ALGAE TEXTILE

A Lightweight Photobioreactor
for Urban Buildings

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

ABSTRACT

By innovating the photobioreactor, the growth of algae can be deployed as a performative and ecological layer within contemporary building systems. Proposed is an *algae textile*: a building–integrated photobioreactor organized as a flexible membrane, whose form can be adjusted according to given programmatic and environmental conditions. This organization translates functions from industrial photobioreactors into forms that can operate at the lightweight scale of an enclosure or partition, demonstrating how algae might be integrated within the layers of a building as an alternative ecology. A typical curtain wall is used as an example to test new standards of geometry and materiality using the membrane, where parametrically–controlled quasiperiodic and conformal geometries are studied. These offer geometric plasticity when generating the reactor's organization, refining its ability to modulate light and view by varying porosity, and tailoring it to the characteristics of a given space. When paired with the minimal dimensions of transparent thin–film polymers, this method of forming enclosures shows how renewable resources such as algae can be positioned within buildings without an expansion in the wall assembly and easily retrofitted into existing ones to create performative next-generation building skins.

To support these qualities, design principles addressing both qualitative and quantitative measures are emphasized, aiming to define a photobioreactor's required behaviours when used specifically as a component within urban buildings. This direct integration of biology in architecture asserts that building material can be seen as a productive entity, contributing to the discourse surrounding postnatural urban ecology, and drawing from research exploring articulated material systems, including Achim Menges' composite membranes and Neri Oxman's use of digital morphogenesis. In this way, the industrial process of algae cultivation can be translated into complimentary building systems which acknowledge both the productivity and the aesthetic of algae: as agile components of a larger renewable resource network, and as icons for a self–sufficient urban lifestyle.

Keywords:

performative building skins, lightweight materials, reactive building membranes, photobioreactor, algae, postnatural ecology, synthetic biology, digital fabrication, parametric design, digital morphogenesis

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CHAPTER TWO

ACKNOWLEDGEMENTS

To seekers of experiment

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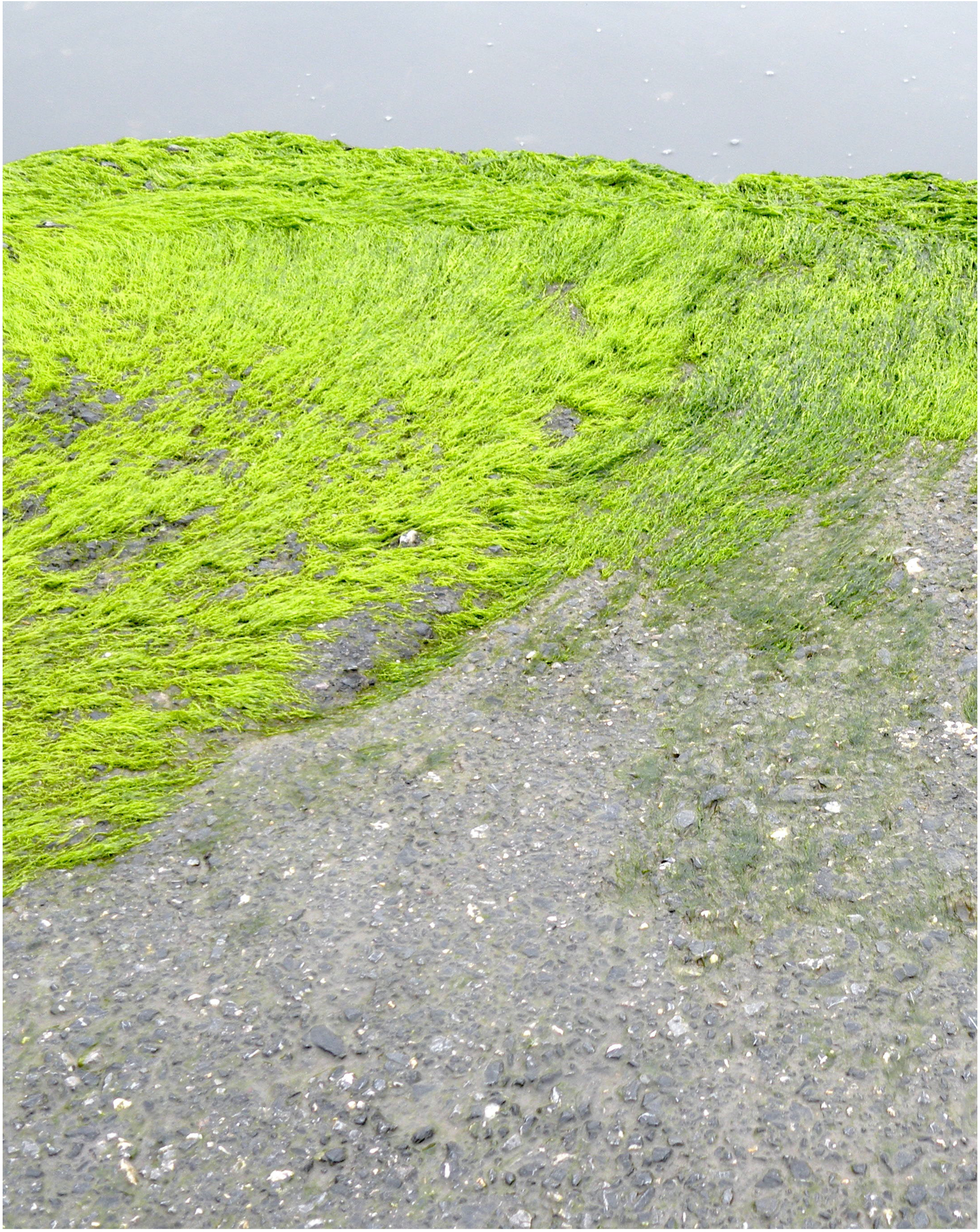
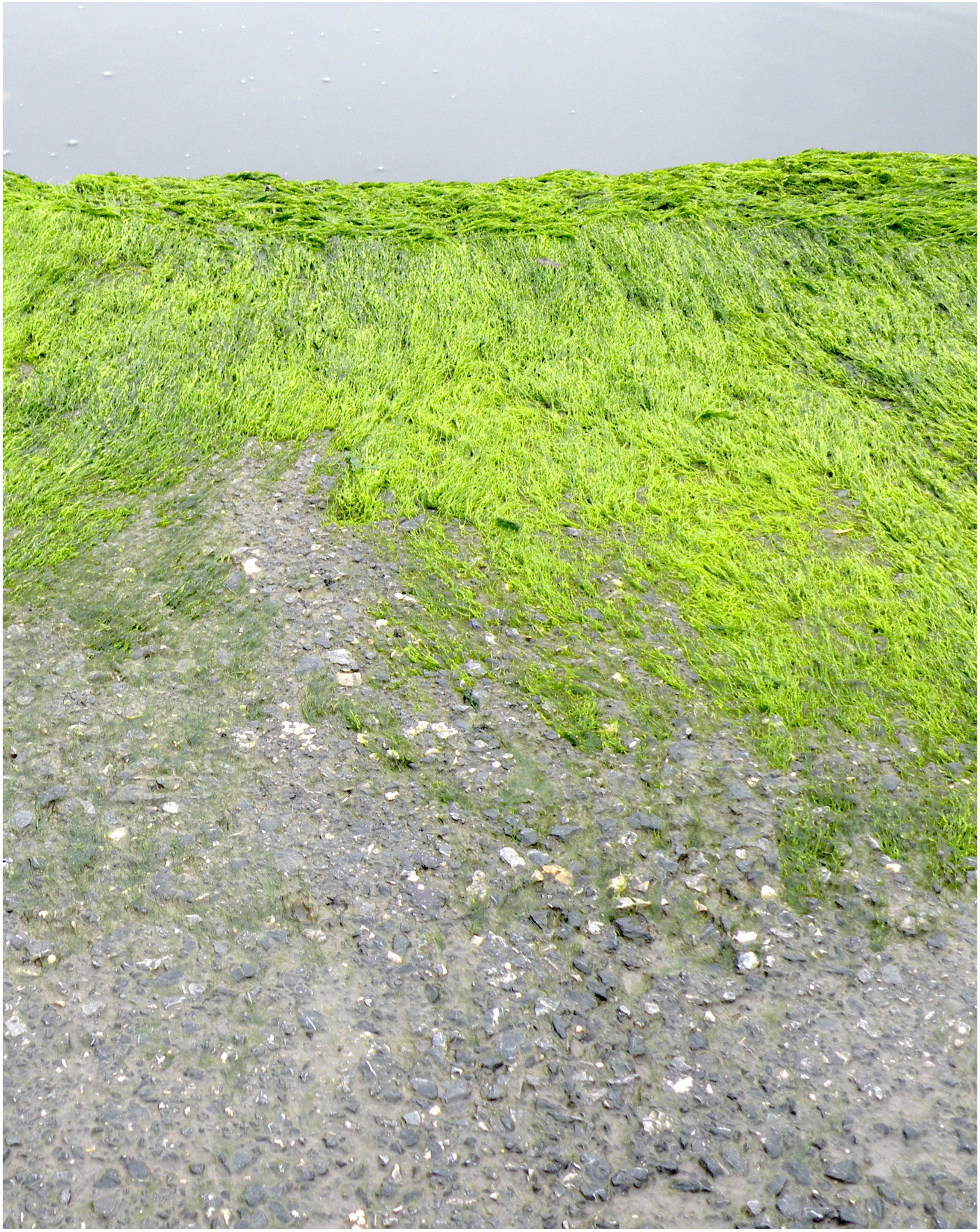




SUMMARY

To identify the possibilities of using algae in building–integrated systems, the first chapter begins by reviewing current methods of algae cultivation and the design of its photobioreactors. This project is undertaken to reveal the potentials of algae and its use as: (1) a renewable resource, and, (2) an alternative ecology in the city, contributing to pollution reduction, sustainable products, and improving the overall well-being of city dwellers. Most importantly, it is to show how this can be done using simple material substrates embedded within the layers of a building. To reconcile the challenges associated with algae's integration into an urban context, a set of photobioreactor design principles are established focusing specifically on a bioreactor's desired architectural characteristics. First, what is the reactor's spatial impact? This is investigated through materiality, construction and the aesthetic it imparts on a space. Second, is the system practical to implement? This is investigated through fabrication, installation and integration within a building's mechanical services. Finally, are there environmental impacts? This is investigated through potentials in carbon neutrality, daylighting and alternative energy in the urban environment. These design principles are used to help define what is needed for a bioreactor in a building–specific context and, in turn, helps to evaluate how the design of the *algae textile* aims to reconcile these challenges. These, together with annotated drawings, illustrate the design intentions and the context within which it rests.

The investigation continues with a second and third chapter. These engage in a complimentary discussion regarding postnaturalism* and machinic theory** as they relate to changing design methodologies and modes of making. This research is used to solidify the intentions behind the desired design characteristics of the algae textile and its use as an architectural bioreactor; where decisions regarding its spatial impact and practicality are driven by lightweight, flexible and adaptable qualities. These themes inform a method of postnaturalist making—using algae as a component in future postnatural ecologies—and motivate the development of materials which support active biological systems in building construction. The design and mechanics of the textile is examined in parallel to theoretical research which draws similar conclusions to reveal their correlation. This extended investigation speculates on the evolution of the algae textile and its place within a postnatural urban condition, and illustrates an implementation scenario of the textile used within a typical curtain wall.

** "Postnaturalism" aims to characterize a new dynamic between architecture and the environment in the age of the Anthropocene: a geological era where the human is dominant. It argues for methods which go beyond sustainability and green building to rectify architecture's effect on the environment and, instead, suggests a movement into a realm where living and non-living boundaries are breached through quasi-biological systems which enter the material palette of architecture. See chapter 2.1 Material Fertility.*

*** "Machinic Theory" describes the qualities found in the study of cybernetics, artificial life, and artificial intelligence; machines which closely mimic biological behaviours. See chapter 2.2 Consulting Machinic Theory.*

1.1

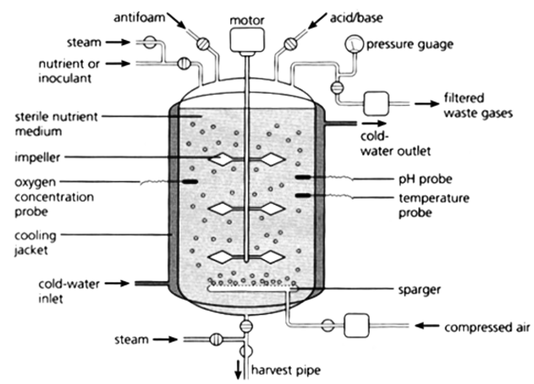
INTRODUCTION

1.1

The Bioreactor in Architecture

The term *bioreactor* refers to any device which has been engineered to support the growth of a biologically–active substance; namely, organ tissue, fungi, cellulose or bacteria. *Photobioreactors* are specific to the growth of phototrophic organisms like algae. These range in design, and can be found in the form of large scale farming operations as open–pond systems, to smaller scale closed–loop systems which circulate algae through a matrix of tubing. While present developments in bioreactor technology focus mainly on industrial applications, there is evident potential in translating the engineering principles of a bioreactor into the architecture of a building through material systems and claddings—making it possible for algae to act as an integral component within the envelope of urban building typologies, and turn impervious urban surfaces into productive entities which emulate the oxygenating benefits of hectares of forestland.

Traditional forms of the photobioreactor lack an ability to adapt to any situation or context. They are often cumbersome, robust or confined to the laboratory bench–top, making it difficult to implement the technology into urban contexts and within buildings. Consequently, it can be argued that this circumstance contributes to the difficulties which exists in making algae an integral part of city life—given its potential benefits. The cultivation of algae in an urban setting can contribute a valuable alternative energy resource, and is an advantageous method for wastewater recycling, air purification, CO_2 sequestration, and nutrient recovery for the production of sellable products such as biofuels, nutritional supplements, pharmaceuticals, fertilizer or bioplastics. Compared to industrial scale algae production—which is focused on producing high–yields of biofuel—it is evident that urban scale algae production is, instead, focused on its distributed environmental and economic impacts. Algae is capable of producing valuable products for society, and makes it an important technology to assess when evaluating renewable resources for the built environment. However, unconventional systems require new standards. Therefore, the development of appropriate standards for algae and its use in buildings could help alleviate current difficulties associated with this emerging technology, and determine its relevance to the creation of a self–sufficient urban lifestyle. Further research in this area will help propel advancements in the technology, and strengthen the future use of algae as a closed–loop resource where it is needed most: in cities and buildings.



1–02 *(above) Technical components of a laboratory bioreactor in section. (www.fermentor.co.in) (below) A bench–top photobioreactor growing algae in a lab. (www.sepmag.eu)*

MECHANICS:

NUTRIENT DELIVERY (INOCULATION)

The nutrient delivery system injects the appropriate fluids into the solar array at a given time through plumbing outfitted with controlled valves and manifolds.

For Starting a New Culture:

The reactor is filled with a 1:10 ratio of concentrated algae culture and growth medium (water and nutrients). This starts the first growth cycle in the reactor.

For Maintaining an Existing Culture:

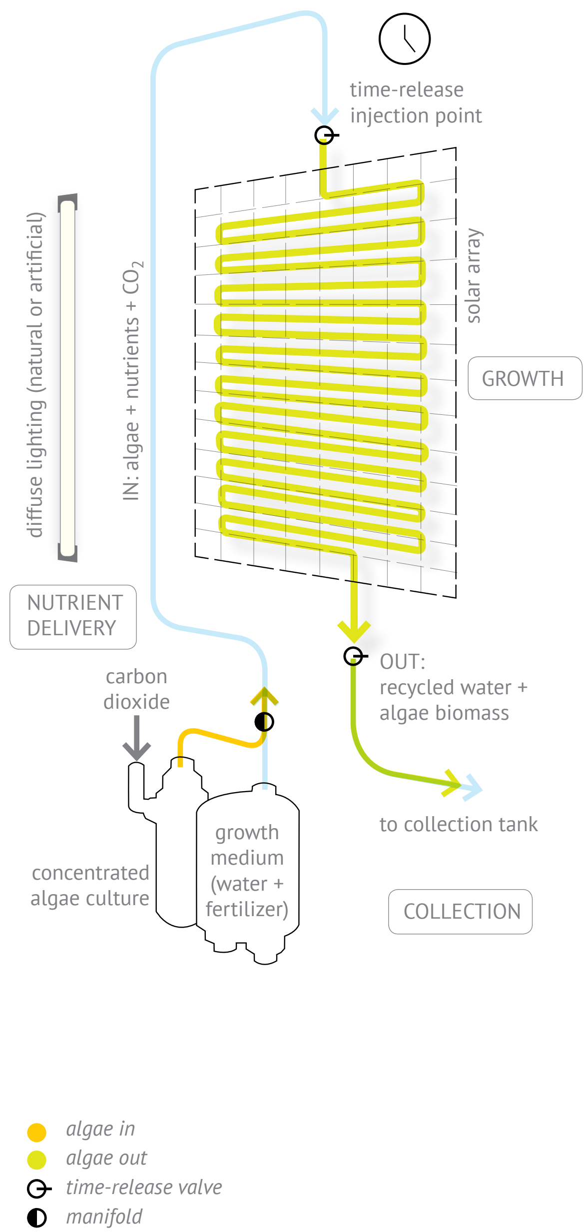
After growth, one tenth of the aged culture is extracted from the solar array and sent to a collection tank for further processing. Then, the system only injects growth medium into the solar array. This replaces what was extracted, creating a new diluted culture within the array and, thus, staring a new growth cycle.

GROWTH

Once the nutrient delivery system has injected the appropriate fluids, the air pump runs continuously to circulate the culture as it is exposed to light within the array. The air pump can either pull in CO_2-rich interior/exterior air, or from a CO_2 tank. In either case, a micron filter should be installed on the end of the pipeline to avoid contamination of the culture.

COLLECTION

After a set growth period, the initial culture will have grown greener and denser. This signifies that the culture is ready for collecting and resetting.

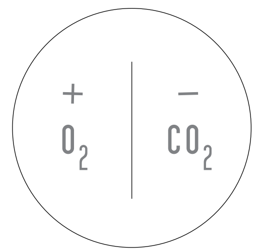


1–03 *Basic photobioreactor components. Developed in consultation with Heather Roshon, technical curator of the Canadian Phycological Culture Centre.*

Assessing Algae's Use in the Built Environment

The benefits of algae are not limited to biofuel production. In fact, experts suggest that algal cultivation is more effective when used to perform other functions, suggesting that, when used in the city, the benefits of algae do not have to be justified by fuel production alone.[1] [See 2.3 *Challenges and Suggested Solutions*]

This study operates under the premise that an algae–based urbanism and its necessary economic and infrastructural network have been established and implemented. The algae textile is intended to offer a complimentary building system for this infrastructural shift, suggesting a possible outlet for algae production in the urban realm using building skins which act as both small–scale generators within a highly distributed network of algae production, and as icons for a new urban culture where users and resource are locally networked.

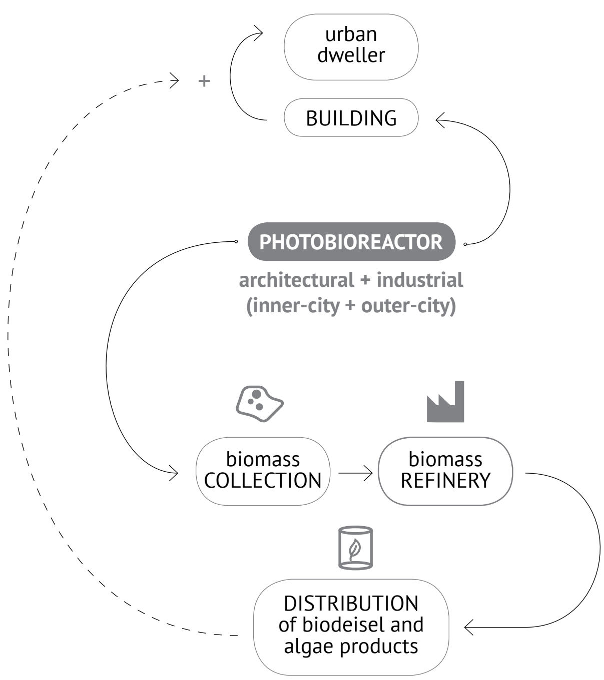


PHOTOSYNTHESIS

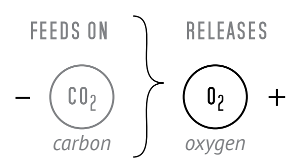
Algae's highly efficient photosynthesis cycle equates the production of oxygen from one algae culture to that of a forest of trees.

This contributes great benefits for clearing polluted air in the city by reintroducing oxygen into the atmosphere and absorbing excess carbon dioxide caused by anthropogenic activity.

ALGAE INDUSTRY NETWORK



RAPID CARBON CYCLING



as highly efficient photosynthesizers, algae produces 70-80% of all oxygen on earth

1 Gundula Proksch, "Growing Sustainability: Integrating Algae Cultivation into the Built Environment," *Introduction*, (Edinburgh Architectural Research Journal (EAR), Volume 33, 2013) http://sites.ace.ed.ac.uk/ear/files/2013/05/147–1621.pdf

1–04 *Algae's benefits in an urban context.*

FOOD
+
FUEL

ENERGY

WATER CYCLING

CLOSED-LOOP

Through its growth and rapid ability to multiply itself algae produces biomass which can be processed into valuable products such as biofeuls, nutritional supplements, pharmaceuticals, or bioplastics.

Therefore, in addition to clearing atmospheric pollutants, algae can contribute to a sustainable economy.

Algae can process, and be grown within wastewater. This puts use to grey water produced from building services, and processes accumulated contaminants in a sustainable way.

By recycling the products of different processes, algae cultivation contributes to a closed-loop approach to future environmental and economic efforts.

HIGHEST YIELDING RENEWABLE ENERGY CROP

121,000 LITRES OF BIODEISEL PER HECTAR PER YEAR

for every litre of biodeisel derived from palm oil, algae can produce 25

EFFECTIVE WASTEWATER TREATMENT

contaminants:

NH_4 — NO_3 — PO_4

ammonium *nitrates* *phosphates*

EATEN BY ALGAE

ALGAE CAN DOUBLE ITS MASS IN LESS THAN

24HRS

WHY IS THIS IMPORTANT?

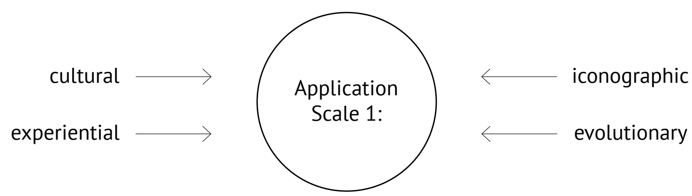
Intent and Application Scales

There is a range of applications and capacities to which algae can be introduced into the urban environment. The algae textile alone cannot encompass every requirement, nor be expected to encompass all applications of algae once it is introduced in an urban setting. This is the reason for centring the intentions of the algae textile around applications which are more akin to Application Scale 1. Here, priorities such as production, yield, and efficiency become secondary in an effort to create sentient urban spaces which use algae to instate changing views of urban ecology through architecture, and only as a piece in a larger algae industry network.

1–05 *(left) The conflicting priorities between urban algae and the architect's needs, and industrial algae and the engineer's needs.*

well suited for the algae textile

< SUITABILITY SCALE >



① **ARCHITECTURAL ARTIFACT**

Priorities

– creating urban place
– an experiential / iconographic urban fixture, as a part in a larger algae industry
– urban air purification (carbon cycling)
– renewable energy (to power lights, etc.)
– urban real-estate, street-level activation
– minimum envelope requirements

Considerations

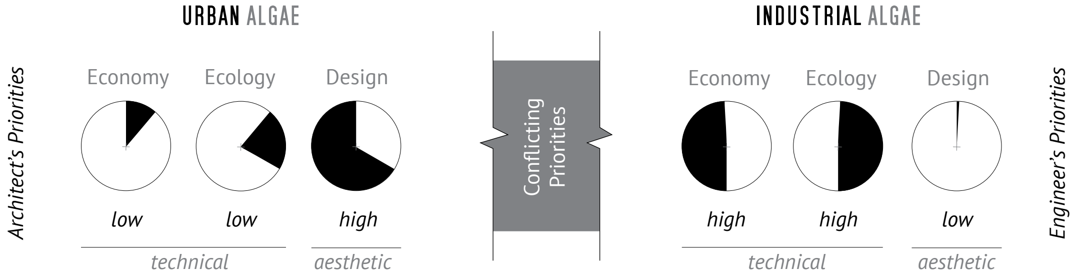
If the algae textile were to be used in this capacity, it must be designed in such a way which allows it to integrate into existing urban building systems: by maintaining minimum dimensions and an ease of installation.

② **URBAN ECOLOGY**: GARDEN, PARK, OR LANDSCAPE

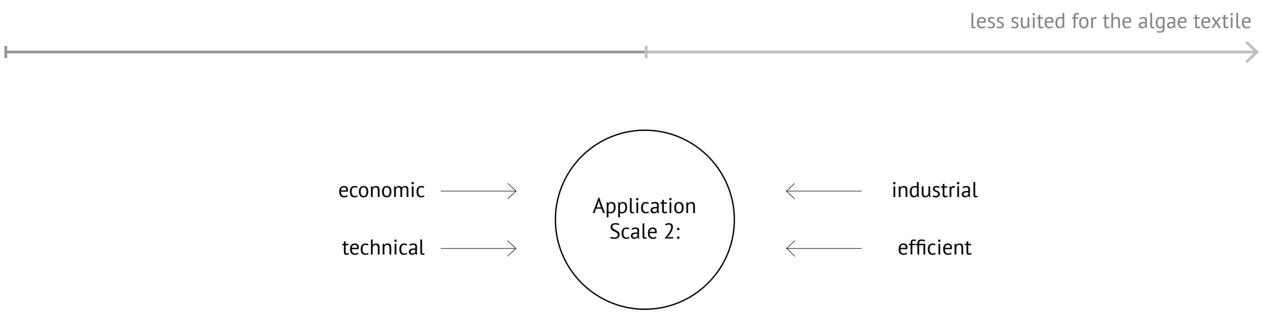
– creating urban place
– a experiential / iconographic urban fixture, as a part in a larger algae industry
– urban air purification (carbon cycling)
– renewable energy (to power lights, etc.)
– urban health and well-being
– mirco greenspace

If the algae textile were to be used in this capacity, a means to deal with exterior conditions and cold climate would need to be addressed.

APPLICATION SCALES
for algae in the built environment



Urban algae efforts place a higher priority towards design rather than technical performance. These are interests which make architects and clients more receptive to accepting algae technology as it does not require a large industrious commitment. There is a place for industrial systems which are more effective, and it should not be suggested to also integrate them into buildings in the same capacity.



3 BUILDING SERVICE

Priorities

- building health and occupant well-being
- self-sufficient (closed-loop resource consumption)
- instate renewable energy systems
- storage and maintenance of product
- solar exposure, access, circulation

Considerations

If the algae textile were to be used in this capacity, a means to coordinate the textile's plumbing network to the building's service and mechanical systems would be needed, and would only act as a part in a larger algae industry network to support a fully algae-based urbanism.

4 COMMODITY: ENERGY, FUEL, AGRICULTURE

- high yield, low cost
- orchestration of product
- industry coordination and economic gains
- storage and maintenance of product
- solar exposure, access, circulation

If the algae textile were to be used in this capacity, it would have to be implemented only as a component in a larger agricultural algae network. The support systems and depth of the material section would have to drastically increase to maintain valid production yields.

1–06 *Application streams for algae in the built environment, covering differing capacities and scales, and outlining the differing priorities and requirements which determine their valid implementation.*

1–07 *Detail of WaterLilly algae wall by Cesare Griffa (cesaregriffa.com, 2014), and Algae Canopy by ecoLogicStudio (ecoLogicStudio, 2014)*

A large range of precedents for the use of photobioreactors and algae in an urban context can be found in current design discourse. For example, *WaterLilly*, exhibited at EXPO Milano 2015 alongside ecoLogicStudio's *Algae Canopy*, is an algae wall system designed by architect Cesare Griffa, who runs an algae–focused practice in Torino. As a prototype for an, "algae–integrated architectural cladding and urban agriculture system,"[2] the project demonstrates how algae—when integrated in buildings—can offer important opportunities for creating innovative energy and food production systems within the city; contributing to a sustainable future.

Griffa also argues for the repurposing of architectural surfaces into valuable and productive entities in the built environment, stating that:

> *Building and architectural surfaces are an incredible resource of space. Urban façades and roofs represent billions of square metres that instead of being made of inanimate material such as concrete, could become clever photosynthetic surfaces that respond to the current state of climate warming.*[3]

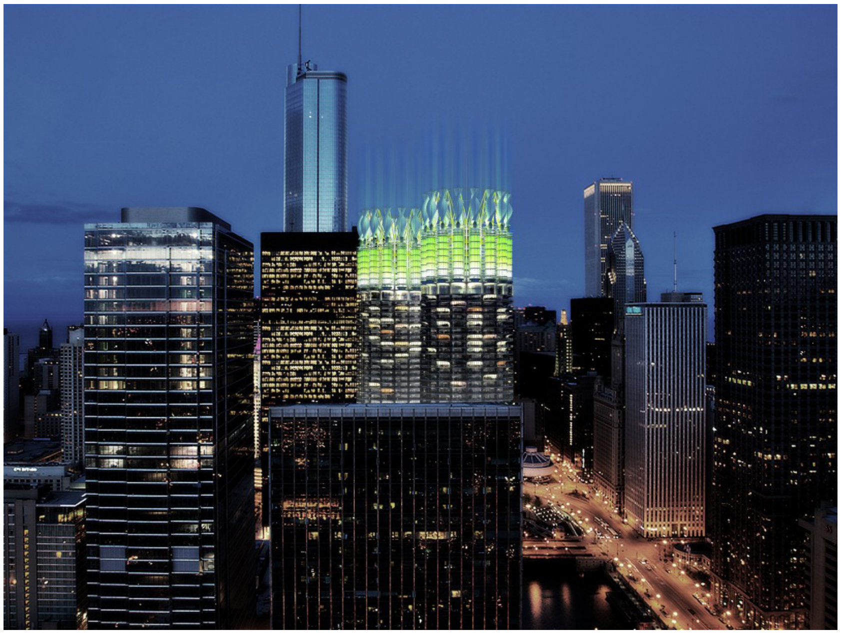
By pairing algae's highly efficient photosynthetic abilities with the creation of a material system that can be easily implemented within existing building stock, projects like this demonstrate the potential benefits to reevaluating and augmenting the architect's traditional palette of material. In doing so, one can begin to innovate a building skin's assembly and the purposes its material may serve within the building.

Urban Algae Canopy will produce the oxygen equivalent of four hectares of woodland and up to 150kg of biomass per day, 60% of which are natural vegetal proteins.

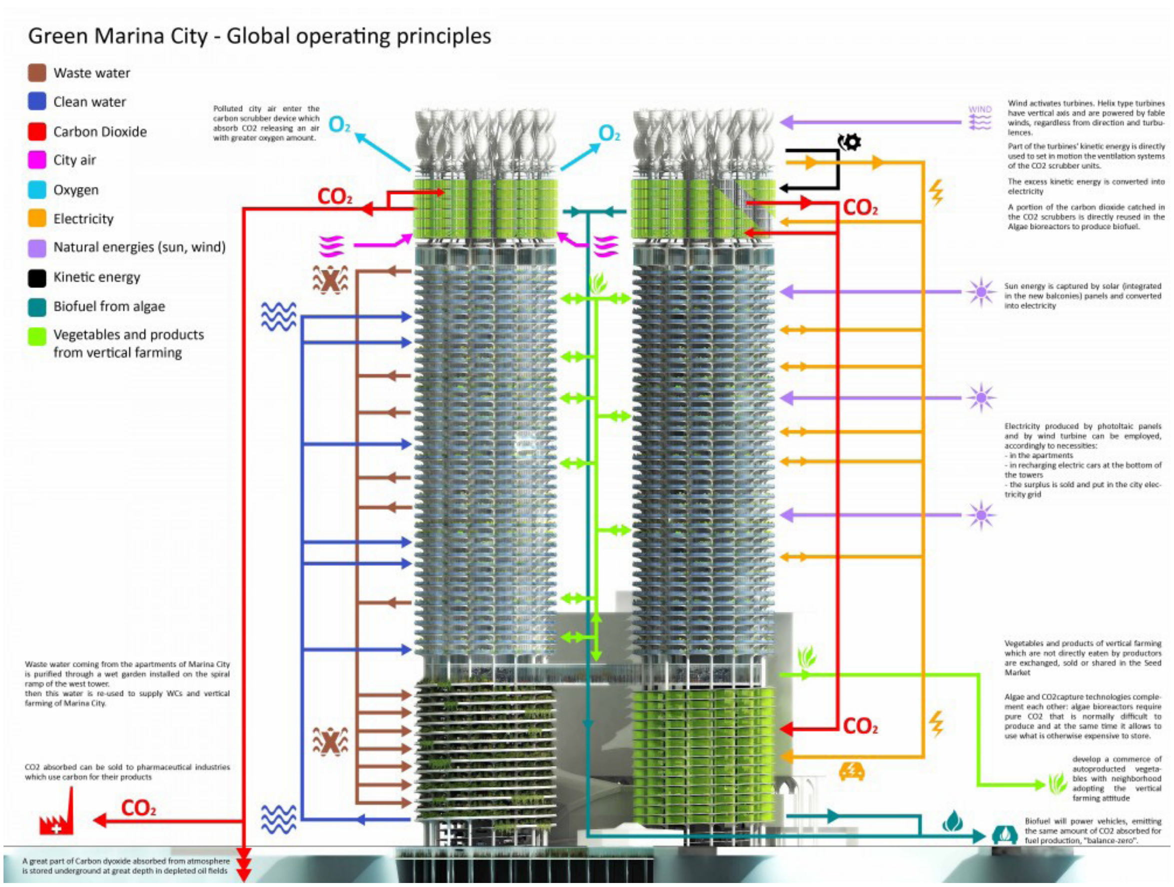
—ecoLogicStudio, EXPO Milano 2015

1–08 *WaterLilly algae wall and Algae Canopy installation at EXPO Milano 2015 (cesaregriffa.com, 2014)*

2 Cesare Griffa, "Algaetecture | Expo 2015 Preview" (cesaregriffa.com, April 7, 2014) http://cesaregriffa.com/2014/04/07/algaetecture–expo–2015–preview–algae–systems–to–design–and–feed–the–city/
3 Cesare Griffa, "Algaetecture | Expo 2015 Preview," 2014.



1–09 *AlgaeLoop retrofit of Chicago's Marina City Towers. (Influx Studio, 2011)*



AlgaeLoop by Influx Studio is a project which uses algae in architecture on a greater scale, proposing a fully integrated algae system for urban towers. By projecting on the future shift to a zero carbon economy, the project aims to identify the spatial implications of algae photobioreactors, and where they could be placed in central urban areas. By proposing a retrofit of Chicago's Marina City towers, Influx studio believes re–use is the most valuable approach. Reusing and retrofitting existing buildings with algae–based technologies places the benefits of algae where the control of CO_2 emissions is most important:

> *This situation reveals the enormous need to introduce a new sustainable model which allows closed loops in terms of providing clean energy, reducing and absorbing CO_2 emissions, and finally, allowing sustainable economic growth. The introduction of the algae green technology has a major role to play to achieve zero environmental footprint in the core of the city.*[4]

If implemented, algae could contribute to increased economic development while reducing green house gas emissions; a potential solution to one of the biggest challenges most cities face for the creation of a sustainable future. By recognizing the importance of algae as a closed–loop energy resource, speculating on how it could be integrated within the built environment, and defining what spatial implications it may require, the *AlgaeLoop* and other algae–based proposals stress an importance on creating an availability for appropriate building systems for algae and the need to clearly define what the *architectural* requirements of a photobioreactor might be—outside of mechanical– or industrial–based criteria.

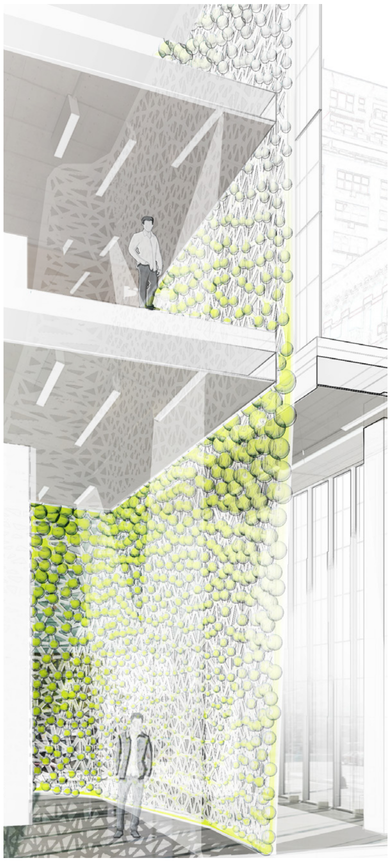
1–10 *AlgaeLoop building section of integrated system. (Influx Studio, 2011)*

4 Alison Furuto, "Algae Green Loop / Influx Studio" (ArchDaily, December 12, 2011). http://www.archdaily.com/191229/algae–green–loop–influx–studio/

DESIGN MODULE
I

TEXTILE DESIGN

1. Spatial Impact
2. Practicality
3. Environmental Impact



1–11 *The algae textile as a building-integrated photobioreactor.*

The algae textile consolidates the components of a traditional photobioreactor into a lightweight system which can be easily integrated within typical urban building assemblies and enclosures. In doing so, traditional partitions can be reinvented into productive entities. The textile takes the form of a flexible polymer membrane which has a network of voids running through its interior. This allows for a growing algae culture to circulate within it, and offers an ability to attach the system to existing structures using simple hardware due to this lightweight character. Given the spatial demands of a building's design, the textile also focuses on providing variability in its form to allow the geometry of these interior voids to coordinate with contextual building conditions such as programme, light or structure. These desires suggest a need for a photobioreactor to be highly customizable when used in an architectural context. If a photobioreactor is able to satisfy the programmatic demands of a building's floor plan, its intended design aesthetic and occupant comfort, then the integration of algae in the built environment may become more prevalent in typical practice. If taken as a method for generating performative building skins, the textile could then be implemented on any given building condition to transform partitions into productive surfaces. Every building has its own context, program, size, view, corridors, orientation, etc., which effect the design parameters of the textile differently. This calls for a tailored approach to derive an appropriate pattern for the given situation, and why it is desired for the geometry of the textile to afford a level of plasticity; which is aided by parametric modelling.

In effect, the needs for a photobioreactor in a building prove to be very different in comparison to those engineered for industrial uses. For the architect, adjusting qualitative parameters such as form, light or occupant comfort often take priority over quantitative parameters such as technical or mechanical outputs. As a result, a set of design principles which focus on the combined qualitative and quantitative requirements of a photobioreactor are needed. Three principles are established for the design of the algae textile: spatial impact, practicality, and environmental impact. These design principles are used to help define what is needed for a photobioreactor in a building–specific context and, in turn, helps to evaluate how the design of the algae textile reconciles these challenges.

Architectural Applications

ARCHITECTURAL ARTIFACT 1

URBAN ECOLOGY 2

BUILDING SERVICE 3

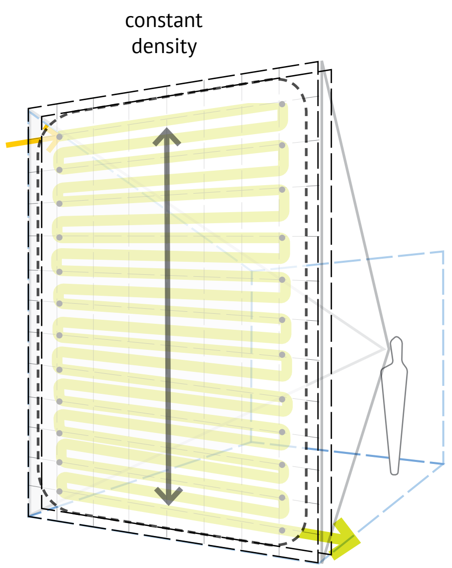
Primary Concerns

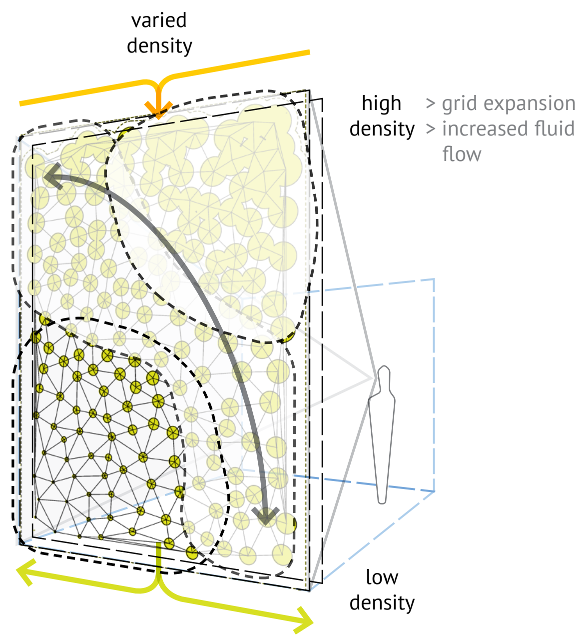
Spatial Impact → Practicality → Environmental Impact

1–12 *Photobioreactor Design Principles* pro / con

Spatial Impact

zone creation

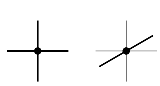




STANDARD PHOTOBIOREACTOR

- translucent
- fixed geometry (low plasticity)
- cumbersome
- low porosity
- robust and obtrusive

Geometric Ordinance
Grid Classification:



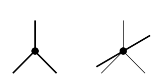
Grid Efficiency:
4 points of connection

Cartesian Array
• Inefficient Meshing (maximum connections)
• Defines ordered points in space
Mesh refinement and adaptation is difficult to resolve if points are modified for variance.

