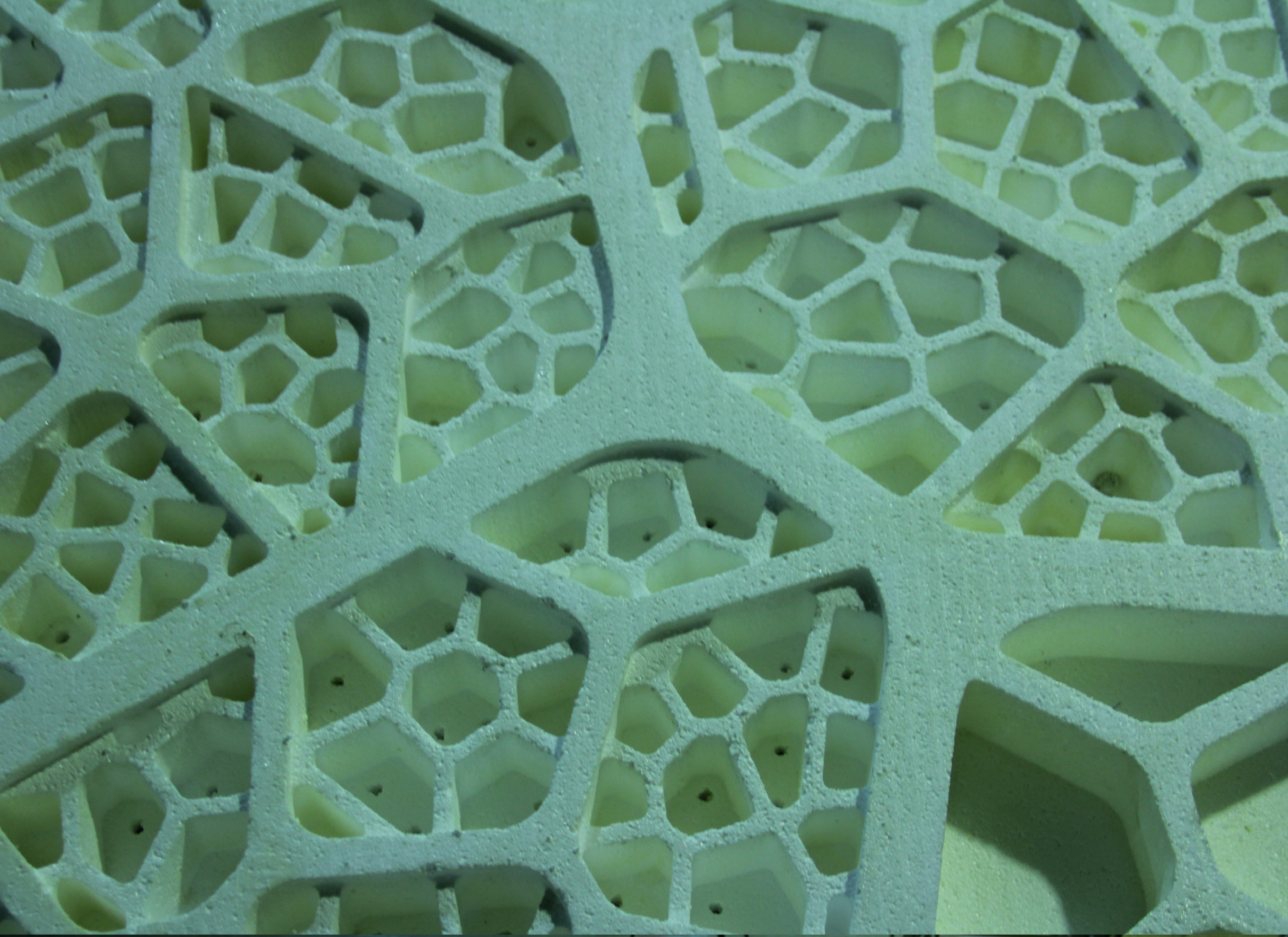
Fabrication Process//
The fabrication process starsts with the design of the panel and 3d model. This 3d model is sent to the milling machine which mills it into a polysteryne panel of 2x1m and 10cm thick. The process takes 9 hours. When the polysteryne is milled, it can move along to be coated.



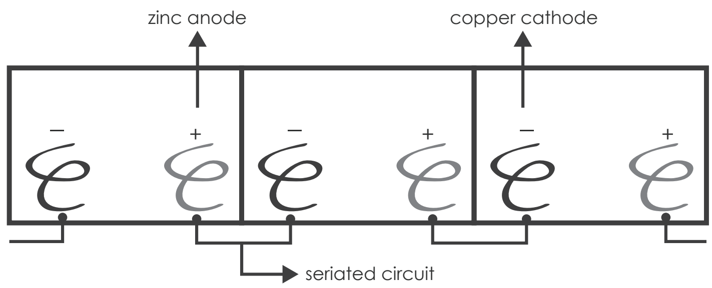



Fabrication Process//
The polysteryne is coated in latex first to close the pores so that less epoxy resin is needed. It takes 3 hours to dry.
After is dried the first layer of epoxy resin can be applied. After 2 hours, the second layer is applied and left to dry. It takes 15 hours to dry and once dried it gives the polysteryne walls enough rigidity to hold the soil.

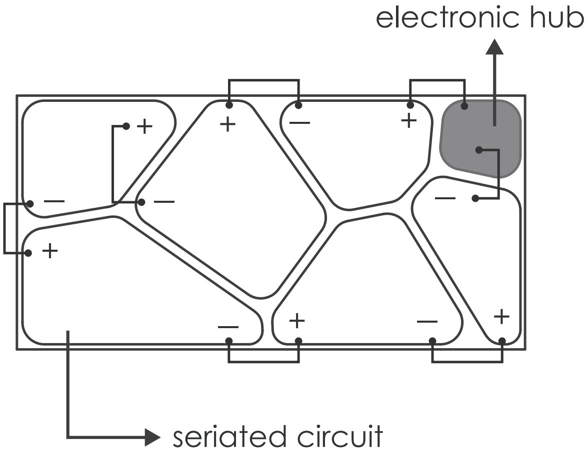




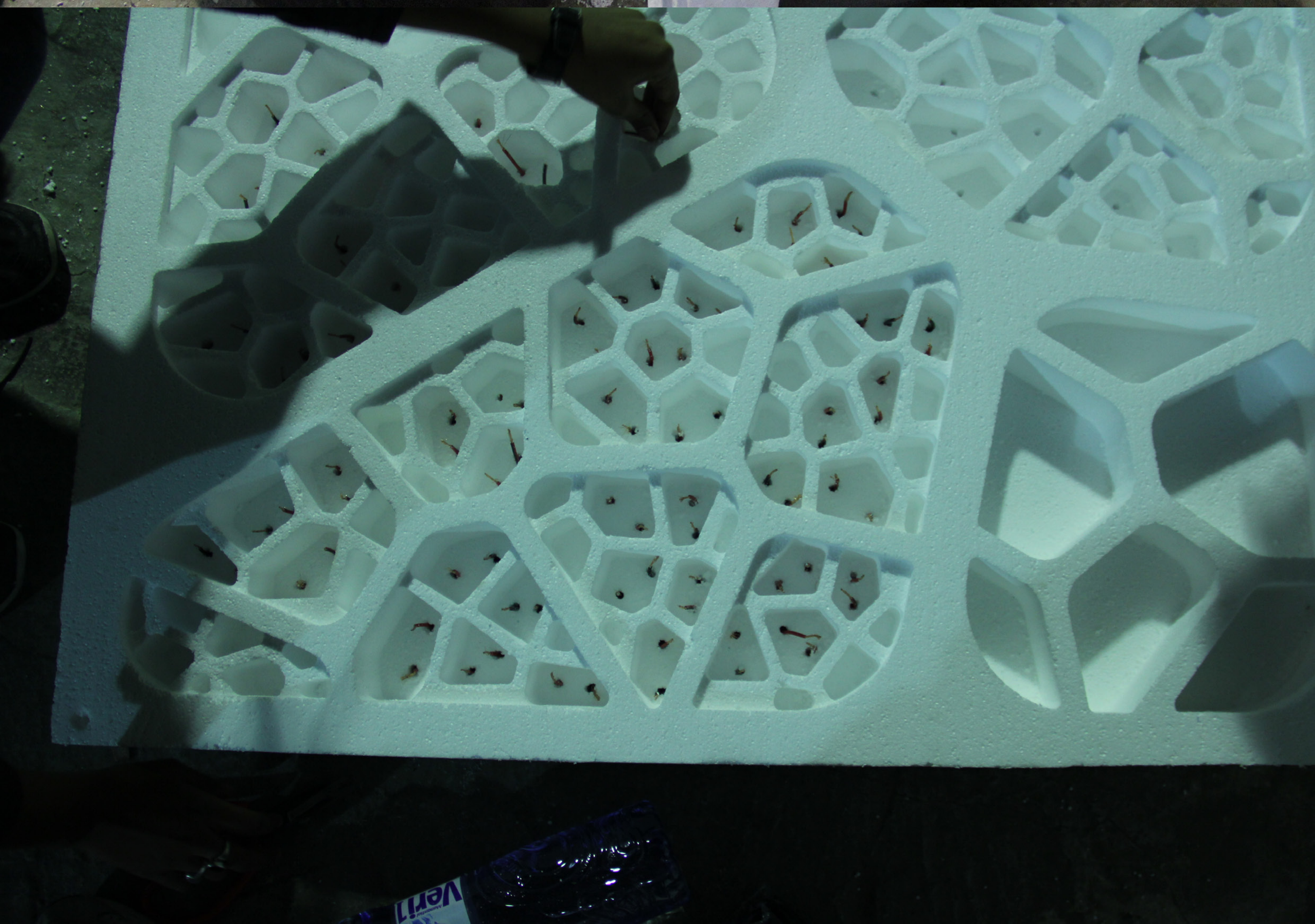

Fabrication Process//
After the resin is applied, the circuit is connected. Each of the small voronoi cells contain a galvanized steel wire coil as anode and a copper wire coil as cathode. These are connected in a series with the surrounding cells. Once all small cells are connected, the big cells then are connected in series again and connected to the electronic hub into the capacitor which is in turn connected to the arduino which manages the voltage output.



cell section

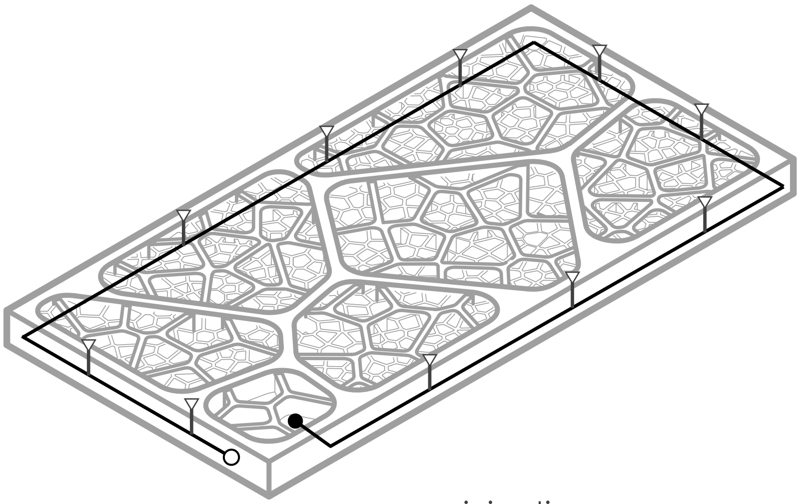


panel circuit

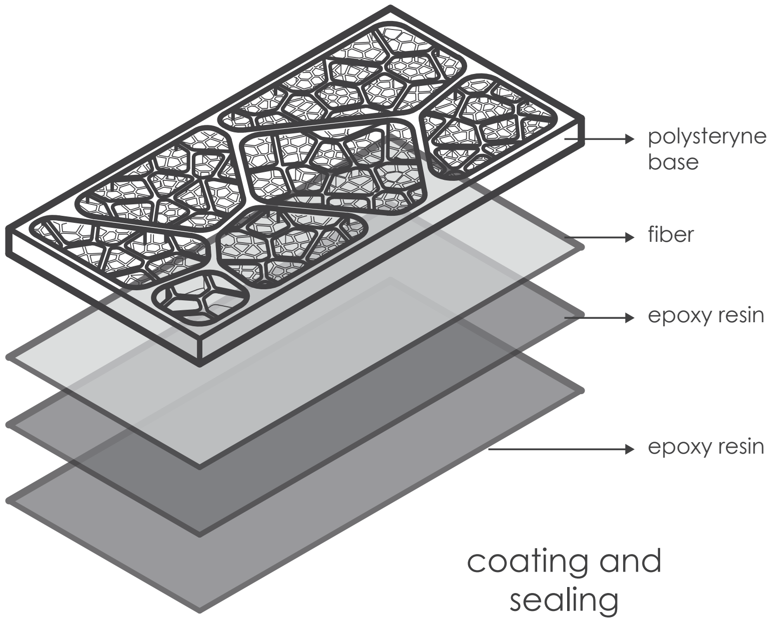


Fabrication Process//
The irrigation system consists of a 5volt pupm connected to a sprinkler system that runs along the back of the panel. The sprinklers come up above the frame and spray water when humidity drops to 40%.

After the irrigation system is applied, the wires and plumbing are sealed on the bottom with a layer of fiber and two epoxy resin coats. The fiber adds rigidity to the base of the piece while holding the wires and cables in place.

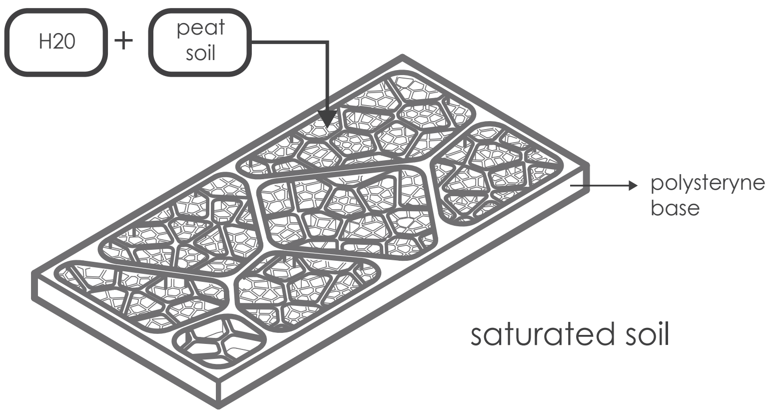


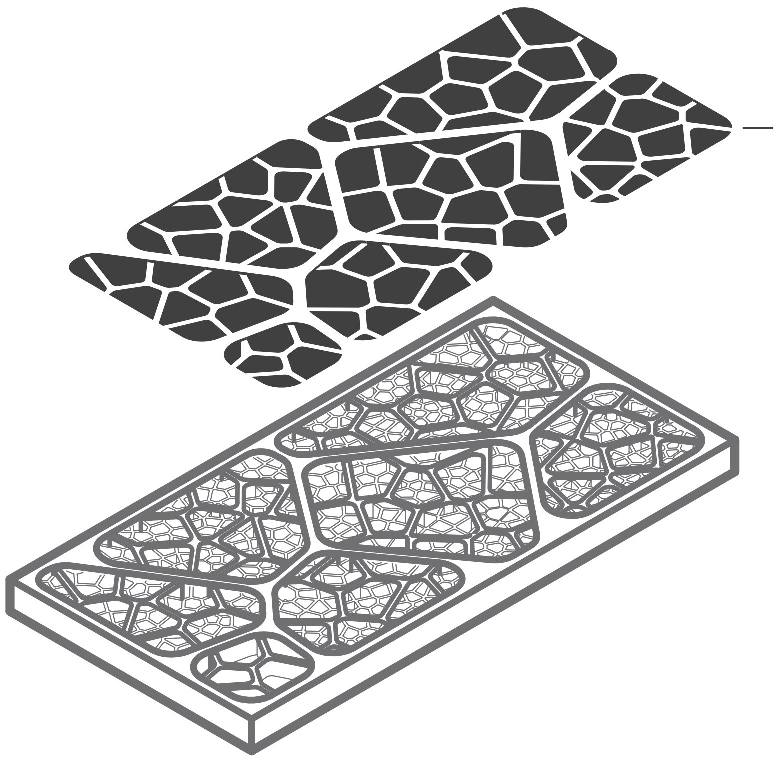
irrigation system



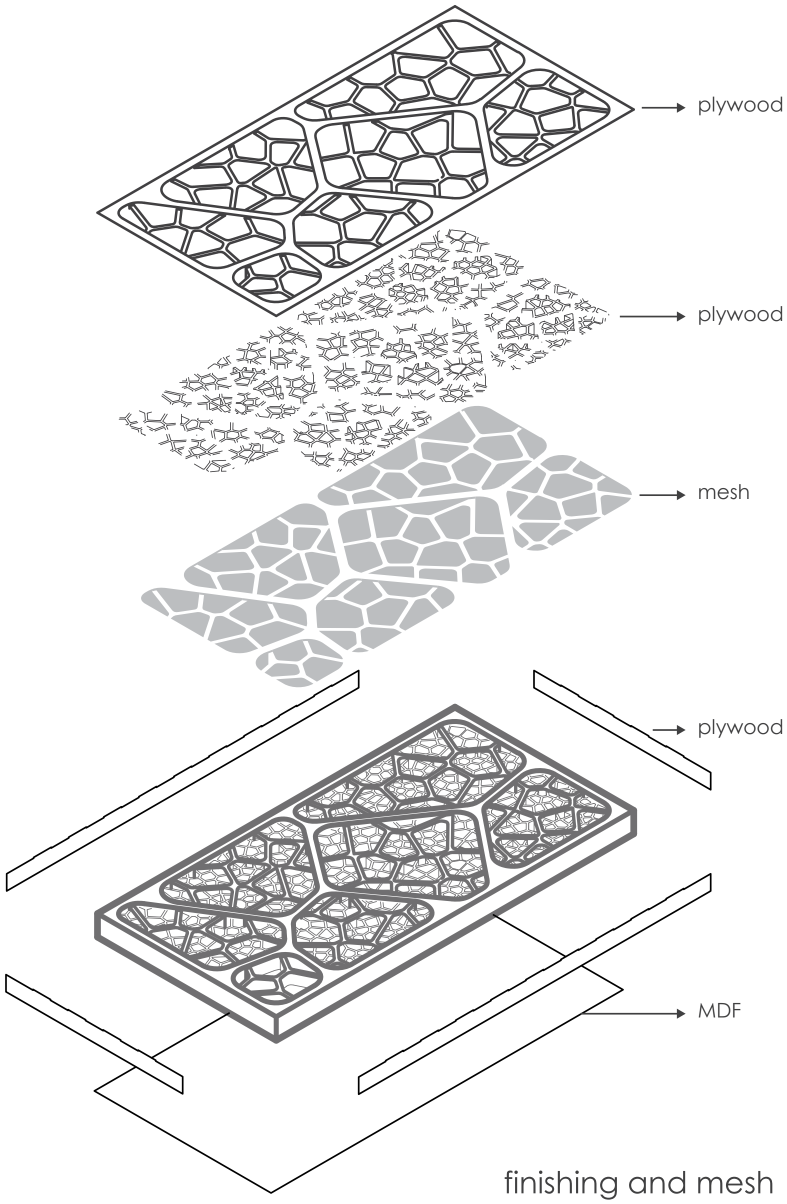
coating and sealing

Fabrication Process//
Once everything is sealed and water proofed the saturated soil is placed. It is saturated to give it the compacity needed to make contact with the anode and cathode. After the soil is placed, the moss is planted into it in the different individual moss cells.