ALGAE TEXTILE

- translucent
- variable geometry (high plasticity)
- lightweight
- high porosity
- subtle and atmospheric

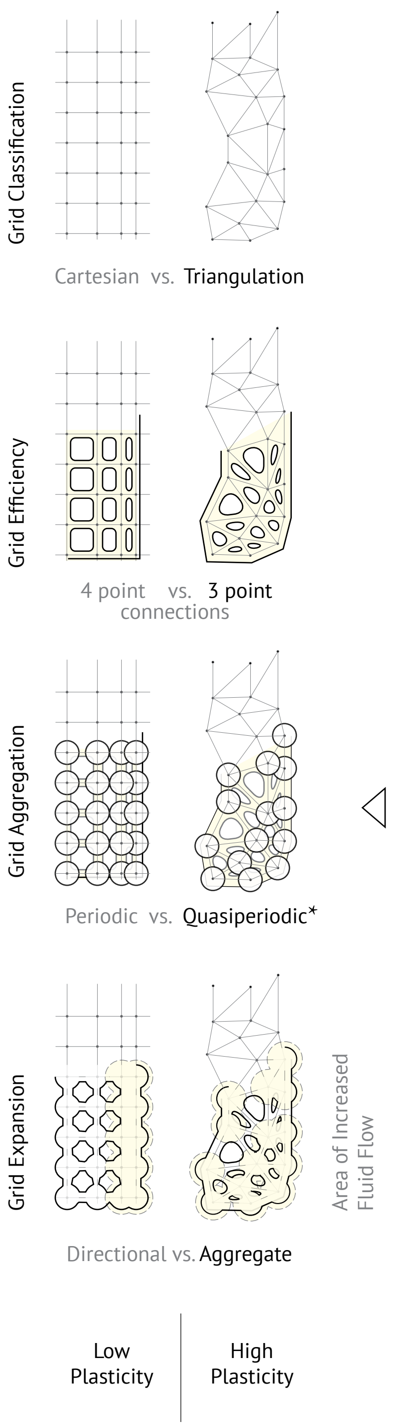
Geometric Ordinance
Grid Classification:



Grid Efficiency:
3 points of connection

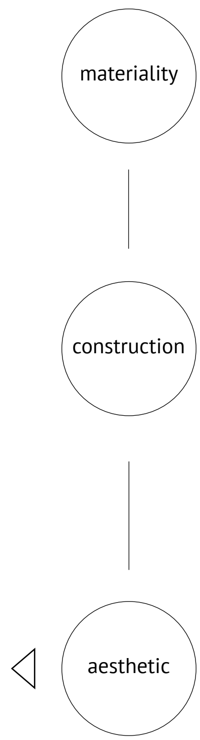
Delaunay Triangulation
• Efficient Meshing (minimal connections)
• Can define irregular points in space
Mesh refinement and adaptation is easy to resolve if points are modified for variance.

1–14 *Plasticity Comparison*



* *Plasticity*: the quality of being easily shaped or moulded. It describes an object which can easily alter according to contextual fluctuations.

* *Quasiperiodicity*: a recurring pattern with a component of unpredictability and irregularity.



factors to assess:

What is the system's dominant material quality?
Opaque? Translucent? Rigid? Flexible?

To benefit the widest range of applications, it is preferred that the photobioreactor be flexible in both material and form, and provide a translucency and subtlety so as to not impede on interior spaces. *[See 1.2 Textile Mechanics, (b)]*

What are the construction characteristics of the system?
Lightweight, or cumbersome?

To make the implementation of photobioreactors in buildings manageable, it is preferred that the attachment and supporting infrastructure of the system are low–profile and minimal. This will also make the reactor suitable for use in both retrofit and new–construction projects. *[See figure 1–25]*

What aesthetic does it impart on a space?
Differing levels of porosity and translucency?
Subtle and atmospheric, or dominant and robust?

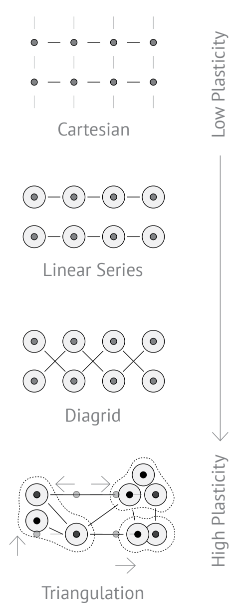
The design of the photobioreactor must also benefit the character of the space it surrounds. For example, its ability to modulate light and shade, or the visual interest provided by its transformation and movement between growth cycles. For this, an ease in generating the networked path within the textile around irregular contextual and environmental conditions is required and, therefore, geometries offering plasticity are desirable.*

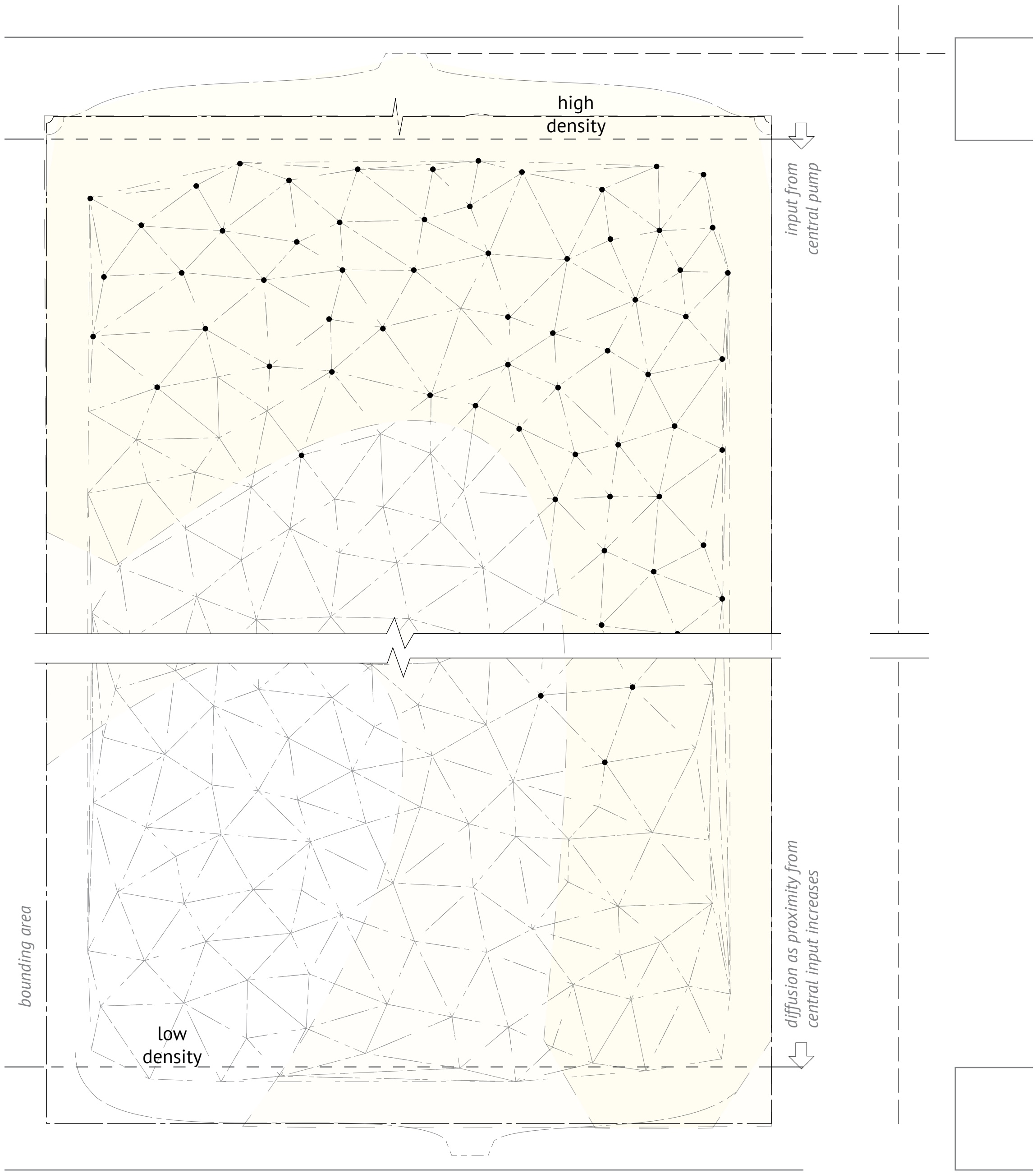
Geometric Plasticity

In mathematics, plasticity is used to describe discrete differential geometry: random triangulations and emergent conformal structures, like in the study of fractals. In neuroscience, it describes how neural structures in the brain change through experience, and in biology, it describes how organisms can change their phenotype in accordance to their environmental surroundings: the branching structure of corals to optimize sun and shade conditions for photosynthesis. In all cases, they are derived through evolved physiological or morphological mechanisms used to cope with contextual fluctuations, and a major component in achieving geometric plasticity.

The Aesthetics of Plasticity

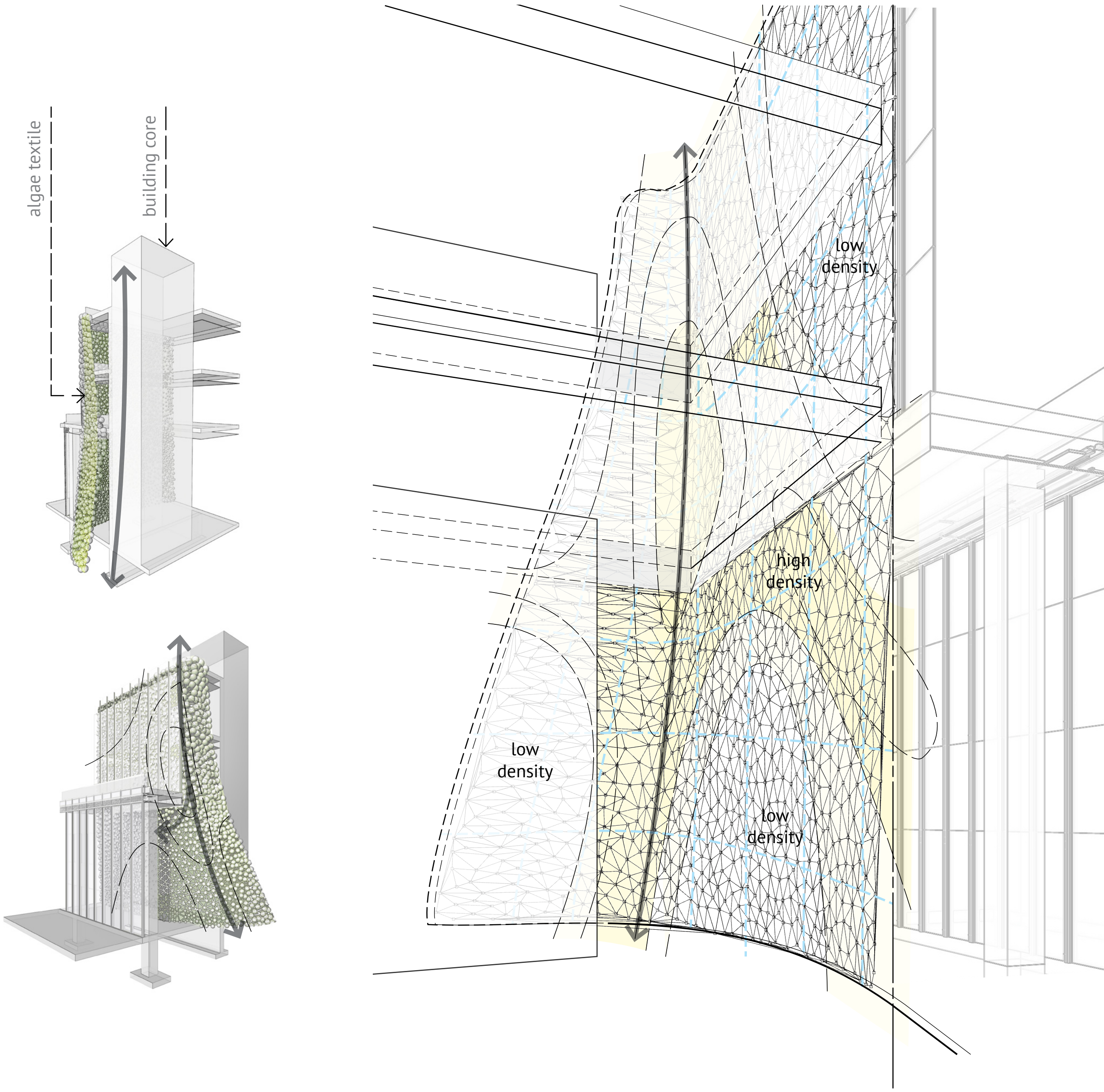
Models of plasticity are prevalent in adaptive systems and can be seen to benefit aspects of design relating to variability. Consequently, the aesthetic it may produce should be studied—suggesting a new paradigm in design which moves away from Cartesian geometries, and towards triangulated and conformal geometries which efficiently alter according to spatial fluctuations given by a context.





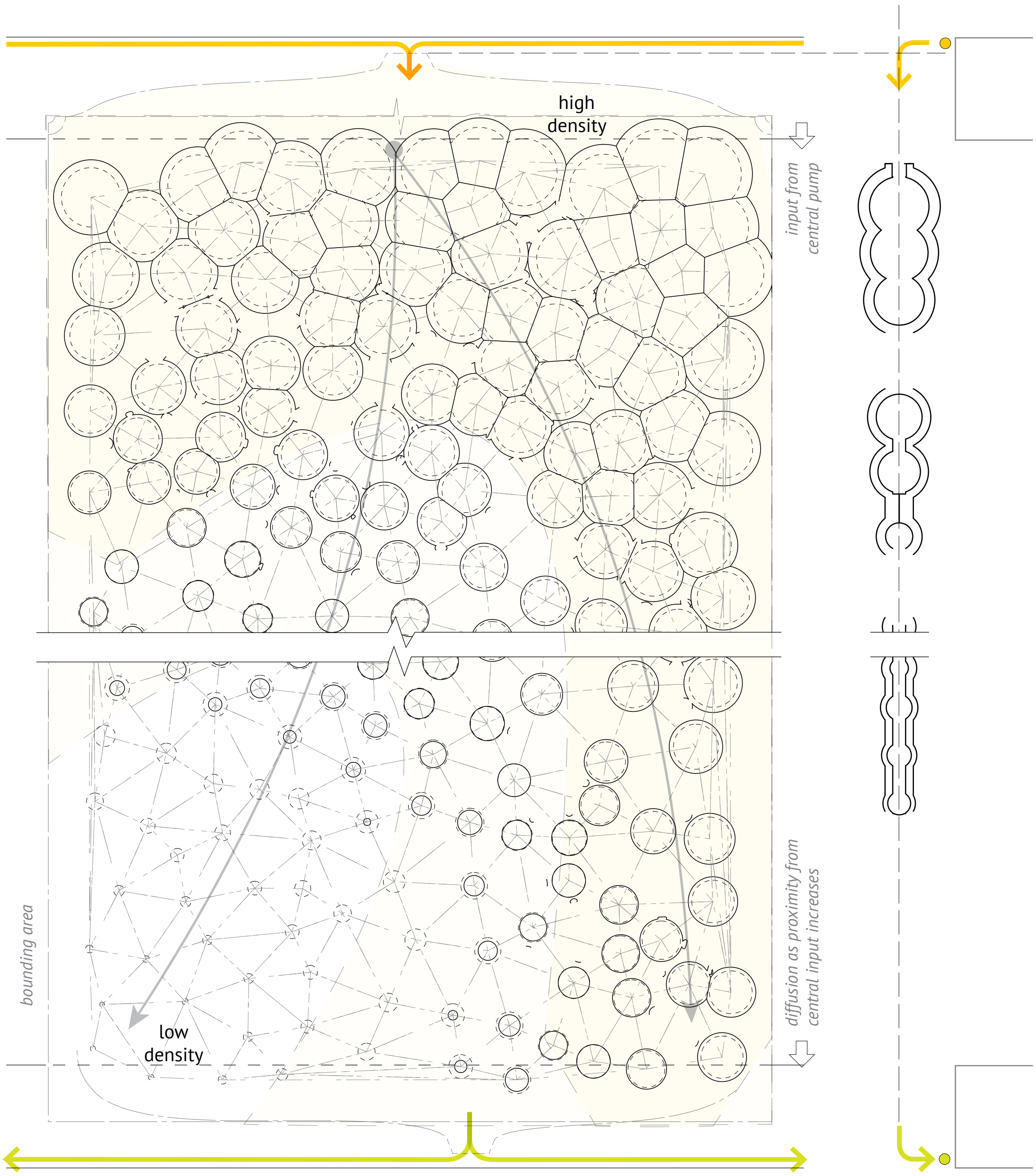
TEXTILE COMPONENT: **AGGREGATION AND DENSITY**

1–15 *Creating the form of the textile begins by defining the area of application and the desired density of the triangulated mesh. This area is represented as a series of points that can be manipulated to either aggregate around structure or openings to tailor it towards its surroundings in the building.*



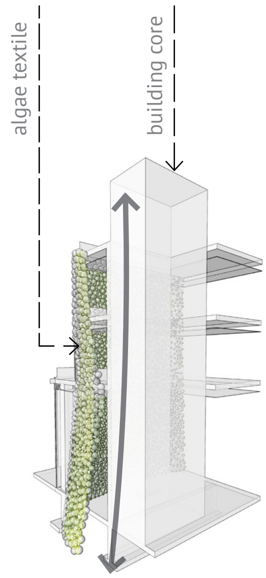
BUILDING INTEGRATION

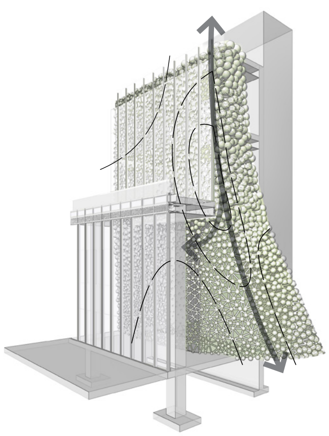
1–16 *In this example the points aggregate in a downward gradient to align the plumbing services of the photobioreactor with the architectural condition given by floor slabs and the building core. Acknowledging where structural and service lines are in relation to where the algae textile is being placed within the building will help generate the best aggregation of points for the membrane.*

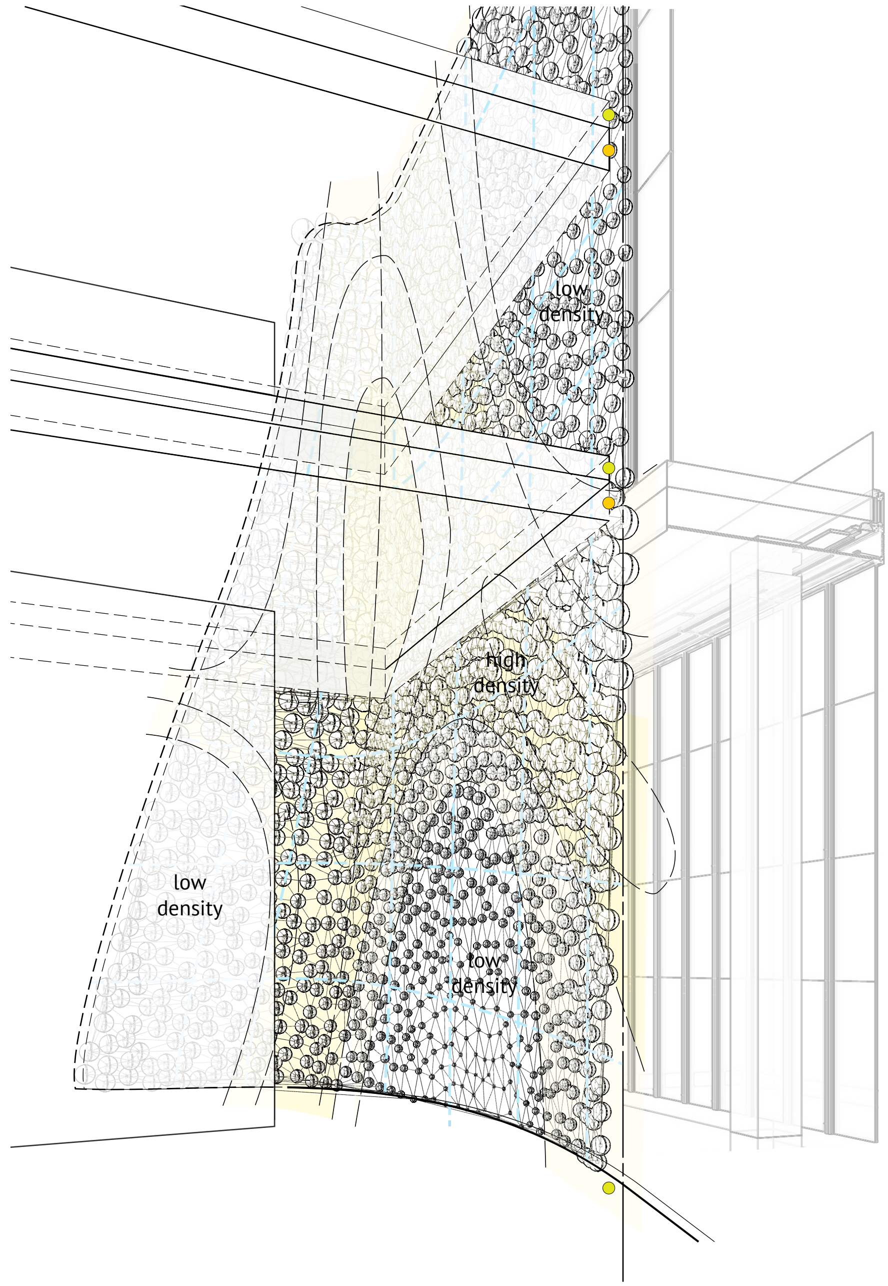


TEXTILE COMPONENT: **VESSEL CONCENTRATION**

1–17 *Once these points are established, locations for input and output valves are chosen. This will effect the diameter of each sphere—which is determined by proximity to the input source of algae. This results in a clumping of vessels with larger diameters closer to the input, where the flow of fluid is the greatest, allowing for areas of the triangulated grid to expand: to increase fluid volume, flow and depth of section at localized areas.*



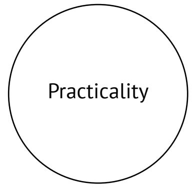


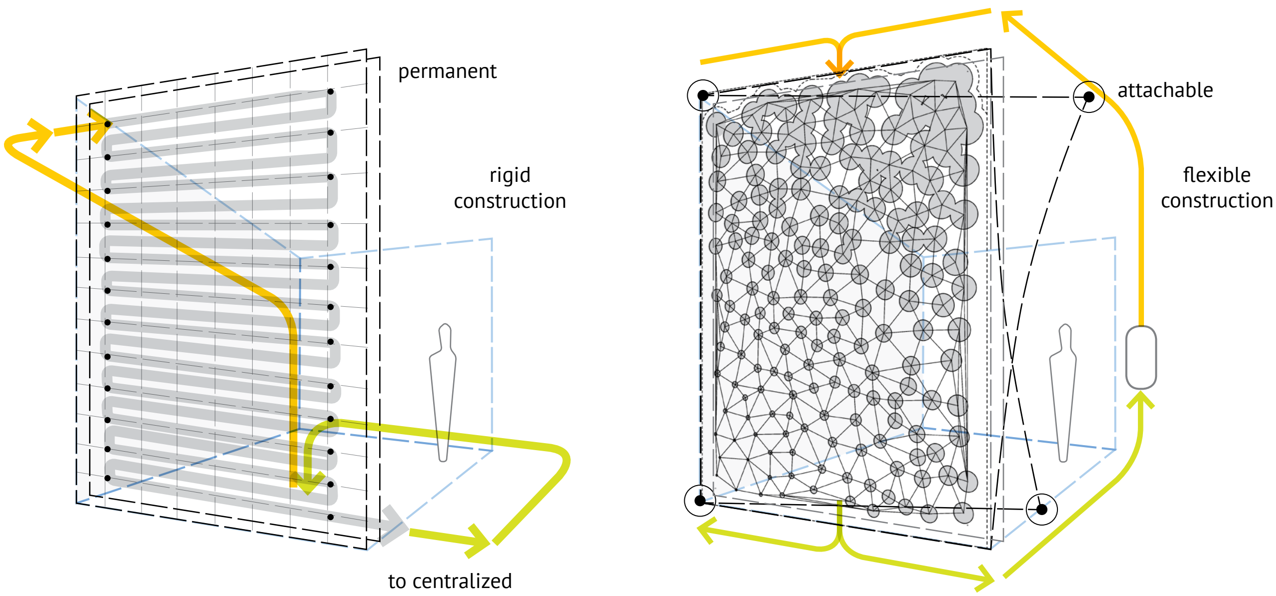


BUILDING INTEGRATION

1–18 *By determining where the concentration of voids lie within the membrane, this component of the textile's design can also determine the spatial impact of the algae textile. The resulting density and concentration of the triangulated mesh and its spherical expansion points can be used to control matters associated with view and light modulation. During the design stage, these are important parameters of control for the architect, as they work through decisions regarding sight lines, occupancy and programme.*

pro / *con*





STANDARD PHOTOBIOREACTOR

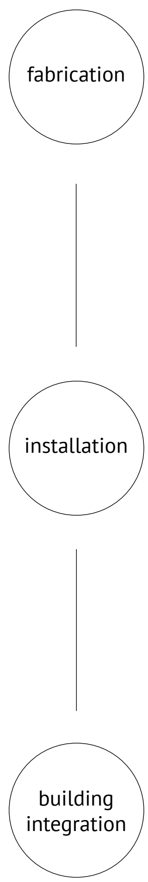
- constructed on-site
- permanent embedded system
- multiple components
- non-adaptable
- large-scale support systems
- high construction coordination

ALGAE TEXTILE

- prefabricated off-site
- attachable and detachable
- minimal components
- adaptable to given architectural situation
- small-scale support systems
- low construction coordination

algae in
algae out

factors to assess:



How is the system implemented?
Constructed on–site, or prefabricated off–site?

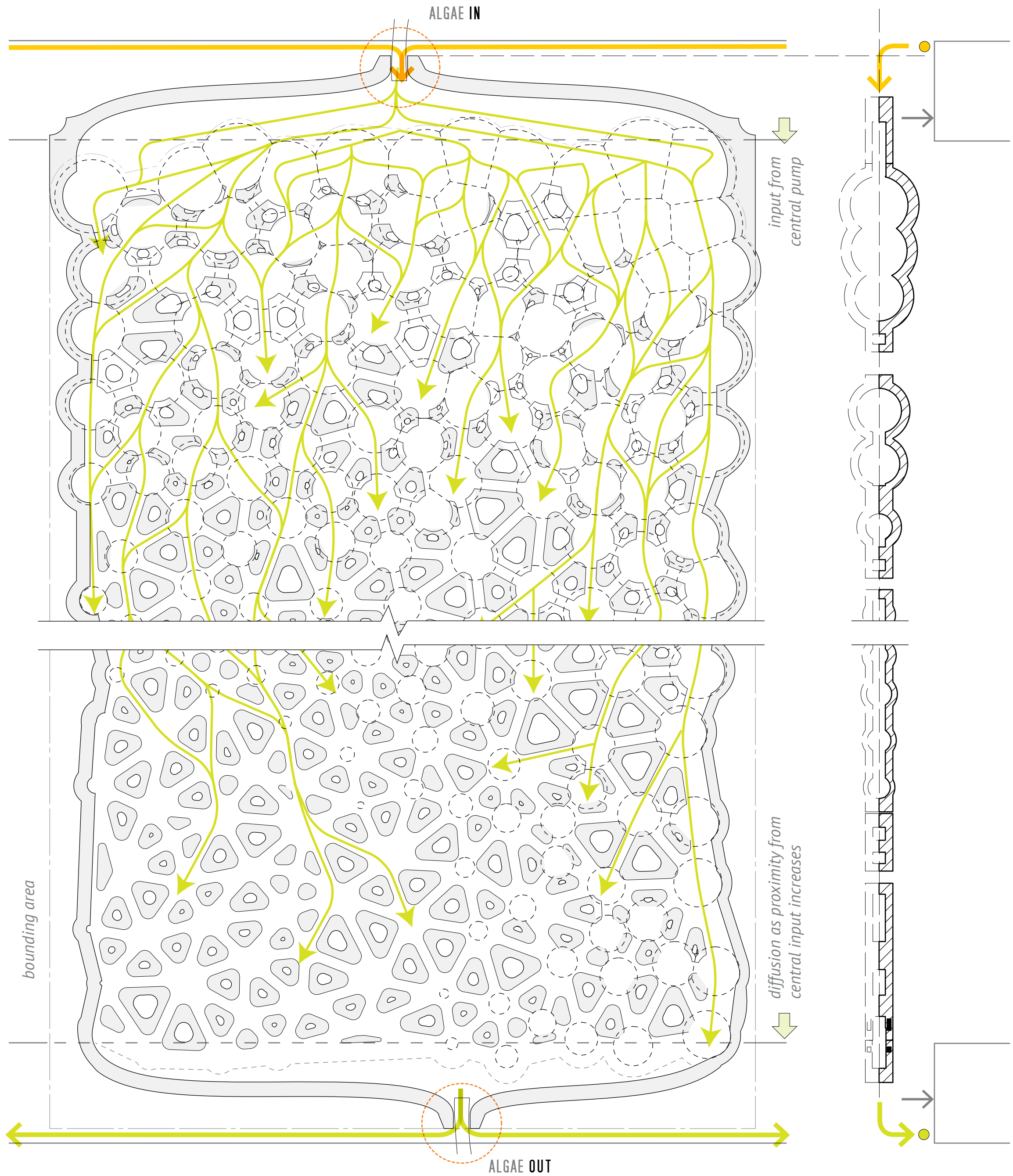
Systems that require construction on–site require physical labour, produce material waste, and accuracy can be compensated. Systems that are prefabricated in a factory environment undergo quality control and the production of the system's parts have been optimized through a mechanized process; improving quality, efficiency and cost.

How involved is the installation process?
What are the attachment mechanisms? Time and ease?
Can it be customized and adapted to various situations?

To increase the use of photobioreactors in buildings, making the installation process simple is highly desirable. If a reactor is able to attach itself to any situation within a given building floor plan—without the need to coordinate multiple large–scale systems within a building's mechanical infrastructure—this could produce a more prolific use of algae in the built environment. [See figure 1–23]

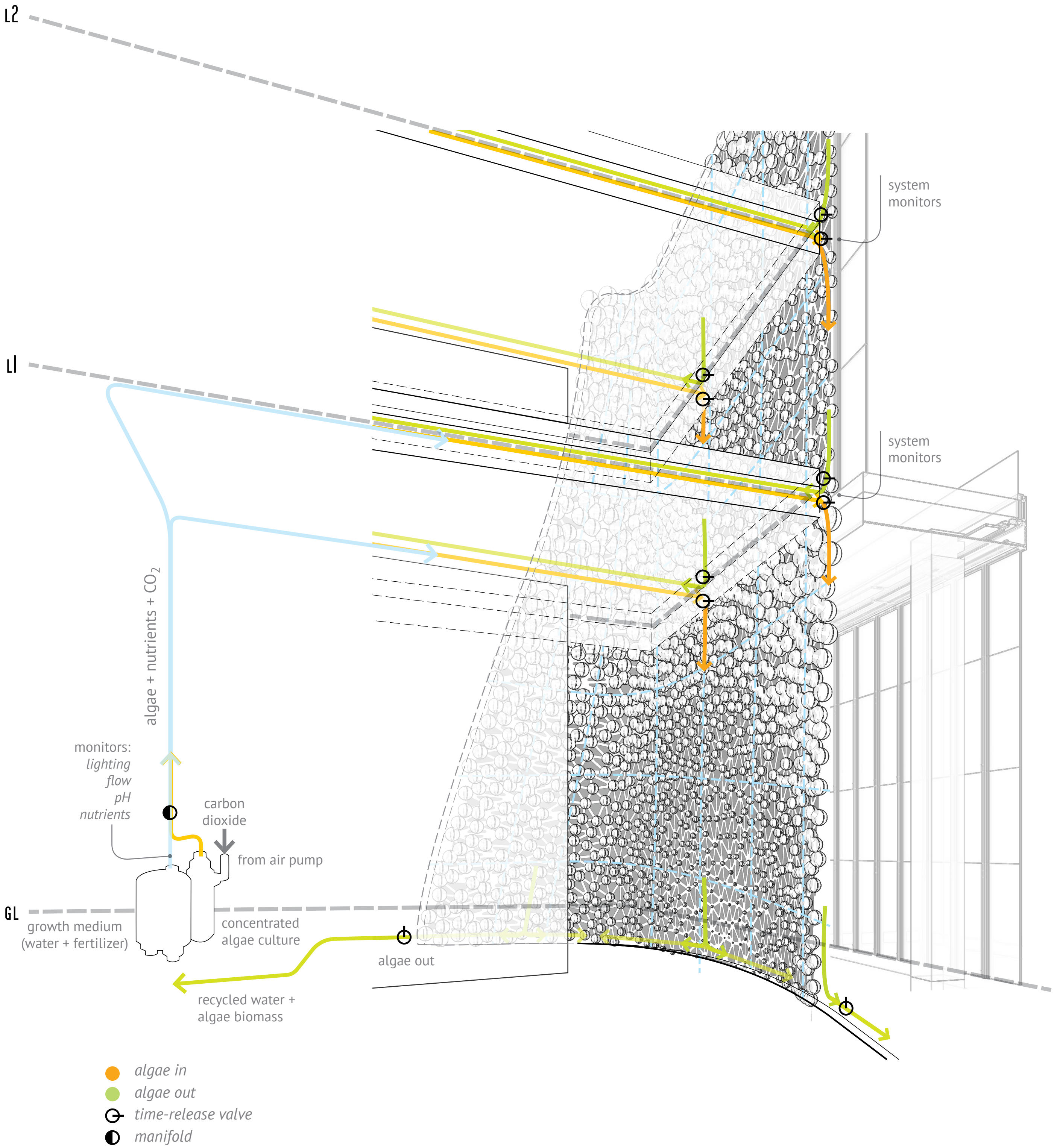
How does it integrate with plumbing and mechanical systems?
Size of support systems needed?
Are there limits to where it can be placed?

The support systems required to run a photobioreactor through a building should not consist of anything more than a plumbing network within building partitions or floor plates, and a central control panel in a service room which can connect to the electrical panel or other mechanical systems such as ventilation, or heating and cooling. [See figure 1–21]



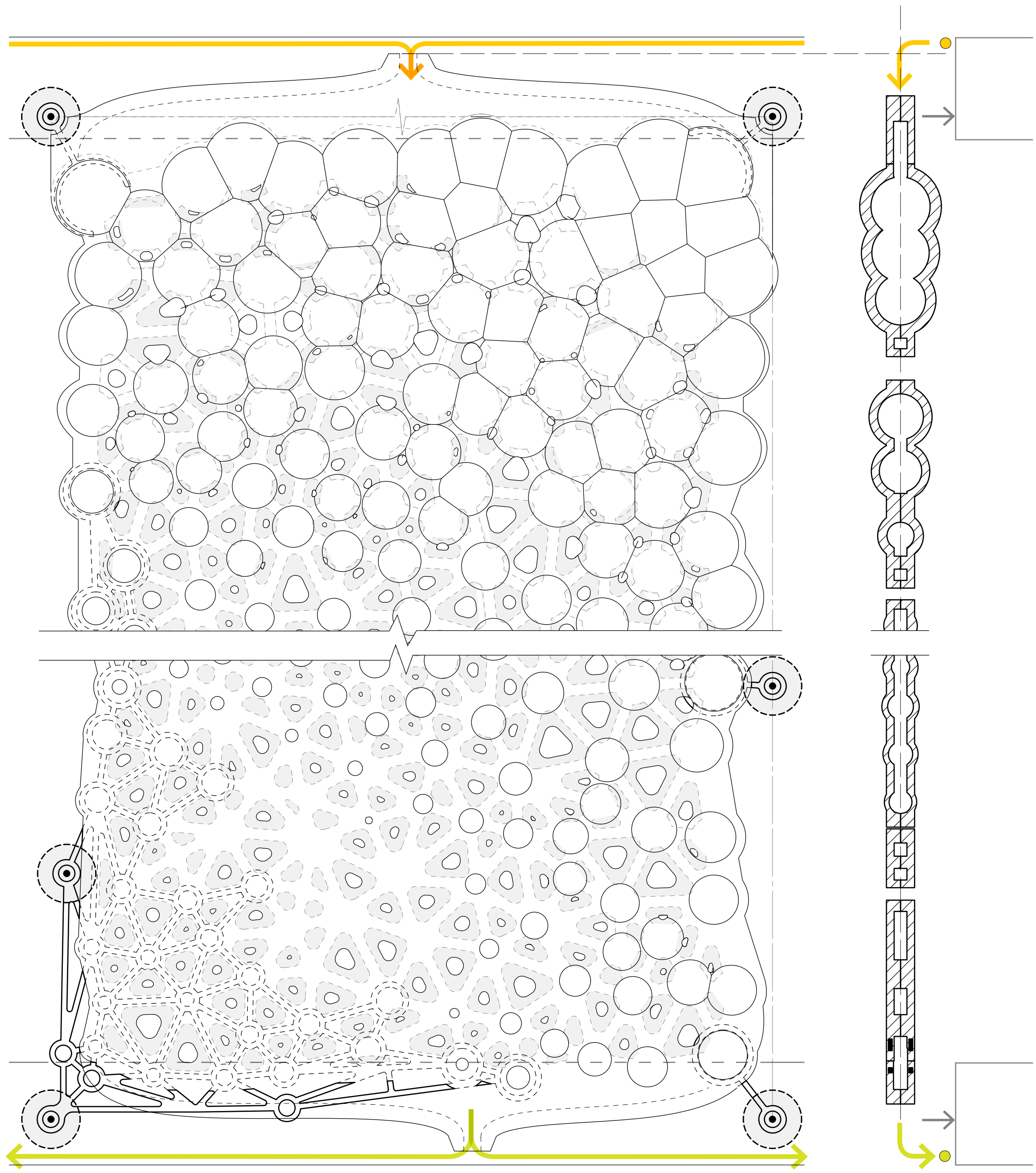
TEXTILE COMPONENT: **FLUID FLOW**

1–20 *The aggregation of spherical voids are connected with a delaunay triangulation network; creating the circulatory system through which the algae culture flows. This interior network of voids created within the textile take the place of the solar array in a traditional photobioreactor.*



BUILDING INTEGRATION

1–21 *In this example, growth medium and algae is injected at the top of each floor slab, and harvested at the bottom of each floor slab. This arrangement dedicates a plumbing system to each floor, making it possible to control the large expanse of the textile in sections. This compartmentalization allows precise and decentralized control in: lighting, flow, pH and nutrients between levels, depending on the portion of the textile.*

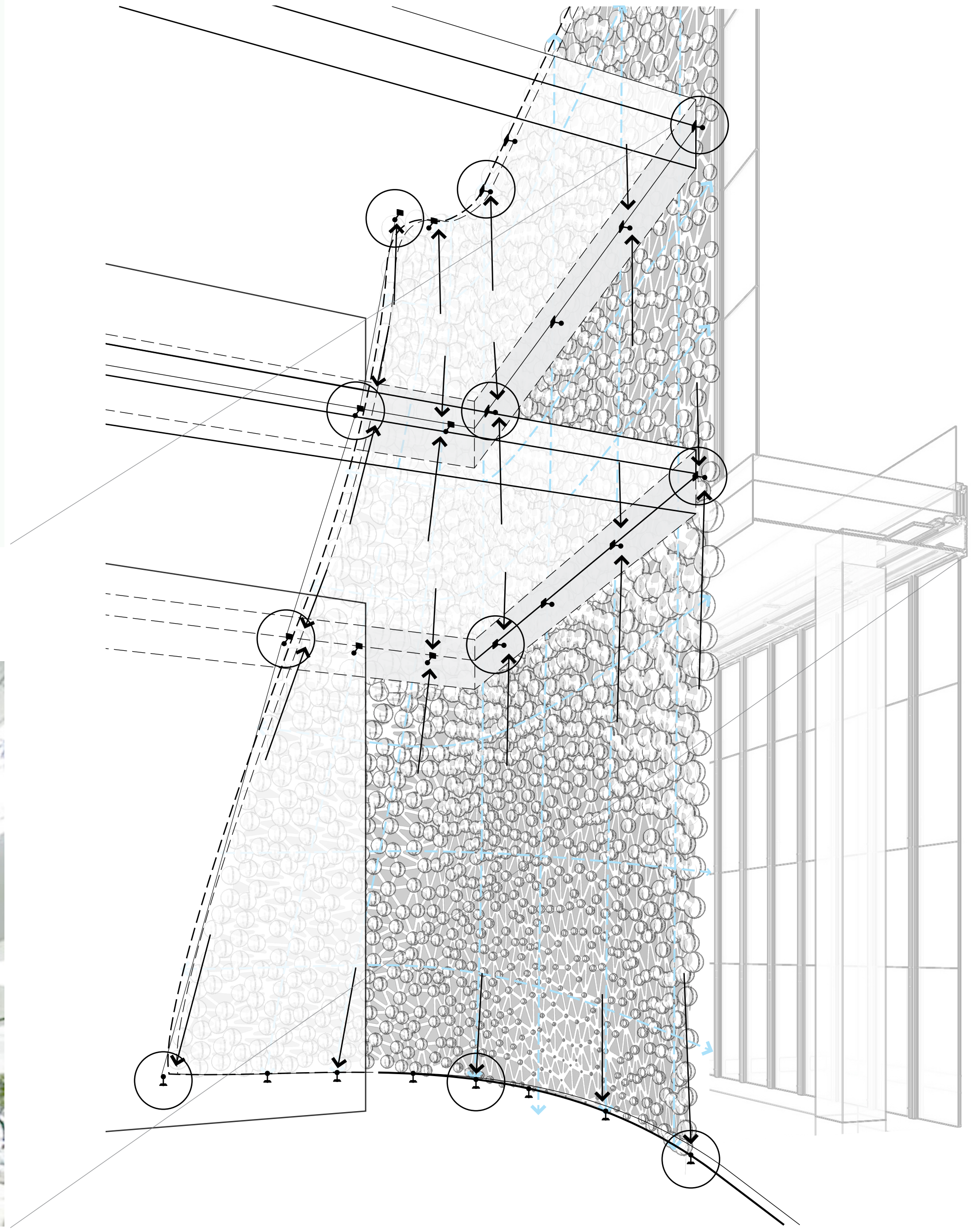


TEXTILE COMPONENT: **EMBEDDED STRUCTURE**

1–22 *During fabrication, structural hooks are placed within the mould and cast within the membrane. Its locations are determined by the density of the network and only exist on the outer perimeter as an attachment mechanism; leaving the interior free to stretch and deform.*

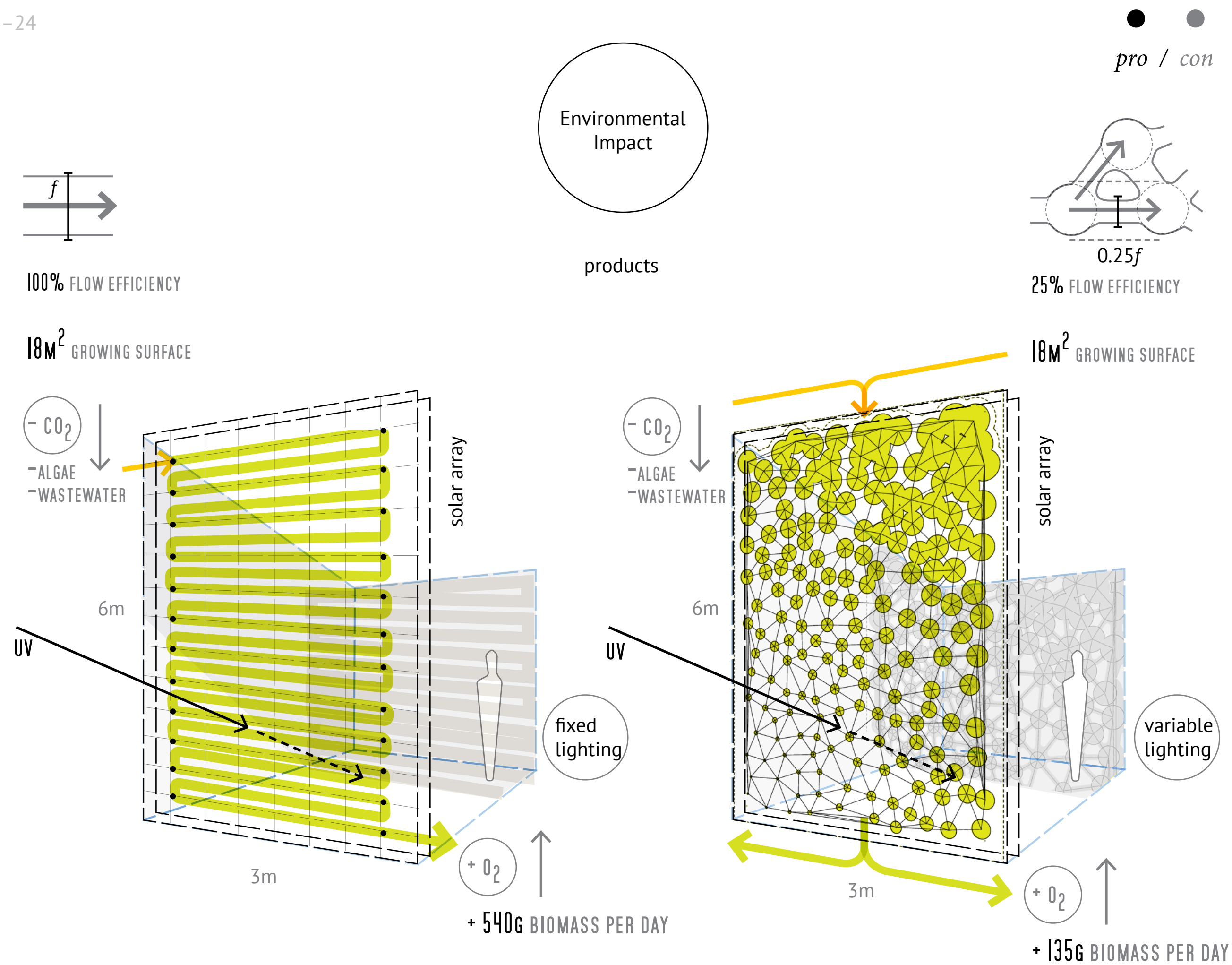
How the embedded hooks in the textile would pin to a spider glass connector.

http://www.metalica.com.br/materiais-para-fachadas-sistema-spider-glass



BUILDING INTEGRATION

1–23 *Points of attachment can be located on the edge of floor slabs or walls using low profile and noninvasive hardware. The embedded structure in the textile can then be hooked onto these pin–points to tension the membrane into place.. The detail shown above illustrates how the hooks in the textile would be pinned to a spider glass connector.*



STANDARD PHOTOBIOREACTOR

- carbon cycling: yes
- water cycling: yes
- renewable energy (high yield)
- fixed lighting and shading condition

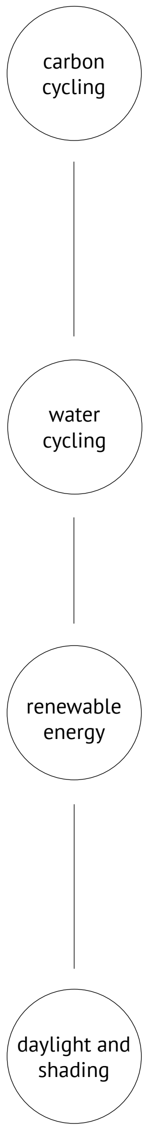
ALGAE TEXTILE

- carbon cycling: yes
- water cycling: yes
- renewable energy (low yield)
- variable lighting and shading condition

* **30 GRAMS** OF BIOMASS **PER SQ.M** OF GROWING SURFACE **PER DAY**

* The *algae production rate variable* is the measure of net harvested algae without the water and is measured in grams per square meter per day. The average appears to be 30 g/m^2/day for a standard photobioreactor, but the range in the literature is 10-60 for outdoor raceways. By the nature of farming, this is a stochastic variable.