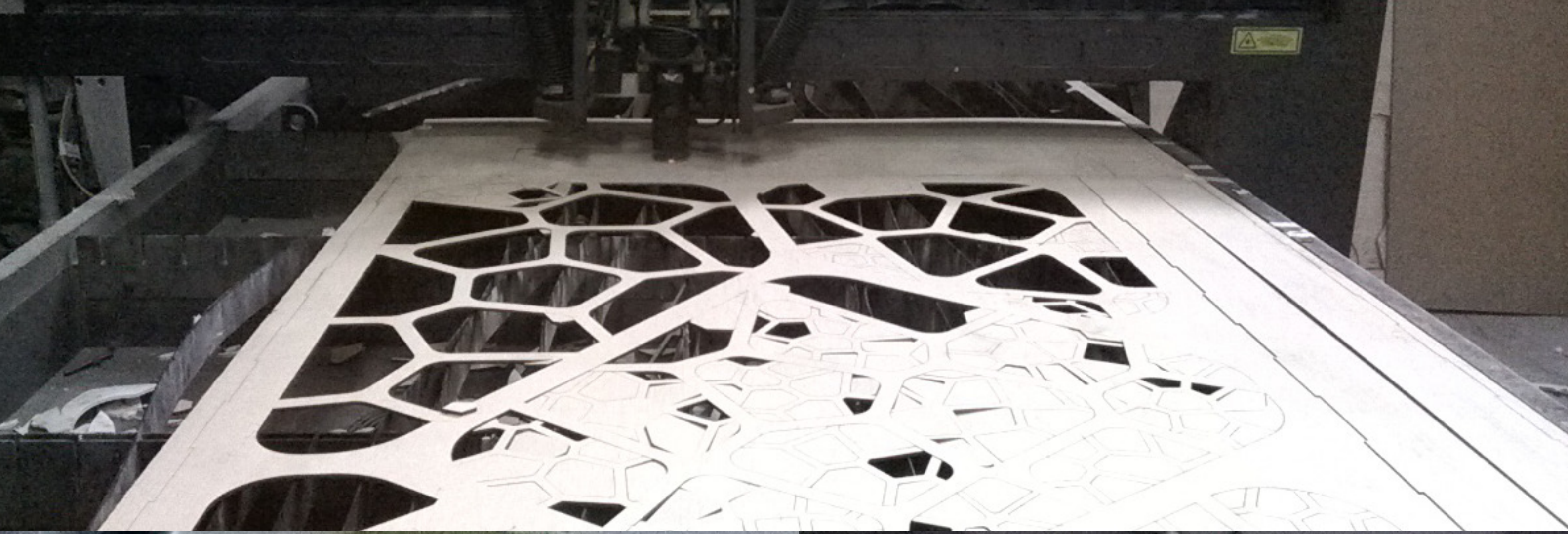


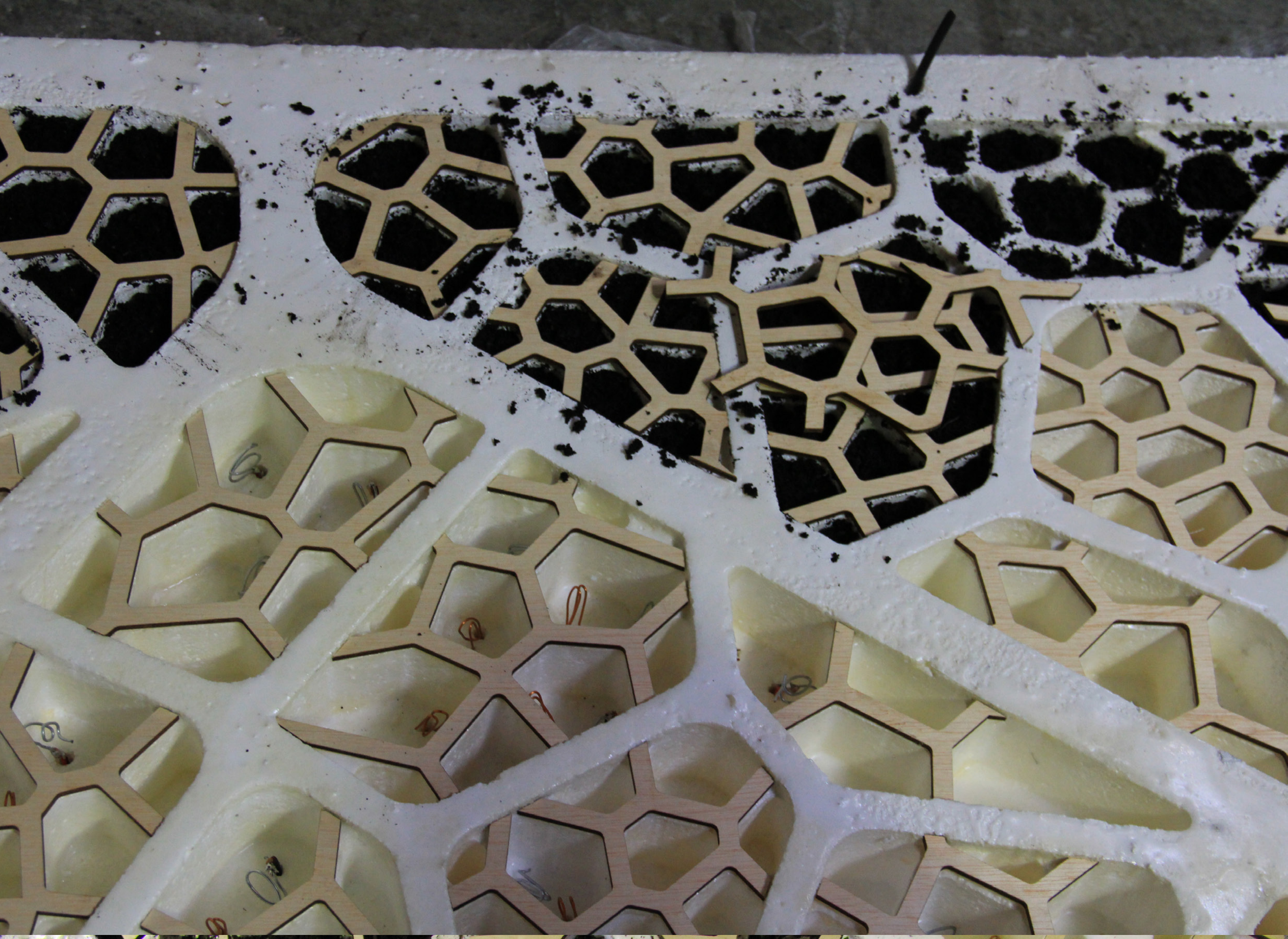


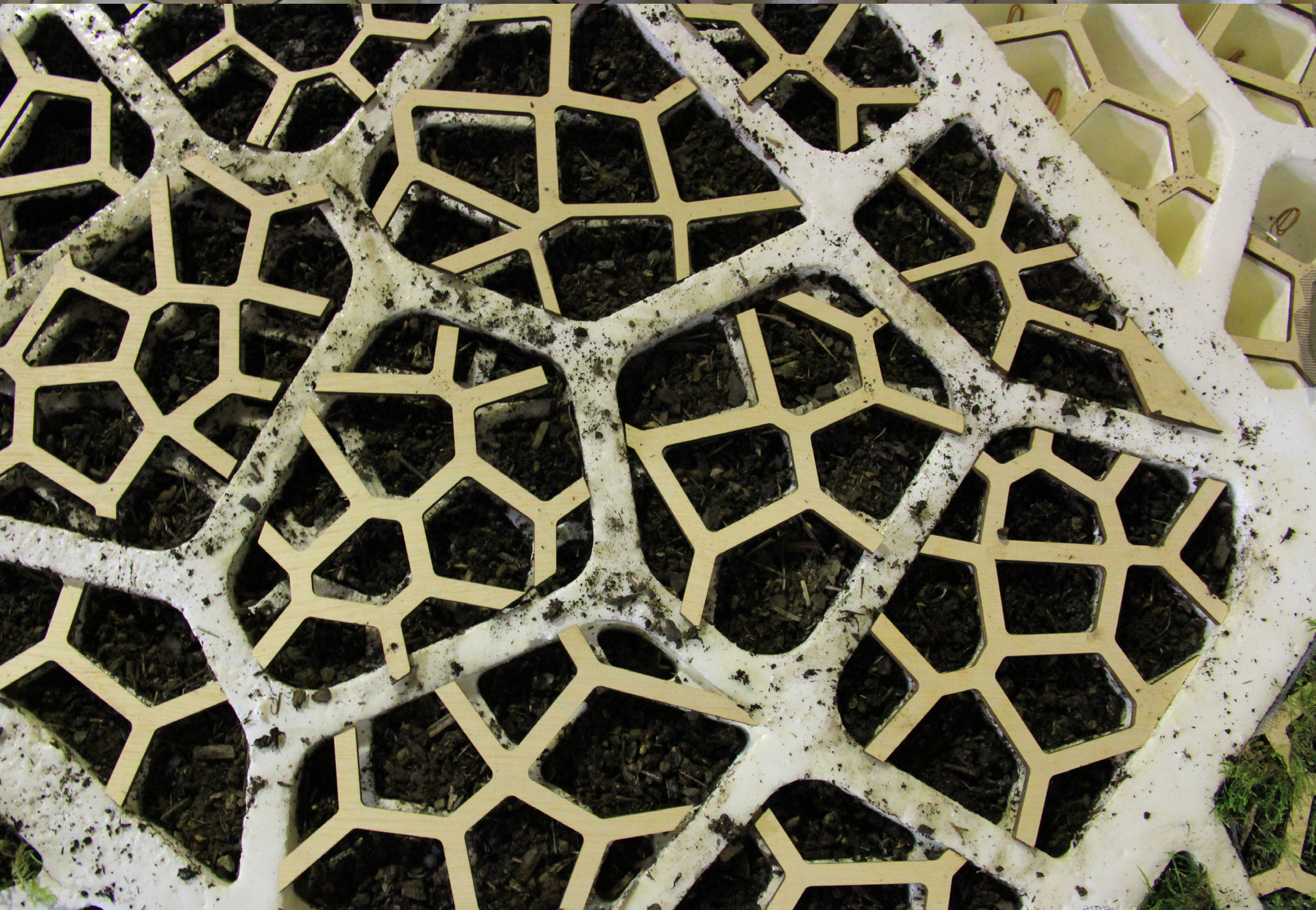
Fabrication Process//
To finish off the panel, 4mm thick plywood is cut with the voronoi pattern and along with the mesh to contain the soil is glued to the top and sides.
On the bottom of the panel an MDF panel is placed to finish sealing and rigidizing the prototype.



finishing and mesh





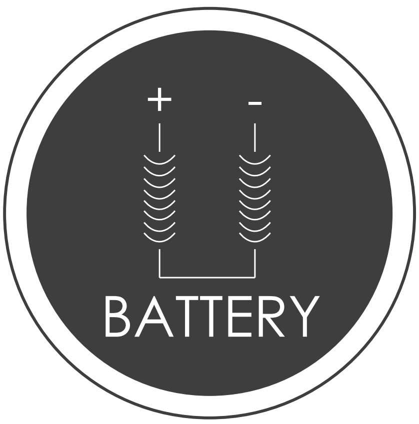




plant


bacteria


soil


+
-
BATTERY

Bio-Photovoltaic Cells BPV-01

This chapter contains research on bio-photovoltaic cells as well as microcial fuel cells. It's aim is to understand how the fuel cells work, what parts compose them, and how to build them.

The following content was researched:

1. Bio-Photovoltaic Cells
2. Microbial Fuel Cells
    - How do they work
    - Electricity generation
    - Types of microbial Fuel Cells
    - Capacitors
3. Redox Process
    - Redox process
    - Capacitors
    - Salt bridges
    - Capacitors
    - Step down converters

Filter:
bio-photovoltaic cells and components

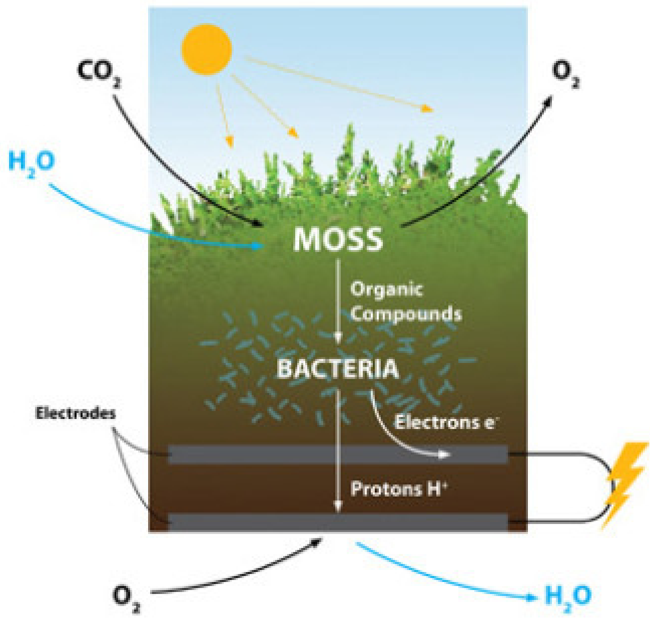
Programs:
energy generation

Bio-Photovoltaics:

What is BPV?

BPV stands for Bio-Photo-Voltaic. BPV devices generate electricity from light energy by exploiting the photosynthesis of living organisms such as cyanobacteria, moss, algae and vascular plants. More information about BPV technology has been published in Catalyst Magazine (Bombelli and Driver, 2011), and the Journal of Energy and Environmental Science (Bombelli et al, 2011; McCormick et al, 2011).

Photosynthesis is a process by which plants and algae convert carbon dioxide from the atmosphere into organic compounds using energy from sunlight. The plants use these organic compounds (like carbohydrates, proteins and lipids) to grow. When the moss photosynthesises it releases some of these organic compounds into the soil, which contains bacteria. The bacteria break down these organic compounds, which they need to survive, liberating by-products that include electrons. These electrons are captured by conductive fibres inside the Moss Table and put to use. In this way the devices harness energy which would otherwise be wasted. This is achieved using an array of 112 'moss pots', which are bio-electrochemical devices. This means that they convert chemical energy into electrical energy using biological material. Each one generates a potential of about 0.4-0.6 volts (V) and a current of 5-10 microamps (µA).



How can the efficiency be improved?
There are several possibilities including:
Increase the rate at which the moss excretes organic compounds into the soil.
Increase the rate at which the bacteria break down the organic compounds and produces electrons.
Improve the electrical connection with the bacteria.
Reduce the internal resistance of the device.

http://biophotovoltaics.wordpress.com/2012/04/16/moss-table-faqs-1-2/

Microbial Fuel Cells:

Definition

A microbial fuel cell is a device that converts chemical energy to electrical energy by the catalytic reaction of microorganisms.

A typical microbial fuel cell consists of anode and cathode compartments separated by a cation (positively charged ion) specific membrane. In the anode compartment, fuel is oxidized by microorganisms, generating CO2, electrons and protons. Electrons are transferred to the cathode compartment through an external electric circuit, while protons are transferred to the cathode compartment through the membrane. Electrons and protons are consumed in the cathode compartment, combining with oxygen to form water.[citation needed]

More broadly, there are two types of microbial fuel cell: mediator and mediator-less microbial fuel cells.

Mediator microbial fuel cell

Most of the microbial cells are electrochemically inactive. The electron transfer from microbial cells to the electrode is facilitated by mediators such as thionine, methyl viologen, methyl blue, humic acid, neutral red and so on.[9][10] Most of the mediators available are expensive and toxic.

Mediator-free microbial fuel cell

Mediator-free microbial fuel cells do not require a mediator but use electrochemically active bacteria to transfer electrons to the electrode (electrons are carried directly from the bacterial respiratory enzyme to the electrode). Among the electrochemically active bacteria are, Shewanella putrefaciens,[11] Aeromonas hydrophila,[12] and others. Some bacteria, which have pili on their external membrane, are able to transfer their electron production via these pili. Mediator-less MFCs are a more recent area of research and due to this, factors that affect optimum efficiency, such as the strain of bacteria used in the system, type of ion-exchange membrane, and system conditions (temperature, pH, etc.) are not particularly well understood.

Mediator-less microbial fuel cells can, besides running on wastewater, also derive energy directly from certain plants. This configuration is known as a plant microbial fuel cell. Possible plants include reed sweetgrass, cordgrass, rice, tomatoes, lupines, and algae.[13][14][15] Given that the power is thus derived from living plants (in situ-energy production), this variant can provide additional ecological advantages.

Microbial electrolysis cell
A variation of the mediator-less MFC is the microbial electrolysis cells (MEC). Whilst MFC's produce electric current by the bacterial decomposition of organic compounds in water, MEC's partially reverse the process to generate hydrogen or methane by applying a voltage to bacteria to supplement the voltage generated by the microbial decomposition of organics sufficiently lead to the electrolysis of water or the production of methane.[16][17] A complete reversal of the MFC principle is found in microbial electrosynthesis, in which carbon dioxide is reduced by bacteria using an external electric current to form multi-carbon organic compounds.[18]
Soil-based microbial fuel cell[edit]
Soil-based microbial fuel cells adhere to the same basic MFC principles as described above, whereby soil acts as the nutrient-rich anodic media, the inoculum, and the proton-exchange membrane (PEM). The anode is placed at a certain depth within the soil, while the cathode rests on top the soil and is exposed to the oxygen in the air above it.
Soils are naturally teeming with a diverse consortium of microbes, including the electrogenic microbes needed for MFCs, and are full of complex sugars and other nutrients that have accumulated over millions of years of plant and animal material decay. Moreover, the aerobic (oxygen consuming) microbes present in the soil act as an oxygen filter, much like the expensive PEM materials used in laboratory MFC systems, which cause the redox potential of the soil to decrease with greater depth. Soil-based MFCs are becoming popular educational tools for science classrooms.[19]
Phototrophic biofilm microbial fuel cell
Phototrophic biofilm MFCs (PBMFCs) are the one which make use of anode with a phototrophic biofilm containing photosynthetic microorganism like chlorophyta, cyanophyta etc., since they could carry out photosynthesis and thus they act as both producers of organic metabolites and also as electron donors.[20]
A study conducted by Strik et al. reveals that PBMFCs yield one of the highest power densities and therefore show promise in practical applications. Researchers face difficulties in increasing their power density and long-term performance so as to obtain a cost-effective MFC.[21]

Electrical generation process

When micro-organisms consume a substance such as sugar in aerobic conditions they produce carbon dioxide and water. However when oxygen is not present they produce carbon dioxide, protons and electrons as described below:[22]

$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^-$ (Eqt. 1)

Microbial fuel cells use inorganic mediators to tap into the electron transport chain of cells and channel electrons produced. The mediator crosses the outer cell lipid membranes and bacterial outer membrane; then, it begins to liberate electrons from the electron transport chain that normally would be taken up by oxygen or other intermediates.