* Richardson, J.W., Outlaw, J.L., & Allison, M. (2010). "The Economics of Microalgae Oil" AgBioForum, 13(2), 119-130. www.agbioforum.org/v13n2/v13n2a04-richardson.htm



factors to assess:

Can it contribute to absorbing CO_2 in polluted air?
(yes / no)

If yes, is it speculated that it could sequester a high, low or moderate amount? This will depend on the scale of the specific application. [See figure 1–25] It should also be taken into consideration where the system pulls its air intake from. For example, systems of this kind can either be outfitted with a system that pulls in filtered air from the exterior environment or from interior rooms; both of which are high in CO_2.

Can it be outfitted with a wastewater reuse system?
(yes / no)

If yes, is it speculated that it could process a high, low or moderate amount? This will also depend on the scale of the specific application.

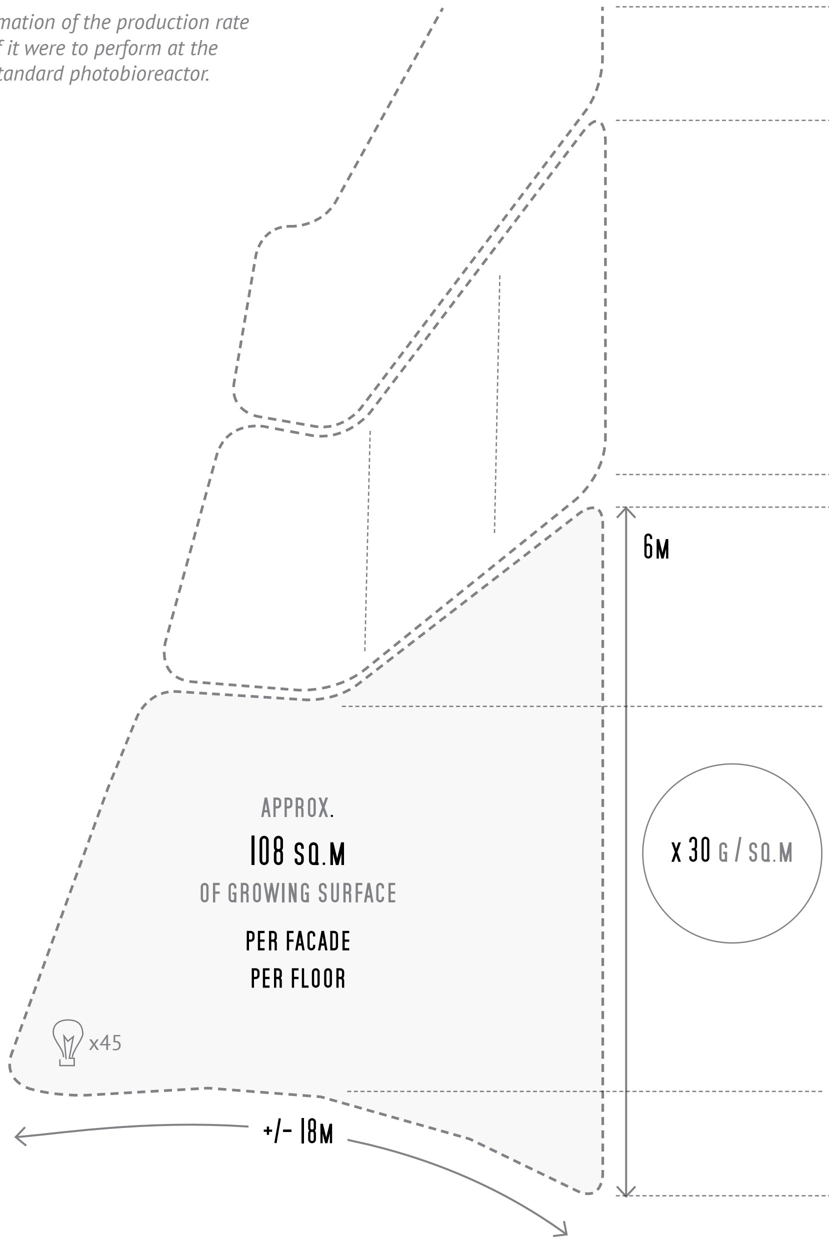
Can it contribute to creating energy on–site using algae biomass?
(yes / no)

If yes, is it speculated that it could produce a high, low or moderate amount? This will greatly depend on the scale of the specific application. If space permits, an on–site processing facility can be included in the buildings plans as part of the service space programme. Otherwise, the biomass produced can be collected and sent for processing off–site.

Can it benefit daylighting and shading of interior spaces?
(yes / no)

If used along the perimeter of the façade, it is desirable to use the textile to shade interior spaces; as is currently done with fritted glass or shading devices. [See 2.1 Textile Functionality] This will help modulate light within interior spaces and contribute to passive cooling efforts. Too much shading, however, will reduce passive heating efforts, therefore an appropriate distribution between transparent and translucent areas must be established to achieve optimal daylighting conditions. [See figure 1–26]

1–25 *Approximation of the production rate of the textile if it were to perform at the capacity of a standard photobioreactor.*



< This elevational area would equate to 3 double-height residential condo units.

A 60W light bulb running 8hr/day uses 1.728 MJ of energy. Therefore, if a 6x18m growing surface can produce 78 MJ/day it could power 45 light bulbs for one day. In the scenario mentioned above, this would power 15 bulbs for each of the three residential units.

If the algae production rate of the textile was developed to be equivalent to that of a standard photobioreactor, then:

APPROX.	
3240 GRAMS =	78 MJ
OF BIOMASS**	OF ENERGY***
PER DAY	PER DAY
PER FACADE	PER FACADE
PER FLOOR	PER FLOOR

* 30 GRAMS OF BIOMASS PER SQ.M OF GROWING SURFACE PER DAY

** 60% OF THAT MASS IS USABLE OIL

** *Oil content fraction* is used to calculate the quantity of natural oil extracted from the algae sludge. Studies show oil content recovered from mass can be as high as 60% using high-lipid strains of algae. Therefore, for the example above 3240g of biomass could recover 1944g of algal biodeisel.

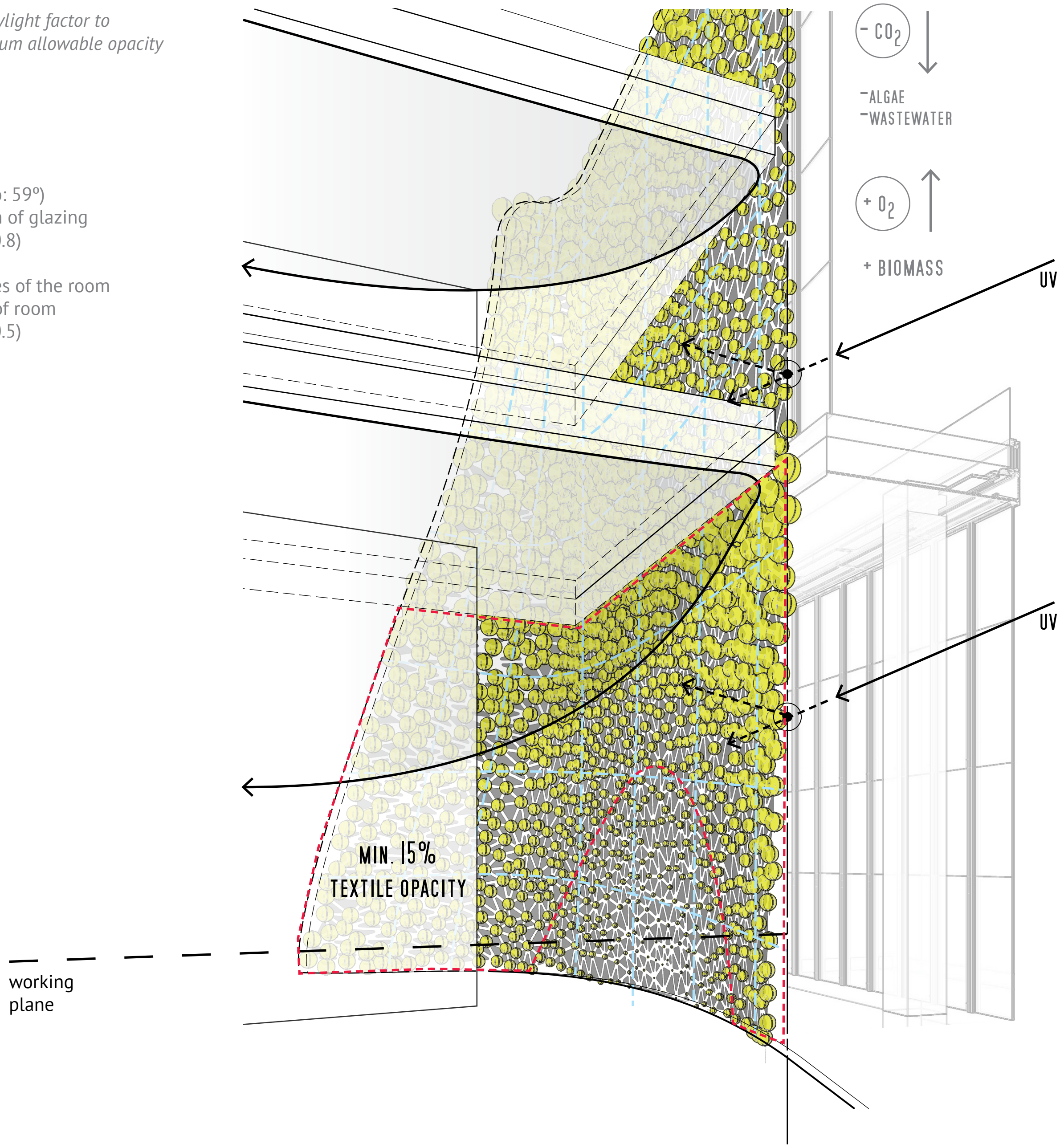
*** Energy density of algal biodiesel = 0.04 MJ/g. Conventional diesel = 0.0431 MJ/g. (1kWh = 3.6MJ).

** Richardson, J.W., Outlaw, J.L., & Allison, M. (2010). "The Economics of Microalgae Oil" AgBioForum, 13(2), 119-130. www.agbioforum.org/v13n2/v13n2a04-richardson.htm
*** Jim Mellentine (2011). "Algal Biodiesel vs. Conventional Diesel: Comparisons and Tradeoffs" Sustainawatt, Biofuels. http://sustainawatt.blogspot.ca/2011/04/algal-biodiesel-vs-conventional-diesel.html

1–26 *Calculating daylight factor to determine the minimum allowable opacity of the textile.*

$$DF = \frac{\theta TW}{A(1-R^2)}$$

θ sky angle (Toronto: 59º)
T light transmission of glazing (standard value: 0.8)
W window area
A area of all surfaces of the room
R reflection factor of room (standard value: 0.5)

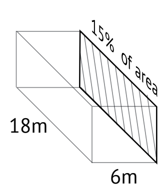


DAYLIGHT FACTOR

According to the British Standards Institution, BS 8206 part 2 CIBSE, a space with a mean daylight factor between 2% and 5% is considered well lit and requires little or no additional lighting during daytime.

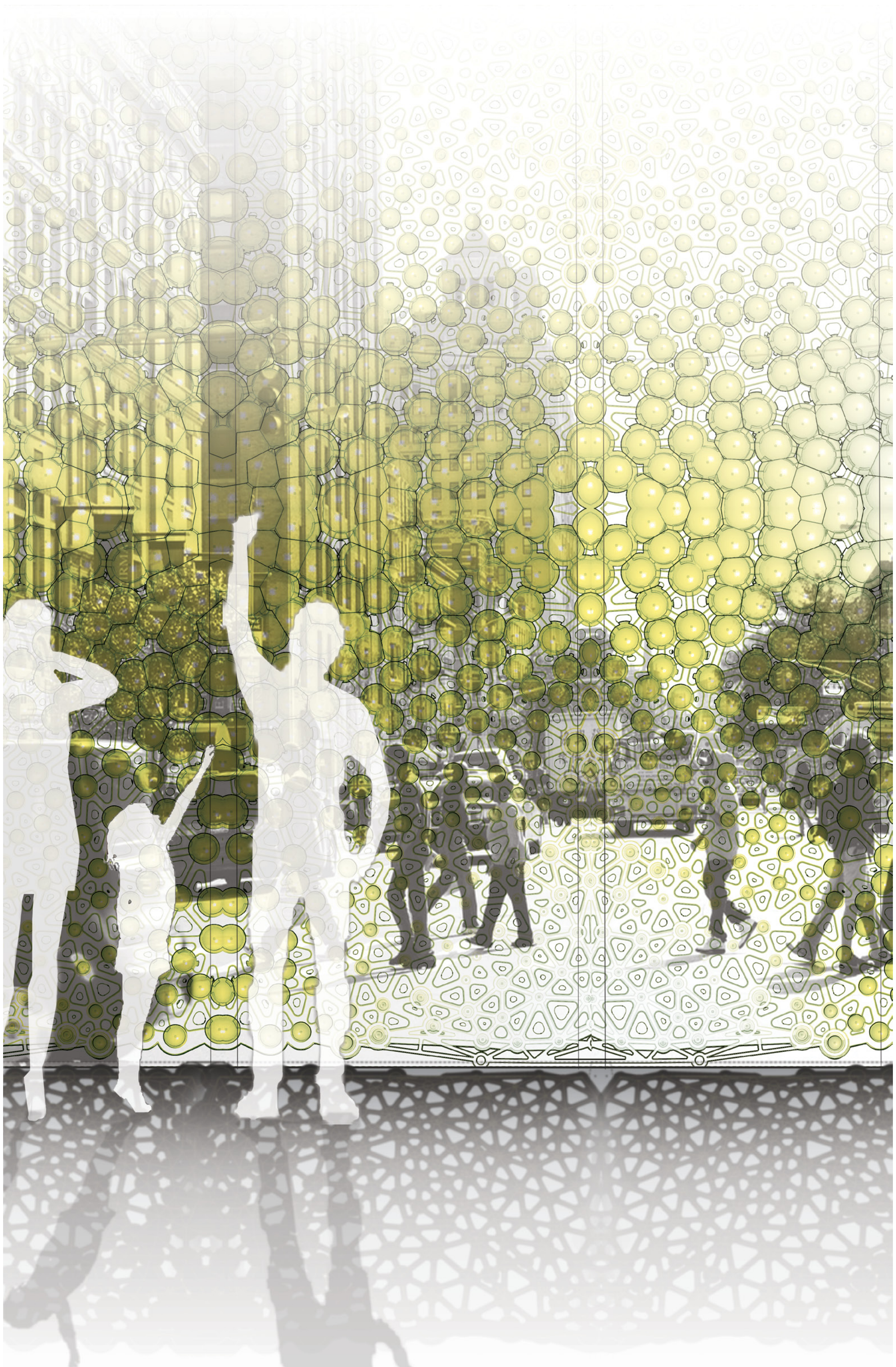
$$DF = \frac{\theta TW}{A(1-R^2)}$$

For 15% textile opacity:

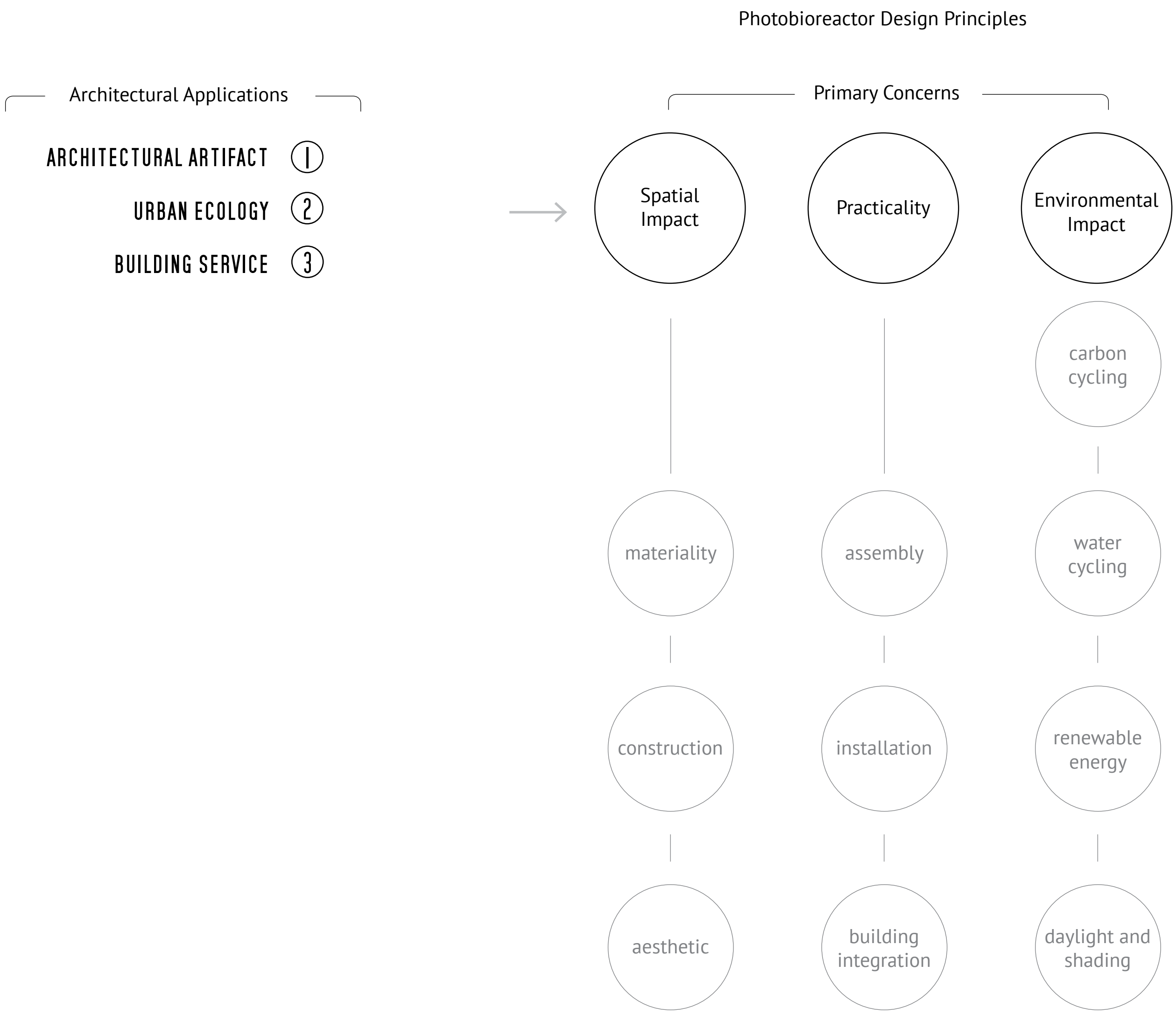


$$DF = \frac{59º(0.8)(16.2)}{432(1-(0.5)^2)} = \frac{765}{324} = 2\%$$

For this space, the textile can have an opacity ≥ 15% for adequate daylight.



1–27 *The algae textile in an urban tower; installed as part of the curtain wall system.*



1–28 *Photobioreactor Design Principles*

As illustrated, the algae textile has been developed with the interest of defining a set of desired behaviours and functions specific to the use of photobioreactors in urban building typologies such as the tower. This criteria is meant to evaluate photobioreactor design against social and environmental requirements—as they have a higher impact on architectural performance, and directly address an architect's interests. By designing photobioreactors to meet building–specific criteria such as spatial impact, practicality and environmental impact, the architect is able to optimize the benefits of using a photobioreactor architecturally, and evaluate their design against both qualitative and quantitative needs. These guidelines are meant to inform the architect on how to design a photobioreactor that is both effective, mechanically, and compatible, architecturally, within the design intentions of a building.

1.2

ALGAE AND THE BIOREACTOR

1.2

Algae is a single–celled organism known for producing 80% of all oxygen on earth through its highly efficient photosynthetic cycle. This ability alone makes it one of the most important organisms in the biosphere[5] because, unlike land plants, which must always dedicate a portion of their energy (90%) towards supporting their physical outer structures, such as roots, leaves and stalks, the algae organism, lacking any sort of physical structure, is therefore able to dedicate 100% of its energy into multiplying itself to produce oxygen.[6] Existing in a range of adapted conditions worldwide, algae can be found in the sea, in freshwater and in wastewater, and range in size from the microscopic, as single–celled organisms which measure only five microns (μ), to the macroscopic, as large seaweeds. Algae is not only important for its photosynthetic efficiency and ability to produce more oxygen than all plants in the world put together,[7] but its amphibious quality and naturally high lipid content plays a role in its oil producing capabilities. This makes algae one of the highest yielding energy crops, and the only one which does not compete for agricultural land. Some estimates suggest that algae could produce up to 15,000 gallons of oil per acre a year which can be used for fuels, pharmaceuticals and other valuable goods,[8] and presents staggering statistics which could redefine everyday life and its relationship to the environment. In architecture, the availability of surfaces which support algae's photosynthesis may mitigate environmental ailments associated with the city: including air purification and renewable energy. As a result, algae's use in an urban context and its influence on architecture is on the rise: in 2013, Arup Engineering unveiled an algae–powered building with a "bioreactive" façade,[9] and researchers in Barcelona have been using microalgae to develop biological concrete which can grow moss and lichen with the equivalence of soil.[10] In this age, "reactive" and "living" qualities are standards in design, and algae–based technologies present themselves as agents to do so, while offsetting the negative environmental consequences of construction.

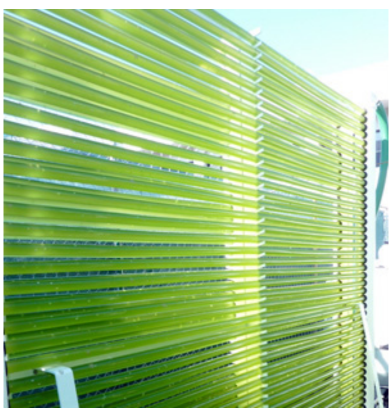
1–29 *Energy Crop Comparison*

Corn	18
Soybeans	48
Safflower	83
Rapeseed	102
Palm	635
Microalgae	5000-15000
	gallons of oil per acre a year

5 Dr. Jack Hall, "The Most Important Organism?" (ecology.com, Sept, 12, 2011) http://www.ecology.com/2011/09/12/important–organism/
6 Mark Edwards, "Algae 101: Algae Medical Solutions Part 1" (algaeindustrymagazine.com, April 7, 2013) http://www.algaeindustrymagazine.com/algae–medical–solutions–part–1/
7 Oilgae, "About Algae," (oilgea.com, accessed Dec. 17, 2013) http://www.oilgae.com/algae/algae.html
8 Oilgae, "About Algae"
9 Bob Yirka, "First Algae Powered Building Goes up in Hamburg," (phys.org, April 12, 2013) http://phys.org/news/2013–04–algae–powered–hamburg.html
10 Universitat de Barcelona, "A New Biological Concrete to Construct 'Living' Façades with Lichens, Mosses, and Other Microorganisms," (Universitat de Barcelona, News, Jan. 15, 2013) http://www.ub.edu/web/ub/en/menu_eines/noticies/2013/01/028.html

1–30 *Open pond bioreactor. (Seambiotic, 2006)*

1–31 *Closed Vertical-Growth Bioreactor*



1–32 *Closed Photobioreactor*

The growth of algae and its cultivation can be optimized simply through the design of the reactor. There are three common types of bioreactors for algae:

Open Pond Bioreactors are the easiest and least sophisticated method of creating a bioreactor. This system utilizes constructed lakes or raceway ponds (15–20cm deep) which are circulated using gravity or paddlewheels. Although these are the most economical to construct, they come with their disadvantages: they are susceptible to contamination, evaporation, poor optimization of light exposure, temperature swings and exposure to changing weather conditions.[11]

Closed Vertical Growth Bioreactors consist of two components: (1) a feeding vessel and (2) a solar array. In this type of system the algae, nutrients and CO_2, are combined and cultured within a feeding vessel. This is then pumped through the solar array (a linked series of plastic bags) which circulates and exposes the culture to sunlight as it travels through the length of the array. In these controlled systems the algae produces higher yields and eliminates the risk of contamination.

Closed Photobioreactors (PBRs) are the most costly systems to implement, however, they produce five to ten times higher yields than the other systems; providing a potential return on investment, and validating the higher upfront cost. Similar to vertical growth bioreactors, their design, instead, maximizes the absorption of energy and nutrients by distributing the surface area of the solar array into a matrix of thin tubing, and, thereby, uses a minimal volume of water. This promotes growth within highly controlled conditions, resulting in this higher production rate.[12]

Comparing algal bioreactors reveals that an emphasis should be placed on operating costs and low water, land and energy usage to validate the design of the reactor. It should, however, be noted that to maximize the reactor's yield, the design should strive to maximize the surface–to–volume ratio* and provide light saturation at optimal intensities.[13] These two parameters greatly effect the growth rate of the algae, and why PBRs are the most productive type of reactor; validating their higher cost.

* In biological and chemical reactions, the surface-to-volume ratio greatly affects the overall "reactivity" of a mixture: the rate at which the chemical reaction occurs.

Controlling this parameter in combination with temperature and light is important for optimizing the growth rate of algae in a bioreactor.

11 Peer M. Schenk, P. Thomas–Hall, S., Stephens, E., Marx, U., Mussgnug, J., Posten, C., Kruse, O., & Hankamer, B., "Second Generation Biofuels: High Efficiency Microalgae for Biodiesel Production," (Springer Online, BioEnergy Research, March 4, 2008) http://link.springer.com/article/10.1007%2Fs12155–008–9008–8/fulltext.html pg. 20–43

12 Gundula Proksch, "Growing Sustainability: Integrating Algae Cultivation into the Built Environment," *Closed Photo–Bioreactor Systems*, (Edinburgh Architectural Research Journal (EAR), Volume 33, 2013) http://sites.ace.ed.ac.uk/ear/files/2013/05/147–1621.pdf

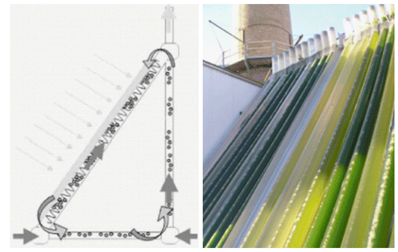
13 Schenk, et al, "Second Generation Biofuels: High Efficiency Microalgae for Biodiesel Production," (Spinger Online, BioEnergy Research, 2008). pg. 20–43

It has also been shown that algae's photosynthetic reaction is optimized when exposed to indirect and middle–intensity light; a level of 1000–10000 lux.[14] It is a common misconception that algae requires prolonged periods of direct sun exposure, when in actuality, this high–intensity exposure results in lower efficiencies, photo–inhibition, or even photo–bleaching of the culture.

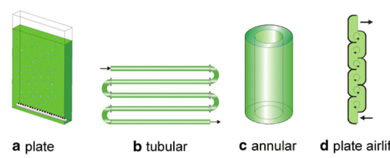
By tailoring the design of the bioreactor to the growth dynamics of algae, the reactor is more effective and can produce higher yields. This is why algae grown in shallow distributed volumes—where the culture is circulated and where light can penetrate the full depth of the vessel—proves to be the most efficient and high–yielding method for growing algae. This is because it provides preferred growing conditions in a highly controlled way; where the growing environment is always at an ideal state. The bioreactor's ability to provide these conditions therefore makes its design an important determining factor in creating effective algae–growth systems:

> *Only new design principles in connection with the knowledge and consideration of microalgal kinetics and growth dynamics can lead to optimal and economically viable systems.[15]*

For example, AlgoMed, in Klotze, Germany, the world's largest algal bioreactor system, uses a triangular bioreactor design that pumps flue gases from one direction and the algae culture in the opposite direction. This generates vortices that intensify the matter exchange (*assimilation*), and is effective even at sub–optimal lighting conditions.[16] The creation of these vortices introduces microbubbles into the culture and boost algae yields by 30 percent.[17] This improves the performance of the bioreactor as microbubbles of CO_2 dissolve faster, keep the suspension well mixed and also help remove oxygen—which is toxic to algae.[18] As a result it is one of the most productive cultivation systems built to date, and shows that agitation is also an important factor in bioreactor design.



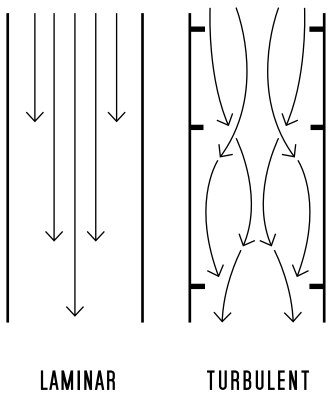
1–33 *AgloMed's triangular bioreactor uses oscillating microbubbles to boost algae yields by 30 percent. It uses 18% less energy than standard sparging systems. The generator improves the performance of air-lift loop bioreactors (ALBs) by producing smaller bubbles, around 20 micrometers versus 1–3mm diameter for sparging. Produces 30% more algae than one fed with conventionally produced bubbles. Microbubbles of CO2 dissolve faster, keep the suspension well mixed, and also help remove oxygen (which is toxic to algae).*



1–34 *Different closed photobioreactor designs commonly employed for production of valuable compounds: (a) plate reactor, the classical approach, (b) tubular reactor, biggest closed photobioreactor is made in this design, (c) annular reactor, acts as bubble column, the inner cylinder is empty to avoid dark parts and to increase surface/ volume ratio, (d) plate airlift reactor with baffles supports flashing light effect by controlled fluid barrels.*

14 Gundula Proksch, "Growing Sustainability: Integrating Algae Cultivation into the Built Environment," *Closed Photo–Bioreactor Systems*, (Edinburgh Architectural Research Journal (EAR), Volume 33, 2013) http://sites.ace.ed.ac.uk/ear/files/2013/05/147–1621.pdf
15 Schenk et all. "Second Generation Biofuels: High–Efficiency Microalgae for Biodiesel Production" (Springer Online, BioEnergy Research, 2008) pg. 20–43
16 Gundula Proksch, "Growing Sustainability: Integrating Algae Cultivation into the Built Environment," *Closed Photo–bioreactor Systems*, (Edinburgh Architectural Research Journal (EAR), Volume 33, 2013. http://sites.ace.ed.ac.uk/ear/files/2013/05/147–1621.pdf
17 Stella Kin, "Airlift Bioreactor Links" (biofuels2010.blogspot.ca, Nov. 24, 2010) http://biofuels2010.blogspot.ca/2010/11/airlfit–bioreactor–link.html
18 Stella Kin, "Airlift Bioreactor Links," 2010.

This agitation and turbulence proves to be important for increasing algae's growth in a bioreactor and can be taken advantage of through oppositional directions of input fluids, or by taking into consideration the type of path the algae is traveling through. Understanding fluid dynamics and the differing effects laminar and turbulent flows have on a moving fluid has the potential to inform methods of increasing the reactivity of algae within a bioreactor even further:



1–35 *Laminar and Turbulent Flow*

Laminar Flow, describes the movement of a fluid which travels smoothly in linear laminations; imparted by its containment within, or movement across a regular path or surface. In this condition, the velocity, pressure and other flow properties at any point in the fluid remains constant.

Turbulent Flow, describes the movement of a fluid which travels with irregular fluctuations and mixing; imparted by its containment within, or movement across an irregular path or surface. In this condition, the velocity, pressure and other flow properties at any point in the fluid are dissimilar and in constant states of change.

Energy Transformation: When flow is turbulent, particles of a moving fluid exhibit increased transverse motion which enhances the rate of energy and momentum exchange between them thus increasing the heat transfer and the friction coefficient. This agitation also increases the reactivity of a fluid, and increases the rate at which particles can assimilate and complete a reaction. This lends itself well with algae cultivation in a bioreactor, where the formation of turbulence and eddies within the algae culture agitates the cells and stimulates their growth—just as the movement of a stream or river would create a turbulent flow naturally to promote the growth of algae.

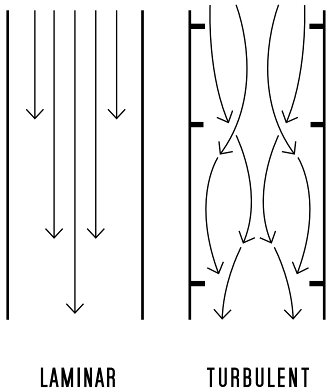
> *In natural bodies of water and in industrial bioreactors, microscopic algae experience laminar and turbulent flows that play a critical role in their dispersion, proliferation and productivity.*
>
> *[...] Existing bioreactors operate under both laminar and turbulent flow conditions. The transition between the two flow regimes depends on the ratio of inertial and viscous forces in a fluid [and] on geometry and particular flow conditions.*[19]

19 Ottavio A. Croze, Gaetano Sardina, Mansoor Ahmed, Martin A. Bees and Luca Brandt, "Dispersion of Swimming Algae in Laminar and Turbulent Flows: Consequences for Photobioreactors," (J. R. Soc. Interface, April 6, 2013, vol. 10 no. 81, 20121041) http://rsif.royalsocietypublishing.org/content/10/81/20121041.full

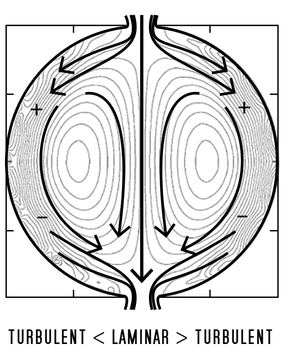
DESIGN MODULE 2

TEXTILE MECHANICS

(a) Bioreactive Optimization
(b) Materiality
(c) Fabrication Methods
(d) Support Systems
(e) Algae Culturing

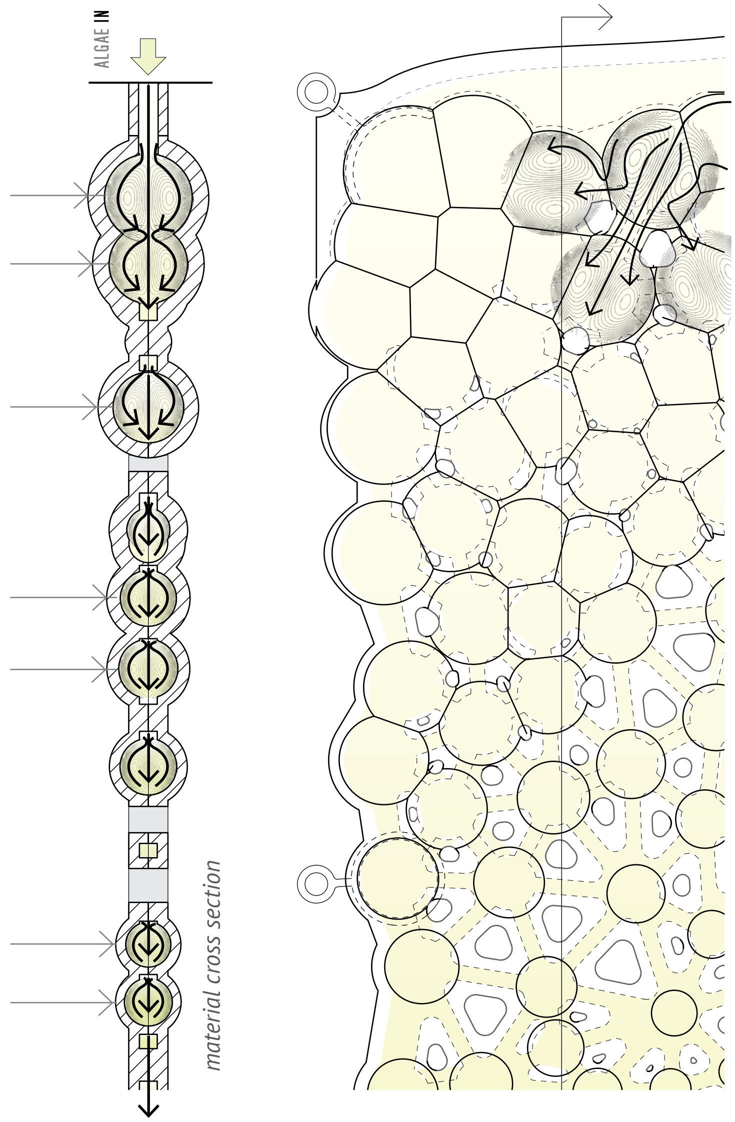


1–36 *Laminar and Turbulent Flow*



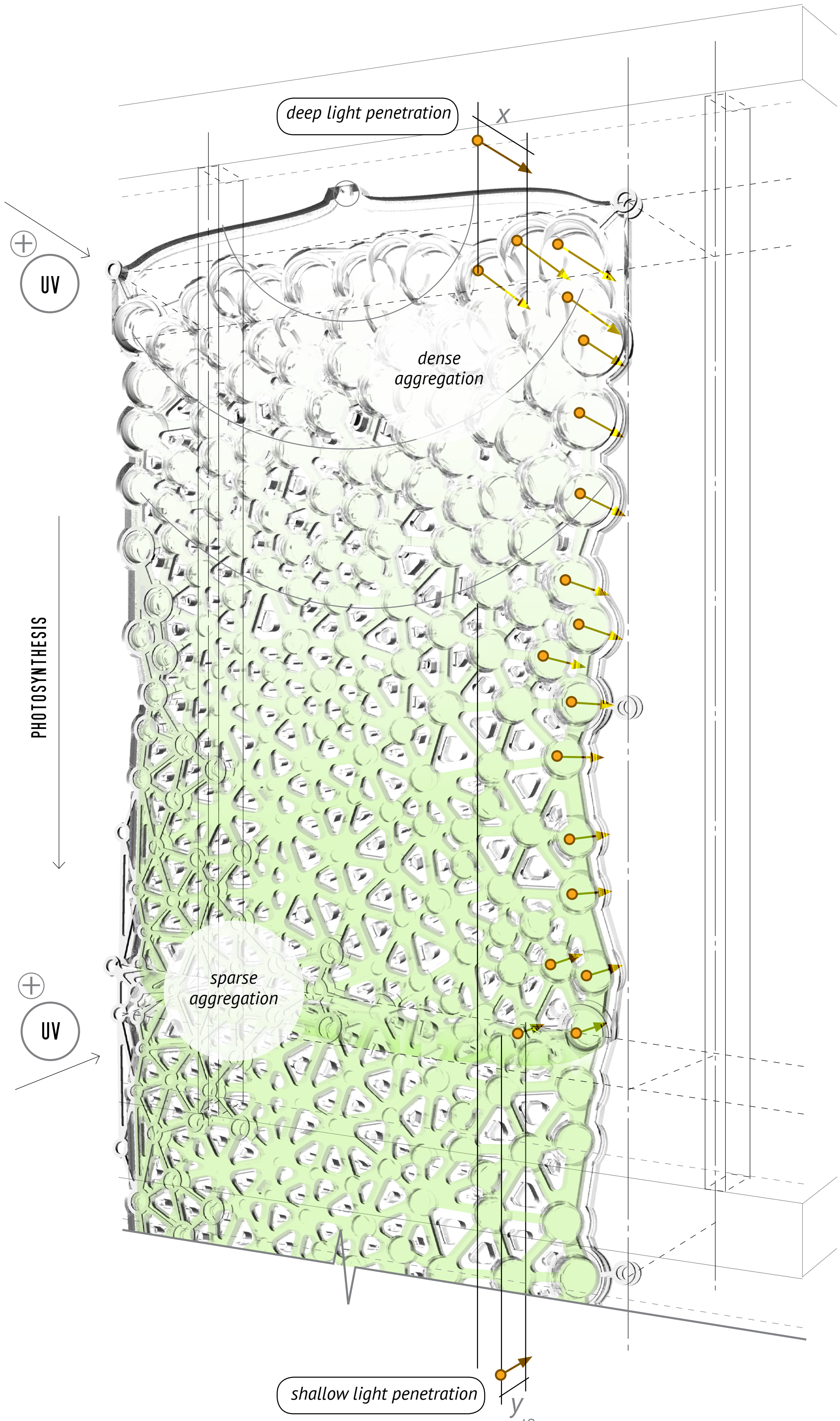
1–37 *Movement of fluid through a sphere, and its transitions between laminar and turbulent flows.*