The now-reduced mediator exits the cell laden with electrons that it shuttles to an electrode where it deposits them; this electrode becomes the electro-generic anode (negatively charged electrode). The release of the electrons means that the mediator returns to its original oxidised state ready to repeat the process. It is important to note that this can only happen under anaerobic conditions; if oxygen is present, it will collect all the electrons as it has a greater electronegativity than mediators.

In a microbial fuel cell operation, the anode is the terminal electron acceptor recognized by bacteria in the anodic chamber. Therefore, the microbial activity is strongly dependent on the redox potential of the anode. In fact, it was recently published that a Michaelis-Menten curve was obtained between the anodic potential and the power output of an acetate driven microbial fuel cell. A critical anodic potential seems to exist at which a maximum power output of a microbial fuel cell is achieved.[23]

A number of mediators have been suggested for use in microbial fuel cells. These include natural red, methylene blue, thionine or resorufin.[24]

This is the principle behind generating a flow of electrons from most micro-organisms (the organisms capable of producing an electric current are termed exoelectrogens). In order to turn this into a usable supply of electricity this process has to be accommodated in a fuel cell. In order to generate a useful current it is necessary to create a complete circuit, and not just shuttle electrons to a single point.

The mediator and micro-organism, in this case yeast, are mixed together in a solution to which is added a suitable substrate such as glucose. This mixture is placed in a sealed chamber to stop oxygen entering, thus forcing the micro-organism to use anaerobic respiration. An electrode is placed in the solution that will act as the anode as described previously.

n the second chamber of the MFC is another solution and electrode. This electrode, called the cathode is positively charged and is the equivalent of the oxygen sink at the end of the electron transport chain, only now it is external to the biological cell. The solution is an oxidizing agent that picks up the electrons at the cathode. As with the electron chain in the yeast cell, this could be a number of molecules such as oxygen. However, this is not particularly practical as it would require large volumes of circulating gas. A more convenient option is to use a solution of a solid oxidizing agent.

Connecting the two electrodes is a wire (or other electrically conductive path which may include some electrically powered device such as a light bulb) and completing the circuit and connecting the two chambers is a salt bridge or ion-exchange membrane. This last feature allows the protons produced, as described in Eqt. 1 to pass from the anode chamber to the cathode chamber.

The reduced mediator carries electrons from the cell to the electrode. Here the mediator is oxidized as it deposits the electrons. These then flow across the wire to the second electrode, which acts as an electron sink. From here they pass to an oxidising material..

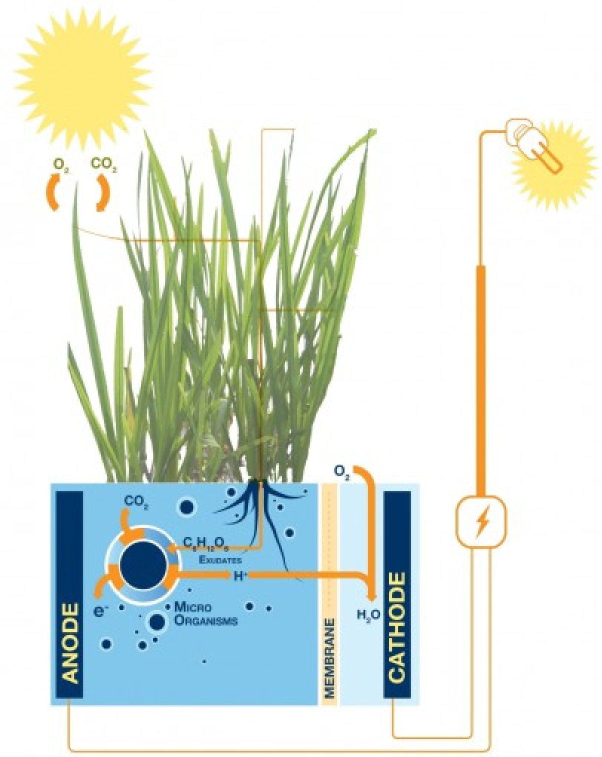
Plant Microbial Fuel Cell
Soil, as it turns out, is full of untapped (electrical) potential.
As green plants go about the business of photosynthesis -- converting energy from sunlight to chemical energy, then storing it in sugars like glucose -- they exude waste products through their roots into a soil layer known as the rhizosphere. There, bacteria chow down on plants' sloughed-off cells, along with proteins and sugars released by their roots [source: Ingham].
In PMFC terms, this means that, as long as the plant lives, the bacteria have a meal ticket and the fuel cell generates power. The first law of thermodynamics, which some translate as "there's no such thing as a free lunch," still applies because the system receives energy from an external source, namely the sun.
But how on Earth, or under it, do microbes generate electricity simply by consuming and metabolizing food? As with love or baking, it all comes down to chemistry.
Broadly speaking, MFCs work by separating two halves of an electro-biochemical process (metabolism) and wiring them together into an electrical circuit. To understand how, let's look at cell metabolism in detail.
In the textbook example that follows, glucose and oxygen react to produce carbon dioxide and water [sources: Bennetto; Rabaey and Verstraete].
$C6H12O6 + 6O2 \rightarrow 6CO2 + 6H2O$
But within individual cells -- or single-celled organisms like bacteria -- this broad statement glosses over a series of intermediate steps. Some of these steps temporarily release electrons which, as we all know, are handy for generating electricity. So, instead of glucose and oxygen reacting to produce carbon dioxide and water, here glucose and water produce carbon dioxide, protons (positively charged hydrogen ions (H+)) and electrons (e-) [sources: Bennetto; Rabaey and Verstraete].
$C6H12O6 + 6H2O \rightarrow 6CO2 + 24H+ + 24e-$
In a PMFC, this half of the process defines one half of the fuel cell. This portion is located in the rhizosphere with the plant roots, waste and bacteria. The other half of the cell lies in oxygen-rich water on the opposite side of a permeable membrane. In a natural setting, this membrane is formed by the soil-water boundary [sources: Bennetto; Rabaey and Verstraete; Deng, Chen and Zhao].
In the second half of the cell, free protons and electrons combine with oxygen to produce water, like so:

$6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$

Protons reach this second half by flowing across the ion exchange membrane, creating a net positive charge -- and an electrical potential that induces electrons to flow along the external connecting wire. Voila! Electric current [sources: Bennetto; Rabaey and Verstraete; Deng, Chen and Zhao].

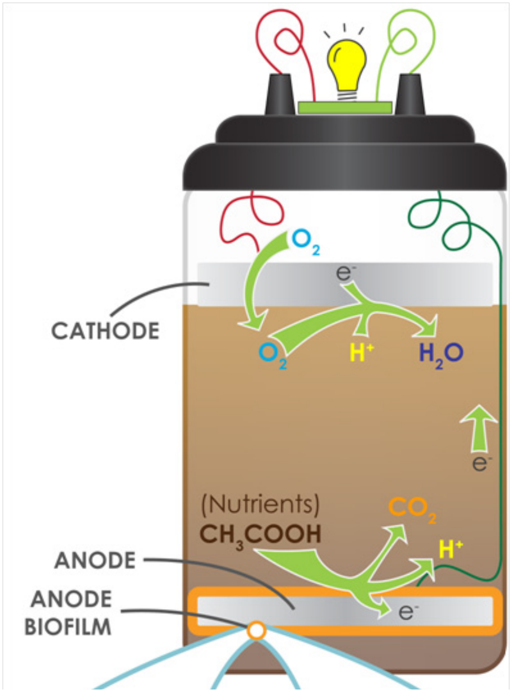
With PMFCs, as with any machine, some energy is lost in running the works -- or, in this case, in growing the plant. Of the biomass built by photosynthesis, only 20 percent reaches the rhizosphere, and only 30 percent of that becomes available to microbes as food [source: Deng, Chen and Zhao].

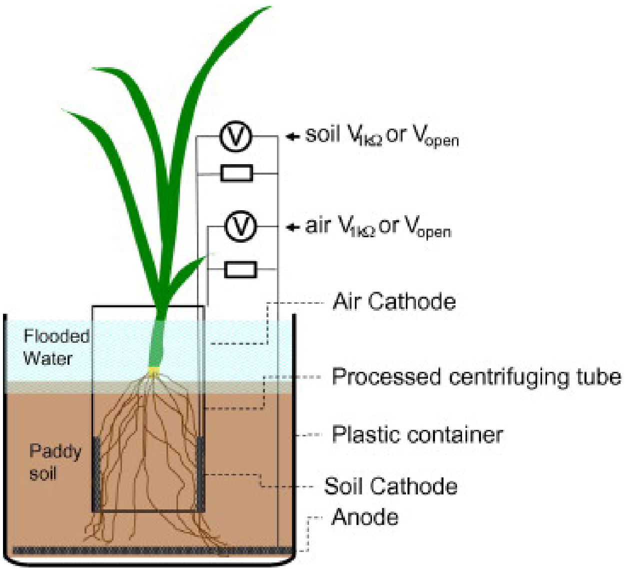
PMFCs recover around 9 percent of the energy from the resulting microbial metabolism as electricity. Altogether, that amounts to a PMFC solar-to-electrical conversion rate approaching 0.017 percent for C3 plants ((70 percent of the 4.6 percent conversion rate) x 20 percent x 30 percent x 9 percent) and 0.022 percent for C4 plants (0.70 x 6.0 x 0.20 x 0.30 x 0.09) [sources: Deng, Chen and Zhao; Miyamoto; SERC].



Soil-Based Microbial Fuel Cell:

This type of fuel cell uses soil as an electrolisis medium. The anode is placed at the bottom of the container where bacterial anaerobic activity takes place and the cathode at the top, in contact with the air, to be able to transfer electrons and create water.





Redox Process:
Redox (reduction-oxidation) reactions include all chemical reactions in which atoms have their oxidation state changed; redox reactions generally involve the transfer of electrons between species.
This can be either a simple redox process, such as the oxidation of carbon to yield carbon dioxide (CO
2) or the reduction of carbon by hydrogen to yield methane (CH4), or a complex process such as the oxidation of glucose (C6H12O6) in the human body through a series of complex electron transfer processes.
The term "redox" comes from two concepts involved with electron transfer: reduction and oxidation.[1] It can be explained in simple terms:
Oxidation is the loss of electrons or an increase in oxidation state by a molecule, atom, or ion.
Reduction is the gain of electrons or a decrease in oxidation state by a molecule, atom, or ion.
Although oxidation reactions are commonly associated with the formation of oxides from oxygen molecules, these are only specific examples of a more general concept of reactions involving electron transfer.
Redox reactions, or oxidation-reduction reactions, have a number of similarities to acid–base reactions. Like acid–base reactions, redox reactions are a matched set, that is, there cannot be an oxidation reaction without a reduction reaction happening simultaneously. The oxidation alone and the reduction alone are each called a half-reaction, because two half-reactions always occur together to form a whole reaction. When writing half-reactions, the gained or lost electrons are typically included explicitly in order that the half-reaction be balanced with respect to electric charge.
Though sufficient for many purposes, these descriptions are not precisely correct. Oxidation and reduction properly refer to a change in oxidation state — the actual transfer of electrons may never occur. Thus, oxidation is better defined as an increase in oxidation state, and reduction as a decrease in oxidation state. In practice, the transfer of electrons will always cause a change in oxidation state, but there are many reactions that are classed as "redox" even though no electron transfer occurs (such as those involving covalent bonds).

When a stick of zinc (Zn) is inserted in a salt solution, there is a tendency for Zn to lose electron according to the reaction,

$Zn = Zn^{2+} + 2\ e^-$.

The arrangement of a Zn electrode in a solution containing Zn^{2+} ions is a half cell, which is usually represented by the notation:

$Zn \mid Zn^{2+}$,

Zinc metal and Zn^{2+} ion form a redox couple, Zn^{2+} being the oxidant, and Zn the reductant. The same notation was used to designate a redox couple earlier.

Similarly, when a stick of copper (Cu) is inserted in a copper salt solution, there is also a tendency for Cu to lose electron according to the reaction,

$Cu = Cu^{2+} + 2\ e^-$.

This is another half cell or redox couple: $Cu \mid Cu^{2+}$.

However, the tendency for Zn to lose electron is stronger than that for copper. When the two cells are connected by a salt bridge and an electric conductor as shown to form a closed circuit for electrons and ions to flow, copper ions (Cu^{2+}) actually gains electron to become copper metal. The reaction and the redox couple are respectively represented below,

$Cu^{2+} + 2\ e^- = Cu$, $\quad Cu^{2+} \mid Cu$.