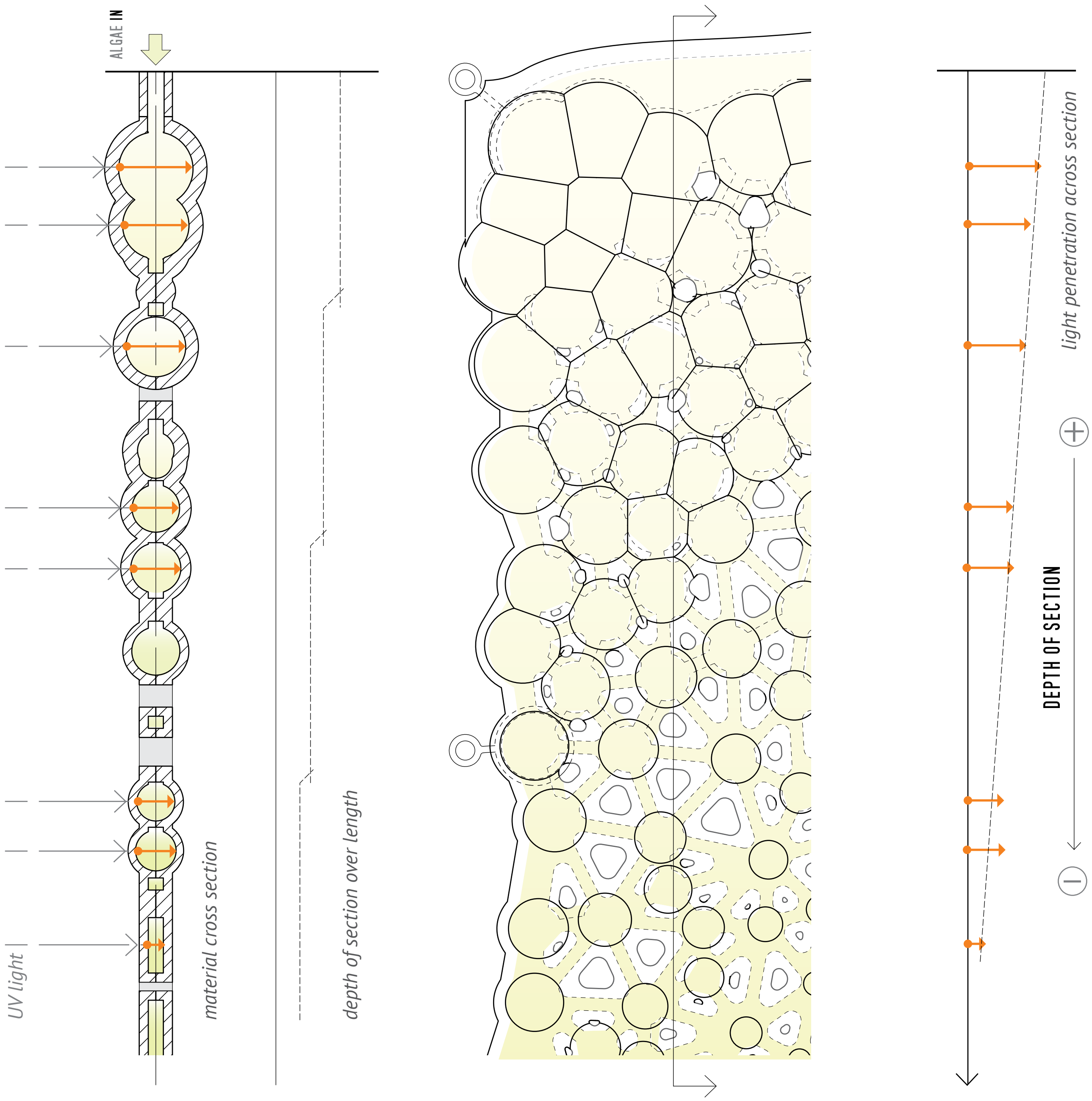
1–38 *(above right) Analysis of the movement of fluid within the length of the algae textile and the effects of an irregular interior path.*



(a) Bioreactive Optimization of the Algae Textile

The algae textile takes the importance of laminar and turbulent flows in a bioreactor and aims to integrate them into its design. By experimenting with its variable surface and irregular interior path, the design aims to promote the agitation and aeration of the algae as it moves within the membrane to stimulate its growth. It can therefore be said that the aggregated network of spherical forms in the textile serve not only a visual purpose in terms of architectural design, but also contribute to the overall mechanical performance of the textile as an effective bioreactor. This is done by closely considering the reactive needs of the algae organism, and is not limited to the principles of fluid dynamics. Environmental conditions such as light, temperature and the surface–to–volume ratio of the growing vessel also affect the rate of proliferation.


deep light penetration
x
UV
dense
aggregation
PHOTOSYNTHESIS
sparse
aggregation
UV
shallow light penetration
y



GROWTH OVER CROSS SECTIONAL LENGTH

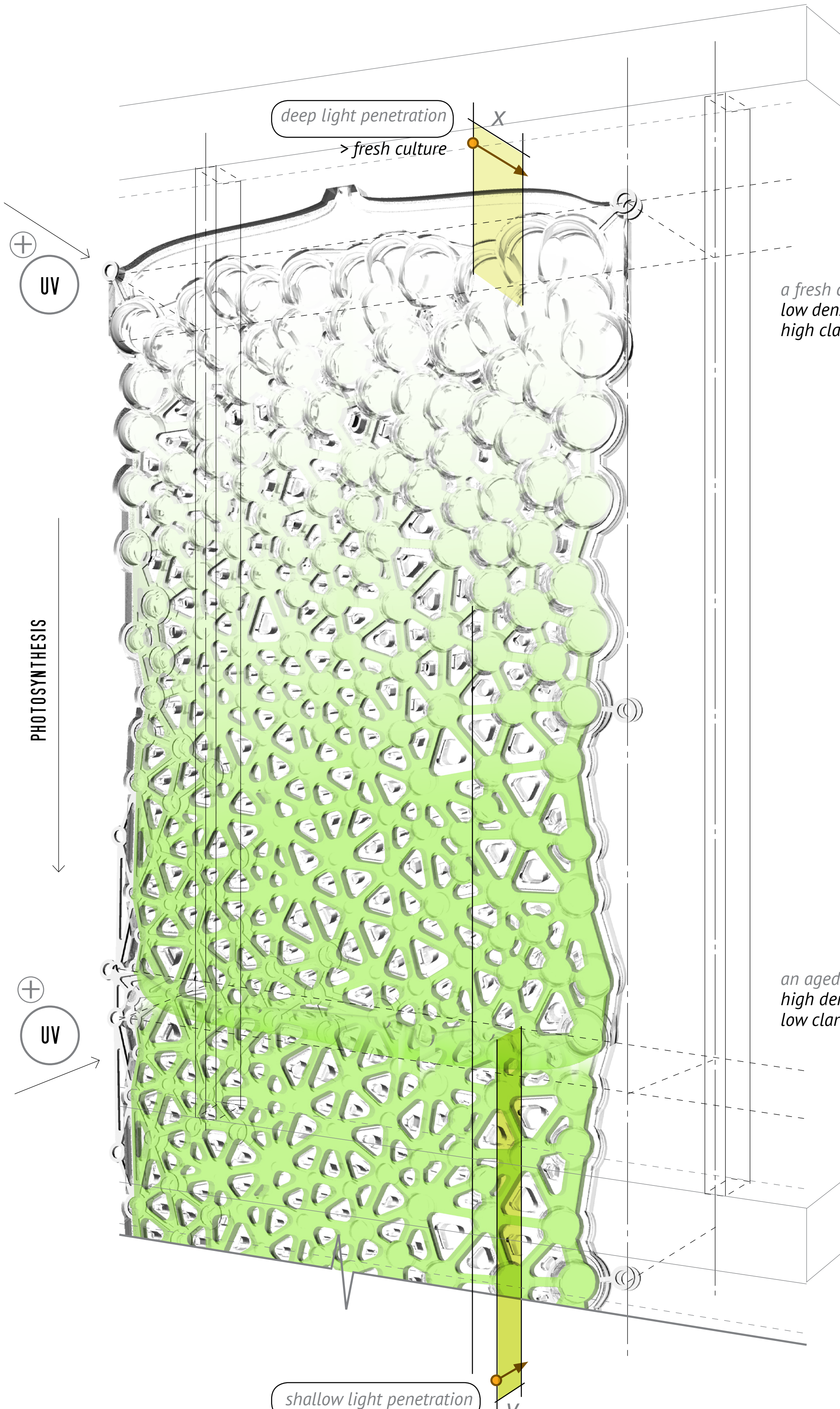
Surface-to-Volume Ratio (SA:V)

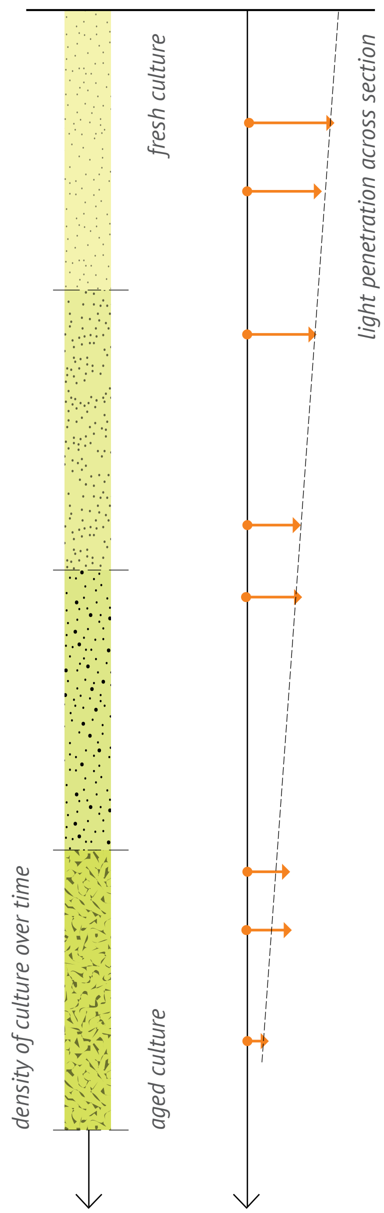
In biological and chemical reactions, the surface-to-volume ratio greatly affects the overall "reactivity" of a mixture: the rate at which the chemical reaction occurs.

Controlling this parameter is important for optimizing the growth rate of algae in a bioreactor.

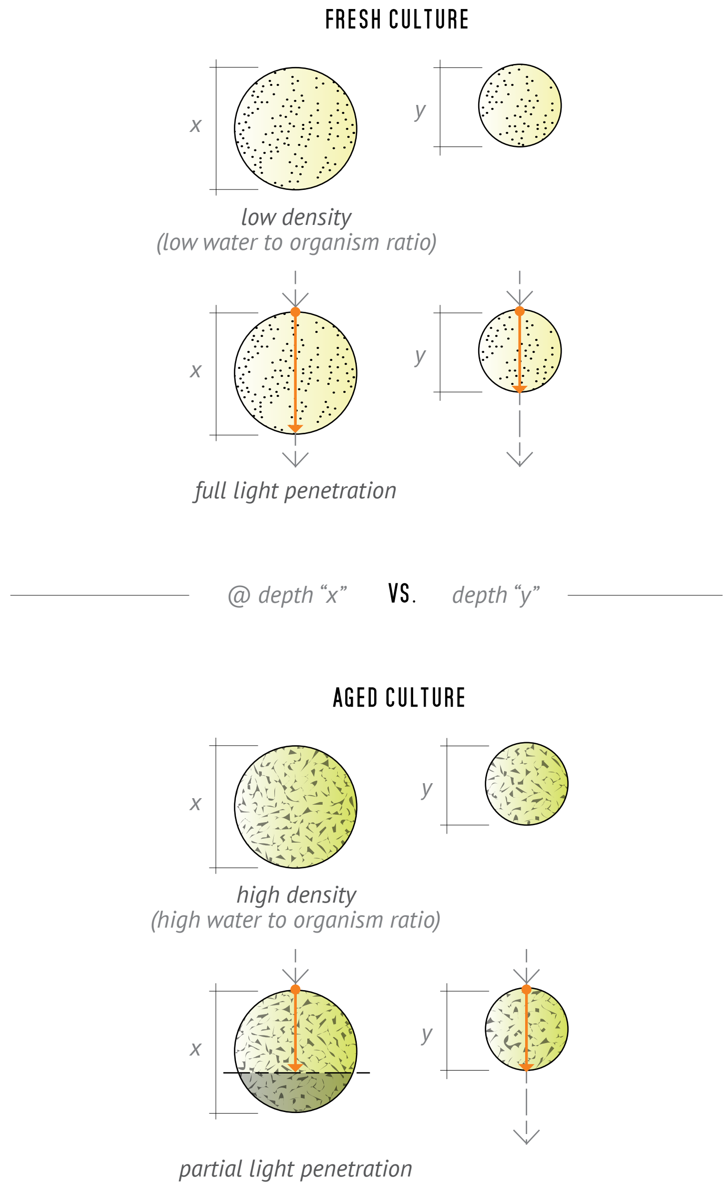
1–39 *Analysis of algae growth over the length of the algae textile and the effects of varied vessel dimensions on lighting.*

These diagrams illustrate how the variegated form of the algae textile takes environmental conditions and the surface–to–volume ratio into consideration. The textile's minimal depth places the algae in a growth environment that is thin and distributed over a large surface. This high surface–to–volume ratio means an even distribution of light and temperature is available to each algae cell suspended in the fluid.

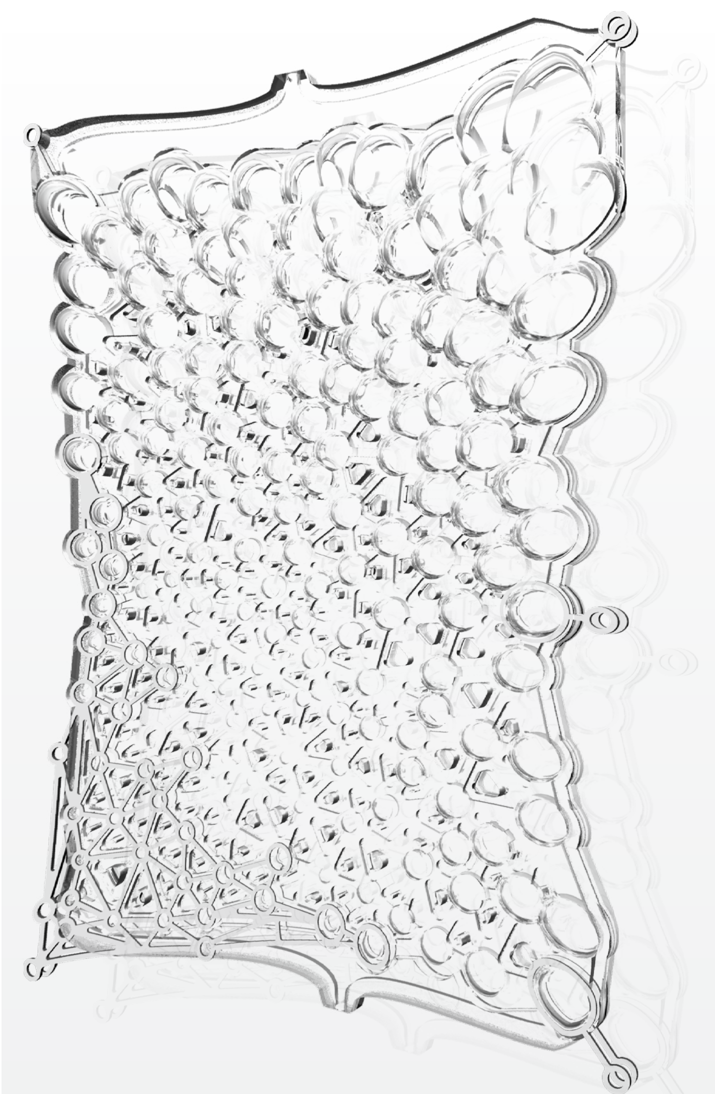

deep light penetration
> fresh culture
x
UV
PHOTOSYNTHESIS
UV
a fresh culture:
low density
high clarity
an aged culture:
high density
low clarity
shallow light penetration
> aged culture
y

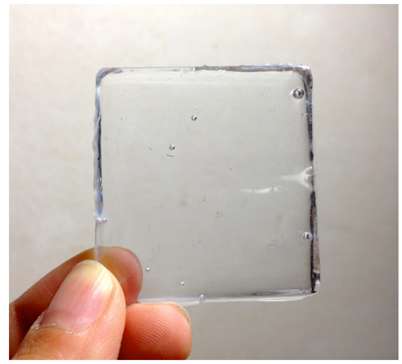


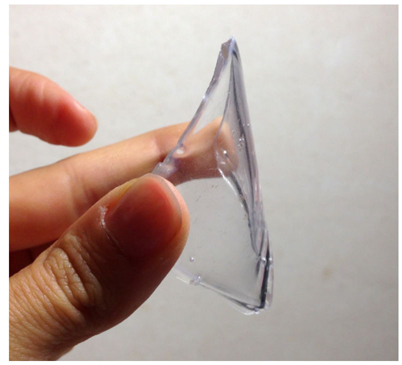
1–40 *Analysis of algae growth over the length of the algae textile and the effects of varied vessel dimensions depending on the culture's age.*

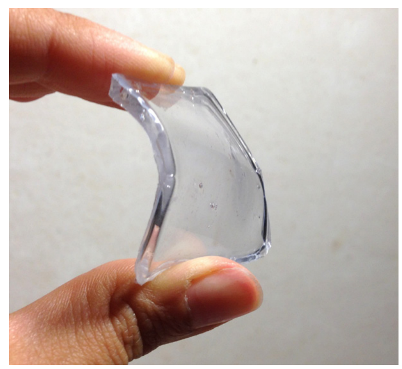


Further, moments of expansion and contraction in the depth of the textile can account for the culture's change in density as it grows: a fresh culture, being less dense, can handle larger depths without loosing full light penetration, whereas, an aged culture, being more dense, needs shallower depths to ensure full light penetration. These needs can be adjusted according to where input valves are located, and will determine where the spherical vessels aggregate and dissipate. It is apparent that algae requires changing conditions along its life cycle, and therefore, variability in its path within the textile can help accommodate for this.









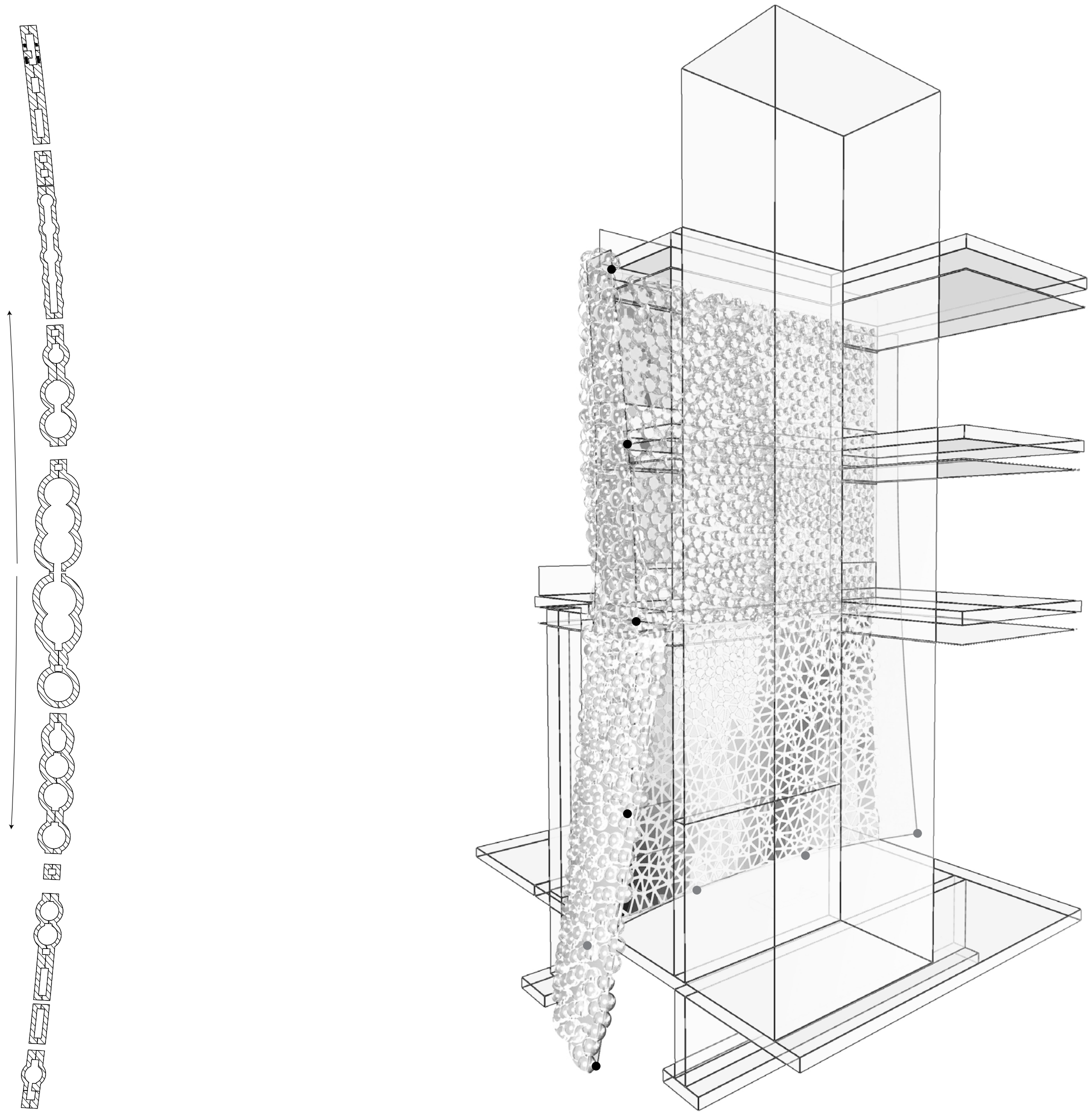
(b) Materiality

To articulate variable geometric conditions within thin dimensions, the algae textile uses polymer–based materials to produce a surface which encapsulates a complex cavity on its interior, while also being elastic, monolithic, water–resistant and durable. A clear polyurethane resin is specifically chosen, as it mimics the characteristics of glass, but delivers a flexible and elastic form; one which can be manipulated in a number of different ways using industrial manufacturing techniques. Polyurethane resins are available in a range of durometers,* from the very hard (Shore–A 100), to the very soft (Shore–A 15), and are widely used in the manufacture of flexible and high–resistance industrial products, such as foam seating, gaskets, hoses, automotive pads and bushings,

1–41 *Sample of polyurethane resin used for the algae textile (Shore-A 60), demonstrating high clarity and flexibility.*

1–42 **The Shore-A Durometer Scale measures the hardness of polymeric materials. Common materials:*

Material	*Durometer*
Chewing Gum	20
Rubber band	25
Door seal	55
Tire Tread	70



1–43 *Application of polyurethane algae textile as a flexible building skin around a building core.*

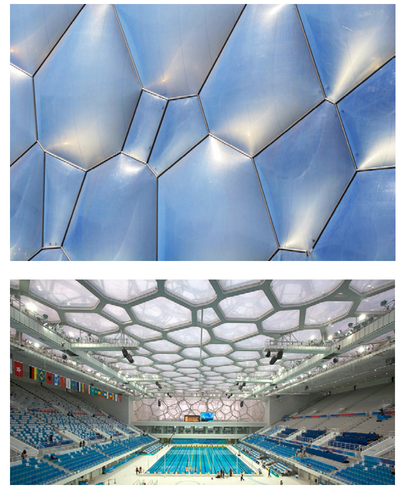
A flexible material constantly seeks for the right balance, "by formation of four-legged nodes that are much more stable than typical architectural nodes of posts and beams [...] so, flexible, elastic organizations become rigid structures.

— Gottfried Semper
"Findings on Elasticity"

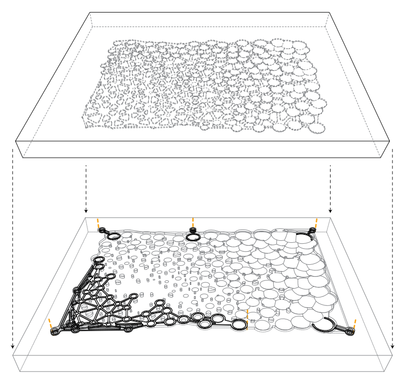
elastomeric wheels and tires, high–performance adhesives, and spandex fabrics. Unlike silicone products, polyurethane is highly durable and resistant to tear. Its molecular composition allows it to have high clarity, and UV resistance, and lends itself well to the creation of strong moulded parts. By exhibiting the qualities of glass in elastic form, the textile can therefore be placed within an existing window wall, creating minimal obstruction and installed using only a network of attachment points to tension it into place. This material characteristic is what allows systems like the algae textile to lie within existing building enclosure systems without a drastic expansion of the wall assembly, and remain in compliance with the spatial limitations of urban real estate.

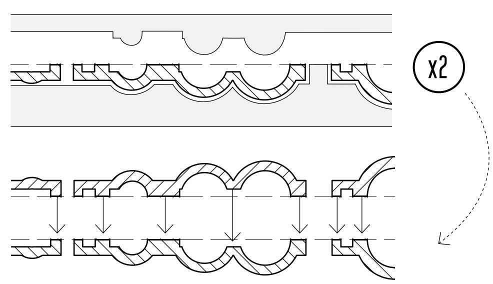
(c) Fabrication Methods

Polymeric materials and the production of complex moulded parts suggests a way of manufacturing custom architectural components which are lightweight, transparent and resilient. The use of plastics in architecture have been widely explored, commonly materializing in the form of tensile structures and composite shell structures. Materials such as polycarbonate, ETFE, and polyurethane are forms of resins which have demonstrated a potential to reinvent traditional building assemblies through their recent use in unconventional building enclosures. For example, the ETFE pillows which clad the Beijing National Aquatic Centre. The enclosure of this building is no more than 0.2mm in thickness, and allows more light and heat penetration than traditional glass, resulting in a 30% decrease in energy costs.[20] Therefore, it is important to understand how these materials are produced, what manufacturing techniques are available, and what limitations or opportunities their materiality presents. Doing so will help inform decisions for designing and producing polymeric building materials. If the algae textile were to be manufactured on an industrial scale, the reaction injection moulding (RIM) process would be used. The RIM process is commonly used to produce polyurethane plastic parts, and is a specialized process wherin the polymer is injected into a heated mould using a pressurized multi–stream mix–head. The heat accelerates the curing time and the pressurized injection ensures proper mixture of the two–part polymer.[21] The specifics of this manufacturing process and the hands–on use of polymeric materials have been integral for formulating the design of the algae textile and the possible methods for its manufacture. Presented here, are experiments undertaken to understand the properties and process of working with polyurethane resin.

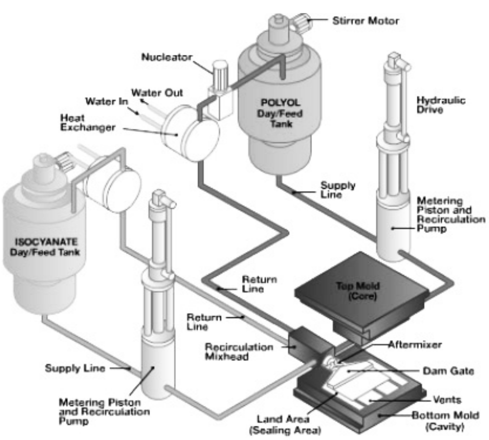


1–44 *ETFE enclosure of the Biejing National Aquatics Centre, constructed for the 2008 Summer Olympics. Photos by Ben McMillan. (arup.com, 2008)*



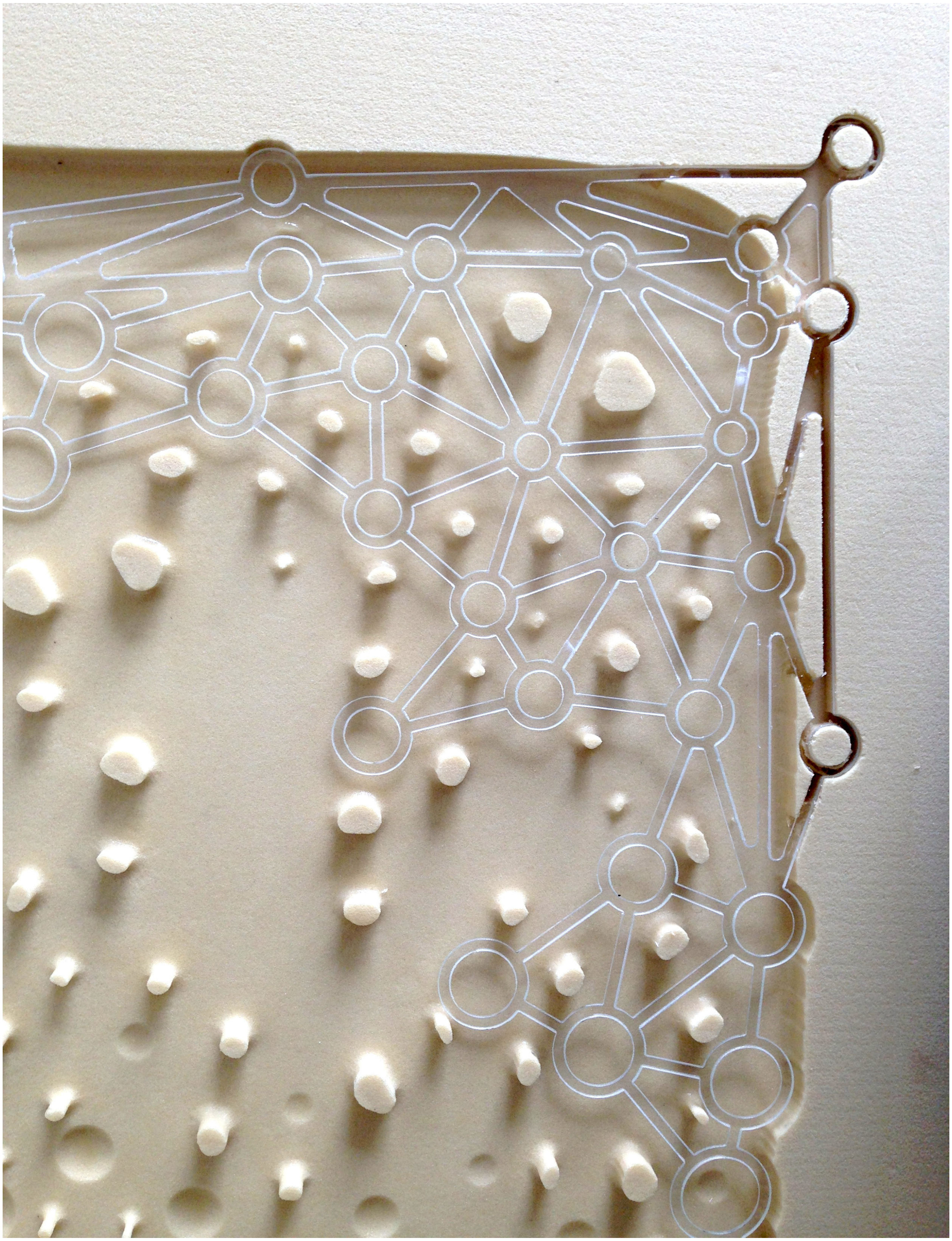


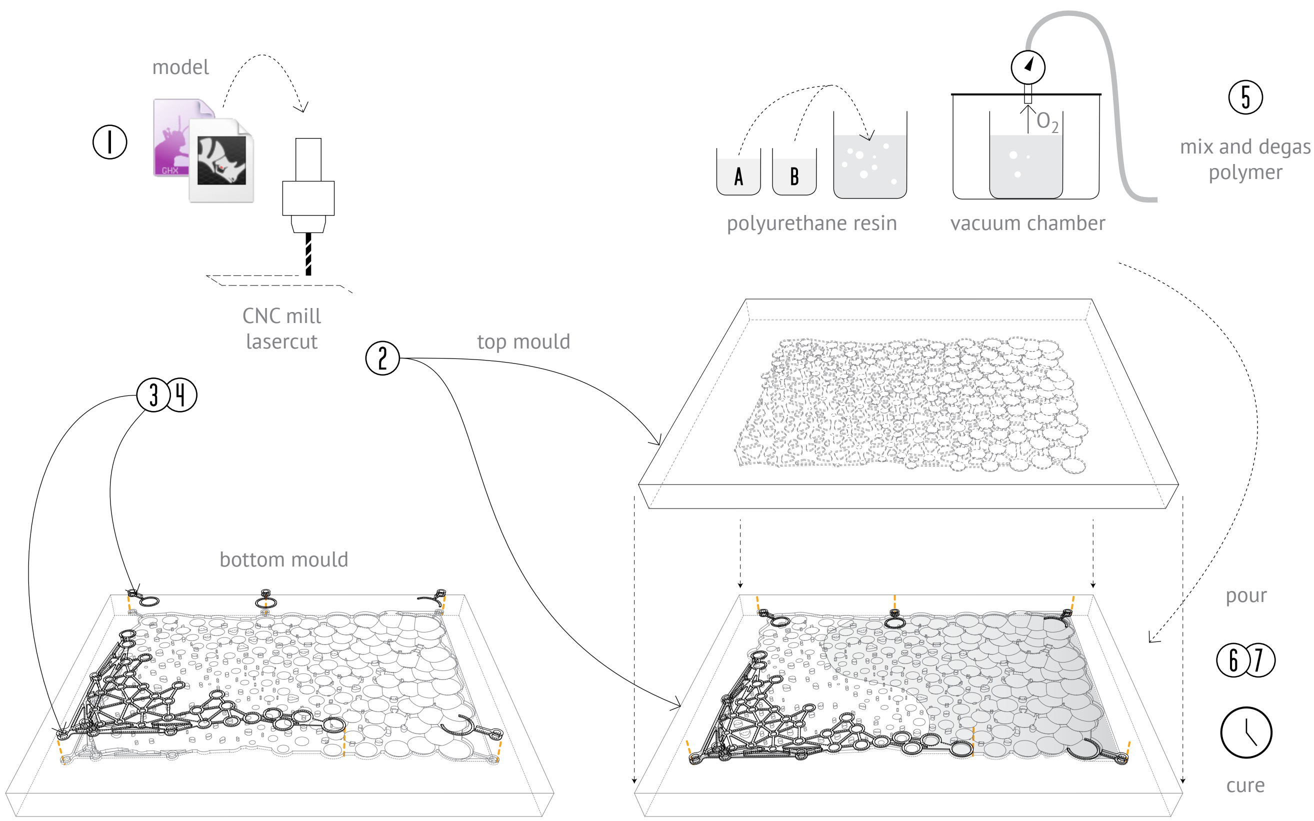
1–45 *(above) Section through the two-part mould that would cast the polyeurethane algae textile. At right, a CNC milled high-density foam mould for the algae textile.*



1–46 *(left) The reaction injection moulding (RIM) process (RIM Manuf., LLC, 2013)*

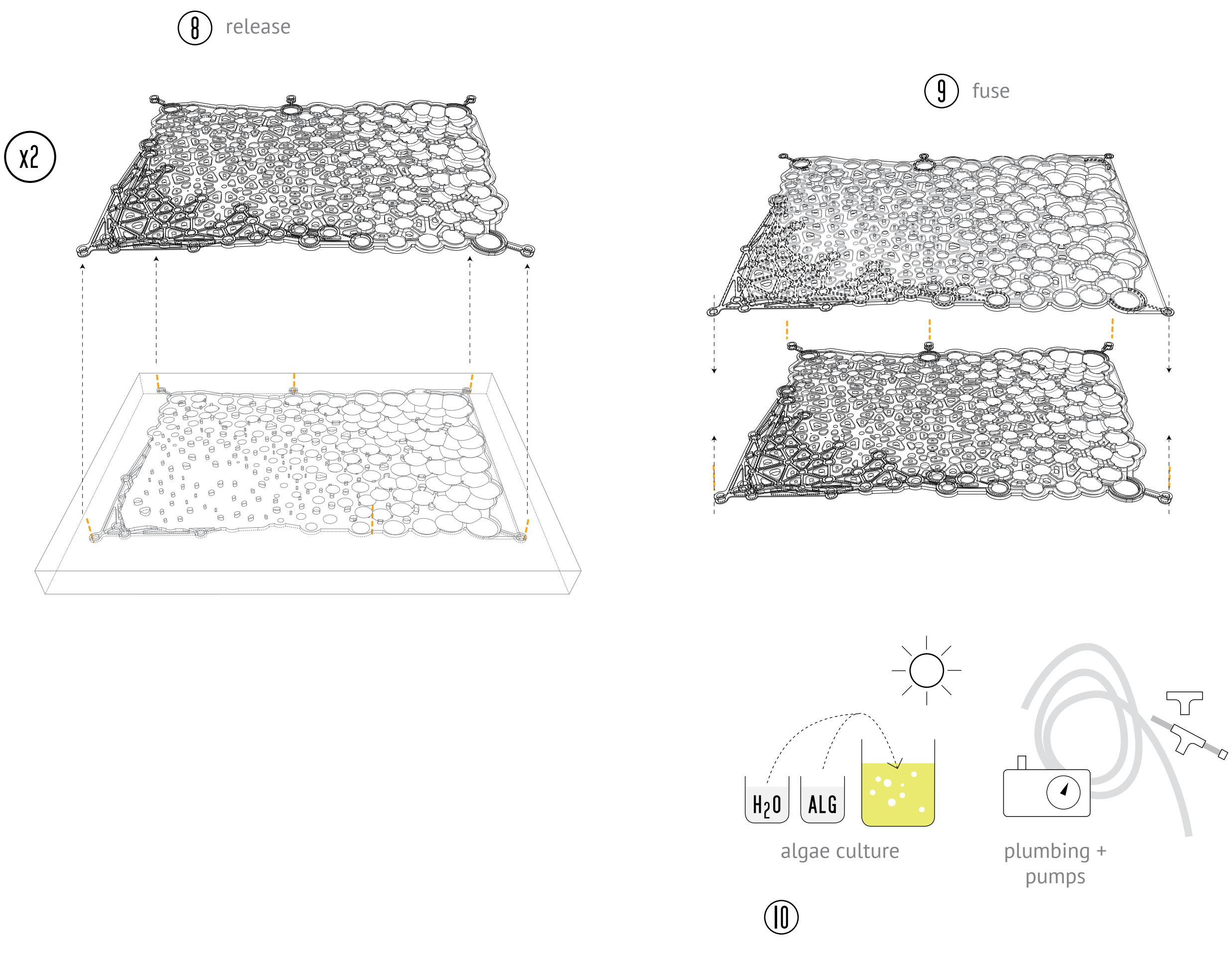
20 Arup Engineering, "National Aquatics Centre (Water Cube)" Projects. (arup.com, 2008) http://www.arup.com/projects/chinese_national_aquatics_center.aspx
21 RIM Manufacturing, LLC, "Reaction Injection Moulding (RIM) Process" (RIM Manufacturing, LLC, 2013) http://www.reactioninjectionmolding.com/rim–process/#prettyphoto/1/



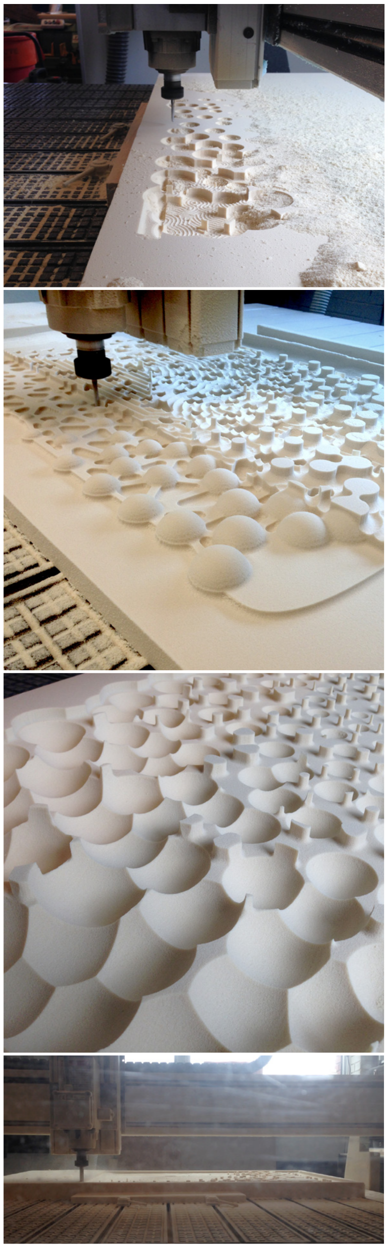


MANUAL FABRICATION SEQUENCE:

1. Prepare the Rhino models and export the .stl files for fabrication
2. CNC mill the two halves of the mould (seal with epoxy after milling)
3. Lasercut the rigid structural inserts
4. Place structural inserts in designated areas in the mould
5. Mix polymer and degas
6. Pour into mould
7. Clamp and let cure
8. Release mould
9. Join two halves using the same polymer (polyeurethane resin)
10. Assemble the plumbing system and algae culture



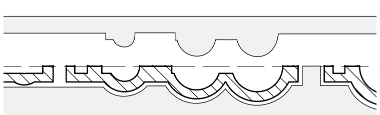
1–47 *Step-by-step manual fabrication process of the algae textile.*



①

CNC MILL HIGH-DENSITY FOAM MOULDS

1–48 *High-density polyurethane foam is used to create the casting moulds for the algae textile's flexible polymer membrane. A positive and negative two-part mould is milled for each half of the membrane. As illustrated below:*



②

SEAL FOAM SURFACE WITH EPOXY

1–49 *To ensure the polymer is transparent and smooth when cast, the porous surface of the milled foam should be sealed with epoxy. If this is not done, the polymer will cast with a rough and frosted appearance. Apply two coats, and allow the epoxy to dry and cure for at least two days. The surface of the moulds are now ready for casting.*

③

APPLY RELEASE AGENT + PREPARE MOULDS

1–50 *A release agent is required to ensure the final part can be taken out of the mould with ease once it is cast. Apply onto all surfaces, and allow to dry until the solvent has dissipated, and the mould is dry to the touch.*

The structural hooks can be placed into their designated area of the mould.

4

MIX POLYURETHANE RESIN

1–51 *The polymer used for the algae textile is a polyeurthrane resin. Start by mixing equal parts A and B to prepare a batch of resin to pour into the mould. No more than 500g (2cups) should be mixed at one time to avoid the risk of exceeding the resin's pot life. Degas each batch before it is poured into the mould to ensure a bubble-free casting.*

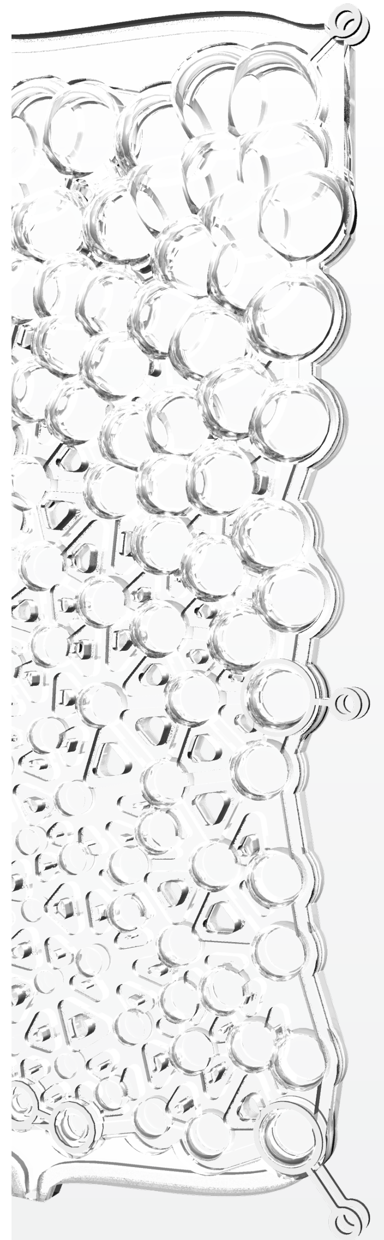
Refer to Material Data Appendix for information on all materials used.

5

ALIGN AND CLAMP MOULDS

1–52 *Once the mould has been filled, align and clamp the top mould into place. Let cure.*

Heat and humidity will effect the length of curing time needed. Any moisture will also create new air bubbles in the resin. Ensure that the casting is being done in a controlled environment.



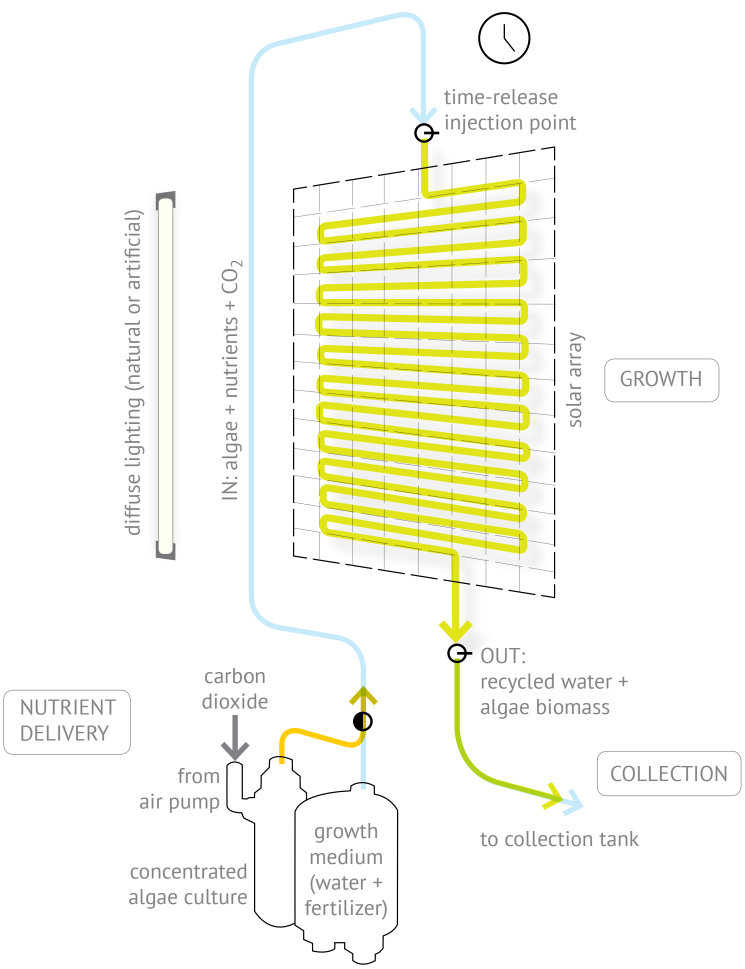
6

RELEASE FROM MOULDS AND FUSE

1–53 *Once the two halves of the membrane have been cast and have cured, they can be released from the mould and fused together to create the hollow and watertight membrane of the algae textile. Due to the self-adhering nature of polyurethane resin, the two halves can be fused together using the same material.*

(d) Support Systems

The components of the algae textile mirror those of a traditional photobioreactor, and therefore, methods of connecting necessary support systems like a water reservoir and air processor are transferable. The textile takes the place of the solar array—the portion of the reactor the algae travels through to expose it to sunlight and promote photosynthesis for reproduction. The use of the textile as the solar array of the bioreactor allows views or light to be controlled in accordance to the surrounding context by manipulating the density of the textile's mesh. These are important parameters for an architect during the planning of a building, and why the textile is a key component for innovating the photobioreactor and its use within buildings.



MECHANICS:

NUTRIENT DELIVERY (INOCULATION)

The nutrient delivery system injects the appropriate fluids into the textile at a given time through plumbing outfitted with controlled valves and manifolds.

For Starting a New Culture:

The reactor is filled with a 1:10 ratio of concentrated algae culture and growth medium (water and nutrients). This starts the first growth cycle in the reactor.

For Maintaining an Existing Culture:

One tenth of the aged culture is extracted from the textile and sent to a collection tank for further processing. Then, the system only injects growth medium into the textile. This replaces what was extracted, creating a new diluted culture within the textile and, thus, staring a new growth cycle.

GROWTH

Once the nutrient delivery system has injected the appropriate fluids, the air pump runs continuously to circulate the culture as it is exposed to light within the textile. The air pump can either pull in CO_2-rich interior/exterior air, or from a CO_2 tank. In either case, a micron filter should be installed on the end of the pipeline to avoid contamination.

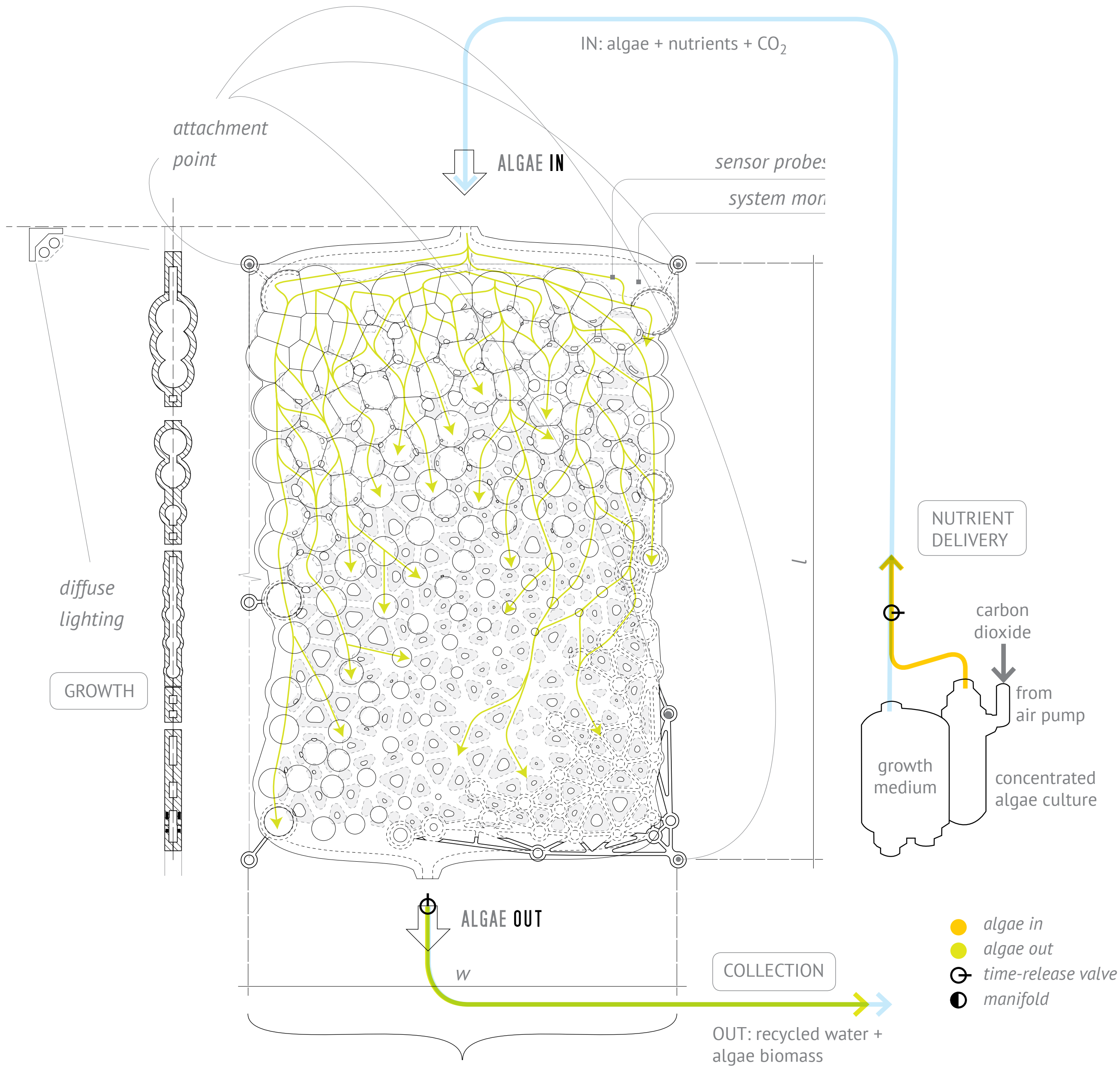
COLLECTION

After a set growth period, the initial culture will have grown greener and denser. This signifies that the culture is ready for collecting and resetting.

algae in
algae out
time-release valve
manifold

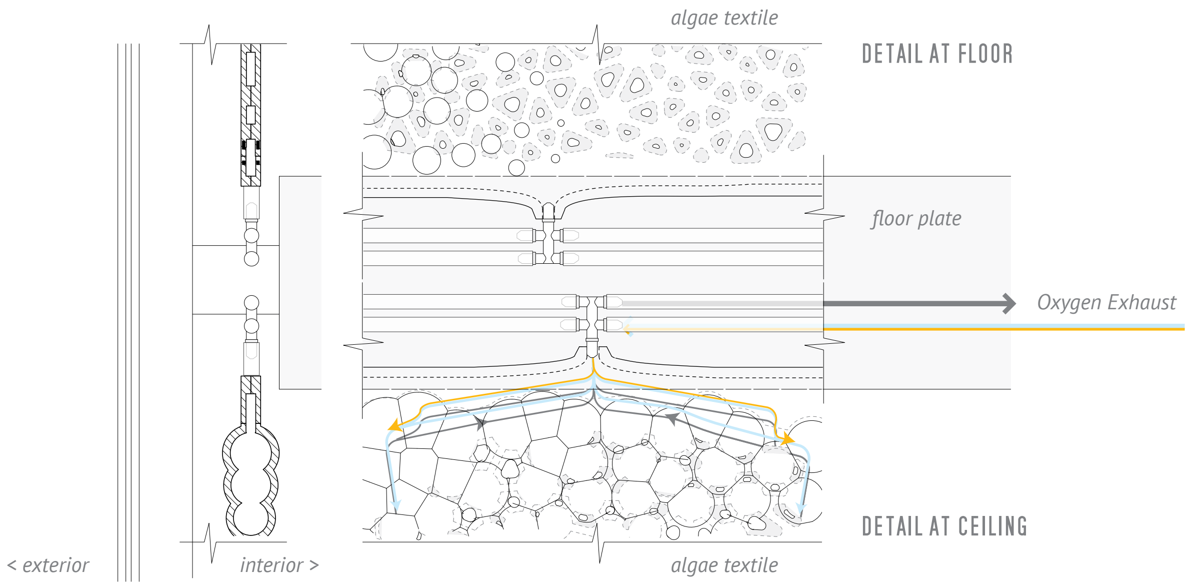
1–54 *(at left) The components necessary for the creation of a working bioreactor. Developed in consultation with Heather Roshon, technical curator of the Canadian Phycological Culture Centre.*

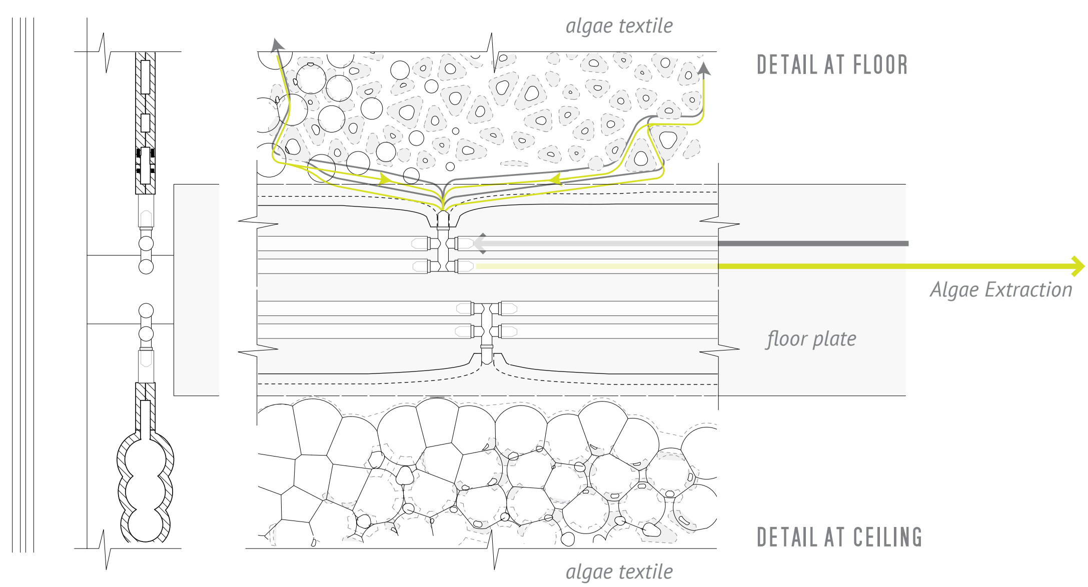
1–55 *(at right) The components of a bioreactor incorporated into the design of the algae textile.*



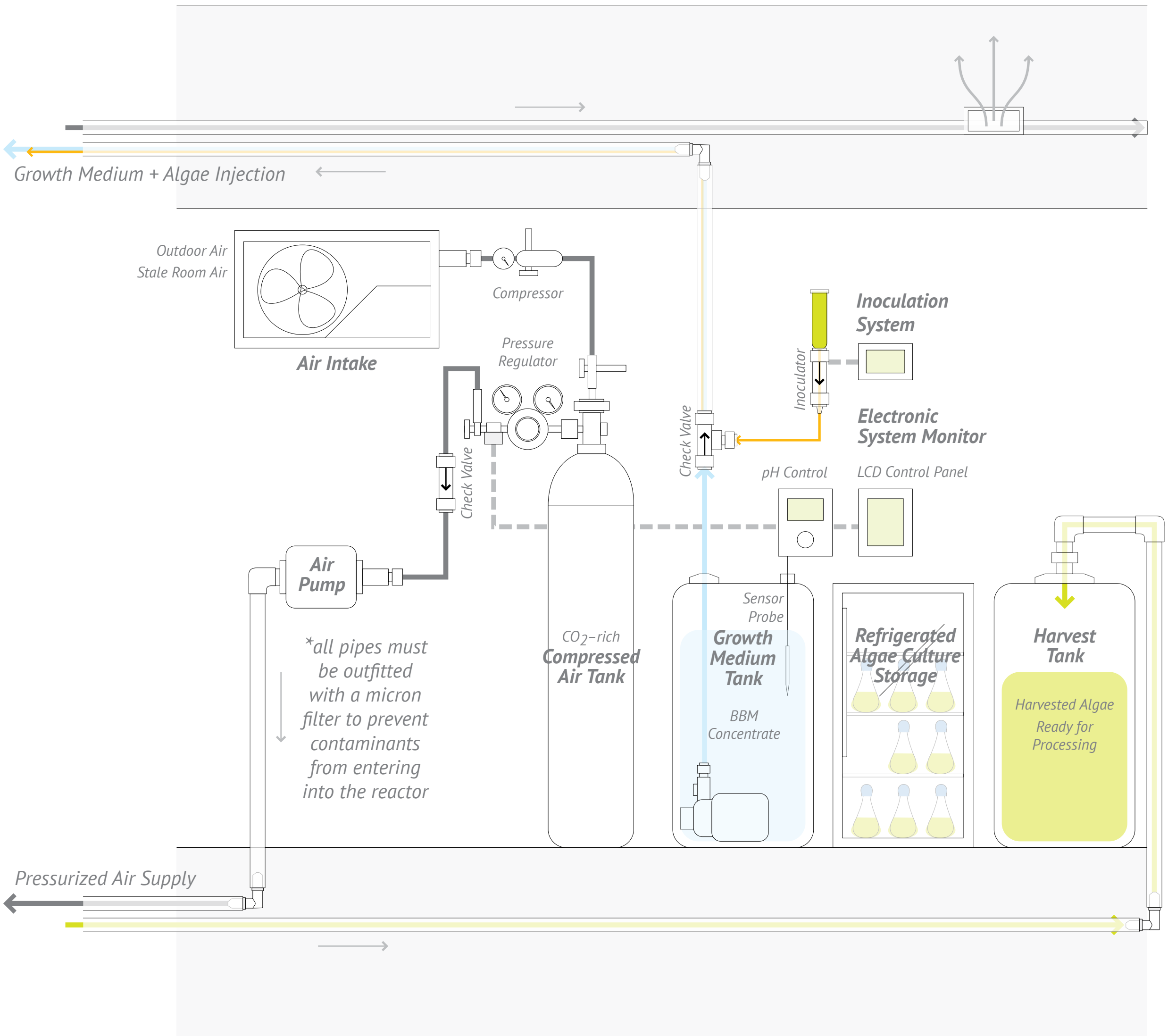
(The Reaction Vessel) + (Agitator and Circulator)

houses culture *stimulates growth*


algae textile
DETAIL AT FLOOR
floor plate
Oxygen Exhaust
DETAIL AT CEILING
< exterior
interior >
algae textile


algae textile
DETAIL AT FLOOR
Algae Extraction
floor plate
DETAIL AT CEILING
algae textile

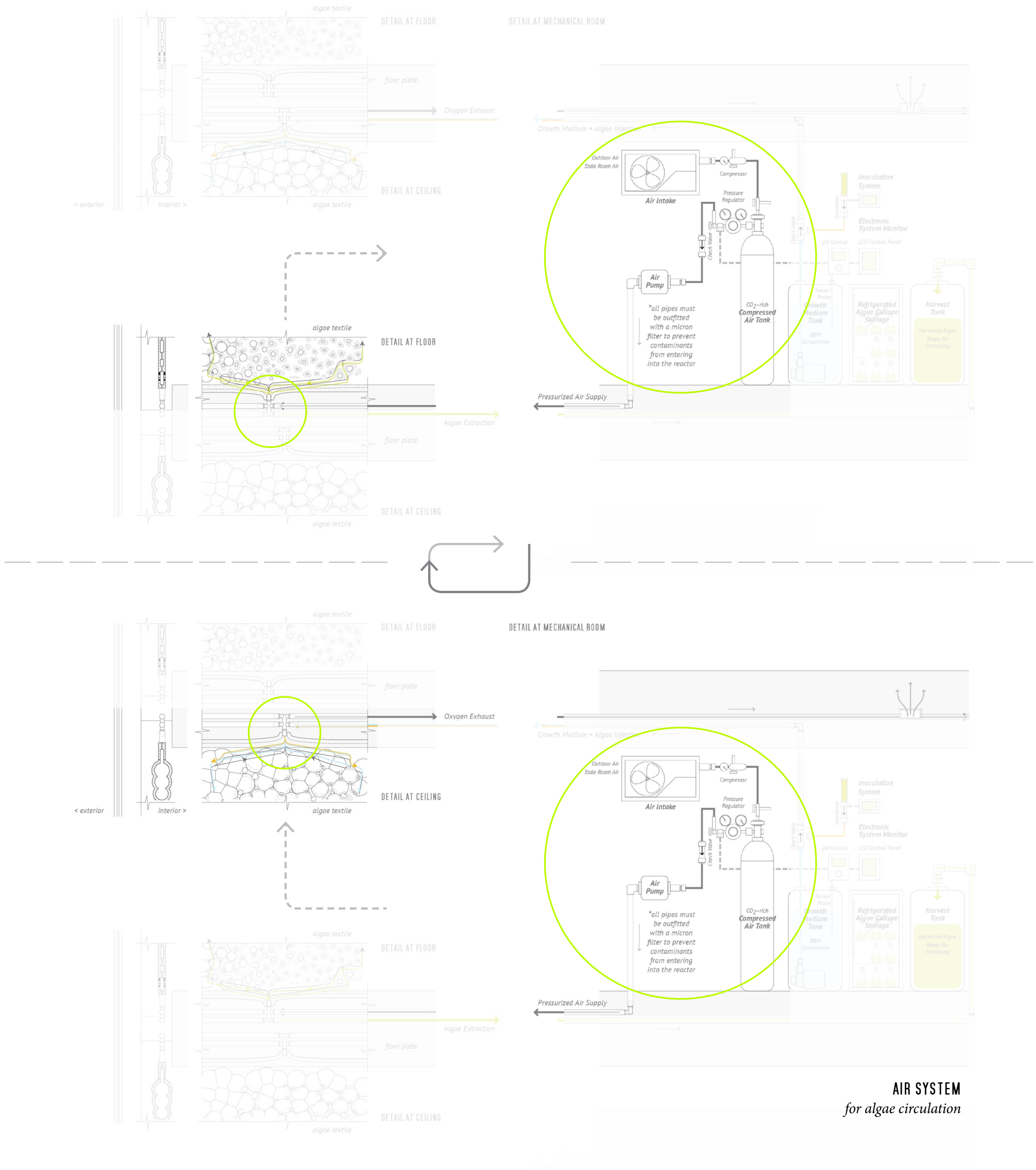
DETAIL AT MECHANICAL ROOM



1–56 *Mechanical details of textile's support systems and their arrangement within a mechanical room and between floor plates.*

However, the textile does not function alone, and requires the integration of various support systems within the plumbing and mechanical infrastructure of a building, including: an inoculation (culture injection) system, an air processing system, a harvesting system and a lighting system. As illustrated here, it is important to detail the ways in which these systems connect to each other and to the building to ensure the textile functions in the desired way.

1–57 ***Inoculation and Harvest System:*** *(1) For starting a culture, the inoculator fills the textile with growth medium (blue line) and then injects a concentrated algae culture (orange line). This is left to grow and photosynthesize. (2) For maintaining an existing culture once it has grown, a portion of the culture is extracted from the textile and directed to a harvesting tank (green line). The inoculator then injects only fresh growth medium into the textile to dilute the culture and start a new growth cycle.*



1–58 ***Air System:*** *(1) Pressurized air is injected at floor level and travels upwards through the textile. This feeds the algae with CO_2 as it photosynthesizes and circulates the culture to promote its growth. (2) The resulting oxygen produced by the algae is exhausted at ceiling level and can be fed into the building's ventilation system thereafter.*

(e) Algae Culturing

By consulting Heather Roshon, the technical curator of the Canadian Phycological Culture Centre, valuable lessons in algae cultivation were gathered to confirm requirements specific to the spatial and environmental parameters which affect algae's growth. Upon speaking with Heather, it was immediately apparent that the way in which environmental parameters are controlled in a lab can directly relate to decisions commonly made during the space planning of a building, including orientation, elevation, heating, cooling and lighting. Through this consultation, an algae culturing guide specific to details regarding space planning was created:

Lab-Grade Growth Medium

Growth medium is a mixture of distilled water and water-soluble nutrients.

Bold's Basal Medium (BBM):
Stock Concentrate

Substance:

$Na_2EDTA.2H_2O$ (Disodium Salt Dihydrate)	10.0 g/L
KOH (Potassium Hydroxide)	6.2 g/L
$FeSO_4.7H_2O$ (Ferrous Sulfate)	4.98 g/L
H_2SO_4 (Sulfuric Acid)	1.0 mL
$CaCl_2.2H_2O$ (Calcium Chloride)	25 g/L
$MgSO_4.7H_2O$ (Magnesium Sulfate)	75 g/L
$NaNO_3$ (Sodium Nitrate)	250 g/L
NaCl (Sodium Chloride)	25 g/L

Trace Metal Solution:

H_3BO_3 (Boric Acid)	2.86 g/L
$MnCl_2.4H_2O$ (Manganese Chloride)	1.81 g/L
$ZnSO_4.7H_2O$ (Zinc Sulfate)	0.222 g/L
$Na\ MoO_4.5H_2O$ (Sodium Molybdate)	0.390 g/L
$CuSO_4.5H_2O$ (Copper Sulfate)	0.079 g/L
$Co(NO_3)_2.6H_2O$ (Colbalt Nitrate)	0.049 g/L

H_3BO_3 (Boric Acid)	11.5 g/L
F/2 Vitamin Solution (optional)	
Distilled or Milli-Q Water	

1–59 *(above left) Image of refrigerated algae specimens at the Canadian Phycological Culture Centre.*

1–60 *(above) Ingredients and preparation of BBM Concentrate: a lab-grade algae growth medium.*

1–61 *(at right) Algae Culturing Guide. These guidelines were created in consultation with Heather Roshon, technical curator of the Canadian Phycological Culture Centre.*

ALGAE CULTURING GUIDE

OPTIMAL GROWING CONDITIONS: *Changes in these conditions can be used to speed up or slow down the rate of growth*

Lighting:

Direct sunlight is not desirable.

Too much light will result in a culture that is not bright green.

Direct light will kill the culture *(photo-bleaching)*.

North facing windows are ideal.

The textile should be setback from the window wall in other orientations, or used with frosted glass to avoid direct sunlight.

Artificial lighting around the textile should be diffuse and evenly distributed. Hot spots should be avoided, cool white bulbs should be used and placed at least 6” away.

Provide low-intesity light during the evening if desired. (1000–10,000 lux)

Temperature:

cold = slow growth   hot = fast growth

Room temperature is ideal for stable growth (20–25ºC)

CULTURING BASICS

Resetting and Multiplying a Culture:

The best way to reset a dense culture is to extract a portion of the culture and refill with the same volume of growth medium.

Always divide the culture to maintain a back up.

A test tube filled with the backup culture can be kept in a refrigerator for a year or longer.

WHAT TO DO IF THE CULTURE DIES WITHIN THE TEXTILE:

Step 1: Extract the existing culture

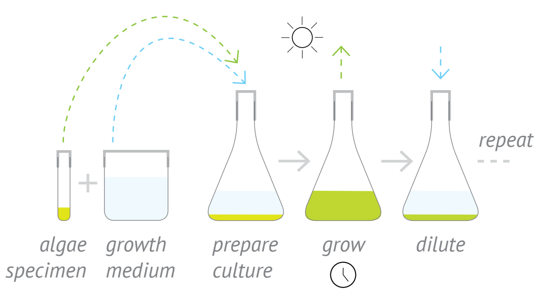
Step 2: Flush the reactor with a water/chlorine solution

Step 3: Flush the reactor with water multiple times

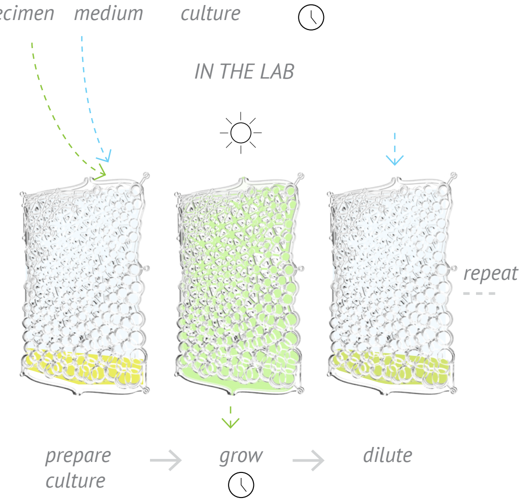
Step 4: Introduce new a culture

To prepare concentrate:
To make 100mL of concentrate, combine stock solutions in the order listed above, to make 100mL total volume. Concentrate may be stored in the fridge in the dark until needed.

To prepare medium:
The final concentrations shown above are to prepare a 100% BBM medium by adding 10mL of concentrate to 990mL of water. This is a very rich medium. If you wish to prepare a dilute growth medium (i.e., 10% BBM), add 1mL of concentrate to 990mL of water. The pH should be approximately 6.8 when prepared. If necessary, adjust the pH with 1N HCl or 1N NaOH. If sterile medium in needed, it may be filter-sterilized through a 0.22μ filter and dispensed aseptically into sterile vessels or autoclaved directly in the vessels.



IN THE LAB

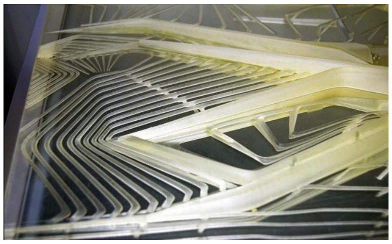


WITHIN THE TEXTILE

1–62 *Flower Street Bioreactor by Emergent Architecture (archello.com, 2011)*

Architectural Precedents

1. Flower Street Bioreactor by Emergent Architects



1–63 *Interior form of the Flower Street Bioreactor (Emergent Architects, 2011)*

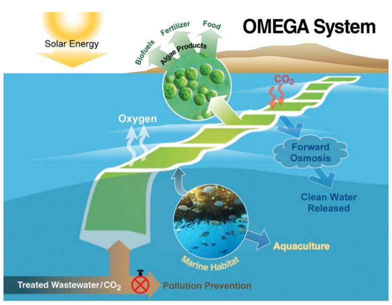
1–64 *The OriginOil LED lighting bio-feedback system (archello.com, 2011)*

Designed as a public fixture to make knowledge of algae technology visually accessible to the public, Emergent Architecture's Flower Street Bioreactor acts as a bioluminescent beacon of algae for public space. Commissioned as a piece of public art in Los Angeles, its aquarium–like design is inserted into a renovated building façade. The bioreactor is made out of molded polycarbonate and embedded with an intelligent LED lighting system that gives the algae the specific growing conditions it needs at any particular time. According to *OriginOil*, the company which developed its Bio–feedback Algae Controller:

> *this is a true bio–feedback system ... the algae lets the LED controller know what it needs as it needs it, creating a self–adjusting growth system.*[22]

This bio–feedback not only helps in supporting algae growth, but creates spectacle and event in the public space which it surrounds. Furthermore, it demonstrates that the combination of bioreactors with integrated intelligent systems can increase opportunities for the integration of algae technology into the built environment. It affords an ability to monitor and maintain the system through digital interfaces which can be controlled at remote locations; thereby reducing any mishaps or liabilities involved with culture–death, providing a means to predict threats ahead of time and mending conditions accordingly.

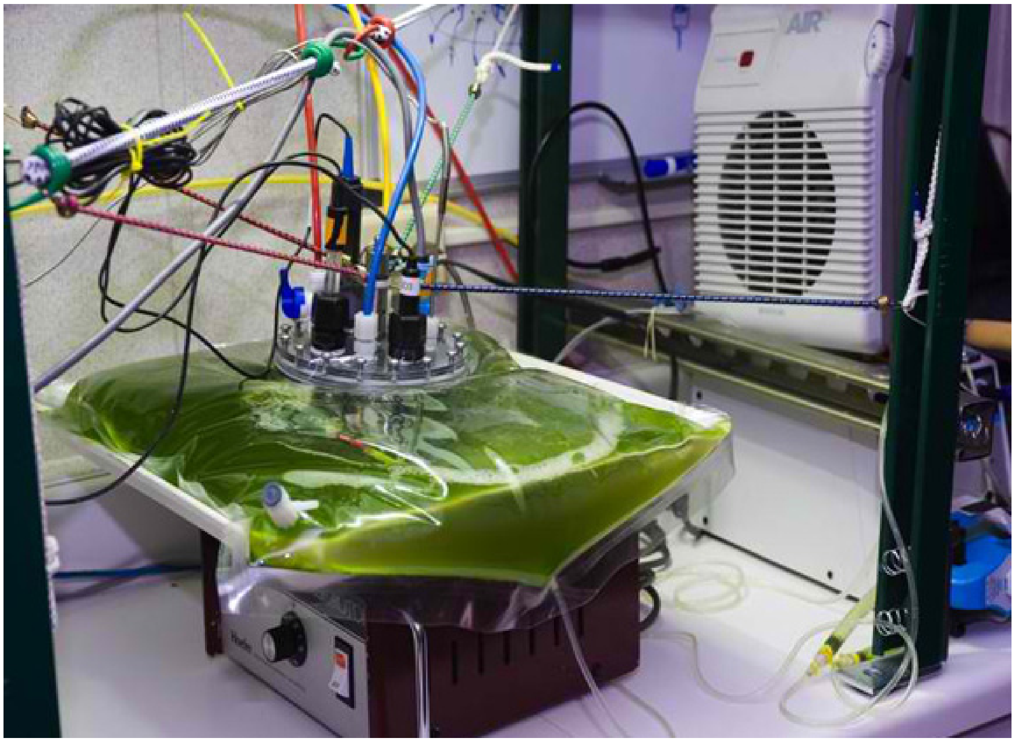
2. NASA OMEGA Project



1–65 *The OMEGA (Offshore Membrane Enclosure for Growing Algae) System. "When deployed in contaminated and 'dead zone' coastal areas, this system may help remediate these zones by removing and utilizing the nutrients that cause them. The forward-osmosis membranes use relatively small amounts of external energy compared to the conventional methods of harvesting algae, which have an energy intensive de-watering process." (PhysOrg.com, 2009). Image courtesy of Ames Research Centre, NASA.*

On a larger scale, NASA's OMEGA Project aims to develop an Offshore Membrane Enclosure for Growing Algae (OMEGA). The goal is to create an efficient and lightweight system for growing algae which does not compete for agricultural land and is non–energy–intensive. The OMEGA system consists of a series of plastic bags made of a semipermeable membrane designed to float on the surface of a body of water. Filled with processed wastewater, freshwater algae grow and feed off of the nutrients in the waste (that would otherwise contribute to marine deadzone formation),[23] and in turn, through the process of photosynthesis, the algae absorb carbon dioxide, produce oxygen and clean the water.

22 Emergent Architecture, "Flower Street Bioreactor," in *Projects*, (archello.com, Jan, 25, 2011) http://www.archello.com/en/project/flower–street–bioreactor
23 Ames Research Centre, "Project Overview," *OMEGA Offshore Membrane Enclosure for Growing Algae*, (NASA, March 28, 2013) http://www.nasa.gov/centers/ames/research/OMEGA/



1–66 *Laboratory monitoring system for algae growing on wastewater. Continuous measurements of temperature, pH, dissolved oxygen, and conductivity (shown) will soon be supplemented with a system to monitor photosynthetic efficiency using Fast Repetition Rate Fluorometry (FRRF). Image by Sigrid Reinsch. (Algae Industry Magazine, 2011)*

The semipermeable membrane system allows for the clean water to be released into the body of water it floats in using forward osmosis (a passive process inherent in the type of plastic membrane used, designed to allow a certain size of molecule out but not in), improving the health of the ecosystem and preventing the otherwise harmful waste from running off into the marine habitat.

Considering the scale of algae production required to meet the needs of human fuel consumption, NASA's task was to solve the problems associated with large–scale algae cultivation. The system could not rely on freshwater needed for drinking water, could not use fertilizers, and could not take up land needed for agriculture nor consider remote non–arable land as pumping water and fertilizers to these locations is uneconomical. These constraints gave Dr. Jonathan Trent, the head scientist on the project, the inspiration for offshore rigs:

> *I think the fact that in all our coastal cities we already have the infrastructure for "disposing" of our wastewater offshore, we need to consider the possibility of using this wasted water and the existing infrastructure for growing microalgae offshore.*[24]

24 David Schwartz, " NASA's OMEGA Scientist Dr. Jonathan Trent," (algaeindustrymagazine.com, August 21, 2011) http://www.algaeindustrymagazine.com/nasas–omega–scientist–dr–jonathan–trent/

As a closed–loop system, the OMEGA is really a system of systems; an “ecology of technologies,” says Trent,[25] which takes algae that would otherwise grow on the surface of the water naturally and harnessing it in a synthetically constructed system which benefits both human and natural environments. Developed in the Ames Research Centre in Moffett Field, California, the OMEGA bioreactor project was licensed with patent pending to Algae Systems LLC, Carson City, Nevada, which plans to develop NASA’s pilot technology and integrate it into biorefineries to produce renewable energy products, including jet fuel.[26]

Algae Strains, from highest to lowest lipid content:

Algae Strain	**Lipids**	**Protein**	**Carbohydrates**
Botryococcus Braunii	86	43–56	20
Chlorella Ellipsoidea	84	5	16
Prymnesium Parvum	22–38	30–45	25–33
Chlamydomonas Rheinhar	21	48	17
*Chlorella Vulgaris**	14–22	51–58	12–17
Euglena Gracilis	14–20	39–61	14–18
Scenedesmus Obliquus	12–14	50–56	10–17
Spirogyra Sp.	11–21	6–20	33–64
Synechococcus Sp.	11	63	15
Porphyridium Cruentum	9–14	28–39	40–57
Spirulina Maxima	6–7	60–71	13–16
Arthrospira Maxima	6–7	60–71	13–16
Dunaliella Salina	6	57	32
Anabaena Cylindrica	4–7	43–56	25–30
Spirulina Platensis	4–9	46–63	8–14
Aphanizomenon Flos–Aqua	3	62	23
Chlorella Pyrenoidosa	2	57	26

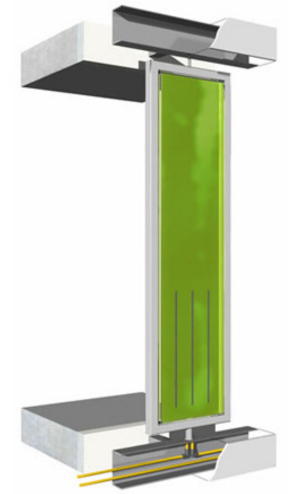
1–69 *Table of algae strains. (Adapted from, “Table 1: Composition of Various Algae (% of dry matter),” on AlgaeIndustryMagazine.com, 2010)*

** This strain is the easiest to grow. It is tough, resilient, and grows well in waste water but dies off in saline water. (These findings were discovered by the NASA OMEGA Project and it is used in their prototypes)*

1–67 *Artist’s conception of an offshore integrated energy “farm” with an OMEGA system supported by wastewater and flue gas from onshore, solar panels on the floating docks, vertical wind turbines, and a wave energy converter (floating orange structure). Illustration by Tom Esposito, TopSpin Design Works, NASA. (AlgaeIndustryMagazine.com, 2011)*

1–68 *As in other coastal cities, the San Francisco treatment plant (red rectangle) is embedded in the city and existing outfalls are offshore (solid red arrow). To accommodate the 65 million gallons per day (MGD), assuming a 5-day retention time for algae growth requires 325 million gallon ponds or photobioreactors. This would require approx 2.3 sq miles of area (green rectangle) on land or offshore. Illustration by Tom Esposito, TopSpin Design Works, NASA. (Algae Industry Magazine, 2011)*

25 David Schwartz, “NASA’s OMEGA Scientist Dr. Jonathan Trent,” (algaeindustrymagazine.com, August 21, 2011) http://www.algaeindustrymagazine.com/nasas–omega–scientist–dr–jonathan–trent/
26 Phys.org, “NASA Develops Algae Bioreactor as a Sustainable Energy Source,” (phys.org Chemistry, Nov. 18, 2009) http://phys.org/news177780192.html



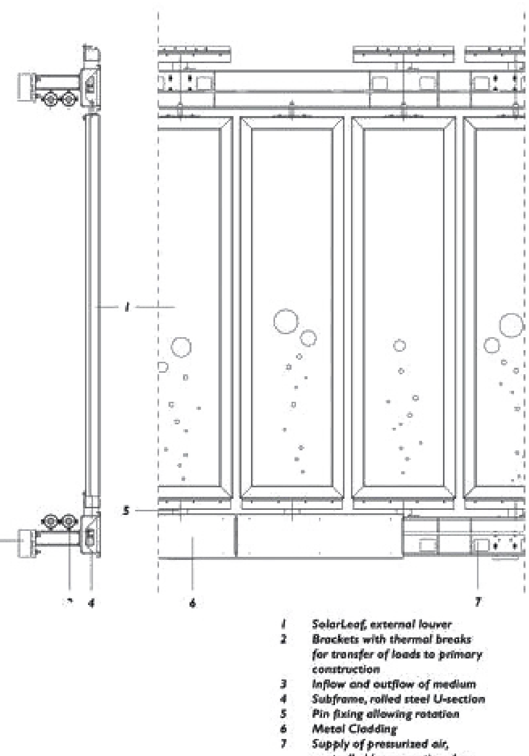
1–70 *Details of BIQ louvre tank façade (gizmodo.com, 2010)*

3. World's First Algae–Powered Building by Splitterwerk Architects, ARUP Engineering & SSC Strategic Science Consultants

Built in Hamburg, Germany, the first algae–powered building was constructed using 129 algae–filled louver tanks as its outer façade. Named the Bio Intelligent Quotient House (BIQ), the 15–unit apartment building demonstrates how algae can be used as a way to heat and cool large buildings. Using algae retrieved from the nearby Elbe River, each louver tank is filled and affixed to outside scaffolding which are mechanically controlled to orient themselves towards the sun, beginning the process of growing a renewable fuel source for the building:

> *When the amount of algae growth in the tanks reach a certain point, some is harvested and taken to a processing facility inside the building. There the biomass is converted to biogas which can be burned to provide heat in the winter.*[27]

The building now serves as a test case to be studied by architects and engineers to continue to determine if algae power is feasible in building construction. With working mechanics, further progress can now be made on the design of the building skin—which at the moment remains bulky and somewhat cumbersome. Further iterations are needed to make the technology's integration into construction a more prolific process. This can be done by examining the possibilities of lightweight and attachable polymer–based membrane systems. [See 2.3 *Textile Implementation*]



27 Bob Yirka, "First Algae Powered Building Goes up in Hamburg," (phys.org, April 12, 2013) http://phys.org/news/2013–04–algae–powered–hamburg.html

Future Developments

The algae textile and the projects presented have implications beyond the immediate context of an algae–based urbanism; this being an awareness of the vast world of biotechnology and its place in architecture. The working territory of biotechnology reaches all facets of natural life and now propagates its influence on a new movement in design and architecture known as *biophilic design.*[28] This method of design consults the processes of all living systems in a direct way rather than a metaphorical way (like in biomimicry) to form design principles. For example, in its simplest form, it can present a method for guiding the growth of plants into architectural forms, or, at its most complex form, it can manipulate micro–organisms for growing valuable products or building materials; made possible by the developing discipline of synthetic biology. This thesis takes a particular approach within this wide field through the making of the algae textile, while assimilating itself with works and theories tied to KieranTimberlake's Refabricating Architecture, Dr. Rachel Armstrong's argument for Vibrant Matter, and Donna Haraway's view of society as a distributed cybernetic network of posthuman and postnatural creations. These theories position the work, and postulates on the relevance biotic ethics and postnatural theory may have towards this changing understanding of environmentalism in contemporary studies.