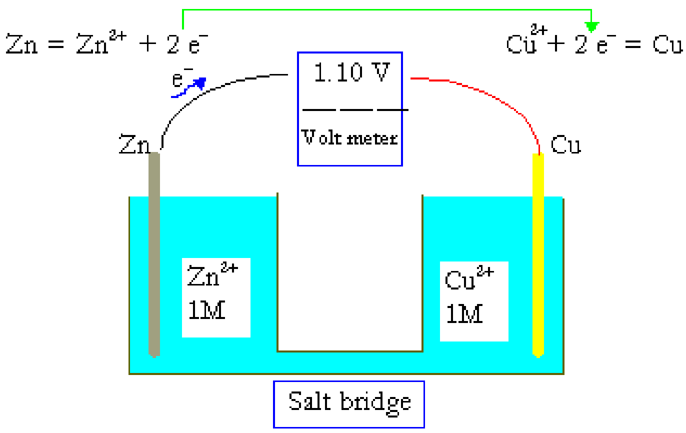
This arrangement is called a galvanic cell or battery as shown here. In a text form, this battery is represented by,

$Zn \mid Zn^{2+} \parallel Cu^{2+} \mid Cu$,

in which the two vertical lines (||) represent a salt bridge, and a single vertical line (|) represents the boundary between the two phases (metal and solution). Electrons flow through the electric conductors connecting the electrodes and ions flow through the salt bridge. When

$[Zn^{2+}] = [Cu^{2+}] = 1.0$ M,

the voltage between the two terminals has been measured to be 1.100 V for this battery.



Salt bridges:
A salt bridge, in electrochemistry, is a laboratory device used to connect the oxidation and reduction half-cells of a galvanic cell (voltaic cell), a type of electrochemical cell. Salt bridges usually come in two types: glass tube and filter paper.
Glass tube bridges
One type of salt bridge consists of a U-shaped glass tube filled with a relatively inert electrolyte; usually potassium chloride or sodium chloride is used, although the diagram here illustrates the use of a potassium nitrate solution. The electrolyte is often gelified with agar (commonly called as agar agar gel) to help prevent the intermixing of fluids which might otherwise occur.
The conductivity of a glass tube bridge depends mostly on the concentration of the electrolyte solution. An increase in concentration below saturation increases conductivity. Beyond-saturation electrolyte content and narrow tube diameter may both lower conductivity.
Filter paper bridges
The other type of salt bridge consists of a filter paper, also soaked with a relatively inert electrolyte, usually potassium chloride or sodium chloride because they are chemically inert. No gelification agent is required as the filter paper provides a solid medium for conduction.
Conductivity of this kind of salt bridge depends on a number of factors: the concentration of the electrolyte solution, the texture of the filter paper and the absorbing ability of the filter paper. Generally, smoother texture and higher absorbency equates to higher conductivity.
A porous disk or other porous barrier between the two half-cells may be used instead of a salt bridge; however, they basically serve the same purpose.
The purpose of a salt bridge is not to move electrons from the electrolyte, rather to maintain charge balance because the electrons are moving from one half cell to the other.
The electrons flow from the anode to the cathode. The oxidation reaction that occurs at the anode generates electrons and positively charged ions. The electrons move thrown the wire (and your device, which I haven't included in the diagram), leave unbalanced positive charge in this vessel. In order to maintain neutrality, the negatively charged ions in the salt bridge will migrate into the anodic half cell. A similar (but reversed) situation is found in the cathodic cell, where Cu^{2+} ions are being consumed, and therefore electroneutrality is maintained by the migration of K^+ ions from the salt bridge into this half cell.
Regarding the second part of your question, it is important to use a salt with inert ions in your salt bridge. In your case, you probably won't notice a difference between NaCl and KNO_3 since the Cu^{2+} and Zn^{2+} salts of Cl^- and NO_3^- are soluble. There will be a difference in the liquid junction potential, but that topic is a bit advanced for someone just starting out with voltaic/Galvanic cells.

Capacitors:
Capacitors are basic electrical components used to store charge and energy. Compared to a battery of equal size, a capacitor stores much less energy and is therefore generally unsuitable as a power source. However, unlike a battery it is relatively quick to charge up making it ideal for coupling with an MFC. Capacitors' charging and discharging behaviours are illustrated in the graphs in Figures 2.2 and 2.3.
The rate at which a capacitor charges or discharges is determined by the equation T=RC where T is a time constant in seconds, C is the capacitance of the capacitor in Farads and R is the resistance in Ohms. While C remains the same for both charging and discharging, R changes. Assuming there are no artificially inserted resistors, for charging, R is the internal resistance of the wires and power source, while for discharging, R is the resistance of the actuator. Therefore T is usually different for charging and discharging. After five time constants, 5RC, the capacitor is over 99% charged (or discharged) and is generally considered full (or empty).
The energy stored in a capacitor is governed by the equation:

$$E = \frac{1}{2}CV^2$$

where C is the capacitance in Farads and V is the voltage in Volts.
Capacitors are used in a wide range of applications, from amplifiers to radars to particle accelerators; generally any electrical system that requires energy storage and a large, quick burst of power.

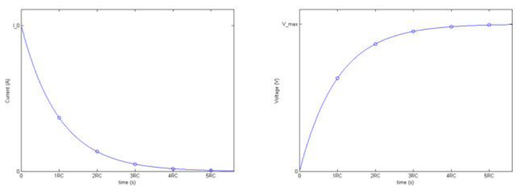


Figure 2.2: Charging a capacitor; current on the left, voltage on the right

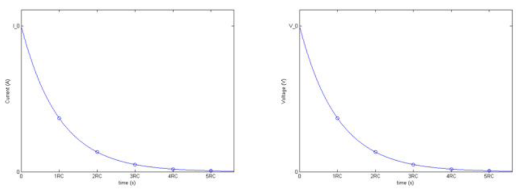


Figure 2.3: Discharging a capacitor; current on the left, voltage on the right

Step down converter:
A buck converter is a step-down DC to DC converter. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses two switches (a transistor and a diode), an inductor and a capacitor.
The simplest way to reduce the voltage of a DC supply is to use a linear regulator (such as a 7805), but linear regulators waste energy as they operate by dissipating excess power as heat. Buck converters, on the other hand, can be remarkably efficient (95% or higher for integrated circuits), making them useful for tasks such as converting the main voltage in a computer (12 V in a desktop, 12-24 V in a laptop) down to the 0.8-1.8 volts needed by the processor.
The conceptual model of the buck converter is best understood in terms of an inductor's "reluctance" to allow a change in current. Beginning with the switch open (in the "off" position), the current in the circuit is 0. When the switch is first closed, the current will begin to increase, but the inductor doesn't want it to change from 0, so it will attempt to fight the increase by dropping a voltage. This voltage drop counteracts the voltage of the source and therefore reduces the net voltage across the load. Over time, the inductor will allow the current to increase slowly by decreasing the voltage it drops and therefore increasing the net voltage seen by the load. During this time, the inductor is storing energy in the form of a magnetic field.
If the switch is opened before the inductor has fully charged (i.e., before it has allowed all of the current to pass through by reducing its own voltage drop to 0), then there will always be a voltage drop across it, so the net voltage seen by the load will always be less than the input voltage source.
When the switch is opened again, the voltage source will be removed from the circuit, so the current will try to drop. Again, the inductor will try to fight against its changing, which it does by reversing the direction of its voltage and acting like a voltage source. Put another way, there is a certain current flowing through the load due to the input voltage source: in order to maintain this current when the input source is removed, the inductor will have to take the place of the voltage source and provide the same net voltage to the load. Over time, the inductor will allow the current to decrease gradually, which it does by decreasing the voltage across itself. During this time, the inductor is discharging its stored energy into the rest of the circuit
If the switch is closed again before the inductor fully discharges, the load will always see a non-zero voltage. The capacitor placed in parallel with the load helps to smooth out voltage waveform as the inductor charges and discharges in each cycle.

Conclusions

- The anode (negatively charged electrode) must be placed in an anaerobic medium. The cathode (positively charged electrode) must be placed in an aerobic medium.
- Plant microbial fuel cells and soil-based microbial fuel cells are the most siuted microbial fuel cell types to turn into bio-photovoltaic cells.
- Water production depends on the type of microbial fuel cell. A proton exchange membrane (PEM) is needed for the positively charged protons to combine with oxigen and negatively charged electrons and create water. Well ariated cathodes without PEM might also create water.
- Saturated soil helps electrolisis to take place and trigger the redox process.
- Bacteria gather around the anode and so it captures their electrons hence, the anode should be placed where the bacteria are most dense.
- Salt bridges are important to keep neutrallity of the medium, soil in BPV's case.
- A capacitor or a step-down converter keeps the voltage and aperage as a continous current which helps the transition from the battery to the appliance.

Soil, Microbes, Moss

BPV - 02

This chapter contains research done on the organic elements of the bio-photovoltaic cell. It explores the parameters that rule soil, microbes, and moss as well as the relationship that bonds them.

The main subjects explored are:

1. Soil
    - types of soil
    - soil pH
    - microbial activity in soil
2. Microbial activity
    - microbe habitat
    - plant-growth related microbes
3. Moss
    - habitat
    - soil and climate parameters

This chapter aims to provide information on how to tamper the organic element of the bio-photovoltaic cell in order to produce the most amount of power while providing a healthy environment to both moss and microbes.

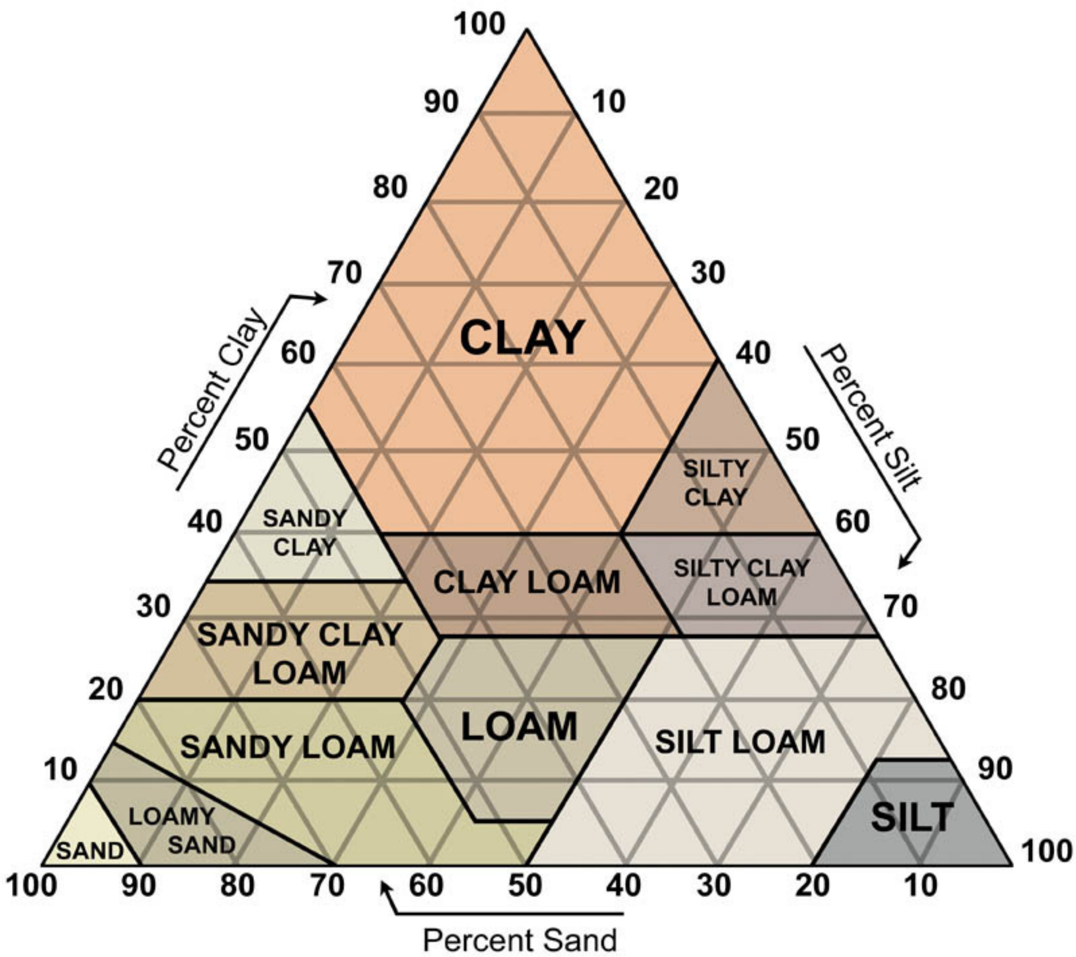
Filter:
organic components of bio-photovoltaic cell

Programs:
soil parameters, microbial life and energy generation, moss habitat and parameters of growth.