This new influence in the field of design strikes up an important discussion, recognizing that, unlike the natural environment, our built environment is simply not designed to support other reproductive functions within its surfaces; other than forming hard, glossed, airtight or decorative enclosures. As a result, it is questioned whether concrete, steel and glass alone can continue to accommodate the needs of our rapidly changing environment, and if the way these materials come together in architecture allow for the symbiotic relationship with nature architects strive for. Conventional assemblies of concrete, steel and glass are too monolithic and weighty to achieve this, yet, the industry continues to implement construction techniques which inevitably tolerate inefficiencies, energy consumption, manual labour and brute force due to construction logistics and, quite simply, to the materials architects have available to build with. However, if a building could simulate the benefits of natural life within its surfaces, a city based on a *productive* materiality could be envisioned; one where lightweight and intelligent membranes define a new building standard.

28 *Biophilic Design emerges from Edward O. Wilson's hypothesis of Biophilia: the urge to affiliate with other forms of life. See chapter 2.1 Material Fertility.*

If a designed material can locally provide nutrients, circulation, ventilation, etc., like a living cell, then it may build the beginnings of an intelligent and closed–loop materiality for the near future of architecture; where surfaces are not only a tool for enclosing but are designed in a way which embeds discreet functionality within their form. This is at the core of designing productive architectural membranes: they benefit both human and natural territories. From a design standpoint, this can mean an articulately meshed interior structure, embedded soft circuitry, or an implantable outer surface—all within minute scales achieved with advance manufacturing and 3D printing. Investigations involving green walls and porous surfaces relate to this desire, however, this paradigm pairs the idea of a "living surface" with intelligent or modifiable mechanical functions—growing, pumping algae, sensing, or reacting to electrical stimuli for example—it is living *machinic** material. This is essentially the materiality of laboratory vessels housed within the scale of a sheet of material. [Refer to 2.2 *Scientific Precedents*]

* *"Machinic"* describes the qualities found in the study of cybernetics, artificial life, and artificial intelligence; machines which closely mimic biological behaviours. See chapter 2.2 *Consulting Machinic Theory.*

Biotic Ethics and its Applications in Architectural Theory

Biotic Ethics is a branch of ethics based not only on the study of species and biospheres, but on the sustenance of life itself, seeking to understand the importance of gene–to–protein networks, their behaviours and their interactions *(transcription)* as the definition of all life, and the key to supporting its future sustenance. Biotic ethics believes that self–propagation is a quality shared by all biota, including humans, and therefore, belonging to life, then implies a purpose to safeguard and propagate life. On this basis, biotic ethics can be defined as the instinctual human purpose to secure its future existence and the complex molecular interactions it involves. These principles are related to *bioethics* and *environmental ethics,* which seek to conserve existing species, but differs in that it extends to include an intimate understanding of organic gene–to–protein networks as the fundamental tools to propagate this environmental proposition. Although rarely seen in current architectural theories relating to "sustainable," or "environmental," design, this new environmental premise could directly inform the creation of these intelligent "living surfaces". Designing architectural components in this manner introduces a continual dialogue between organic and inorganic matter, and incites mutual exchanges between the occupants of a building, the components of its assembly, and the environmental context it finds itself in. For example, this can be seen in how the algae textile supports the interchange between algae, air pollution and an occupant's well–being in an effort to support the basic sustenance of biotic life in the context of densely urbanized land.

“IS THE NATURAL RELEVANT? HAS IT EVER BEEN?

Liam Young, “Artifice Earth” in *Volume*, Vol. 35, 2013, pg. 16.

The Mechanization of Nature: Towards a Postnatural Materiality

The mechanization of nature in the built environment is a concept which sees the replacement of natural processes with artificially–aided equivalents as a tool for sustaining future ecological health. With rapidly densifying urban centres, fertile landmass becomes scarce or nonexistent. How can cultivation in the city be aided by technology and implemented through materiality to reinvent green space? What does this future “urban nature” (aided by machines) look like? Does it include bionic organisms? Can cultivation occur in the absence of fertile ground? Earthless cultivation sees the practice of growing living material without the use of soil; where cultivation and organic fertility is altered from natural means to construct the same results using technology. Liam Young states:

> *The next stage of biology is in actuality a human technology. We talk of the “Anthropocene”, a period of geological history in which, from the engineering of bacteria to the terraforming of landscapes, at every scale, we are the dominant force shaping our planet. We have made an “artifice earth”, reengineered and reordered, controlled and determined. I want to start with this question, is the natural relevant? And has it ever been?*[29]

In this sense, the mechanization of nature has already been occurring for centuries and in trying to help nature humans have only transformed it beyond recognition, and further, to its recreation within a petri dish in a laboratory. In this paradigm, the negation of technological progress in environmentalism is believed to be illogical. In response, to make material artifacts “alive” and synonymous with nature, architects must borrow from biology, manufacturing and material science, to create sentient, or smart, material systems.

1–71 *Specimens of an Unnatural History (Liam Young, 2010)*

29 Liam Young, “Artifice Earth.” (Volume Magazine, Vol. 35, April 2013) pg. 16.

2.1

MATERIAL FERTILITY

2.1

MATERIALITY IN A POSTNATURAL ERA

> *Posthumanism challenges the long–standing conception of the building as an object autonomous from its environment and governed by disciplinary interiority.*[28]

A *postnatural* quality between humans, nature and technology becomes increasingly evident within recent design discourse surrounding sentient systems and smart materials—inciting new questions for an architecture that can be resilient or reproductive within a changing environmental context. Studies in postnatural– and posthumanism aim to characterize this new dynamic between architecture and the environment in the age of the *Anthropocene:* a geological era where the human is dominant. Postnaturalism and posthumanism argue that this requires methods which go beyond sustainability and green building to rectify architecture's effect on the environment, and instead requires a movement into a realm where living and non–living boundaries are breached through cybernetic and biological substrates which enter the material palette of architecture.[29]

What is materiality in a postnatural era?

1. A direct use of biology in architecture to redefine architecture's relationship to the environment.

2. Architecture and advanced science—to materialize that new relationship with the environment (through material science, synthetic biology, and/or systems engineering).

3. Modes of making which are lightweight, intelligent and able to navigate between a natural–synthetic interface—these define new standards of geometry and assembly in a postnatural era.

28 Ariane Lourie Harrison, ed., "Architectural Theories of the Environment: Posthuman Territory" (Routledge, New York, 2013) pg. 3.
29 Harrison, ed., "Architectural Theories of the Environment" pg. 24.

Biologically Direct

Postnatural materiality suggests modes of making that are biologically direct. In other words, they do not abstractly represent biological structures, but it itself becomes a quasi–biological structure. Therefore it is *biophilic*, not *biomimetic*.

> *Biophilia: the urge to affiliate with other forms of life.*[30]

Recent discussions involving biophilic design and synthetic biology have emerged within the architectural field. These discussions are influential for their non–metaphorical references of biology in architecture, and moves away from merely mimicking the geometry and form of biological structures. Instead, it suggests a new type of construction process directly involved in the engineering of biological systems embedded within constructed artifacts. Together, biophilic theory and the potential convergence of architecture and synthetic biology is powerful and suggests an emergent material construction process, bringing lifelike, intelligent and resilient properties to building materials. As a result, this thesis looks at potential methods for developing growing or evolutionary materials; suggesting that if this becomes widespread, it may build the beginnings of an intelligent and closed–loop materiality for the near future of architecture—an era of *material fertility.* Designers have an innate desire to pursue the aesthetics of biology in their designs, but they often remain as static representations, offering nothing in return to the biological world. Materiality in a postnatural and posthuman era asks whether material can possess an agency and perform productive tasks. Can fertility, therefore, be actively employed in construction to alter our preconceived notions of materiality?

When the theories behind biophilic design are applied to smaller scales, such as in the composition of building material rather than architectural form, its application becomes more prolific. The creation of biophilic material—*architectural material which behaves like those found in nature*—could advance the implementation of biotechnologies like algae into built structure, and facilitate the need for productive links between nature and culture. In fact, biophilic design in this context embraces advanced technology's power to form complex materials which can align humans with nature; a contrast to traditional views which suppress technology to conserve nature.

30 Edward O. Wilson, "Biophilia," (Harvard University Press, 1986)

Architecture and Advanced Science

Disciplines such as material science, synthetic biology and systems engineering are characterized by an ability to manipulate and distill complex systems, and to navigate between the natural and synthetic. When exercised in collaboration with architects, this could materialize movement toward a postnatural environmentalism using complex material assemblies.

Take, for example, the emerging discipline of synthetic biology: what is it, and why should architects pay attention to it? Synthetic biology is a growing field of science which studies methods for constructing biological organisms artificially. Using a bank of known specimens, genetic code and/or chemical reactions, they select desired behaviours from this vast library and combine them to produce a synthetic cell with the desired characteristics. In this sense, synthetic biology is akin to computer engineering in many ways, but uses biological coding rather than computer coding to produce products, offering:

> *... a palette of materials, technologies and methods that help architects explore the design and execution of architectural programs beyond the conceptual and practical constraints of modern design practices, which currently limit the possibilities for the profession.*[31]

The products of synthetic biology could provide designers with a workable library of living–agents which are entirely fabricated or taken directly from the natural world, like algae. If material systems are developed to support them, these products can then be translated into building materials which can reverse the current effect our buildings have on the environment.

For example, algae is a living medium we can easily construct with. Living and rapidly reproducing, algae efficiently performs photosynthesis, the fundamental natural phenomenon which turns carbon dioxide (CO_2) into oxygen (O_2). This carbon absorption and oxygenation makes algae a beneficial addition in material construction to aid in purifying pollutants found in the city—and it is not the only one. Advancing discoveries in synthetic biology offer even more sophisticated living agents such as programmable bacteria and cells which can be specifically designed to process different contaminants depending on the application, or regenerate and heal themselves. Even further, bacterial cellulose and fungi present a method to grow material from first principles in a rapid and renewable way, while also being highly biodegradable at the end of their life cycle. This presents a fertile way of making.

31 Petra Bogias, quoting Rachel Armstrong, "The Algae Textile," Ch. 2.2 *Consulting Machinic Theory and Synthetic Biology: An Interview with Rachel Armstrong,* (University of Waterloo, Masters of Architecture Thesis, 2014) p. 109

Fertile |ˈfərtl|

adjective

(of soil of land)
Producing or capable of producing abundant vegetation or crops: fields along the fertile flood plains of the river.

(of seed or egg)
capable of becoming a new individual.

(of person, animal or plant)
Able to conceive young or produce seed.

(of a situation or subject)
Fruitful and productive in generating new ideas.

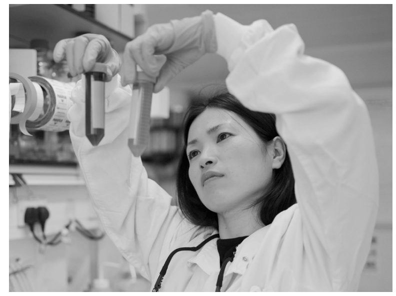
physics (of nuclear material)
Able to become fissile by the capture of neutrons.[28]

(of a material or architecture)
A productive material interface for the built environment. They are biologically receptive and synthetically alive.

fruitful, productive, high-yielding, rich, lush.[29]

28 Fertile, Oxford American Dictionaries.
29 Fertile, Oxford American Thesaurus.

2–01 *The knit of flexible tubing connects multiple glass vessels in a modularized system. (Sawa, Bio Design, 2012)*



2–02 *Architect, textile designer and self-made biologist, Marin Sawa. (designboom.com, 2013) http://www.designboom.com/technology/algaerium-bioprinter-by-marin-sawa-digitally-yields-health-food/*

2–03 *Visible transformation of the algae as it absorbs carbon during photosynthesis. (Sawa, Bio Design, 2012)*

2–04 *Different algae species are monocultured then brought together in the spherical vessels of the Algaerium. Using vessels creates an in vitro environment. (Sawa, Bio Design, 2012)*

2–05 *The spherical vessels of the Algaerium with an inner membrane of alginate and outer membrane of glass. The alginate allows the algae source to be contained in an aqueous environment and the glass allows the system to be integrated as a built system. (Sawa, Bio Design, 2012)*

The future proliferation of sentient systems and bio–digital design relies on the notion that designed objects take on evolutionary qualities. This need is launching a new stage of architectural practice and, with it, a population of designers interested in exploring what biology and technology have to offer in their work. The future of practice, therefore, calls for a renewed toolkit of materials and manufacturing processes involving living matter that can be used in construction.

Architect and textile designer, Marin Sawa, works within this realm. Her interest in smart materials has given her expertise in multidisciplinary design, allowing her to successfully combine textiles, biology and architecture. For her project, *Algaerium*, she has created living surfaces as a reinterpretation of textile, which cultivate and produce green energy from algae. She hopes to bring biofuel producing contraptions into the built environment with her designs, using strains of algae that are adapted to their design environment as a source of green energy.[32] The algae is grown in specially designed glass spheres composed of an inner membrane made of alginate and an outer membrane of glass, which allows the algae to photosynthesize naturally—absorbing carbon dioxide and producing oxygen. The spheres are connected by a knit of flexible tubing which circulates the algae and water solution which is carefully prepared with artificial colour–changing elements that respond to carbon dioxide levels. Additionally, Sawa is able to use bioluminescent strains of algae which makes the system glow with changing levels of sunlight and the movement of water.

The path taken by designers towards the understanding of biology and technology is varied, but their role as mediators between scientific research and the public is the fundamental piece of this puzzle. The designer's ability to cross–pollinate information and techniques from areas outside their discipline makes them vital to the progression of the bio–digital economy, as this desire to integrate biological processes in the built environment increases.

Fertility in biology is based on birth, death and rebirth—the seed, the sprout, the cell, the metabolism—the idea of production and reproduction is inherently cyclical. This is never the case with human consumption so methods of compensation need to be developed. Considering that the construction industry is one of the largest producers of all carbon emissions on earth, fertile and productive material interfaces derived with advanced sciences like synthetic biology could play a role in absorbing our carbon emissions and reducing material waste and redundancy.

32 William Meyers, "Ecological Object Engineering" in *Bio Design*, (The Museum of Modern Art, 2013) pg. 88

The field of synthetic biology was launched by a pair of papers published in the 20 January issue of Nature. The first—by Michael B. Elowitz and Stanislas Leibler—presented a synthetic genetic oscillator. The other—by Timothy S. Gardner, Charles R. Cantor, and James J. Collins—presented a synthetic genetic toggle switch, showing that it was feasible to model, design and construct synthetic gene networks out of bimolecular components.[33]

What is synthetic biology (SB)?

A science and engineering field that wants to turn biology into a true technology.[34]

And how can it help architecture?

With the aim of making biology accessible to the needs of everyday life, SB applies engineering principles such as standardization, modularization, using hierarchies of abstraction or the decoupling of design and fabrication to biological systems in order to establish a whole new set of applications for society.[35]

These advancements potentially allow for promising industrial applications, further shrinking the gap between mechanical, cultural and organic coexistence. The study of synthetic biology:

... approaches the potential applications from the economic, environmental, social and ethical perspective ... to present a balanced evaluation of the technical, economic, environmental and societal ramifications of SB applications.[36]

Technologies developed by the emerging discipline of synthetic biology pose an urgency for designers and architects to familiarize themselves with this growing bank of usable materials and processes. A key characteristic of synthetic biology, which separates it from traditional biology, is that it applies biological knowledge with techniques adopted from engineering:

33 Charles W. Schmidt, MS. “Synthetic Biology: Environmental Health Implications of a New Field” (Environmental Health Perspectives, 2010 March) 118(3): A120.
34 Markus Schmidt, “Synthetic Biology: Industrial and Environmental Applications” (Wiley–Blackwell, 2012) Preface, xvii.
35 M. Schmidt, “Synthetic BIology” Preface, xvii.
36 M. Schmidt, “Synthetic Biology” Preface, xvii.

Synthetic biology follows a hierarchical structure, building up systems from smaller components. At the lowest level are the parts, which are pieces of DNA that encode for a single biological function such as an enzyme promoter. These parts are then combined into the next layer, a device, which is a collection of parts that performs a desired higher order function, for example production of a protein.[37]

The power of this approach, [...] is that a device does not need to be produced from scratch every time, but, rather, it can be created from existing standard parts.[38]

These concepts, which are widely used in engineering and manufacturing, are currently being applied to synthetic biology. This is known as the Parts, Devices and Systems approach to synthetic biology design.[39]

Parts, Devices and Systems, as they apply to synthetic biology, can be defined as follows:

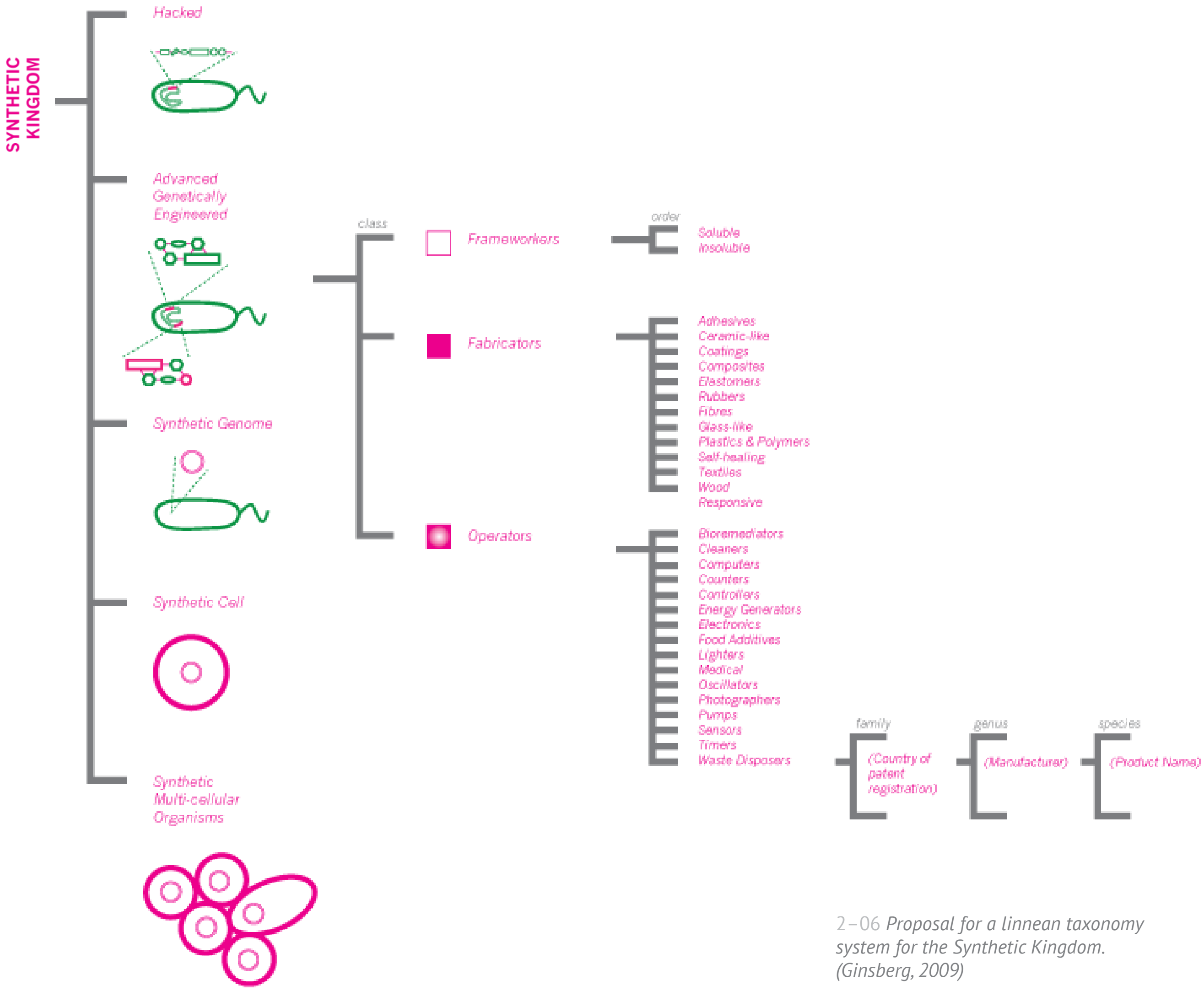
(1) Parts (bioparts)—these encode biological functions (currently synthetically designed DNA).

(2) Devices—these are made from a collection of parts (bioparts) and encode human defined functions (e.g. logic gates).

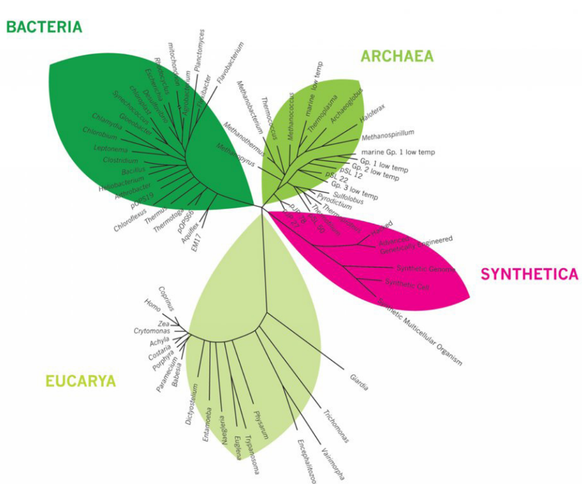
(3) Systems—systems perform tasks, such as counting, and potentially in the future, intracellular control functions.[40]

Through these guiding principles, the construction of a simple gene circuit therefore is comprised of a promoter, ribosome binding site, protein coding sequence and terminator which is done by joining four sections of DNA. For example, four Parts (bioparts) that are hacked from native gene sources (which have the desired function) are reassembled into a complete genetic strand which creates the genetic device with the desired function (a synthetic genome, which forms the nucleus of the synthetic cell). These are placed in hosts such as baker's yeast (Saccharomyces Cerevisiae) or E. Coli bacteria (Cyanobacteria). These growing bases are where the newly constructed genome is left to develop.

37 Baldwin et al. "Synthetic Biology: A Primer" (Imperial College Press, 2012) pg. 73.
38 Baldwin et al., "Synthetic Biology: A Primer" pg. 19–20.
39 Baldwin et al., "Synthetic Biology: A Primer" pg. 20.
40 Baldwin et al., "Synthetic Biology: A Primer" pg. 20.



2–06 *Proposal for a linnean taxonomy system for the Synthetic Kingdom. (Ginsberg, 2009)*



2–07 *The Synthetic Kingdom (Ginsberg, 2009)*

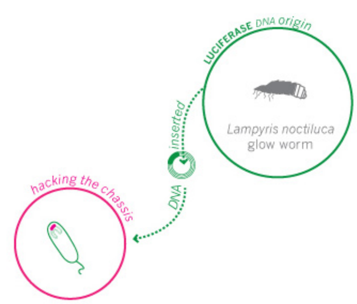
What would a postnatural materiality look like if these new theories and technologies were to reinvent conventional materials? Modes of making which are lightweight, intelligent and able to navigate between a natural–synthetic interface are the design tendencies the postnatural movement suggests. Modernist theories of standardization and rationality are being exchanged for optimized, prolific and responsive tendencies. This is the definition of materiality in a postnatural and posthuman era: a future where the organic, the cultural and the technological are compatible and sympathetic through their material interactions. When biology becomes an entity used in information technology, and inactive matter becomes an active mind (a self–aware entity in physical space), then humans are endowed with the capability of creating autonomous mechanisms that impregnate the environment with quasi–biological structures. In so doing, the division of nature and culture is no longer distinguishable, and each slip and glide past each other like habitants of a complex ecosystem. A postnatural view of environmentalism is at the forefront here. Traditionally, environmentalism has viewed human behaviour as the source of destruction; where minimized intervention in nature is seen as the answer to cultural and environmental equilibrium. Postnaturalism, in contrast, does not view technology as a source of destruction, but realizes technology's ability to resolve the problems which exist between human–culture and nature. It argues for an aggressive and prolific intervention into nature; one that is productive and far from passive, stating that, culture's effect on the environment can never be fully reversed, and so, it is about making that effect a productive one. What is needed is what posthuman theorist Katherine Hayles calls, *dynamic relationality:*[41] where nature can no longer be conceived of as neutral ground but a highly–networked amalgam of human, animal, and technology; a natural–synthetic interface. This new nature–culture paradigm closely parallels a body of research regarding cybernetic theory initiated in the 1970's, with contributions by not only Hayles, but Bruno Latour, Michel Callon and Manuel de Landa, and lays the philosophical basis for a postnatural environmentalism. Through studies in this research, it can be said that lightweight assemblies enabled with cybernetic and quasi–biological functions could manage culture's interface with the natural environment at a more productive state. This is due to their ability to manage combinations of complex and opposing systems.

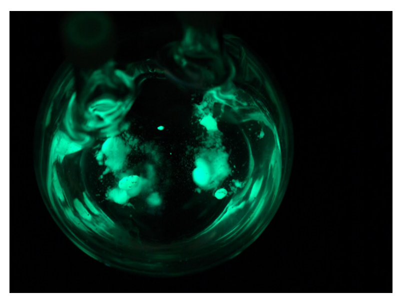
41 Katherine Hayles, Ariane Lourie Harrison, ed., "Architectural Theories of the Environment: Posthuman Territory" (Routledge, New York, 2013) pg. 38.

For example, the use of biological systems such as algae or programmed organisms will require innovations in materiality to house them within urban buildings and structures. However, simple ways of housing these technologies within these buildings currently do not exist—given that their implementation in our built environment has the potential to increase the resilience between the built and non–built. The insertion of artificiality in the environment is always a topic of concern, but with the increasingly constructed nature of our world and growing environmental concerns, translating methods from synthetic biology into systems for building construction has the potential to produce a productive relationship with the natural systems that border our urban environments—allowing for a fertile and cyclical way of producing valuable building materials. Fertility can be engaged here on multiple levels: in cultural histories, psychological archetypes, and most importantly, in processes of making. Fertility therefore offers a productive design space for thinking about material construction, suggesting that the archetypal mother and its futuristic counterpart—found in a petri dish—unite where advanced modes of making recapitulate the action of birth in material artifact. This reveals the need in architecture for an *evolutionary* relationship between the design process, its resulting artifacts and their material articulation.

> *[Technology] is matter manipulated into equipment for growth ... where the organized matter becomes ultra–organized into a transcendence of itself, a future generator, a creating trans–machine.* [42]

Some designers already work in this way. Daisy Ginsberg is a designer with background expertise in synthetic biology. She focuses her research on the characteristics of DNA sequences and then applies them to design problems. She is also known for creating a taxonomy of the synthetic kingdom—which strives to define where the byproducts of synthetic biology would lie within the greater kingdom of our biosphere—stating that, “we'll simply have to insert an extra branch to the Tree of Life to classify them.”[43] Synthetic biology's hybridity and organically–engineered characteristic, “puts our designs back into the complexity of nature





2–08 *Unlimited Energy Luminaire. The enzyme Luciferase offers an alternative to toxic mercury used in energy-saving light bulbs. (Ginsberg, 2009)*

42 Paolo Soleri, “The Bridge Between Matter & Spirit Is Matter Becoming Spirit; the Arcology of Paolo Soleri” (Garden City, NY: Anchor, 1973) p. 3.
43 Daisy Ginsberg, “The Synthetic Kingdom” (daisyginsberg.com, 2009).

rather than separating us from them."[44] For Ginsberg, increasing our knowledge in the construction of DNA (as fundamental building units) will allow us to advance the intelligence of the objects we design from a cellular level.

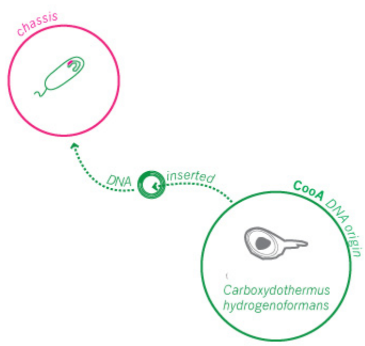
Her works explore biologically derived replacements to chemicals found in everyday designed objects. For example, the *Unlimited Energy Luminaire* uses the enzyme *Luciferase*, which offers an alternative to toxic mercury used in energy–saving light bulbs. She also designs bacterial–based machines which act as bio–sensors. Her carbon monoxide sensor uses the protein CooA, which binds to carbon monoxide molecules, causing a transcription of the reporters *DsRed2Zs* and *Yellow1* creating an orange–coloured alarm. Daisy's work and its intentions reflect similar motivation as the algae textile: if the objects we design can benefit the biosphere on an alternate level, or give back a valuable resource, then the idea of material fertility is a valiant notion to pursue in design.

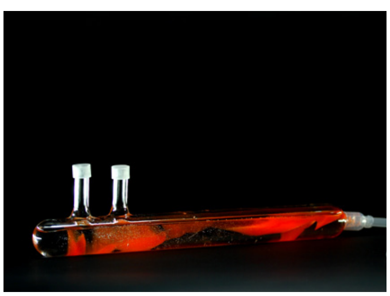
Daisy's use of synthetic biology offers a look into what this field of research can contribute to the field of design, and makes it possible to speculate on its scalability into architectural objects. For example, this aspect of synthetic biology assimilates itself with bioremediation: a process which uses natural and engineered organisms rather than chemicals to remove pollutants from contaminated environments. The process uses microbes such as *Pseudomonas** which are able to mineralize contaminating compounds and oxidize completely to CO_2. Like Daisy's biosensors, the idea is to use biological sources rather than chemical sources to produce valuable tools for remediation:

> *Synthetic biology–based approaches may provide a way of capturing, storing and recycling carbon dioxide. This may be through the re–engineering of existing organisms or the creation of novel carbon processes, especially using bottom up approaches where inorganic chemistry is linked to living processes through agents, such as the emerging protocell technology.*[45]

Algae is a primitive form of this objective—being an organism that processes carbon naturally. This future vision of bioremediation aims to develop a tailored range of synthetic organisms that could persist in the environment.[46] These contained organisms will be able to monitor their surroundings for toxins and pollutants and then execute the necessary steps programmed into their chemistry

* *Pseudomonas:* a free-living bacterium commonly found in soil and water. The genus is well known to microbiologists because it is one of the few groups of bacteria that are true pathogens of plants. (Todar's Online Textbook of Bacteriology, textbookofbacteriology.net/pseudomonas)





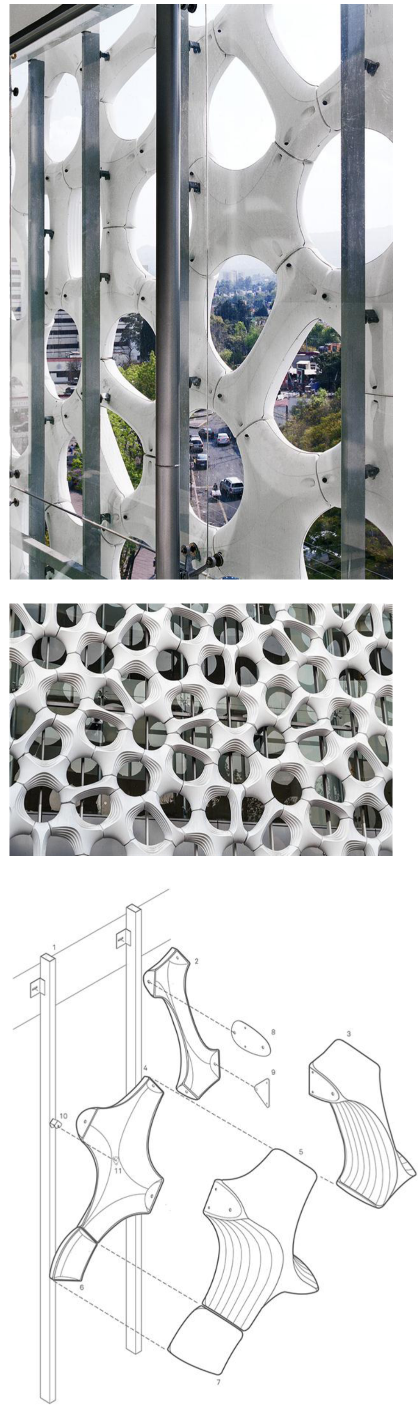
2–09 *Carbon monoxide (CO) bio-sensor. These bacterial sensors contain the protein CooA, which binds to carbon monoxide causing transcription of reporters DsRed2Zs and Yellow1 creating an orange-coloured alarm. (Ginsberg, 2009)*

44 Ginsberg, "Synthetic Kingdom," 2009.
45 Markus Schmidt, ed., "Synthetic Biology: Industrial and Environmental Applications" (Wiley–Blackwell, 2012) xxiii.
46 Baldwin et al. "Synthetic Biology: A Primer" (Imperial College Press, 2012) pg. 117.

to rectify the problem; acting as "sentinels in the environment."[47] This approach is especially advantageous as it not only captures and stores carbon, but will, "recycle it into fuels and biopolymers with positive environmental impact,"[48] by mimicking and possibly surpassing the natural abilities of algae—something which current chemical processes cannot do. What is needed now, is the material systems that contain these organisms safely in the environment, and what the creation of the algae textile aims to test and explore.

Bioremediation using algae and tailored organisms can integrate themselves into architecture through its use in carbon–inhaling materials, and has the potential to transform the decorative architectural skin into legitimate quasi–biological skins that feed off of urban pollutants and produce valuable products in return.

In 2011, the company *Alcoa* unveiled an air–purifying material technology. The material contained titanium dioxide which has the ability to absorb toxins by releasing spongy free radicals when exposed to UV light and moving air.[49] Since its discovery, the technology has been implemented in clothing and in architecture. The Mexico City hospital is one of these projects. The building is completely wrapped in a skin of *Prosolve370e* tiles made of the titanium dioxide impregnated material. In doing so the building skin serves three purposes: (1) a perforated sun–screen, (2) an air–purifier, and (3) a decorative façade. Furthermore, the shape of the sunscreen proves to also be significant: it creates the necessary turbulence to slow down air flow and scatter the UV light across its surface; both of which increase the effectiveness of the chemical reaction.

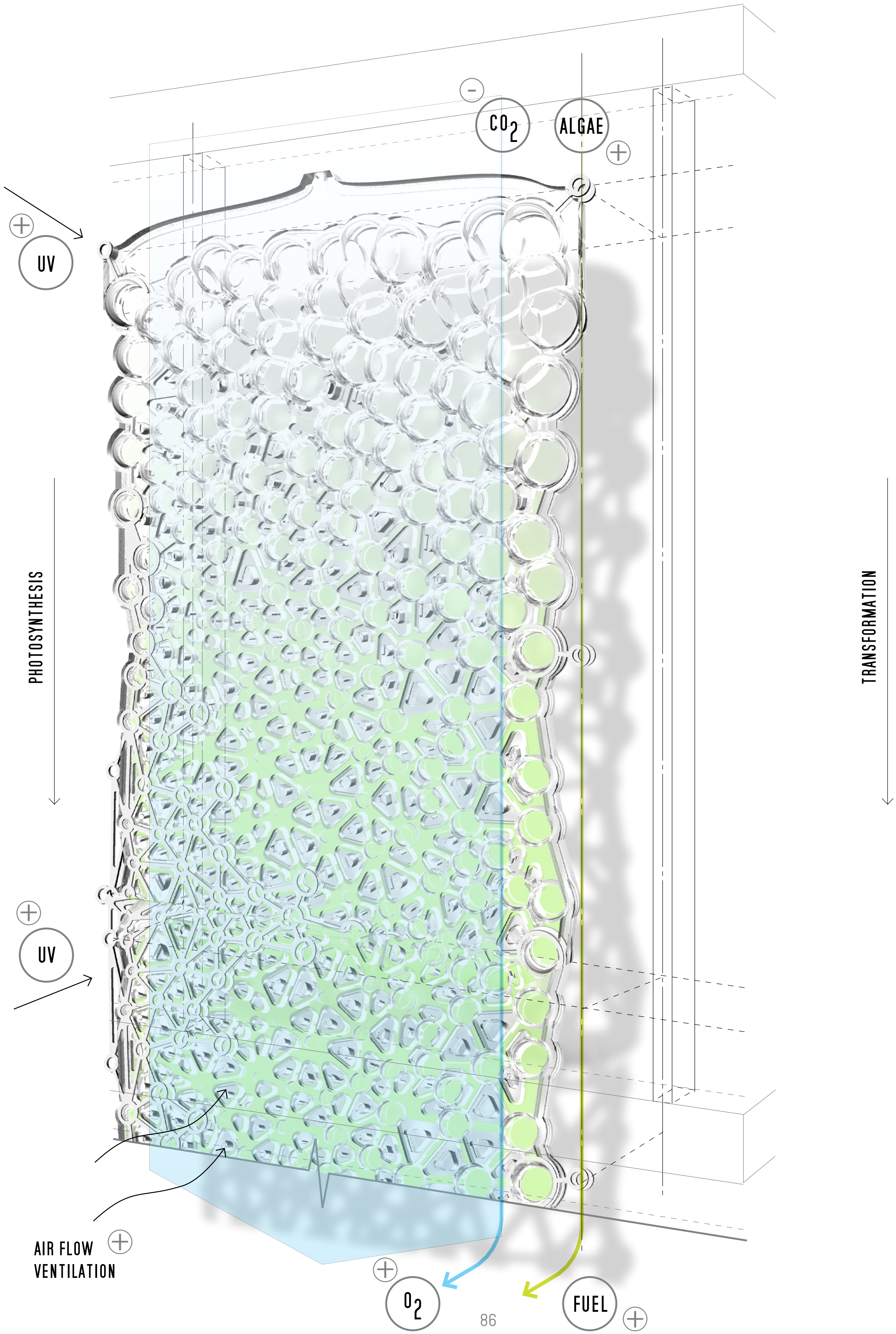


2–10 *Details of the Mexico City Hospital façade (architectmagazine.com, 2013)*

47 Baldwin et al. "Synthetic Biology: A Primer" pg. 117.
48 Markus Schmidt, ed., "Synthetic Biology: Industrial and Environmental Applications" (Wiley–Blackwell, 2012) xxiii.
49 Gizmodo, "5 Smart Building Skins that Breathe, Farm" (gizmodo.com, 2013) http://gizmodo.com/5–smart–building–skins–that–breathe–farm–energy–and–g–1254091559

DESIGN
MODULE
3

TEXTILE FUNCTIONALITY


CO2
ALGAE
UV
PHOTOSYNTHESIS
TRANSFORMATION
UV
AIR FLOW
VENTILATION
O2
FUEL

superfunction

function	*function*	*function*
1	2	3
A PERFORATED BUILDING SKIN FOR MODULATING DAYLIGHT + AIR FLOW	**A CARBON ABSORBING AIR–PURIFIER**	**AN ENERGY PRODUCER + VALUABLE RESOURCE**
For example, its ability to modulate light, shade and air flow for occupant comfort, or its visual transformation and movement between growth cycles.	*Algae's highly efficient photosynthesis cycle equates the production of oxygen from one algae culture to that of a forest of trees.*	*Algae biomass can be processed into valuable products such as biofeuls, nutritional supplements, pharmaceuticals, or bioplastics.*
Shading of the interior space is a desired quality if used along the perimeter of the façade. This will help with passive cooling and modulating light within interior spaces.	*This contributes great benefits for clearing polluted air in the city by reintroducing oxygen into the atmosphere and absorbing excess carbon dioxide caused by anthropogenic activity.*	*Therefore, in addition to clearing atmospheric pollutants, biomass produced by the algae textile can contribute to a sustainable economy.*

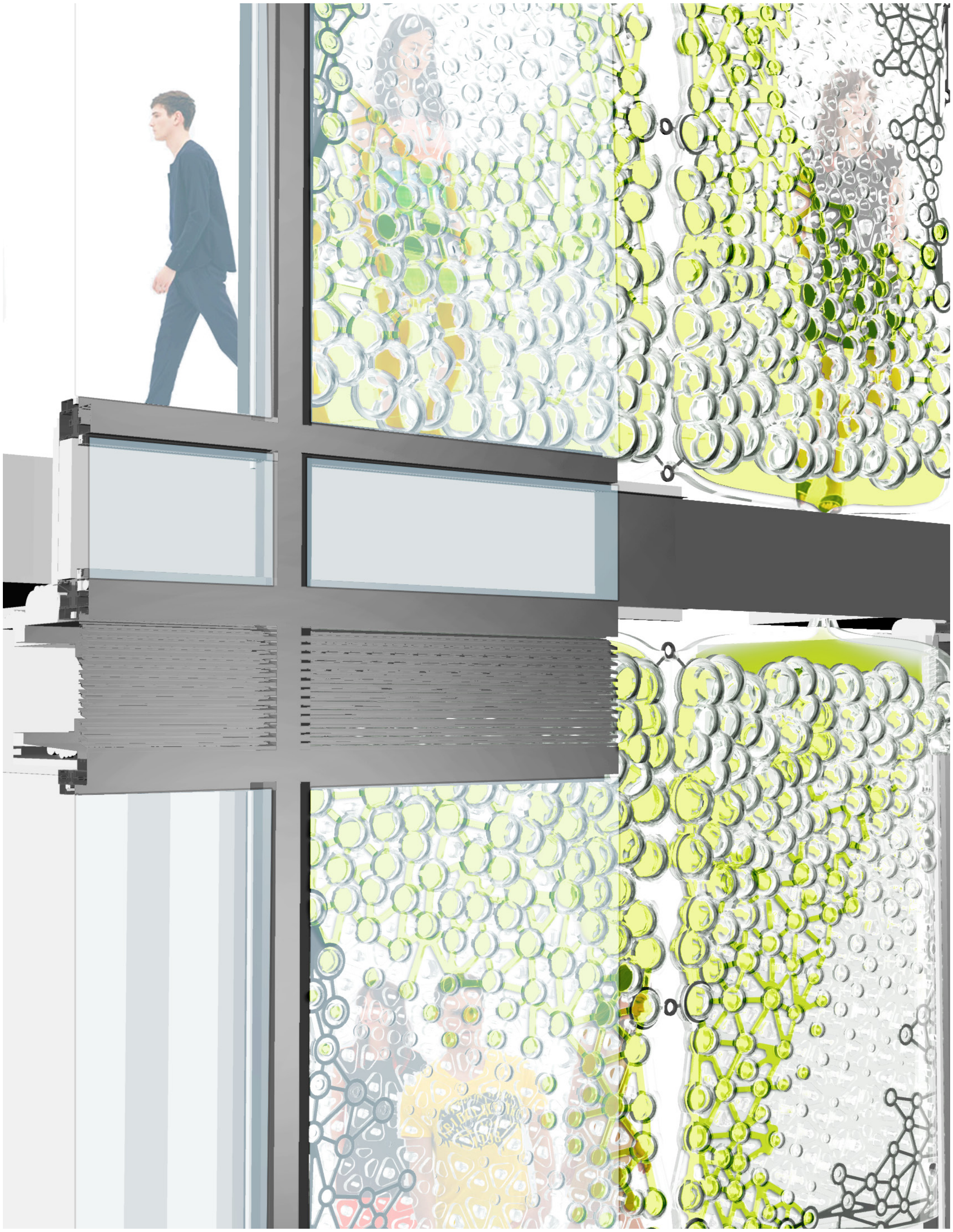
subfunction

→ **THE DECORATIVE ARCHITECTURAL SKIN** ←

2–11 *The functions of the algae textile.*

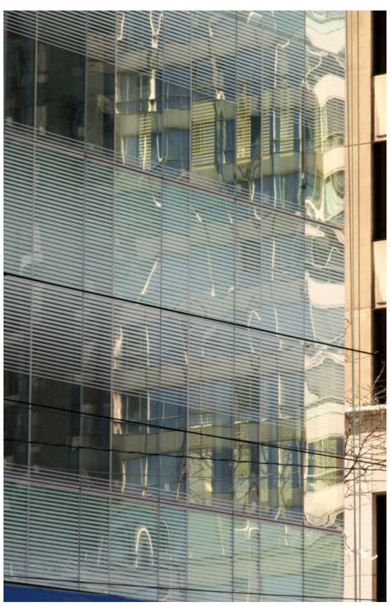
Algae Textile Functionalities

Like *Alcoa's* air–purifying material technology, the algae textile was developed in the interest of suggesting a method for producing quasi–biological materials for architecture: where construction materials are not inanimate objects, but rather, are receptive and interlaced with other functions to form productive material interfaces for the built environment. The algae textile's ability to act as, (1) a perforated building skin, (2) a carbon absorbing air–purifier, and (3) a valuable energy resource makes it a building material which offers productive functions within its form—bringing it beyond the function of a decorative skin and justifying the intricacies of its appearance. The geometry and appearance of the textile have been developed in the interest of increasing its ability to cultivate algae, while also benefiting the spatial affects it has on a surrounding space—a quality that is limiting and difficult to achieve with the traditionally robust nature of industrial photobioreactors, which in turn limits their use.



2–12 *Zone creation within the textile around floor plates and mullions, and the ocular affects produced.*

2–13 *Detail of glass frits applied in a varied pattern (Louis Vuitton New York)*



2–14 *SickKids Hospital: Peter Gilgan Centre for Research and Learning (Diamond and Schmitt Architects, urbantoronto.ca, 2013)*

If taken as a method rather than a definitive design, the idea of the algae textile, and the continued development of similar building materials, could transform the traditional idea of the decorative architectural skin by superseding its decorative function with productive functions such as air purification, energy production, or light modulation. As such, they are designed with the additional interest of performance, together with aesthetics. Every building has its own context, program, size, view, corridors, orientation, etc., which effect the design parameters of its enclosure differently. This requires a tailored approach, and why it is important for the geometry of the textile to afford a level of alteration and plasticity; which is given through its parametric modelling.

For example, the use of parametric design on enclosures can generate geometry in a prolific way to optimize the dimensions of openings or the density of a grid. If used correctly, geometric conditions can be individualized and specifically tailored to a portion of the building. Maximizing parameters such as light, circulation, building programme, or occupancy becomes as simple as applying the same standardized part to the entire surface. This has potentials in re–skinning applications or performance–based design—where a complex façade geometry can be generated and fluidly manipulated to control these parameters on a customized level, and can already be seen in existing material systems commonly employed in contemporary building enclosures. For example, applications of fritted glass aim to reduce the intensity of light which passes through a window wall simply by fusing varied densities and patterns of opaque ceramic directly onto the sheet of glass. This material technology provides a streamlined way of managing common problems associated with glass enclosures, reducing the affects of direct sunlight and heat gain without the need for auxiliary systems such as shading devices.

The algae textile can be applied using the same logic, but has the added benefit of, (1) supplying a source of ecology to purify air and uplift an occupant's well–being, (2) supporting the growth of a renewable resource for a self–sufficient urban lifestyle, and (3) controlling light and shade in a space by adjusting the placement of spherical vessels within the textile's form. In this way, the textile can be used in the same way as ceramic frit patterns, giving varied ocular affects to designated portions of an expanse of glass. In both these examples, the use of gradients and variation is key to achieving these subtle effects within streamlined dimensions. By embedding productive functions within material, the desire for emergent, complex and optimized qualities within traditionally rigid systems therefore incites a method of design where geometry is optimized and where material is machine.

2.2

CONSULTING MACHINIC THEORY AND SYNTHETIC BIOLOGY

2.2

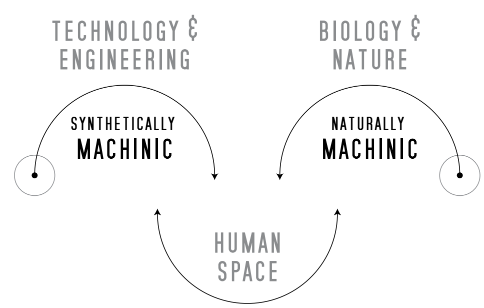
> *I suggest that this realm is the site of "becoming machinic," fully explicable as neither a natural evolutionary process nor a human process of construction. Rather, it is a process of dynamic self–assembly and organization in new types of assemblage that draw both the human and the natural into interactions and relays among a multiplicity of material, historical and evolutionary forces. In this new space of machinic becomings, an increasingly self–determined and self–generating technology thus continues natural evolution by other means.*[50]

We are now in an era of machinic proliferation. Electronic devices are replacing everyday tools and redefining the paradigm between humans, nature and technology. From microchips and robotic arms, to biomechanical implants and living materials, our machines are now interlaced with complex capabilities—becoming precise replicators in a contemporary world rich with synthetic and virtual tendencies—rather than robust binary translations. The digital industrial revolution allows complexity and optimization *within a mechanized state*—something unattainable in the first industrial revolution of the twentieth–century. Our perception of industrial activity—once defined by heavy manufacturing, resource exploitation and manual labour—is instead reduced into instruments we can hold in the palm of our hands and implant in our bodies, turning mechanical assemblies into *machinic* assemblies with lifelike and biological behaviours.

machinic: Of or relating to machine–like qualities and technical interaction. Automation within human environments. Machinic also describes the qualities found in the study of cybernetics, artificial life, and artificial intelligence.

proliferation: Defined as a rapid increase in numbers, it is also a term which describes the rapid reproduction of a cell, part, or organism. Automation within natural environments. (Fertile and healthy)

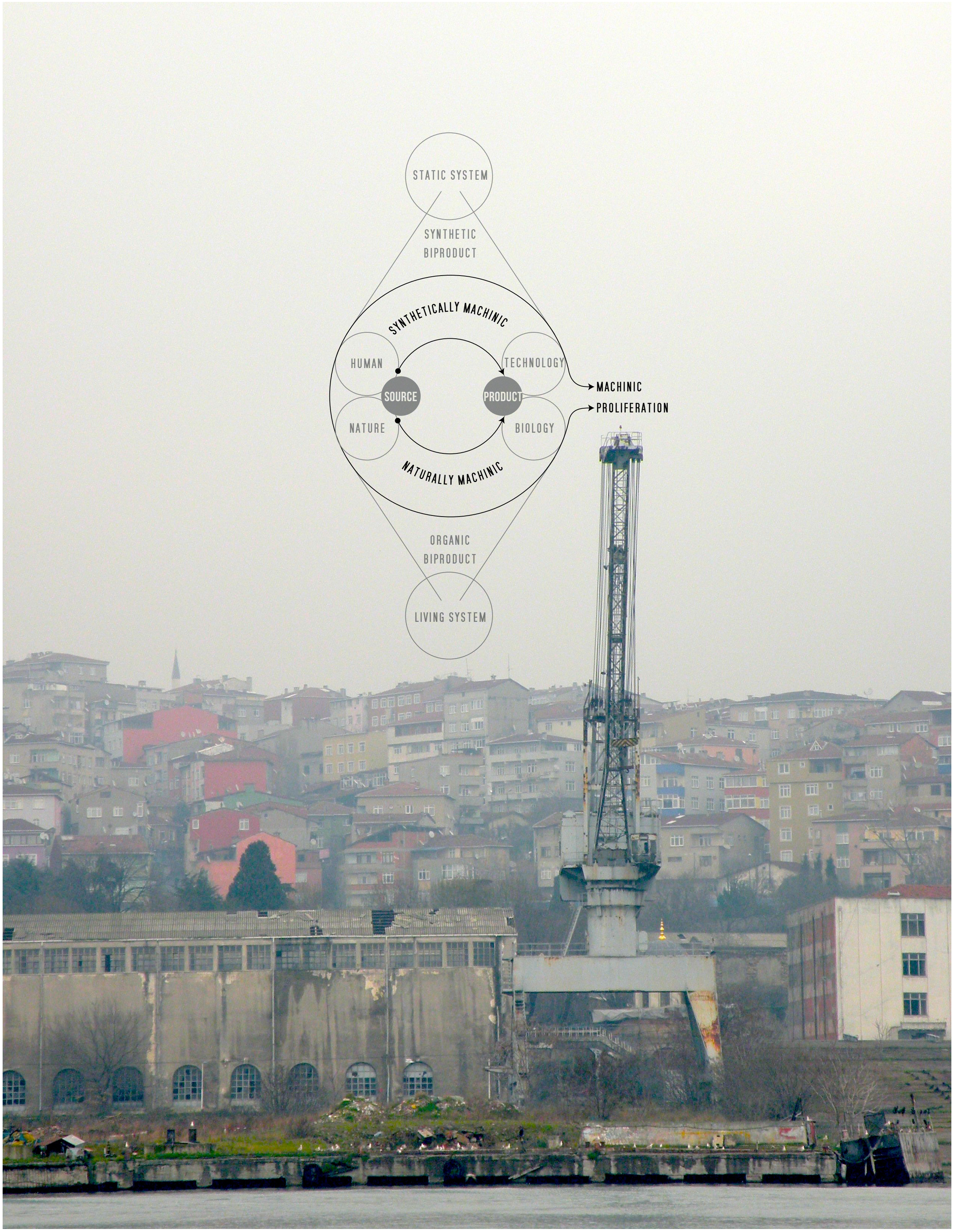
Machinic proliferation sees architecture and industry as living organisms. Synthetic constructions traditionally thought of as rigid and solidified, are now fluid and mobile. A viral and parasitic behaviour that is unexpectedly desirable.



2–15 *(above) Diagram of machinic behaviour in technology versus machinic behaviour in biology and nature; where humans must navigate in between.*

2–16 *(right) Synthetically machinic versus naturally machinic systems; their combination producing "machinic proliferation."*

50 John Johnston, "The Allure of Machinic Life: From Cybernetics to Machinic Philosophy." (The MIT Press, 2008) p. 107–108


STATIC SYSTEM
SYNTHETIC BIPRODUCT
SYNTHETICALLY MACHINIC
HUMAN
TECHNOLOGY
SOURCE
PRODUCT
NATURE
BIOLOGY
NATURALLY MACHINIC
MACHINIC PROLIFERATION
ORGANIC BIPRODUCT
LIVING SYSTEM

Architecture has over the past century finally become a machine, with as much as fifty per cent of the cost embedded in systems, not structure, walls and roof.[51]

We think the material or machinic aspect of an assemblage relates not to the production of goods but rather a precise state of intermingling of bodies in a society. [...] Even technology makes the mistake of considering tools in isolation: tools exist only in relation to the interminglings they make possible or that make them possible. [...] Tools are inseparable from symbioses or amalgamations defining a Nature–Society machinic assemblage. They presuppose a social machine that selects them and takes them into its "phylum": a society is defined by its amalgamations, not by its tools.

We always get back to this definition: the machinic phylum is materiality, natural or artificial, and both simultaneously.[52]

The term *machinic* is Deleuzian in origin. In *A Thousand Plateaus* machinic denotes the working relationship between two oppositional systems: the behaviours of a machine, to the behaviours of an organic body, for example, and how they come together as a harmonious "assemblage". Not to be confused with its colloquial definition, *"of or relating to machines,"* the theoretical bounds of the term reach far deeper than this simplified dictionary entry, and forms an important theoretical basis for current research in artificial intelligence and human–machine learning.

51 Stephen Kieran, James Timberlake, "Refabricating Architecture," *Argument*, McGraw–Hill Professional; First Edition, 2003. pg. xiii

52 Gilles Deleuze and Felix Guattari, "A Thousand Plateaus: Capitalism and Schizophrenia" (University of Minnesota Press, 1987) p. 90, 409

“WE ALWAYS GET BACK TO THIS DEFINITION: THE MACHINIC PHYLUM IS MATERIALITY, NATURAL OR ARTIFICIAL, AND BOTH SIMULTANEOUSLY.

For the design of buildings—a complex mechanical assembly—machinic theory as described by Deleuze and Guatarri could form the beginnings of a material shift in architectural design: one where the material assemblies in a building continually play with the boundaries of organic and inorganic. Material systems such as the algae textile aim to incite this new perspective of material assembly. By housing organic compounds within the sheets of material which compose buildings, the algae textile is a preliminary development for the study of machinic assemblages in building construction.

Gilles Deleuze and Felix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia*, 1987

What can't be coded can be decoded if an ear aye seize what no eye ere grieved for.

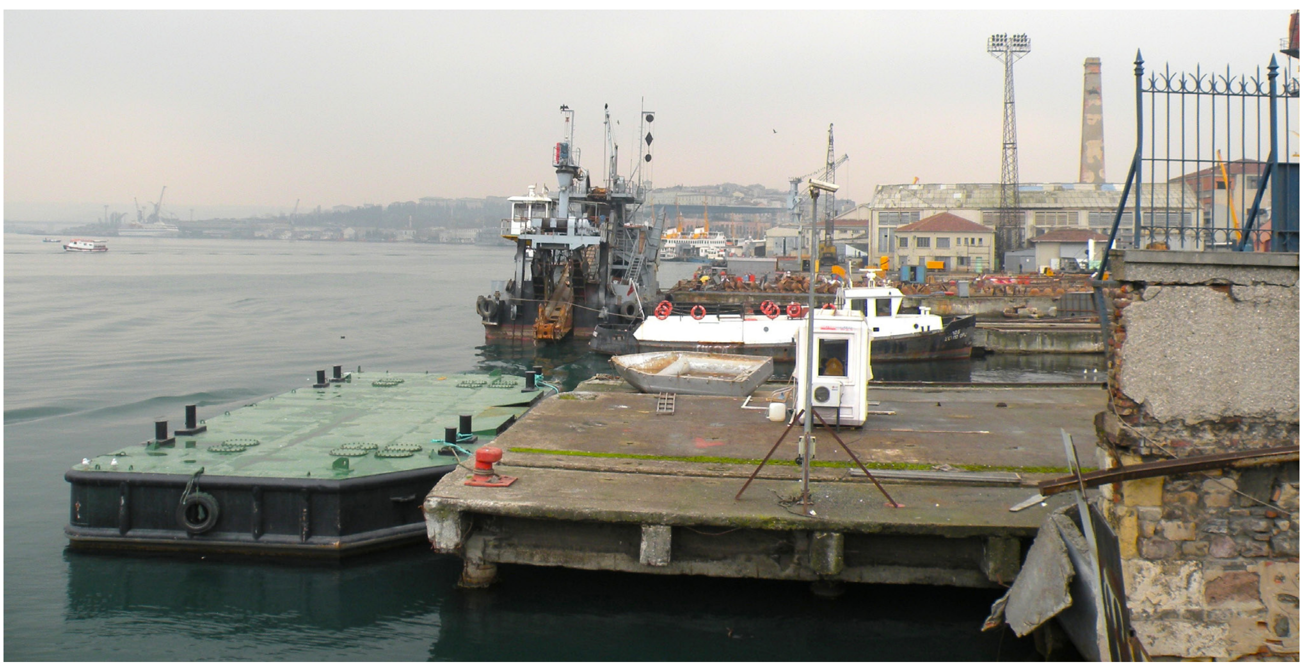
— James Joyce, *Finnegans Wake*

Machinic systems are those informed by biology and aided by technology. Traditionally thought to hinder our engagement with the environment, technology is instead becoming ubiquitous and emergent, as binary machines become devices manipulated with elaborately coded behaviours to behave in a sentient way, and forms the core of machinic theory. For building design, the core of this theory lies in reinventing the way architects use and compose materials, and innovating industrially produced materials into new types. This will incite a movement towards the creation of machinic building material and is fundamental for the continued development of postnatural architecture—where design decisions are driven by lightweight, flexible and adaptable qualities. The design of *machinic* systems, unlike earlier mechanical forms, have the capacity to alter themselves and to respond dynamically to changing situations."[53] Machinic building material could also be designed to behave in these ways. Analogous to high–tech devices, building material could be dynamically informed using embedded sensor networks and active monitoring systems integrated within the thickness of a sheet of material. The invention of the the silicon chip, for example, realized a method of compiling the independent components of a discrete circuit into one fully integrated microchip, eliminating the need for manual assembly and achieving a monolithic assembly at minute scales using photolithography. The development of machinic building materials could also employ this methodology, suggesting a use of resilient and diffuse materials, and soft integrated assemblies in building construction.

The raw materials which compose buildings present themselves as a possible outlet to apply these behaviours. Concrete, steel and glass—which have become defaults in our construction palette—can therefore be challenged, and new technologies allow us to do so. An emergence in the study of artificial life, commonly found in scientific disciplines, has a place in building construction in this respect. A growing body of theoretical research concentrated on autonomous agents, artificial protocells, evolutionary robotics and swarm systems all contribute to this growing theory of machinic life and its creation. They offer momentum and solidity to this development and make clear that the goal of machinic life is not that of mimicking the forms and processes of organic life, but achieving complexity and autonomy in their own right. It is imminent in their coded behaviours, allowing them to foster an internal intelligence. In doing so, concrete, steel and glass can effectively become skins, membranes, cells, nerves, etc.—materials which are impregnated with supplementary functions and adapt to changing circumstances. This forms the basis for the assembly of machinic material: they are autonomous and self–aware and proposes a need for a renewed method of material design for the construction of buildings in a postnatural era.

2–17 *The raw materials which compose the periphery of the Golden Horn estuary (Istanbul, 2013)*

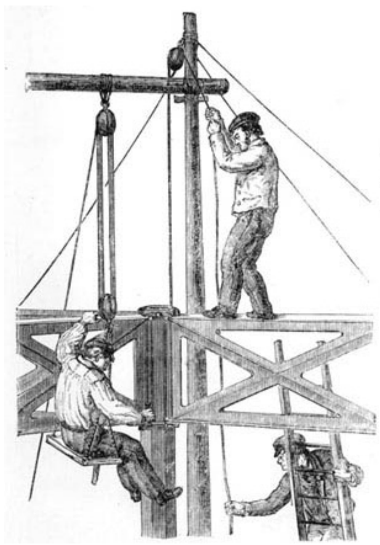
53 John Johnston, "The Allure of Machinic Life" (MIT Press, 2008). Preface.



2–18 *Golden Horn port lands (Istanbul, 2013)*

Industrial Progress

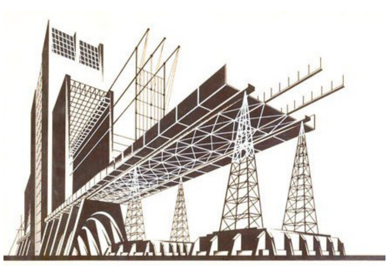
The first industrial revolution resulted in rationalization, simplification of production and standardization of assembly at the expense of economy. In fact, "Industrialization in construction was first introduced at a time when the pace of technical progress had begun to slow down."[54] Karel Teige, author of *Minimum Dwelling* and modernist critic, argues that the most characteristic indicator of construction technology is, "a trend toward systematic improvement of existing achievements, rather than a search for new, radical discoveries and inventions."[55]



The mechanical nature of the first industrial revolution is what incites change in technological advancements seen today, demanding:

> *...a new orientation of science and technology towards the organic, the gentle, the non–violent, the elegant and beautiful.*[56]

As a result, science and technology struggles to leave "the past and present as pregnant not only with possibilities which become real, but with virtualities which become actual."[57] The industrialization of architecture led to the development of heavy machinery, but still relied heavily on human labour to construct its fixed parts. The digital industrialization of building construction sees a liberation of the conflicts which exist between material, human and machine. New machines are able to produce complex shapes and assemble multipart systems in an automated way, therefore economy at the expense of complexity no longer applies. While industrialization in architecture brought rationalization and standardization to preserve economy, the digital industrialization of building construction allows nuanced complexity and variation in a mechanized state—complexity, therefore, comes for free.



[See 2.3 *Postnaturalist Making*]

The future of architectural practice is changing. The accessibility of complexity using computation and digital–fabrication has armed designers with the ability to replicate complex systems, initiating a movement which sees the physical world gradually merging with the digital one, an era where "technology is rendered more biological to the point where, [...] 'we make the landscape and the landscape also makes us.'"[58]

2–19 *The Crystal Palace, The Great Exhibition, 1851.*

2–20 *Chernikhov, Industrial architecture*

54 Karel Teige, "The Minimum Dwelling" (MIT Press, 2002) pg. 187.
55 Karel Teige, "The Minimum Dwelling" (MIT Press, 2002) pg. 187.
56 E.F. Schumacher, "Small is Beautiful" (Vintage, 1973).
57 Manuel De Landa, "The Machinic Phylum" (TechnoMorphica, 1997) http://v2.nl/archive/articles/the–machinic–phylum
58 Daan Roosegaarde, "Interactive Landscapes" (NAi Publishers, 2011) pg. 6.

Economist, journalist and progressive entrepreneur, Dr E.F. Schumacher, has analyzed the effects of industrialization on a global scale. He argues for, what he calls, Intermediate Technology (also known as Appropriate Technology)—a smaller and gentler approach to industrial standards—what he describes as *technology with a human face:*

> *...it might be wise to have a look at technology itself. If technology is felt to be becoming more and more inhuman, we might do well to consider whether it is possible to have something better—a technology with a human face.*[59]

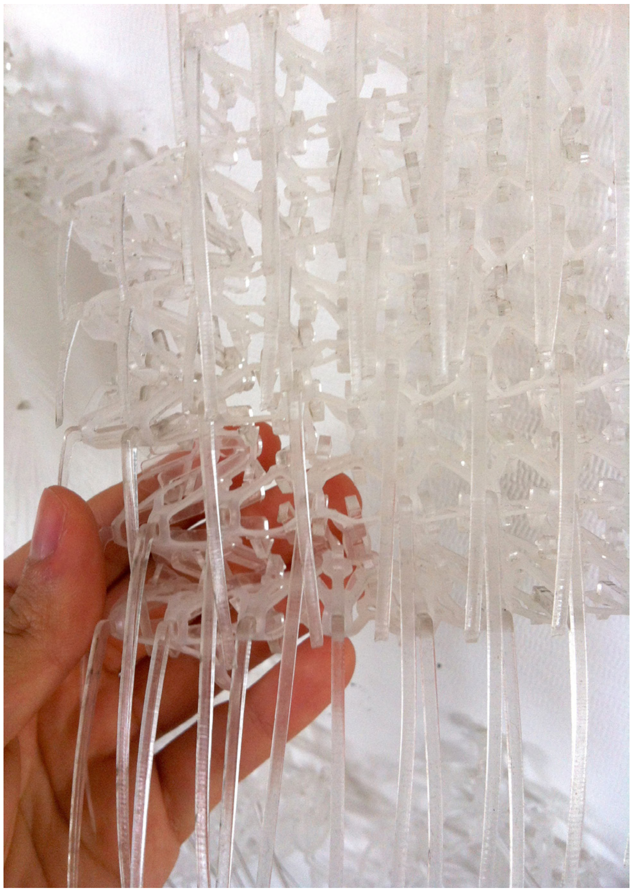
An increased engagement in the understanding of advanced technologies can alter the perceived disengagement it has with the physical environment. Technology which exhibits *humane* qualities, therefore, possess biological characteristics at small and multiplied scales. When applied to construction, this effectively turns inanimate buildings into living companions implanted in the environment.

As a preliminary development, the algae textile aims to engage biological processes in the urban realm. It posits that, with the help of technology and novel manufacturing procedures, materials developed for the building construction industry could introduce an exchange between processes of the environment and processes of a building. Algae is seen as an organic compound which can provide this organic dialogue within a constructed system. Photobioreactors in the laboratory already achieve this dialogue between machine and organism on a small scale. They support the life of algae by providing its environmental needs synthetically, including temperature, light, pH, and nutrients. If the principles of the laboratory bioreactor are applied on a large scale, the support and growth of algae could incite an exchange between a building and its environment, performing atmospheric circulation using photosynthesis to introduce more oxygen into the atmosphere and producing a renewable resource.

Buildings made from fixed parts lack this ability to engage with beneficial environmental exchanges. Resource depletion places further urgency in the need to reinvent building material to lessen the effects of the construction industry on the environment. Further, modernist theories of form, such as the regularized grid and platonic forms, no longer seem applicable to contemporary needs or concerns. These methods were fashioned against industrialized priorities; those of stability, regularity and rigidity. They are hierarchical and top–down, resulting in the reductive qualities present in today's built environments.

2–21 *Golden Horn Industrial Port (Istanbul, 2013)*

59 E.F. Schumacher, "Small is Beautiful" (Vintage, 1973) pg. 120–121.



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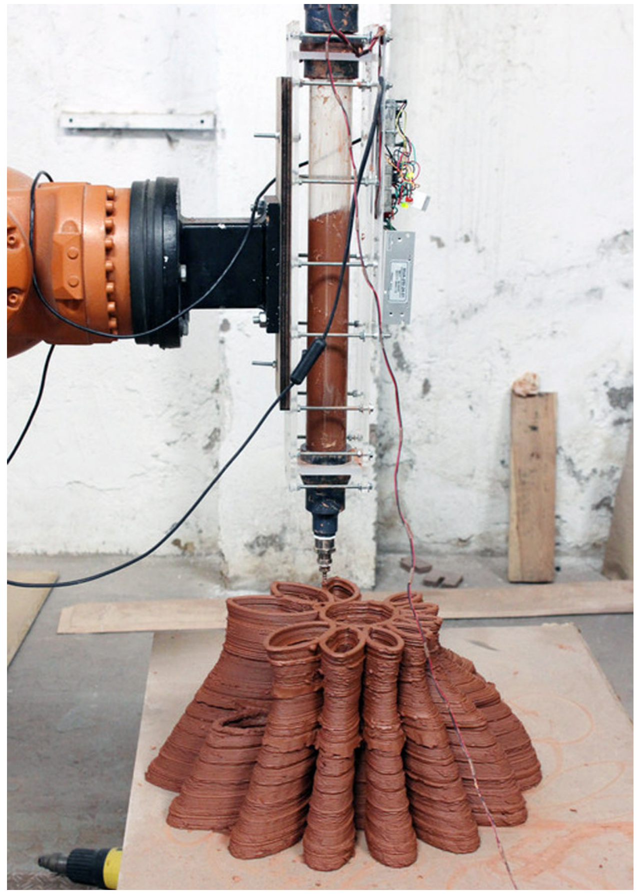

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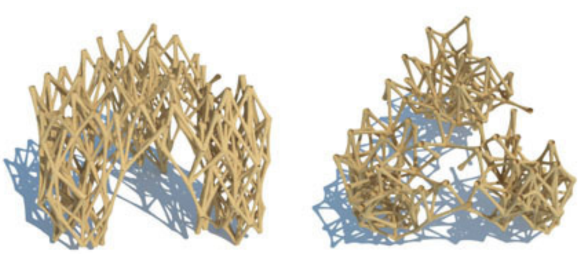
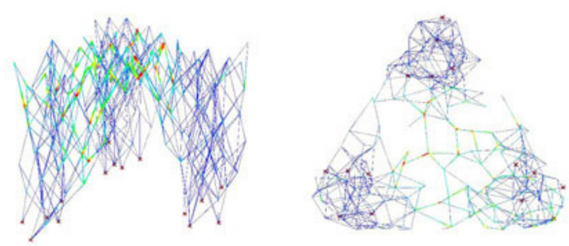




1–35

The future of construction argues for the opposite, leaving the task of inventing models of construction which instead rely on diffuse forms which display resilience, irregularity, and adaptability. They are nonhierarchical and bottom–up. Inventing ways to construct softly and with variation is the primary task for the digital industrialization of building construction. The first step is to develop a renewed library of tools and materials to achieve it.

Digital and Biological Progress

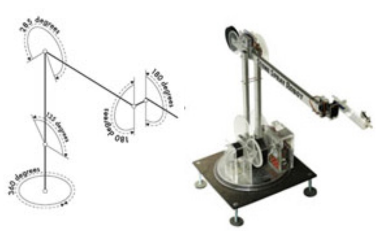
Advanced industrial tools have the ability to align human and organic systems in the built environment. Their implementation in building construction requires a design process which integrates elements of biology and machine thinking, where designers, "need to relearn the craft and skills needed to 'hack' these heterogeneous elements into new combinations."[60] This defines the digital industrial revolution. When architects and designers become adept in other modes of making, these new combinations become radically more accessible and prolific.

2–22 *Resilient material by Philip Beesley for Iris Van Herpen. (Author, PBAI, 2013)*

2–23 *FabClay explores construction which is fully optimized and human independent, focusing on a material's communication with machines and the ability to achieve complex forms. (fabclay.com, IAAC, 2012)*

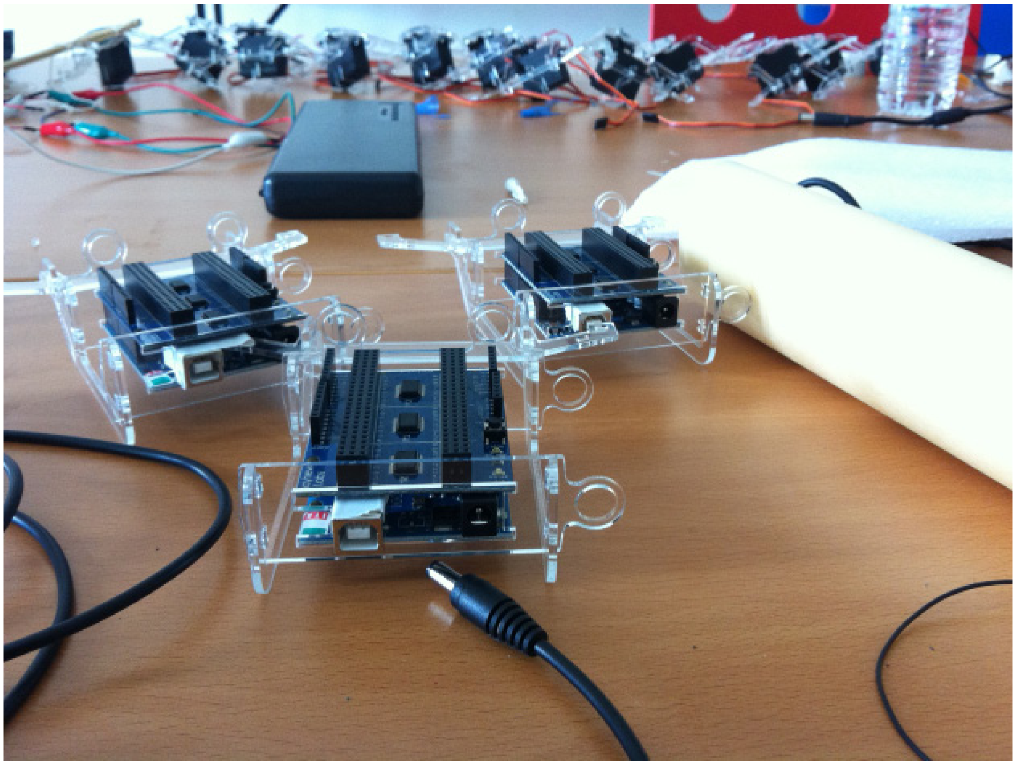
2–24 *The FabBots project directed by Marta Malé-Alemany focuses on designing the devices which generate multi-material complex matter formations. Programming matter will give us the ability to construct architectural components that are multi-functional and optimized. (Fabbots, 2012)*

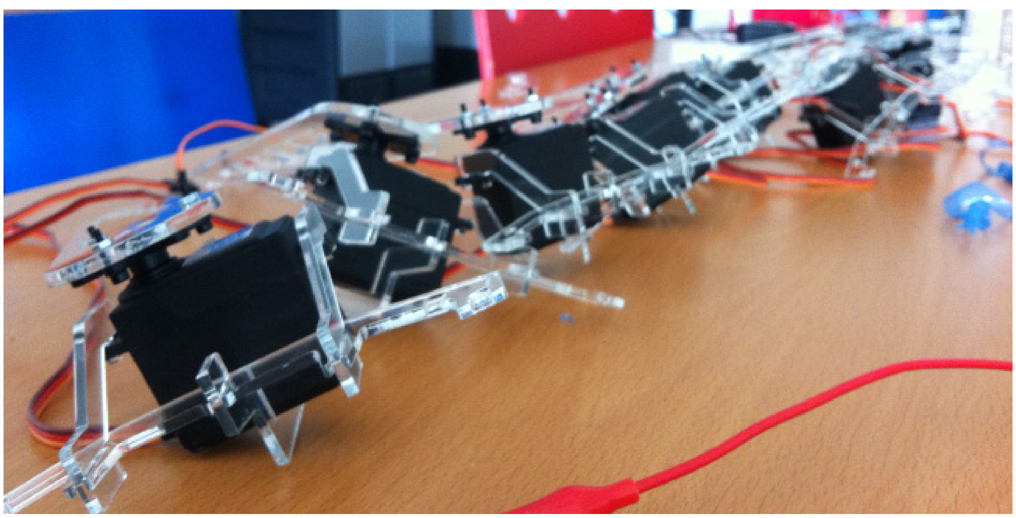
The digital industrial revolution has sparked change in a multitude of disciplines in current contemporary study. With new and novel products being released daily, technology has accelerated work flows and production. Engineers and computer scientists have taken advantage of this most. The goal is now to equate these advancements in the discipline of architecture. This will require training beyond the traditional bounds of architectural education. With many designers taking it upon themselves to learn new methods, tools and software, it is possible to make architecture's transition into the digital industrial revolution a productive one, rather than one focused on aesthetically driven form–finding. Architects who are adept in these modes of making (coding and fabrication, for example) will be in high demand, resulting in a "new norm" for the building industry. These new tools make possible the original intent of creating new radical discoveries and inventions to industrialize building construction; where architects and designers act within incubators and platforms for innovation in collaboration with the high–tech industry. Standardization and rationality are therefore being traded in for optimized, prolific and responsive tendencies. This is the movement towards near living building assemblies and incites possibilities for the creation of a biosynthetic future. A future where the organic, the cultural and the technological are compatible and sympathetic.



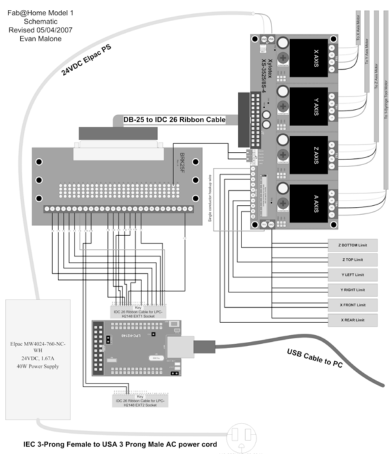
[Recall 2.1 *Material Fertility*]

60 Manuel De Landa, "The Machinic Phylum" (TechnoMorphica, 1997). http://v2.nl/archive/articles/the–machinic–phylum





2–25 *Digital components you can build with. Arduino microprocessors and a string of servo motors (by the author, F_RMlab, 2013)*



2–26 *"There is an abundance of scientific evidence which shows that the human brain and nervous system constitute a marvelous and complex 'goal–striving mechanism', a sort of built-in automatic guidance system [...] Cybernetics does not tell us that man is a machine, but that man has and uses a machine. It also tells how that machine functions and how it can be used." (Xavier, Philosophical Reflections, 2012)*

The creation of evolutionary qualities in building material using technology redefines the working scale of architectural thinking down to the nanometre. Shrinking electronics and our ability to manipulate biological cells with synthetic biology have proven that we are in fact living in a society laden with machines which support human life, encouraging social theorists to quantify this technological progression as the beginnings of a cyborg era:

> *Nature and culture are reworked: the one can no longer be the resource for appropriation or incorporation by the other.*[61]

The cyborg world calls for a constant exchange and interplay between nature and culture. One does not conquer the other:

> *a machine, therefore, is not necessarily a mechanical device. [...] the term machinic refers precisely to this working together of heterogeneous flows of parts and processes.*[62]

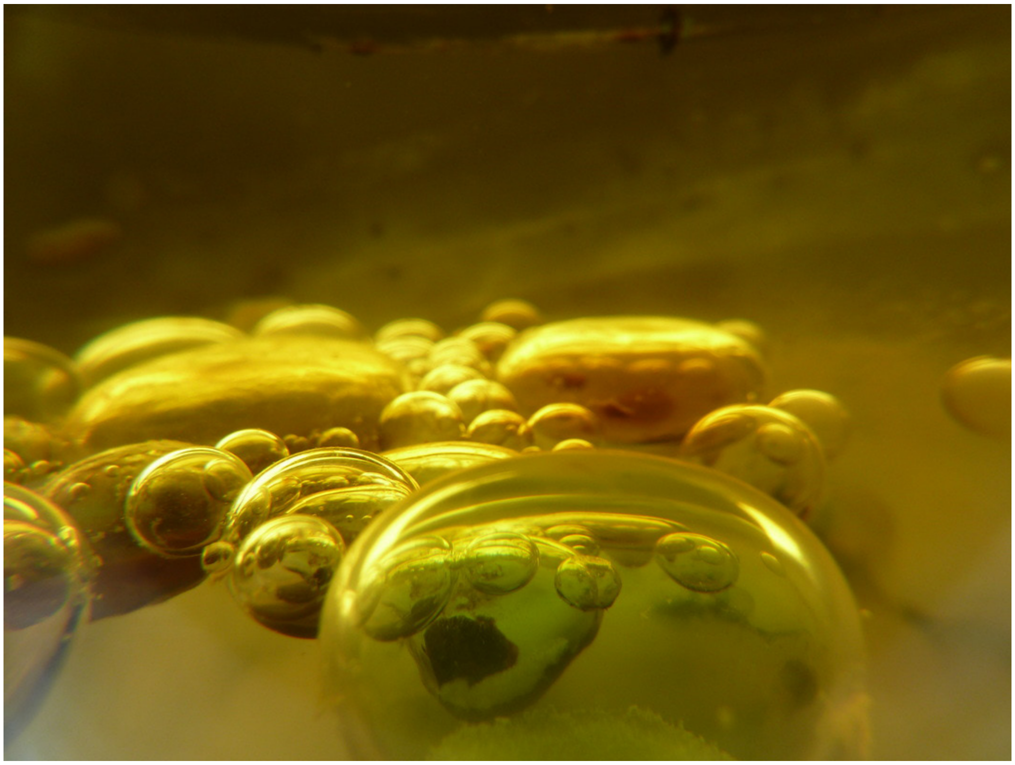
Sociologist and professor of the history of consciousness at the University of California, Santa Cruz, Donna Haraway, is a leading thinker on the lasting struggle between humans and their relationship to machines. For Haraway, human culture is already a form of cyber creation—a *technoculture* populated with cyborg humans. She argues that, in this present world, there does not exist a human that has not been altered by some other device: fortified foods, cosmetic alteration, pharmaceuticals, prosthetics, pace–makers—this is the realm of post–human society and transgenic organisms; cyborgs already live among us for Haraway. We ourselves are anthropomorphic beings. Digitized industrialization introduces the anthropomorphology of technology, and therefore, the anthropomorphology of architecture:

> *Perhaps what it means to be human is about not retaining our humanity...*

and instead introducing human qualities into the objects and tools we design. With an incredible wealth of knowledge now available on the understanding of our universe, digitized industrialization will have a major effect on architectural practice, as it orchestrates the space of human beings, it requires a design process informed by biology and aided by technology. With new technologies being introduced everyday and the understanding of cybernetic creation growing in depth, how do architects now build with living matter?

It is up for debate whether cells produced through synthetic biology can constitute a synthetic life form. Petra Schwille, a professor at the Biotechnology Centre of the Dresden University of Technology, says that synthetic microbes are more analogous to an interspecies clone, "inserting the genome from one organism into the chassis of another [is] different from synthesizing an entire living cell from

61 Donna Haraway, "A Cyborg Manifesto" (Socialist Review,1985)
62 John Johnston, "The Allure of Machinic Life" (MIT Press, 2008) pg. 112.