Types of soil:
There are 5 different soil types that gardeners and growers usually work with. All five is a combination of just three types of weathered rock particles that make up the soil: sand, silt, and clay. How these three particles are combined defines your soil's type—how it feels to the touch, how it holds water, and how it's managed, among other things.
Sandy: Sandy soil has the largest particles among the different soil types. It's dry and gritty to the touch, and because the particles have huge spaces between them, it can't hold on to water. Water drains rapidly, straight through to places where the roots, particularly those of seedlings, cannot reach. Plants don't have a chance of using the nutrients in sandy soil more efficiently as they're swiftly carried away by the runoff.
Silty: Silty soil has much smaller particles than sandy soil so it's smooth to the touch. When moistened, it's soapy slick. When you roll it between your fingers, dirt is left on your skin. Silty soil retains water longer, but it can't hold on to as much nutrients as you'd want it to though it's fairly fertile. Due to its moisture-retentive quality, silty soil is cold and drains poorly.Silty soil can also easily compact, so avoid trampling on it when working your garden. It can become poorly aerated, too.
Clay: Clay soil has the smallest particles among the three so it has good water storage qualities. It's sticky to the touch when wet, but smooth when dry. Due to the tiny size of its particles and its tendency to settle together, little air passes through its spaces. Because it's also slower to drain, it has a tighter hold on plant nutrients. Clay soil is thus rich in plant food for better growth.
Peaty: Peaty soil is dark brown or black in color, soft, easily compressed due to its high water content, and rich in organic matter. Peat soil started forming over 9,000 years ago, with the rapid melting of glaciers. This rapid melt drowned plants quickly and died in the process. Their decay was so slow underwater that it led to the accumulation of organic area in a concentrated spot.Although peat soil tends to be heavily saturated with water, once drained, it turns into a good growing medium. In the summer though, peat could be very dry and become a fire hazard. (I kid you not—peat is the precursor of coal.) The most desirable quality of peat soil, however, is in its ability to hold water in during the dry months and its capacity to protect the roots from damage during very wet months. Peat contains acidic water, but growers use it to regulate soil chemistry or pH levels as well as an agent of disease control for the soil.

Salty: The soil in extremely dry regions is usually brackish because of its high salt content. Known as saline soil, it can cause damage to and stall plant growth, impede germination, and cause difficulties in irrigation. The salinity is due to the buildup of soluble salts in the rhizosphere—high salt contents prevent water uptake by plants, leading to drought stress.

Loamy: The type of soil that gardens and gardeners love is loamy soil. It contains a balance of all three soil materials—silt, sand and clay—plus humus. It has a higher pH and calcium levels because of its previous organic matter content. Loam is dark in color and is mealy—soft, dry and crumbly—in your hands. It has a tight hold on water and plant food but it drains well, and air moves freely between soil particles down to the roots.



Soil and pH:

Different types of plants need different levels of soil pH to survive and thrive. Soil with a pH ranging from 1 to 6 is considered acidic. If the pH level is exactly 7, it's neutral, and soil with a range of 8 to 14 is alkaline. Soil pH varies from region to region and one garden to the next. Most plants need a pH between 6.5 and 7, but others need acidic conditions that can be created by vinegar. Be sure to test your soil and determine its exact pH before amending it with vinegar, and then check the pH regularly to ensure your vinegar regime is not making the soil too acidic for your plants.

Acidifying garden soil will lower its pH so that ericaceous plants such as camellias, blueberries, heathers and rhododendrons can grow. It is usually only required if soil pH is neutral or alkaline. Sulphur is the most common acidifying material. Peat is no longer recommended.

Before adding any acidifying materials you need to check your soil pH to see how much (if any) you need to add.

A soil pH test measures the acidity or alkalinity of the soil. A pH 7.0 is considered neutral. Above pH 7.0, the soil is alkaline and below pH 7.0, the soil is acid. See our page on soil pH testing for more detail.

It is especially worth testing soil pH before designing or planting a new garden that will contain ericaceous plants, or when growth of ericaceous plants is disappointing or shows signs of chlorosis (yellowing of the leaves).

Testing can be done at any time but, if carried out within three months after adding lime, fertiliser or organic matter, the test may give misleading results.

If your soil pH test comes back at 7.0 or lower, you already have acidic soil, but acidifying further, to between pH 5.0-6.0, may be necessary if you intend to grow ericaceous (lime-hating) plants. For other plants, if the pH is much below 6.5, you may wish to increase the pH by adding lime.

To lower the pH level of soil and make it more acidic, vinegar can be applied by hand or using an irrigation system. For a basic treatment, a cup of vinegar can be mixed with a gallon of water and poured over soil with a watering can. According to the Vinegar Institute, this is ideal for plants like azaleas and rhododendrons. Alternately, an injector can be used to add vinegar to irrigation lines, which then evenly distribute the solution.

Sulphur is the common acidifying material. Soil organisms convert sulphur into sulphuric acid, so acidifying the soil. The more finely ground the sulphur the more quickly the bacteria can convert it; sulphur dust is quicker acting than sulphur chips. However, acidification by sulphur takes weeks to have an effect, and when the soil is cold in winter, months might be needed.

Soil parameters:

Soil Texture

Soil has the following types of texture: Sand (0.05-2.0 mm), Silt (0.002-0.05mm), and Clay (< 0.002mm)[1]. Sands are loose and single-grained (that is, not aggregated together). They feel gritty to the touch and are not sticky. Each individual sand grain is of sufficient size that it can easily be seen and felt. Sands cannot be formed into a cast by squeezing when dry. Clay is the finest textured of all the soil classes. Clay usually forms extremely hard clods or lumps when dry and is extremely sticky and plastic when wet.[4] Soils that are coarse textured are less likely to have a well-defined structure and therefore fewer structured pore space than s soil high in clay content.[5]

Soil pores

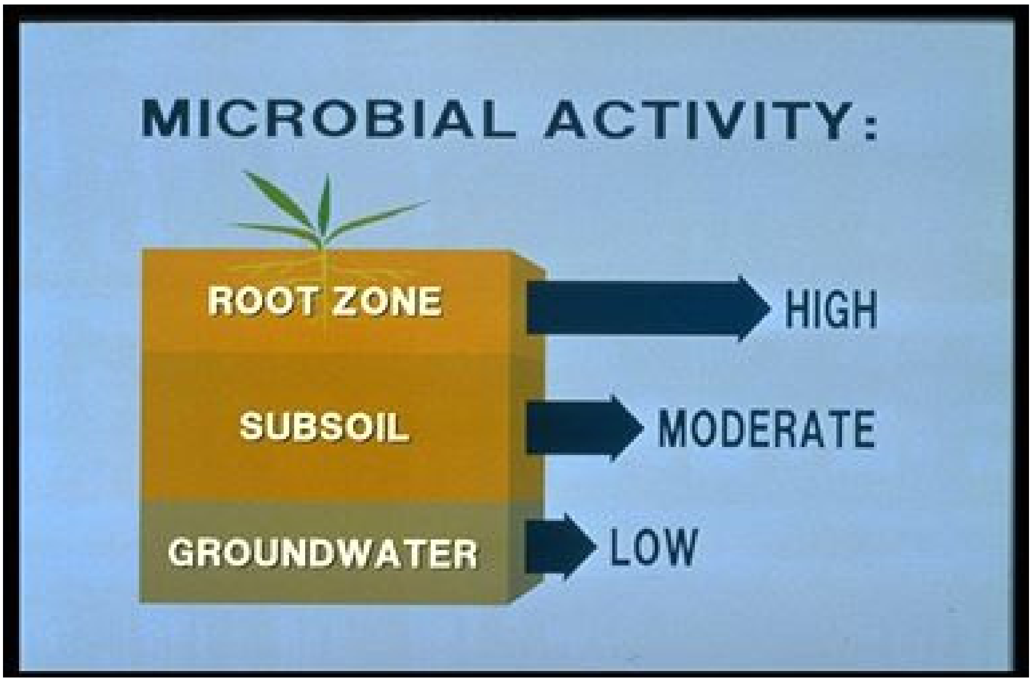
Soil pores play a major role in water and air movement. Also, soil microorganisms reside in pores. Pore space is largely determined by size and arrangement of aggregates and affects the movement of water, air, and organisms in soil. Soil pore size distribution: Macropores (>75um) Mesopores (30-70um) Micropores (5-30um) Ultramicropores (0.1-5um) Crytopores (<0.1um). The average particle size could be determined by knowing the soil type and the percentage of sand, clay, and silt.

Soil Structure

Aggregation of primary soil particles is a critical determinant of soil structure.Structure is strongly affected by climate, biological activity, density and continuity of surface cover, and soil management practices. Soils that are coarse textured are less likely to have a well-defined structure and therefore fewer structured pore space than s soil high in clay content. Ecological relationships among soil organisms are influenced by soil structure.

Soil water

Soil water is essential for soil microorganisms. Without some water, there is no microbial activity. Sandy soils with large diameter particles (coarse texture) can contain less water than clay soils with small diameter particles (fine texture).[6] The formation of primary soil particles into soil aggregates creates an ideal environment for most bacteria. [1] As the amount of available water decreases, the ability to take up water in the soil differs among organisms. Fungal hyphae have the ability to extend through soil pores and obtain water, but bacteria do not share the same advantage.[1]



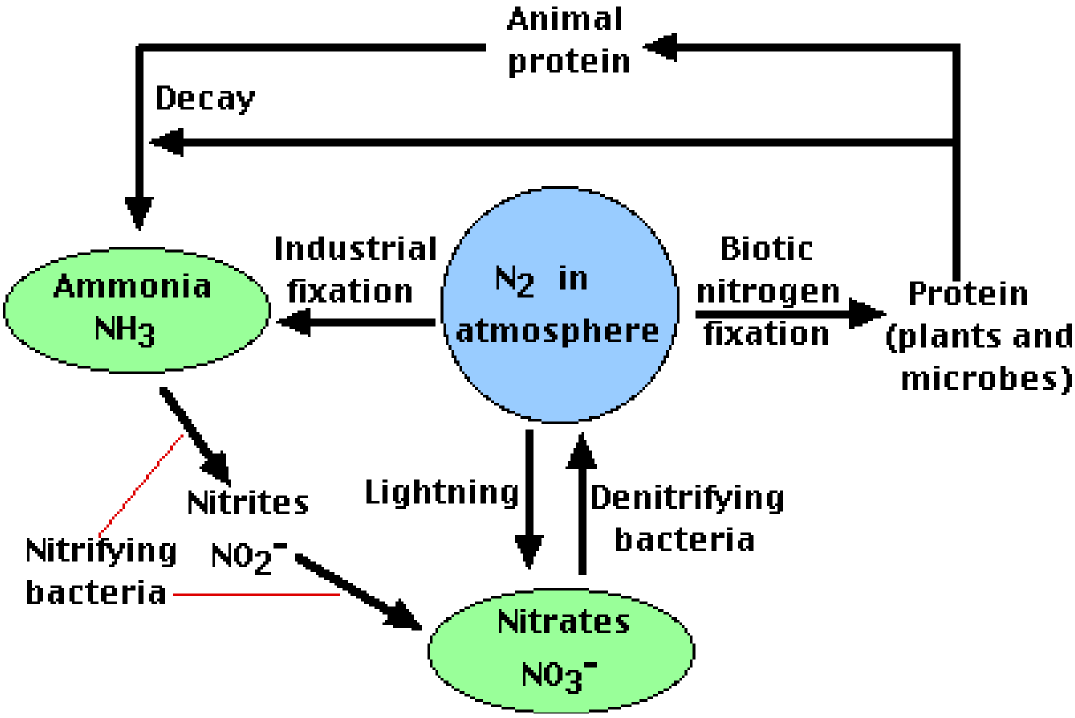
Temperature

Soil temperature greatly influences the rates of biological, physical, and chemical processes in the soil. Within a limited range, the rates of chemical reactions and biological processes double for every 10 degree increase.Soil temperature governs the rates and directions of soil physical processes and chemical reactions, and influences biological processed. Different pathogen species and strains have different thermal limits for survival, germination and infection.[5]

Soil aggregates

Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles. The space between the aggregates provide pore space for retention and exchange of air and water. Aggregation affects erosion, movement of water, and plant root growth. [7] Polysaccharides produced by soil bacteria and humic substances produced by fungi improve aggregation.

Microbial activity in soil:
Microbial activity, measured in terms of biomass and respiration, reflects the flux of carbon through biotic systems. This page explores the soil environmental and physical factors regulating microbial activity. Microbes are vital to the world's ecosystems, being integral parts of the carbon and nitrogen cycles and affecting plant growth and survival. Microbes, like all other organisms, are affected by a variety of factors and have developed specialized niches.
Chemical Factors
pH changes in soils is due to both biotic and abiotic processes in the soil. Consuming or releasing H+ through redox reactions and fermentation, and/or from rainfall that leaches bases in soil and thus lowering the pH [1]. The majority of soil microbes thrive in neutral pH (6-7) due to the high availability of most nutrients in this pH range, but there are examples of microbes (especially fungi) that can tolerate pH of 1 to 13 [1]. Some organisms that can tolerate extreme pH include bacteria in Halomonas and Archea Archaeoglobus. Alterations in pH can render essential microbe enzymes inactive and/or denature proteins within the cells and prevent microbial activity from occurring [1]. pH changes can also effect microbes in their access to metals and organics that react differently under varied pH régimes [1].
Oxygen levels dictate the oxidation-reduction reactions that occur and largely what microbial processes occur. In the presence of oxygen, O2 will be used for aerobic respiration, but when concentrations are low other electron acceptors are used (such as sulfur, iron, etc.) [1]. This phenomenon can be seen in flooded soils. Some microbial enzymes require O2, so the level of O2 can regulate the enzymatic activity. Some products of O2 reactions are toxic (such as superoxide radical O2-) and without the proper enzymes to inactivate these toxins microbes are susceptible to harm.
Cation Exchange Capacity (CEC) The CEC is the total amount of exchangeable cations that a soil can hold at a specific pH [1]. The negatively charged soil particles allow for charged soil microorganisms (due to charged organic molecules) to be attracted or repelled from soil. The ability to be held or repelled from the soil influences the ability of microbes to uphold their presence in the soil. The full understanding of how this mechanism works is not understood yet, but postulated mechanisms include: ion exchange attractions, weak attractive forces, coordination bonding, and hydrogen-bonding. The CEC of the soil also influences the availability of nutrients in the soil for microbial use, as charged nutrient particles also will be held or moved through the soil based on its charge [1].



Plant Growth-Promoting Rhizobacteria (PGPR)

Rhizobacteria colonize roots. PGPR bacteria colonization promotes plant growth and seed germination and helps plants resist environmental stresses and diseases. Harmful root colonization is caused by deleterious rhizosphere microorganisms (DRMO). DRMO bacteria remove water and nutrients from the plant supply. PGPR bacteria are able to promote plant growth by colonizing before and thus preventing the colonization of DRMO. Pseudomonas is a genus containing many PGPR bacteria. Azotobacter and Azospirillum are also PGPR bacteria because of their production of gibberellic and indoleacetic acid, which are plant growth-stimulating hormones. [1]

Rhizobacteria are root-colonizing bacteria that form a symbiotic relationship with many plants. The name comes from the Greek word rhiza, meaning root. Though parasitic varieties of rhizobacteria exist, the term usually refers to bacteria that form a relationship beneficial for both parties (mutualism). Such bacteria are often referred to as plant growth promoting rhizobacteria, or PGPRs. The mechanism by which the PGPRs promote the plant growth is not clearly understood, but it is believed occur through siderophore production, mineral assimilation, phytohormone production, and most importantly asymbiotic Nitrogen fixation.
Nitrogen Fixation is one of the most beneficial processes performed by rhizobacteria. Nitrogen is a vital nutrient to plants; gaseous nitrogen (N2) is not available to them due to the high energy required to break the triple bonds between the two molecules. Through nitrogen fixation, rhizobacteria can convert gaseous nitrogen (N2) to ammonia (NH3), making it an available nutrient that can support and enhance growth in the host plant. The host plant provides amino acids for the bacteria so they do not need to assimilate ammonia. The amino acids are then routed back to the plant with newly fixed nitrogen. Nitrogenase is an enzyme involved in nitrogen fixation. It requires anaerobic conditions so membranes within root nodules provide these conditions (Figure 1). The rhizobacteria need oxygen to metabolize, so plants provide oxygen in the form of Leghemoglobin, a hemoglobin protein produced within plant nodules. Legumes are well known nitrogen fixing crops and have been utilized for centuries in crop rotation to maintain soil health.
Some known varieties of PGPR bacteria include Pseudomonas putida, Azospirillum fluorescens, and Azospirilum lipoferum. Though microbial inoculants are indisputably beneficial for crops, they are not widely used in industrial agriculture, as large-scale application techniques have yet to become economically viable. A notable exception is the use of rhizobial inoculants for legumes such as peas. Inoculation with PGPRs ensure efficient nitrogen fixation; they have been employed in North American Agriculture for over 100 years

Rhizobacteria can live in a symbiotic relationship with plants. The plant growth promoting rhizobacteria, or PGPRs provide many benefits to surrounding plants, such as nitrogen fixation.Rhizobacteria often live in "nodules" found on plant roots, where they use plant produced leghemoglobin that carries oxygen to the rhizobacteria.While not widely used, inoculation of crops with PGPRs was introduced into North American agriculture over a century ago.

Moss:
While mosses often grow on trees as epiphytes, they are never parasitic on the tree.
Mosses are also found in cracks between paving stones in damp city streets, and on roofs.
Some species adapted to disturbed, sunny areas are well adapted to urban conditions and are commonly found in cities. Examples would be Rhytidiadelphus squarrosus, a garden weed in Vancouver and Seattle areas; Bryum argenteum, the cosmopolitan sidewalk moss, and Ceratodon purpureus, red roof moss, another cosmopolitan species.
A few species are wholly aquatic, such as Fontinalis antipyretica, common water moss; and others such as Sphagnum inhabit bogs, marshes and very slow-moving waterways.Such aquatic or semi-aquatic mosses can greatly exceed the normal range of lengths seen in terrestrial mosses. Individual plants 20–30 cm (8–12 in) or more long are common in Sphagnum species for example.
It is generally believed that in northern latitudes, the north side of trees and rocks will generally have more luxuriant moss growth on average than other sides.[17] This is assumed to be because the sun on the south side creates a dry environment. South of the equator the reverse would be true. However, naturalists feel that mosses grow on the damper side of trees and rocks.[3] In some cases, such as sunny climates in temperate northern latitudes, this will be the shaded north side of the tree or rock. On steep slopes it may be the uphill side.
Place your moss in fairly acidic soil. Mosses prefer a soil pH between 5.0 and 6.0. Tamp down the soil where you will place your moss, as loose soil will inhibit growth since mosses expand with spores and not roots.
No vascular system to transport water through the plant or waterproofing systems to prevent tissue water from evaporating, they must have a damp environment in which to grow, and a surrounding of liquid water to reproduce.
Are autotrophic they require enough sunlight to conduct photosynthesis
Grow chiefly in areas of dampness and shade, such as wooded areas and at the edges of streams. morning sun and daytime shade is best.
Since mosses do not have true roots, they require less planting medium than higher plants with extensive root systems. With proper species selection for the local climate, mosses in green roofs require no irrigation once established and are low maintenance.[21]

Rhizobacteria are root-colonizing bacteria that form a symbiotic relationship with many plants. The name comes from the Greek word rhiza, meaning root. Though parasitic varieties of rhizobacteria exist, the term usually refers to bacteria that form a relationship beneficial for both parties (mutualism). Such bacteria are often referred to as plant growth promoting rhizobacteria, or PGPRs. The mechanism by which the PGPRs promote the plant growth is not clearly understood, but it is believed occur through siderophore production, mineral assimilation, phytohormone production, and most importantly asymbiotic Nitrogen fixation.
Nitrogen Fixation is one of the most beneficial processes performed by rhizobacteria. Nitrogen is a vital nutrient to plants; gaseous nitrogen (N2) is not available to them due to the high energy required to break the triple bonds between the two molecules. Through nitrogen fixation, rhizobacteria can convert gaseous nitrogen (N2) to ammonia (NH3), making it an available nutrient that can support and enhance growth in the host plant. The host plant provides amino acids for the bacteria so they do not need to assimilate ammonia. The amino acids are then routed back to the plant with newly fixed nitrogen. Nitrogenase is an enzyme involved in nitrogen fixation. It requires anaerobic conditions so membranes within root nodules provide these conditions (Figure 1). The rhizobacteria need oxygen to metabolize, so plants provide oxygen in the form of Leghemoglobin, a hemoglobin protein produced within plant nodules. Legumes are well known nitrogen fixing crops and have been utilized for centuries in crop rotation to maintain soil health.
Some known varieties of PGPR bacteria include Pseudomonas putida, Azospirillum fluorescens, and Azospirilum lipoferum. Though microbial inoculants are indisputably beneficial for crops, they are not widely used in industrial agriculture, as large-scale application techniques have yet to become economically viable. A notable exception is the use of rhizobial inoculants for legumes such as peas. Inoculation with PGPRs ensure efficient nitrogen fixation; they have been employed in North American Agriculture for over 100 years

Rhizobacteria can live in a symbiotic relationship with plants. The plant growth promoting rhizobacteria, or PGPRs provide many benefits to surrounding plants, such as nitrogen fixation.Rhizobacteria often live in "nodules" found on plant roots, where they use plant produced leghemoglobin that carries oxygen to the rhizobacteria.While not widely used, inoculation of crops with PGPRs was introduced into North American agriculture over a century ago.

Conclusions

From the research done, the following parameters are concluded:

- Clay or peaty soils are the most siuted for moss and microbial growth, since they retain water and nutrients. Their structure is well define which helps microbes and moss' rhizoma to settle. They both hold water for long periods which is helpful when creating damp environments.
- Rhizobacteria promote plant growth. They live in the plants roots and need water to survive. The mayority of microbes thrives in neutral pH (6-7)
- Moss required less planting medium, prefers shaded, damp environments and slightly acidic pH(6-7), compressed soils.
- Vinegar and sulfur may be used for acidifying soils. Vinegar also helps in the electrolisis process.

Project Analogies

This chapter contains a recopilation of projects of similar nature to the prototype to be designed. The projects where chosen by their analogies to bio-photovoltaic cells, microbial fuel cells, or relevant instalations. The following list of projects are exposed:

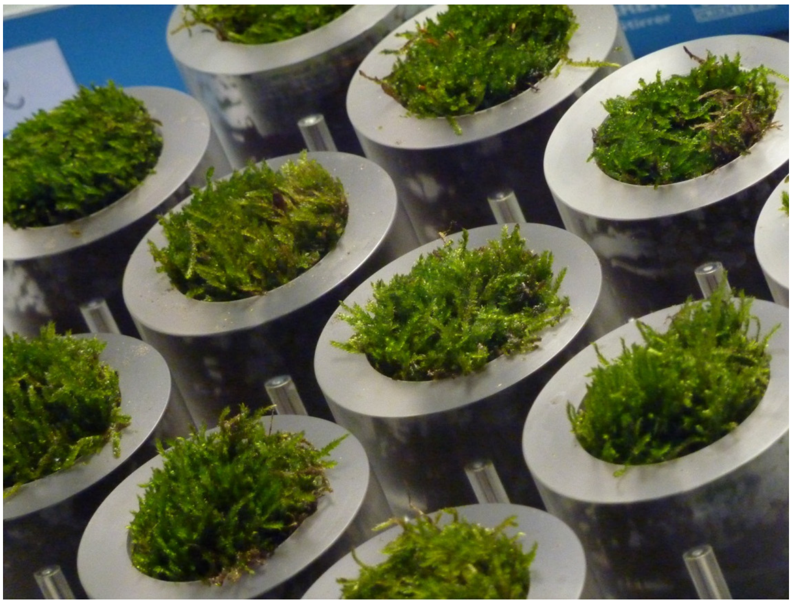
1. Moss Table
2. MudWatt
3. MicroBio
4. Nomadic Plants
5. VoltPot
6. Hanging Moss Garden
7. Surface Deep

BPV - 03

Filter:
project analogies and previous experiments

Programs:
microbial fuel cells, BPV projects, installations

The Moss Table:
The table incorporates an array of BPV devices which generate electricity. At present the energy generated by the table is not used to power anything. Instead an animation has been created which responds to the current output of the table. In this way people can 'see' the energy produced by the table.
Does the moss power the lamp?
No, it cannot currently generate enough energy to power the lamp. BPV technology is at an early stage of development and there are significant technical hurdles to overcome before products like the table are commercially viable.



Does the moss power the digital chock?
Yes – It can power small devices like a digital clock using some of the units operating inside the Moss Table.

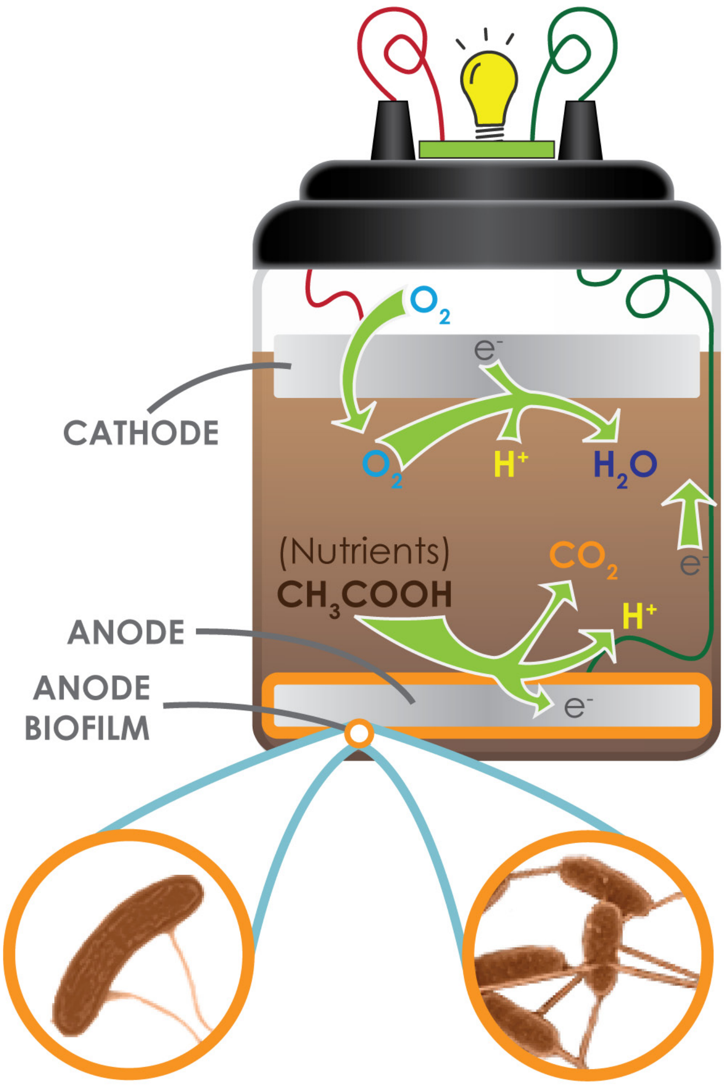
Why does the table incorporate a lamp?
The table is a concept product which demonstrates a potential future application of the technology. The idea behind the table is that energy generated during the day would be stored in a battery. In the evening this energy could be used to power a lamp.

How much energy is produced by the Moss Table?
Currently the table can produce about 520 Joules (J) of energy per day. A typical laptop requires about 25J per second, so in a day the table would produce enough energy to power a laptop for just 20 seconds!

The MudWatt:
MUDWATT™ MFC KIT

Explore the power of microbes with the MudWatt™ Microbial Fuel Cell (MFC) Kit. Simply fill this kit with soil from your backyard (or someone else's backyard), along with anything you find in your refrigerator. Within days the attached LED light will start to blink using only the power produced by the electricity-generating microbes in your soil!

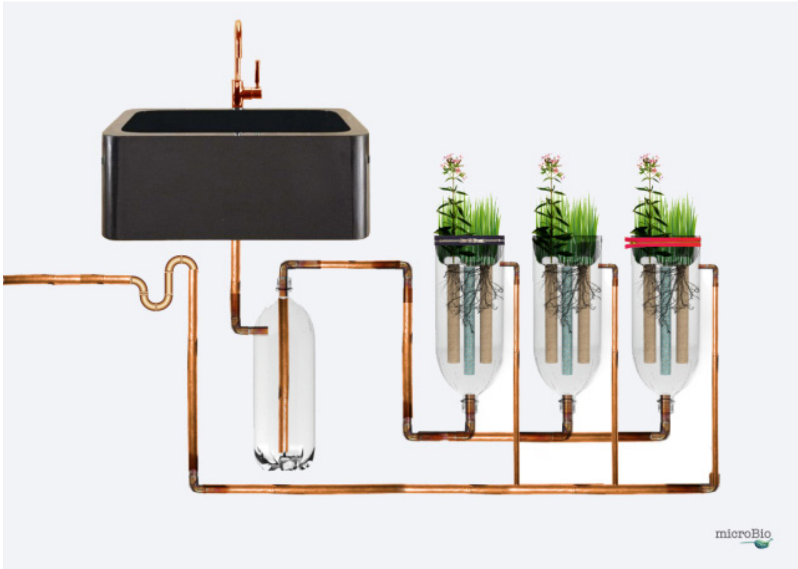
The MudWatt™ is the perfect educational kit for classrooms and hobbyists since it incorporates a wide range of scientific topics. It's easy to incorporate the MudWatt™ into a class discussion on microbiology, soil chemistry, electrochemistry, or electrical engineering. Visit our Community Page to share ideas and data and take part in the development of MFC technology!



Microbes are ubiquitous throughout virtually all soils and sediments on the planet. Among these diverse communities of microbes are particular species with unique metabolic abilities that enable them to expel electrons onto oxidized metal compounds, such as rust. In a sense, these so-called "electrogenic" microbes are able to "breathe" metal compounds much like humans and other organisms breathe oxygen. MFCs employ these unique abilities by providing the electrogenic microbes with a certain configuration of two inert, graphite-based electrodes placed in environments with different levels of oxygen

MicroBio:
Project microBio explores the possible applications for MFCs in households. We've focused in the potential of MFCs to reduce water consumption and pollution, since some of the microbes in the MFCs can also feed out of the nutrients and complex sugars found in grey waters.

The water already used in an activity (e.g. dishwasher) enters the microBio system. The first bottle from left to right is prevents the access of substances that may affect the microbes. It is a plastic bottle with a bore diameter of 2.5 centimetres on a side which acts as a grease trap.



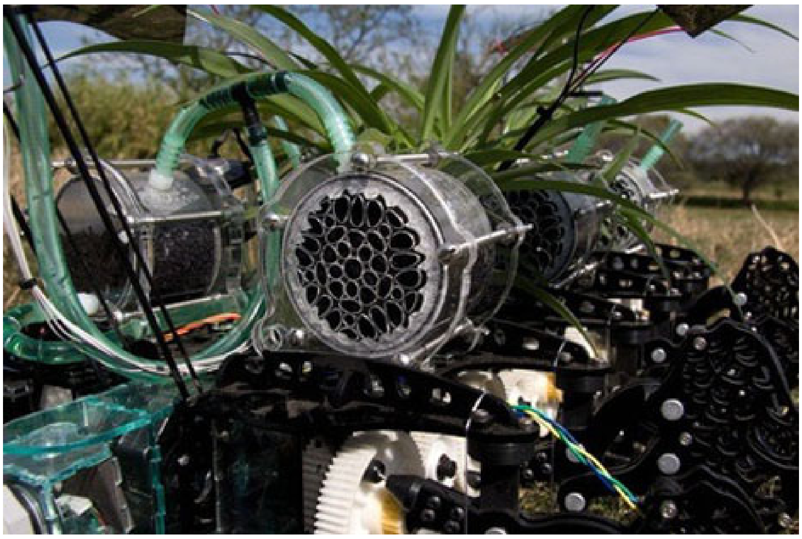
The next 3 bottles are MFCs that play a fundamental role as they are responsible for metabolizing the organic waste remaining on the water, releasing electrons in the process. The microbes' ability to digest organic compounds in the water, will ideally decrease its contamination by 63%.

Each of these 3 bottles has 2 types of plants: Saponaria and Reed Mannagrass, two species of plants that capture CO2 from the environment and release carbohydrates through its roots, providing a nutrients source to the microbes. These plants can be trimmed periodically to create organic soap.

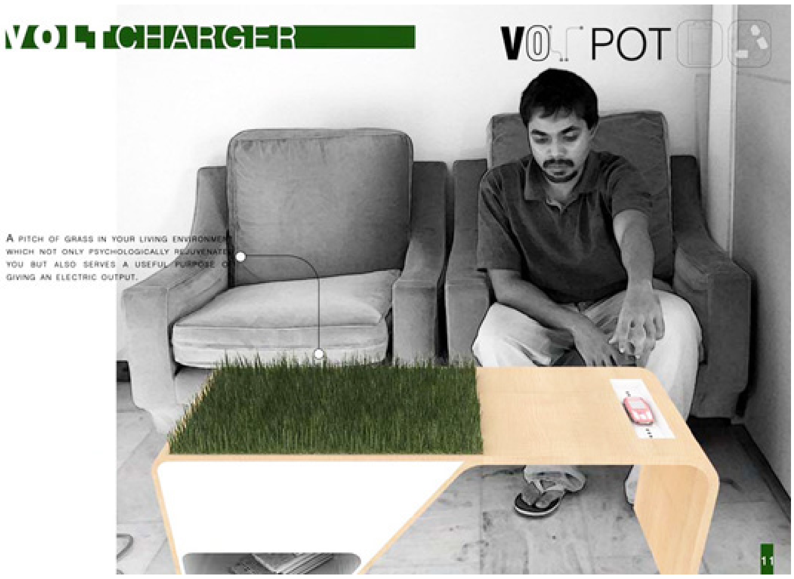
Each of the MFCs uses the KeegoTech MFCs monitor (hacker board with LED light) to prove the generation of electricity.

Nomadic Plants

What if an army of mobile robots could transform polluted water into plant life? Tracing a fine line between robot and plant, art project and self-sustaining mini-ecosystem machine, Mexican artist Gilberto Esparza's hybrid creation "Nomadic Plants" (Plantas Nomadas) is a quirky contraption that actively seeks polluted water to feed the vegetation and microorganisms living symbiotically inside its body.



Using a microbial fuel cell, the robot is designed to run on the bacteria found in polluted water, which are broken down and transformed in to energy that feeds the brain circuits of the robot. This is in turn allows the vegetation carried by the robot to grow. Says Esparza: "When these microorganisms need nourishment the machine seeks out dirty water, which is then decomposed to create energy; any surplus is used to emit a noise and sustain plants carried on its back. The machine and plants becomes co-dependent."



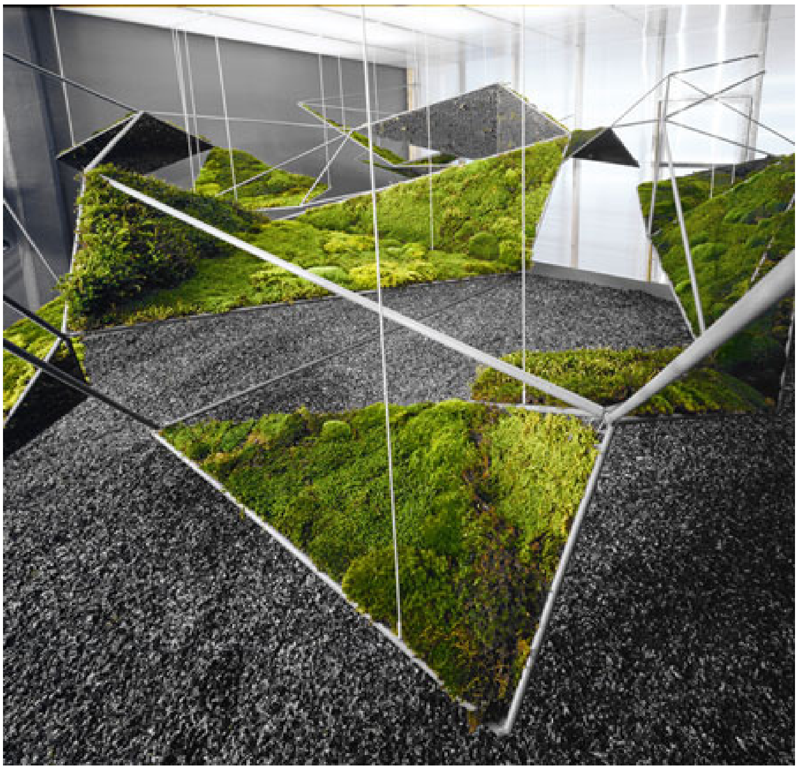
VoltPot:

Part coffee table and part planter, this awesome Volt Pot puts the environment to work indoors by harnessing the power of dirt to charge your gadgets! The fresh green planter pot has a built-in Microbial Fuel Cell that is capable of generating enough energy to charge small electronics, giving users an additional reason to bring the outdoors in.

Marrying sleek interior aesthetics with technology, Nectar Design believes that being sustainable is much more than skin deep, and has the ability to go beyond its natural green state.

Hanging Moss Garden:
Hanging Moss Garden

from the moistscape Installation, Henry Urbach Gallery, New York NY



Surface Deep:
When visitors stroll through Quebec's Redford Gardens, the first of many large installations they come upon is Surface Deep, an undulating, moss-covered structure designed by international architecture firm asensio_mah in collaboration with students from Harvard's Graduate School of Design. It was built last summer, but with this year's Metis International Garden Festival, Surface Deep is once again getting major foot traffic in the most literal sense of the word. Surface Deep is a mountable, climbable series of snaking panels that invites visitors to explore it in its entirety, from its long, sweeping form to its small, mossy nooks.