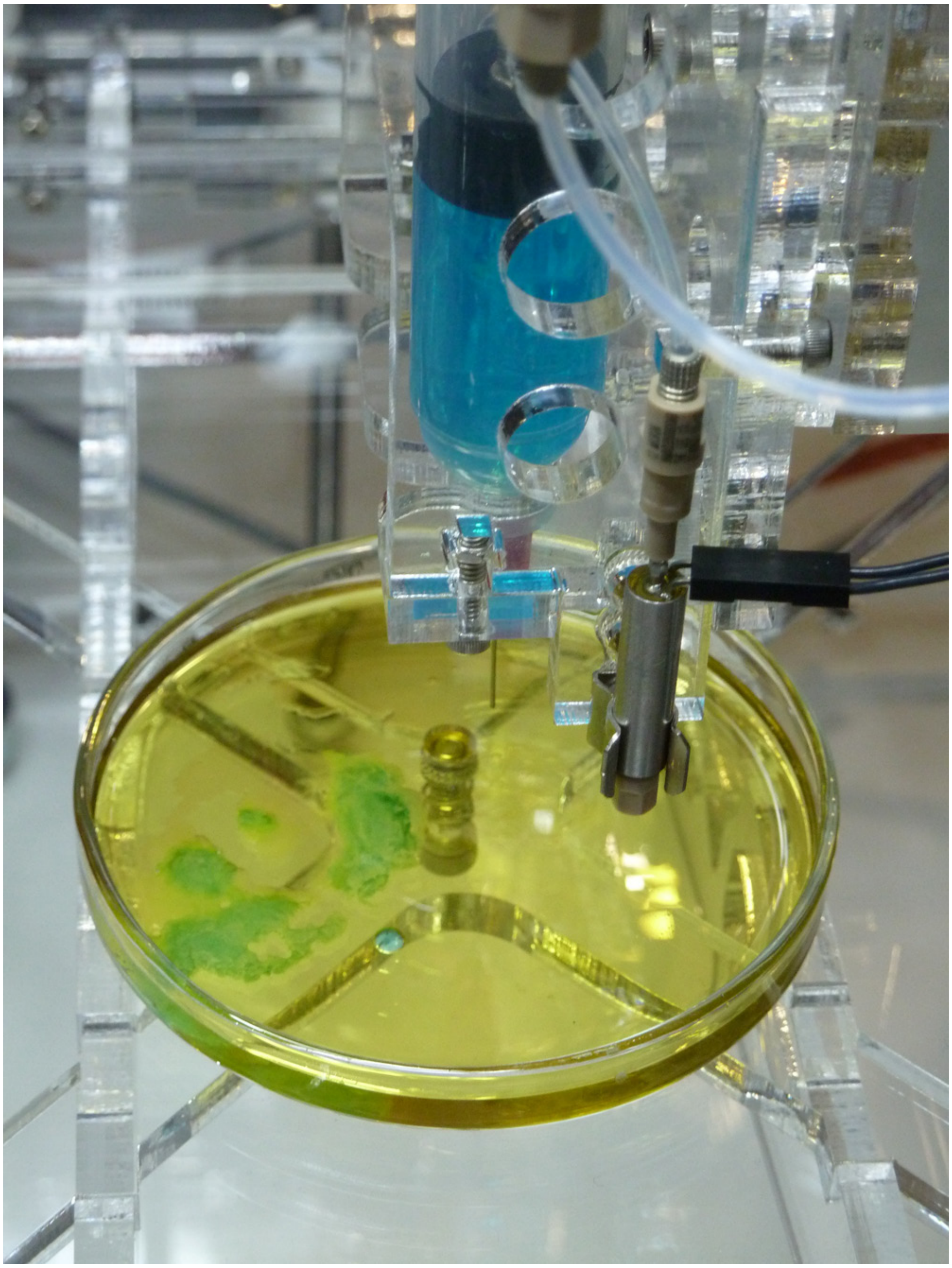
2–27 *Oil and water solution of a protocell base. At three-months old, crystals appear at the oil/water interface and mineralization occurs due to the diffusion of metal ions. (Rachel Armstrong, AD, 2011)* fatty acids and proteins." To her, the byproduct of synthetic biology is more like, "a bacterial robot than a type of synthetic life."[63]

Known as "minimal cells," the byproducts of synthetic biology are seen more as basic manufacturing platforms than intelligent forms of life. Just as computers and software perform the basic functionality of most disciplines, cells form the basic functionality, or circuitry, in the creation of synthetic genomes in synthetic biology. The minimum cell, which is a cell which has had all nonessential cells removed creating a blank slate to construct off of, essentially forms, "a universal chassis onto which you layer everything else,"[64] says Pamela Silver, a professor of systems biology at Harvard Medical School.

Bioengineering in synthetic biology continually posits on the interrelation between machine and organism. With programmable bacteria and the establishment of a library of different types of standardized genetic elements and DNA fragments, biologists in this field like to refer to computers in order to explain their work:

> *They want to design synthetic biology products analogously to the hierarchical structure of computers, which consist of modules with different gates carried out by physical layers. [...] This comparison to computers seems to be more than a mere analogy between machines and organisms; rather, the bioengineered products should ultimately constitute real machines. [...] Interestingly, the aim of producing novel types of living organisms in synthetic biology not only implies the production of living from non–living matter, but also the idea of using living matter and turning it into machines, which are traditionally considered non–living. [...] It can be said that synthetic biology as a whole approaches the borderline between living and non–living matter from both sides, the living and the inanimate. [...] in this traditional meaning living organisms and machines have many common features. Both types of entities convert energy into mechanical forces. Many organisms and machines can move, all of them have an overall body–plan, which means that they are composed of different types of smaller subunits. Each single part of an organism or a machine has a different structure from the whole (in contrast to, e.g. a stone). Furthermore, organisms as well as machines follow a specific program.*[65]

63 Charles W. Schmidt, MS. "Synthetic Biology: Environmental Health Implications of a New Field" (Environmental Health Perspectives, 2010 March) 118(3): A118–A123.
64 Markus Schmidt, ed. "Synthetic Biology: Industrial and Environmental Applications" (Wiley–Blackwell, 2012)
65 Anna Deplazes and Markus Huppenbauer, "Synthetic Organisms and Living Machines: Positioning the Products of Synthetic Biology at the Borderline Between Living and Non–Living Matter" (Systems and Synthetic Biology, Dec 2009; 3(1–4): 55–63) http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2759422/



2–28 *Test using the Fab@Home 3D Printer using CAD software to accurately distribute chemical solutions from syringes into an olive oil base. (Rachel Armstrong, WIRED, 2011)*

Synthetic biology products are widely seen as organic computers not only for analogously behaving like machines, but in addition, for facilitating the navigation between living and non–living realms—something traditional machines lack. In other words, manufactured organisms should not be viewed as threats to society but as a new way of building tools which can reverse our current effects on the environment.

Material Computing

Researchers of emergent matter such as Leroy Cronin, Martin Hanczyc and Rachel Armstrong suggest that the creation of architectural material which is fully responsive will only progress if they are made up of the same thing which forms all living matter; cells. Cellular matter, therefore, creates near living building material through an emergent and bottom–up methodology, suggesting that if complex combinations of traditional building material and living cells are realized, then this extends architecture which is simply *inspired by biology* into genuinely biological architecture; supplying architects of the future with a new breed of materials which are metabolic and living.

For example, the protocell—the metabolic and living material used by Dr. Rachel Armstrong and Neil Spiller, founders of AVATAR Research Group at The Bartlett Faculty of the Built Environment—is an artificially manufactured cell which can be programmed chemically to exhibit a multitude of characteristics. It effectively creates DNA'ed matter in a synthetic way. The protocells used by Armstrong and Spiller are, in effect, self–assembling agents, based on the chemistry of oil and water, with the capacity to create an available range of different "species" using varying recipes.[66] This ability to program different characteristics into the protocell's behaviour effectively places it as a complex and organic machine, and "the responsiveness of protocells to stimuli means they can be regarded as computing units."[67] This breakthrough proves that there is an available ability to create artificial life that is useful in the creation of physical material which is autonomous and self–aware. Protocell technology, therefore, has the potential to form the basis for new smart materials in architecture.[68]

66 Simon Sellars for the Australian Design Review, "Living Architecture: An Interview with Rachel Armstrong" December 19, 2011. http://australiandesignreveiw.com/features/15151–intervew–rachel–armstrong
67 Rachel Armstrong and Neil Spiller, "A Manifesto for Protocell Architecture: Against Biological Formalism" (Architectural Design (AD), Vol. 81, No. 2, March/April 2011) pg. 24.
68 Martin Hanczyc, "Structure and the Synthesis of Life" (AD, Vol. 81, No. 2, March/April 2011. Pg. 28. Cited from: MM Hanczyc and T. Ikegami, "Chemical Basis for Minimal Cognition" in *Artificial Life* 16, 2010, pg. 233–43.

This is organic machinery we can build with. It is not a matter of imitating nature. It is about producing a direct synthetic equivalent. Complexity and organicism in building construction, therefore, can be realized with unconventional combinations of new and novel discoveries not native to the architectural discipline; where protocells and single–celled organisms like algae present us with viable agents for material computing in architecture.

Today, machine–thinking strives to parallel itself with natural phenomoena, rather than remaining alien to them. Industrial progression in building materials therefore needs to keep pace, and a reevaluation in the construction industry may prove to be a valuable exercise. As organisms are the biological processors of the natural world, machines are the biological processors of the synthetic world. If we envision living organisms as complicated machines, then hybridizations of organic machines and industrial machines could forge new ways of making everyday space—through form, function, *and* in material assembly.

What is a Protocell?

Imagine a surface, able to grow, swell, digest, repair, or even, self–adjust to changing environmental conditions. Emerging research in biotechnology—including synthetic biology, natural computing, tissue engineering and bioinformatics—could offer architects abilities in creating building assemblies which exhibit near living qualities. The protocell offers capabilities in material computing and, therefore, the ability to apply the principles of synthetic biology in building construction.

Used by chemists and biologists, a protocell is an chemical representation of an artificially living cell stripped down to essential elements. Therefore, they have living qualities and behaviours, but are not tied to any specific DNA (like in the process of growing an entire living cell from fatty acids and proteins), and therefore cannot be considered as fully living.

> See this interview on frmlab.com:

http://frmlab.com/2014/01/07/living-agents-in-construction-protocells-and-natural-computing-with-rachel-armstrong/

2–29 *"Dynamic droplets act as agents for a design philosophy that examines the complex relationships between people, materials, the environment and our technologies in an ecological age." (Armstrong, 2012)*

An Interview with Rachel Armstrong

Here, I ask Rachel Armstrong about her design philosophy involving protocells, sharing what its future place might be in the architectural profession.

PB: How can the protocell help, or be applied to architecture?

> *RA: "Protocell" is a controversial term, which depending on whose definition of the term you read may refer to a fully artificial cell [Rasmussen 2003], or as a collection of chemistries that are not fully 'alive' but which exhibit behaviours that are usually associated with living things [Hanczyc, 2011]. In my work, I have used the term 'protocell' to refer to the latter, chemical entity, rather than the former notion of an artificial life form.*
>
> *My work with protocells has proven most personally rewarding when it has been applied as a design philosophy. Protocells may be regarded as empowered 'agents', rather than inert objects, that are capable of forming new relationships that are not predetermined by geometry, or programming languages. This is to say that my work with protocells explores the possibility of constructing architectural programs using agents that build substrate, or material, relations—rather than being expressed through a hierarchy of objects, or by completing a pre–determined outcome.*
>
> *In this context the protocell embodies a design philosophy that is not quintessentially modern where nature and culture are separated by linguistic tropes. Indeed, design experiments with protocells seek to explore notions of reality that are in keeping with Bruno Latour's 'Actor Network Theory' or Graham Harman's 'Object Oriented Ontology'. These perspectives resist the forms of 'purification' that are artificially thrust on reality through human–centred discourses (based on linguistics) that polarize experience into realism (which is concerned with the hierarchical ordering of objects) and relativism (which is concerned with networks of relationships).*
>
> *Accordingly, 'protocells' therefore offer a palette of materials, technologies and methods that help architects explore the design and execution of architectural programs beyond the conceptual and practical constraints of modern design practices, which currently limit the possibilities for the profession.*

PB: The Venice project envisions the protocell reconstructing the foundations of Venice. Can you see it being applied to a smaller scale—in architectural materials, for example?

RA: Protocells are not 'just' programmable, dynamic droplets, but refer to a much broader portfolio of materials, methods and technologies that seek an ecological paradigm for the production of architecture. They may therefore be applied, within the physical limits of possibility, to a whole range of contexts, materials and scales. For example, a protocell 'paint' has been proposed in collaboration with Lee Cronin's research group at the University of Glasgow, where oil droplets could form the basis of a carbon capture paint, with a two stage drying process. The protocell paint is designed to fix carbon dioxide from the atmosphere and to change colour when it's 'full'. This speculative product encapsulates the kind of approach that working with protocell systems may offer architecture.

PB: What conditions are necessary for protocells to thrive? Closed container with controlled inflow and outflow of liquid? Reaction vessel? Circulatory system?

RA: Protocells are not objects and do not possess a single, fixed geometry. In other words they are innately empowered and therefore possess a degree of 'autonomy' in their design interactions. This empowerment is derived from their materiality (or, chemical composition), which is conferred by being at a state of non–equilibrium. In this sense protocells may be thought of as being co–designers of systems, not merely materials or instruments that obey human–led architectural programs. As the system reaches equilibrium, protocells lose their visible liveliness and function as 'objects'. However, the innate agency of protocells can be prolonged by providing a flow of energy such as, heat or chemistry, into the system. So, protocells can still operate as dynamic agents in closed environments, but are most likely to persist in an open environment when they are receiving a flow of matter or energy. In other words, protocell interactions may be optimized when infrastructures that nourish the desired interactions support them. To date, our work with infrastructure has been conducted within significant constraints working with closed, sealed systems but future installations propose to establish free–flowing, nutrient enriched support systems.

PB: Can protocells be added to any material host?

RA: Protocells cannot be used in any context. They are composed of a discrete set of chemistries whose interactions exist within definable limits of possibility and are constrained by factors such as, temperature, pH or the presence of other chemistries and protocells. The use of protocells therefore is context–sensitive and designers need to carefully consider their appropriateness to the presenting design challenges. Protocells should not be used in the same way that 'nanotechnology' has often been applied – as a conceptual glue to make design solutions work when fundamental principles in the overall strategy are flawed. They are not deus ex machina!

PB: Can protocells be programmed to process certain compounds in the environment? Carbon? Heavy metals? Urban run–off and effluents?

RA: Protocells are a range of chemical technologies that potentially could be constructed to perform a portfolio of operations. While none of the programs mentioned here, currently exist as protocell assemblages, there is no a priori reason why architects, working with chemists, could not produce dynamic chemical systems that could differentially process and respond to complex environments in the ways described.

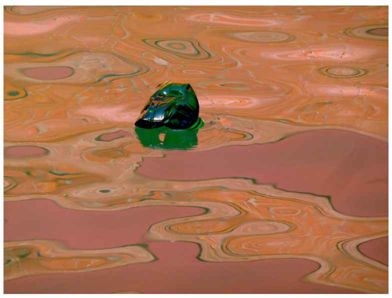
PB: For this to take hold, a widespread cultural acceptance of synthetic organisms is needed. How do you see this happening? Personal computers started out as a military device until it was commercially available to the public, could the same cultural shift start to happen when the potentials of synthetic biology are more widely understood; bringing living organisms out of the lab and into public space?

RA: Protocells are not 'organisms'. In my definition of protocells, they are simply assemblages of chemistries that exhibit remarkably lifelike interactions. However, they do not have the full status of being truly 'alive'. Yet, as lifelike entities, protocells do influence our surroundings and great care and designers working with them should afford consideration. While protocells may be considered agents capable of 'natural computing', being able to make simple decisions about their operations within a particular context the participation of people is required for them to perform useful work. However, the extraordinary liveliness of protocells does raise the question about the ethical status of nonhumans in an ecological era, a question that is raised (but not resolved) in Jane Bennett's 'Vibrant Matter' and also in Myra Hird's 'Origins of Sociable Life: Evolution After Science Studies'. All designers working with these agents should consider the ethical and moral challenges posed by working with lively materials and apply them appropriately and with consideration.

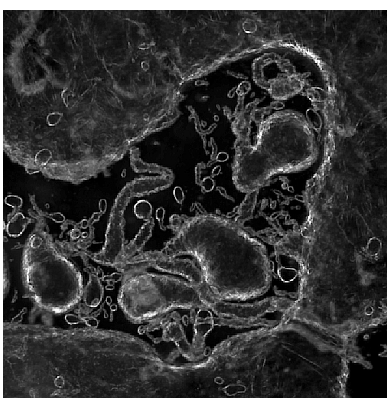
PB: Describe what natural computing and self–assembly means to you.

RA: Self–assembly is a spontaneous material property that is possessed by substances that are at far from equilibrium states. Self–assembly alone is not a form of design.

Natural computing is a form of computation that harnesses the properties of natural systems such as, self–assembly and therefore is an applied relationship to complex phenomenon. It is possible to apply principles of natural computing to design with materials capable of self–assembly.



2–31 *"Plastic bottle in Venetian canal. This photographic composition embodies the notion that there is no easy separation between nature, artifice and language in our modern world." (Armstrong, 2010)*



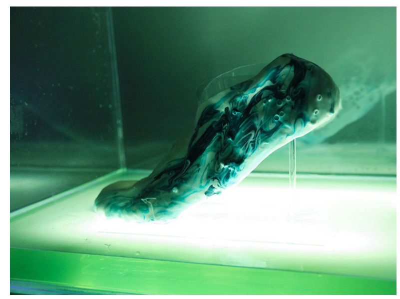
2–30 *"Protocell construction. Protocells are not objects and cannot be described through simple geometric formulae or programming languages." (Armstrong, Micrograph x4 magnification, 2009)*

I'd like to thank Rachel immensely for sharing her thoughts on these topics with me. The creation of architectural material which is fully responsive calls for construction methods engaged with living agents. Doing so requires a design method which involves the same substances which form all living matter: cells. Cellular matter can therefore create architectures of a near living state if complex combinations of traditional building material and living cells are realized, and extends architecture which is simply *inspired by biology* into genuinely biological architecture; supplying architects of the future with a new breed of available materials which are metabolic and living.

Scientific Precedents

1. The Protocell Running Shoe

In 2013, Shamees Aden, released her design for the protocell running shoe at the *Wearable Futures* conference in London. Working with expert researcher in protocell technology, Martin Hanczyc, Aden has been successful in developing the protocell mixture for regenerative running shoes. The shoes would be 3D–printed to fit like a second skin on the owner's foot and, "react to pressure and movement created when running, puffing up to provide extra cushioning where required."[69] The shoe membrane would also need to be cared for, much like a plant, by storing them in a protocell solution to rejuvenate the cells at the end of each day. Aden speculates, "the results could become reality by 2050,"[70] with the hopes that the project will help others understand the possibilities protocell technology offers to design futures. The synthetic cells tailored for the shoe is created by combining different protocell mixtures, and scientists are continuing to produce artificially living systems that can be programmed with different behaviours, including a responsiveness to pressure, light or heat.



2–32 *The Protocell running shoe (Aden, Dezeen, 2013)*

2–33 *The Protocell Shoe (Armstrong, 2012)*

As an evolved version of the Protocell Shoe by Rachel Armstrong,[71] Aden's shoe shows the development of protocell technology over the course of just one year, showing a close and promising view of the future.

69 Dezeen, "Self–Repairing Trainers 3D–Printed from Biological cells by Shamees Aden," (Dezeen.com, Dec. 11, 2013) http://www.dezeen.com/2013/12/11/3d–printed–trainers–synthetic–biology–protocells–shamees–aden–wearable–futures/
70 Ibid., (Dezeen, 2013)
71 Bruce Sterling, "Architectural Fiction: Rachel Armstrong, 'Protocell Shoe'" Wired, Jan. 2, 2012. http://www.wired.com/beyond_the_beyond/2012/01/architecture–fiction–rachel–amstrong–protocell–shoe/

At the University of Glasgow, Leroy Cronin examines how we can manufacture architectural elements, beginning at the nanoscale, with the production of inorganic cells. Working with a new class of nanoscale inorganic molecules, the research group is working on their ability to reconfigure these cells to allow the fabrication of scalable new building materials:

> *The ultimate aim is to reduce the fundamental building block of building materials from the centimetre (real bricks, nails, concrete blocks) to the same dimensions as the building blocks of biology and to produce inorganic cells.*[72]

If the building blocks of architecture can be reduced and understood in parallel to the evolved and complex building blocks of biology, then Cronin and his research team believe that a more sophisticated ability to manipulate material may be possible in architecture; working from the bottom up:

> *If evolution can be engineered to occur in living, unsophisticated building blocks, then it may well be possible to evolve sophisticated materials with properties as yet inaccessible with conventional technologies.*[73]

2–34 *"I am 100 per cent positive that we can get evolution to work outside organic biology," says Lee Cronin at the University of Glasgow. His building blocks are large "polyoxometalates" made of a range of metal atoms – most recently tungsten – linked to oxygen and phosphorus. By simply mixing them in solution, he can get them to self-assemble into cell-like spheres. Image by Murdo Macleod. (Sanderson, NewScientist, 2011)*

Their experiments show their creation of inorganic cells arranged so that inter–cellular communication is possible. This intercellular communication is vital, as it allows them to precisely control the passing of nutrients and functions between each cell in the synthetic molecular matrix—giving them the ability to program desired responses to environmental changes into the material in question. These responses can include changes in: luminosity, translucency, opacity, reactivity to heat, light, or pressure, power generation, or self–repair.

The Cronin Group take advantage of 3D–printing's capabilities to make a variety of reaction vessels from quick–setting silicone (otherwise known as typical bathroom sealant). To test their chemical solutions, the silicone vessels are interlaced with other materials like conductive polymers (which trigger chemical reactions) and fibre optics (for monitoring the reactions)—calling this process a printed vessel made from, "catalyst–laced ink."[74] This new labware, which they call "reactionware" may redefine the bounds of Chemistry, which:

72 Leroy Cronin, "Designing New Architectural Design Principles with 'Living' Inorganic Materials" (AD, Vol. 81, No. 2, March/April 2011) pg. 35–36.
73 Cronin, AD, pg. 35–36.
74 Bruce Sterling, "Fabbed, Interactive, Laboratory ReactionWare," (Wired, April 16, 2012) http://www.wired.com/beyond_the_beyond/2012/04/fabbed–interactive–laboratory–reactionware/

> *... for the last 200 years, has been done in a fixed, passive reactor," says Cronin, referring to the conventional glass flasks and other vessels that are standard issue in most chemistry labs. "That has just changed."*[75]

This new tailor–made ability in chemistry could therefore progress into relevant application in building construction, allowing for designed vessel conditions which can then be placed in various architectural situations—chemistry, therefore, is no longer confined by the space of the laboratory flask.

3. Bubble-wrap Bioskins – ACADIA 2013

Turning sheets of material into reaction vessels is a common thread found in these scientific precedents. They require the design of a material substrate which acts as an armature for the impregnated medium which runs through them—much like the algae textile houses the live reaction of algae. This method has the potential to turn static sheets of material into metabolizing entities. During the 2013 ACADIA Conference, an informal workshop using basic chemistries was held in F_RMlab with Rachel Armstrong. The workshop gave a broad look into the ideas behind protocell technology and self-assembling chemistries, helping to introduce an understanding for creating material from the bottom–up. In this workshop, Rachel demonstrated how the notion of the collective protocell can be housed within a material armature, using common bubble–wrap as the housing vessel.

Basic Chemistry:

1. Soluble salt bases:

cobalt nitrate (red to purple hues)
nickel nitrate (green)
copper sulfate (blue)
calcium chloride (white)

2. With alkalized alginate (alginate + sodium hydroxide):

(alginate is the 'glue' that makes algae work, and it is also commonly used in tissue engineering, as it closely replicates the function of the natural extracellular matrix for growing cells. It is a basic carbohydrate, providing many hydroxyl groups which will attract the metal ions in the salts towards it, facilitating the chemical reaction). The alkalized alginate is the transformational bed.

75 Bruce Sterling, "Fabbed, Interactive, Laboratory ReactionWare," (Wired, 2012)

2–35 *Materials needed: coloured salts, hot plate, alginate, syringes, needles and scraps of bubble wrap. (By the author, 2013)*

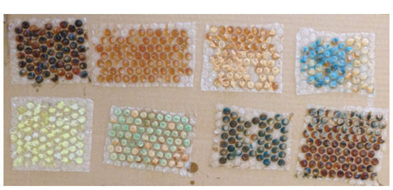
2–36 *Soluble salt bases: sodium chromate (yellow), nickel nitrate (green), calcium chloride (white), copper sulfate (blue), colbalt nitrate (red). (By the author, 2013)*

2–37 *Mixing sodium hydroxide and alginate into hot water. (By the author, 2013)*

2–38 *Hot plate of alginate and its injection into bubble wrap with a syringe and needle.*

2–39 *Bubble wrap injected with alkalized alginate. (By the author, 2013)*

2–40 *Alginate after being injected with calcium chloride solution, producing a white precipitate. (By the author, 2013)*



2–41 *Bubble–wrap swatches produced during the workshop, using various combinations of salts. (By the author, 2013)*

By mixing these ingredients, the sodium hydroxide in the alginate turns the salts into carbonates. Each result in different molecular structures (i.e. molecular self-assembly) and produce the insoluble precipitates formed in the bubble–wrap.

How it Works:

The salts used have a metal ion and a sodium ion. The sodium provides the negative ion (anion) and the metals provide the positive ion (cations). When the ions compete in the reaction the insoluble precipitates are formed. This happens because we are, "changing the front end of the molecule by increasing the concentration of competitors in the [injection] facility," says Rachel. More simply, this experiment demonstrates the basic chemistry of forming polymers (also similar to your basic everyday chewing gum). Polymers possess branch like molecular structures giving it its interlaced and flexible character.

Non-dynamic structures are used in this workshop rather than live protocells typically found in an oil and water solution. The chemical process of creating Traube cells (artificial cells resembling frog spawn made from a solution of copper sulfate and potassium ferricyanide) is a reaction which simulates protocell behaviour. Though the results are static, using alginate to create an insoluble precipitate within the pockets of the bubble–wrap demonstrates the principles behind protocell behaviour. The workshop produced various swatches of synthetic embryonic bodies within the bubbles of small pieces of bubble wrap used as reaction vessels.

In this experiment, the bubble–wrap acts as a testing bed for the creation of designed reaction vessels—a customized container within which live reactions are placed—similarly to how the algae textile houses the live reaction of algae. The bubble–wrap is the physical container the designer is able to manipulate and adjust according to what affects are desired from the chemistry. It is the vehicle which bridges emergent chemical reactions with stable physical material, allowing designers to *make* with chemical and biological matter.

You can view all photos from the workshop here: "Playing with Chemistry" Album and here "Toronto Chemistries" Album on Rachel's Facebook Page.

> See this on frmlab.com/2014/01/03/living-architecture-workshop-acadia-2013-in-review/

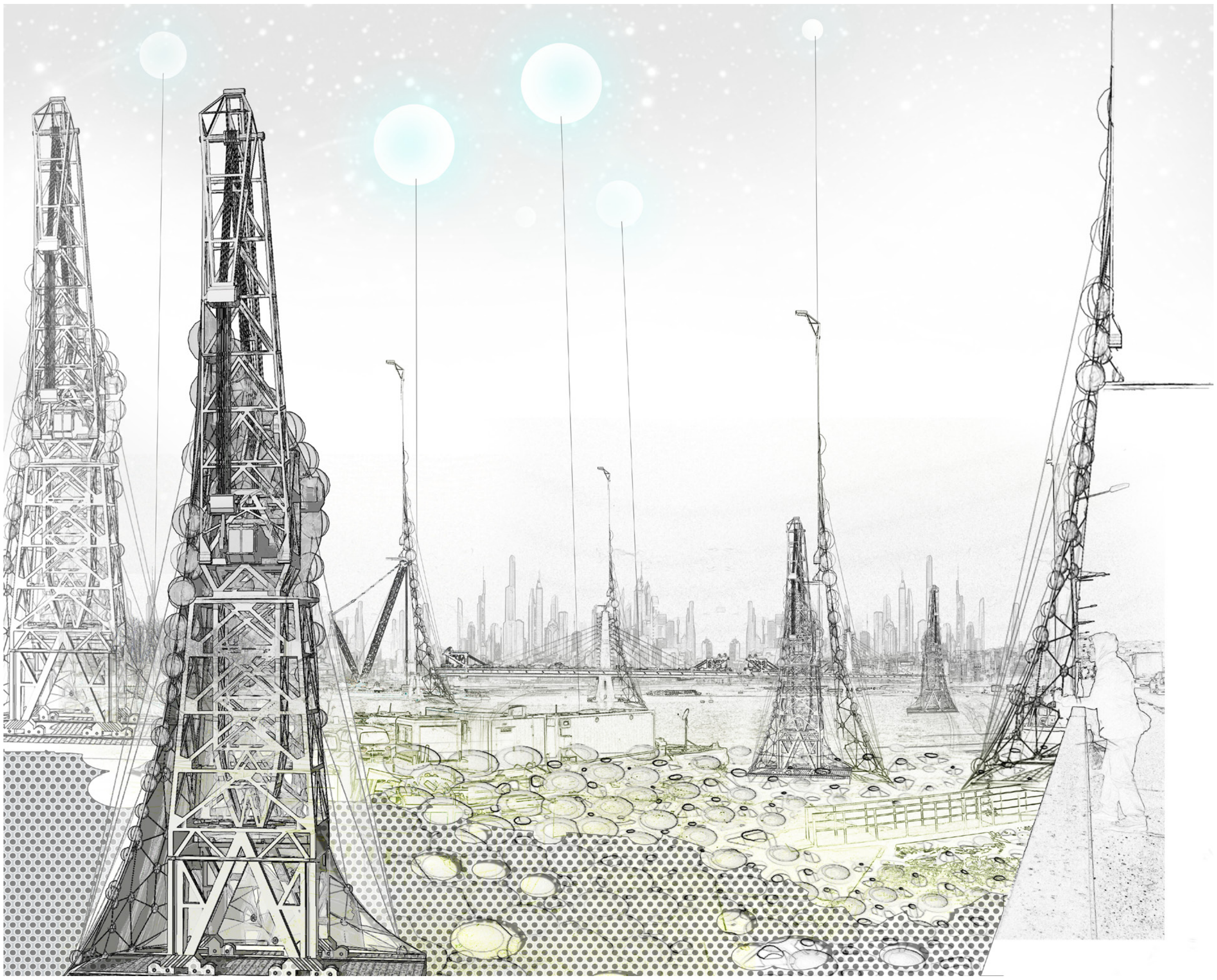
Machinic Theory in Building Construction

Building construction can be considered a complex mechanical assembly and, therefore, is fit for the application of machinic theory, where materiality is seen as the vehicle for its application. This examination of machinic theory and synthetic biology informs the theoretical basis of this thesis. It strives to reorder the way architects think about material, and the tools used in its creation. It attempts to progress Deleuze and Guattari's notion of the "machinic phylum," where natural and artificial become interchangeable: "a materiality, natural or artificial, and both simultaneously."[76] Today, technology has everything to do with biology. Networks and databases are digital ecosystems. They sync to one another and adapt when changes are made. This is coding—a digitized DNA for objects—and it allows them to behave with prolific and lifelike qualities. With this rapid progression of digital technology, machines may grow and proliferate just as wildly as plants, cells, and parasites—next, is to see this progression in the creation of usable building materials. Technology which changes the way material is composed places the architect in control of the physical matter which composes their buildings. The dominance of digital modes of making (open source technology and accessible manufacturing, for example) therefore accommodate automated creation; allowing for a productive interaction between creator, machine and environment. Evolutionary machines:

> *In strong theories of [Artificial] Life [...] are understood not simply to simulate life but to realize it, by instantiating and actualizing its fundamental principles in another medium or material substrate. Consequently, these machines can be said to inhabit, or "live," in a strange, newly animated realm, where the biosphere and artifacts from the human world touch and pass into each other, in effect constituting a "machinic phylum."*[77]

To create machinic material, typical notions of the assembly of concrete, steel and glass must be questioned. An in–depth understanding of biology and material science is needed to advance this theory's application in building construction, and it's viability and implementation are major areas in need of continued study. Building materials directly informed by biology, therefore, offer a promising reevaluation of what our physical world is composed of. It is not a matter of simply mimicking the aesthetic and formal qualities we find in the natural world; it must live and breathe it, simulating life in a constructed state.

76 Gilles Deleuze and Felix Guattari, "A Thousand Plateaus: Capitalism and Schizophrenia" (University of Minnesota Press, 1987) pg. 90, 409
77 John Johnston, "The Allure of Machinic Life" (MIT Press, 2008) pg. 1 – 2.



" AS THE INTERBREEDING OF BIOLOGY AND TECHNOLOGY GIVES BIRTH TO A COLLECTION OF ARCHITECTURAL BEASTS, ROBOTIC INFRASTRUCTURES, AND HACKED MILITARY DEVICES...

WE GAZE OUT...ACROSS THE NEAR FUTURE POPULATION OF OUR AUGMENTED WILDERNESS.

2–42 *Visualization of a future urban wilderness, augmented by machinic bioskins. (By the author, 2013)*

Specimens of an Unnatural History: A Near Future Bestiary by Liam Young
Kerb 19 Journal of Landscape Architecture, *Paradigms of Nature: Post Natural Futures*, Pg. 12

2.3

POSTNATURALIST MAKING

2.3

Mass–Customization

> *Today's master architect is an amalgam of material scientist, product engineer, process engineer, user, and client who creates architecture informed by commodity and art.*[79]

Mass–customization and its creation through digital making processes defines the design space of the twenty–first century. When the architect is able to engage in all processes of the design in a multidisciplinary way—from the creation of material to the processes that make it happen—then we may be able to see the return of an architecture which works symbiotically between design process, the resulting artifact after its construction, and its material articulation:

> *The role of the architect in this evolving world of construction processes remains squarely centred on architecture formed about an idea of use and place, but we must also have tentacles extended deep into assembly, products and materials.*[80]

Therefore, the architect's job is no longer solely to define the formal and aesthetic qualities of a project and exclude themselves from the, "means and methods of making, thus turning architects into mere stylists."[81] They must orchestrate the processes and design the systems that make the building possible. Therefore, it is the, "designer of processes that show the way forward for art."[82] An architect who designs through making and who researches through making has an articulate understanding of the artifact they are producing, and in turn, the design is resolved through its processes. This works twofold: when, "producers [the engineer] engage in design, and designers [the architect] engage in production,"[83] the technical sophistication of architecture increases dramatically; bringing the architecture to a level of resolution that is "manufacture–ready," or "site–ready" before a shovel even breaks ground.

79 Stephen Kieran, James Timberlake, "Refabricating Architecture" (McGraw–Hill Professional; First Edition, 2003). pg. xii
80 Kieran, Timberlake, "Refabricating Architecture" pg. 31
81 Kieran, Timberlake, "Refabricating Architecture" pg. 7
82 Kieran, Timberlake, "Refabricating Architecture" pg. 7
83 Kieran, Timberlake, "Refabricating Architecture" pg. 13

In this paradigm, there is a fundamental differentiation between the reductive nature of mass–*production* and the prolific nature of mass–*customization:*

> *Customization ran at cross purpose to the twentieth–century model of mass production. Mass customization is a hybrid. It proposes new processes to build using automated production, but with the ability to differentiate each artifact from those that are fabricated before and after. The ability to differentiate, to distinguish architecture based upon site, use and desire, is a prerequisite to success that has eluded our predecessors. With the information control tools we now have we are able to visualize and manage off–site fabrication of mass customized architecture.*[84]

Plasticity: Fluid Geometries

Mass–customization depends on the fluid ability to manipulate geometry through computation, and can be seen in the work of harbingers of this new paradigm such as Patrick Shumacker's Parametricism or Morphogenic Design pioneered be Micheal Hensel, Achim Menges and Michael Weinstock who argue for high–level variability. In the past century, the field of architecture and engineering have been based and understood in terms of definitive geometric definitions of physical objects and space, producing static models and predicated on the idea that form is fixed by a given function. Though, in natural phenomena *and* in computational algorithms, the opposite is true. Their behaviour is dynamic and emergent, and depend on a high level of geometric plasticity. [Recall 1.1 Textile Design, Spatial Impact]

Form–generation in biology is strictly dependent on dynamic and emergent transformations; two elements are rarely the same and mutation and morphogenesis is a common occurrence. A similar pattern can be seen in algorithmic geometry. Geometry in the algorithms of a generative design process define a set of instructions which evolve various states of the final geometry. Parametric controls allow for the production of an infinite series of possible outcomes thereafter. Therefore, in generative design, "form follows data,"[85] to produce dynamic models which can replicate spontaneous pattern formations like those found in complex systems. Generative design, therefore, opens up a design space where material and medium are algorithmic,[86] and, therefore, highly plastic.

84 Stephen Kieran, James Timberlake, "Refabricating Architecture" (McGraw–Hill Professional; First Edition, 2003). pg. xiii
85 Fran Castillo, "Generative Systems: A Paradigm for Modelling Complex Adaptive Architecture" (Complexitys.com, July 2, 2012). http://complexitys.com/english/complexitys–culture/generative–systems–a–paradigm–for–modelling–complex–adaptive–architecture/
86 Fran Castillo, "Generative Systems" (Complexitys.com)

Generative geometries suggest a shift from static models towards dynamic ones inspired by computational logic. What Bruce Sterling calls "processuality,"[87] and what Lev Manovich calls the era of "info–aesthetics."[88] Both suggest a postmodern change in design theory inspired by the craft of software—which is built on tree structures, responsiveness and adaptive behaviour—and akin to phenomena known in biology. For Sterling, processuality and info–aesthetics, or "computational aesthetics," can be related to naturally occurring events such as, "the growth of plants, and boiling liquid."[89] Thus, designing with generative geometry allows designers to determine subtle relationships between patterns, structures, processes and form to achieve high–level variability.

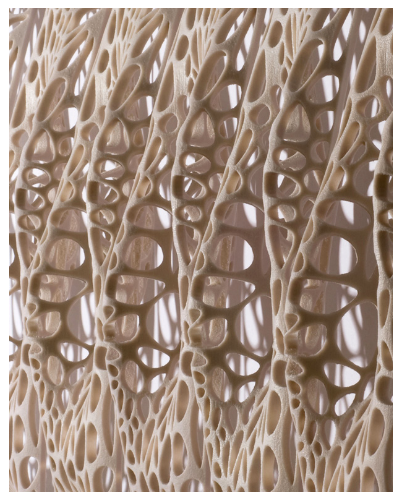
For example, Neri Oxman, professor and graduate of MIT Media Lab, uses generative modelling to create her material experiments. Heavily inspired by forms found in biology, her philosophy is rooted in material–based design computation:

> *In this approach, material precedes shape, and it is the structuring of material properties as a function of structural and environmental performance that generates design form.*[90]

Neri's Ph.D. thesis explores this philosophy—"material ecology," as she calls it—and produces a collection of material artifacts that test different forms and fabrication methods. This places *materiality* as a priority in achieving novel progressions in architecture. As KieranTimberlake state:

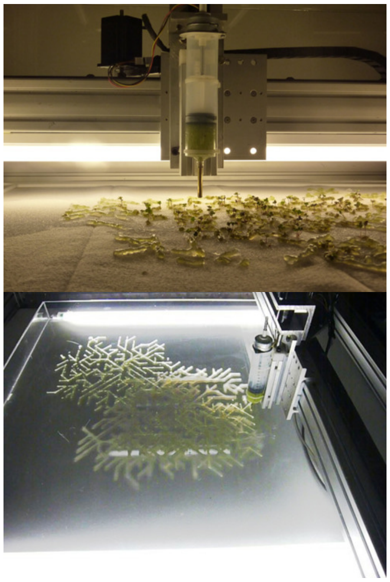
> *... new materials may indeed suggest new methods of assembly and give rise to new forms [...] material can be a progenitor of form.*[91]

Her project *Monocoque 2* tests integrated construction techniques which merge materiality with the inherent structural needs of form. Thickening and thinning of the structure is based on computationally–evaluated multi–scalar loading conditions at each unique joint and determines the required density of the voronoi pattern needed to keep the structure from failing.



2–43 *Monocoque 2 (Neri Oxman, 2011)*

87 Bruce Sterling, Omar Vulpinari. ed. "Designing Processes Rather than Art" (Fabrica, 2008) pg. 4. Available at: http://www.scribd.com/doc/47661318/Fabrica–Bruce–Sterling–s–Workshop–Booklet
88 Lev Manovich, "Info–Aesthetics: Information and Form" (manovich.net, 2010) http://www.manovich.net/IA/#manifesto
89 Bruce Sterling, Omar Vulpinari. ed. "Designing Processes Rather than Art" (Fabrica, 2008) pg. 4. Available at: http://www.scribd.com/doc/47661318/Fabrica–Bruce–Sterling–s–Workshop–Booklet
90 Neri Oxman, "Material–based Design Computation" *Abstract*, (MIT Department of Architecture Thesis, Ph.D of Philosophy in Architecture, Design and Computation, April 30, 2010).
91 Stephen Kieran, James Timberlake, "Refabricating Architecture" (McGraw–Hill Professional; First Edition, 2003). pg. 119



2–44 *Urban Eden project (Allison Kudla, 2011)*

2–45 *Hy-Fi's MoMA PS1 Pavilion for summer 2014. (Hy-Fi, 2014)*

Alternatively, the Urban Eden project by Allison Kudla uses:

> *[...] a computer controlled four–axis positioning table to "print" intricate bio–architectural constructions out of live plant cells. Suspended in a clear gel growth medium, these cells continue to divide and flourish, gradually filling in the construction. The algorithmically–generated patterns drawn by the system are based on the Eden growth model and leverage mathematical representations of both urban growth and cellular growth, thereby connecting the concept of city with the concept of the organism. This project is working to make concrete the idea of dynamic and fluid computer space altering the expression and formation of a living and growing biological material, via its collaboration with an engineering mechanism.*[92]

Another, from Hy–Fi, is MoMA PS1's installation for the summer of 2014. The pavilion will be made of organic material serving as an example of *physically* generative material using mycelium bacteria. The pavilion's bricks will be biologically engineered to grow themselves from plant waste and fungal cells forming ameba–like towers around the PS1.

> *Instead of mining sandstone or carting in metal by truck, all of Hy–Fi's prep work will take place on–site, explains Benjamin, principal architect at The Living and director of Columbia University's Living Architecture Lab. The bricks, produced by the startup Ecovative, are grown from mycelium, or mushroom cells that grow upwards and outwards like a branch. Combined with agricultural waste like corn stalks, the materials fuse and shape into a solid brick—or into whatever shape the architect wants.*[93]

If architects and builders were able to grow their materials in–situ, this method could present a radical alternative to building the cities of the future— "one that's inspired by biology, [and] stretched even further by human technology."[94] Growing materials effectively eliminates shipping, their carbon footprint is zero, repairs can be injected (rejuvenated) on site with no waste material to demolish or throw away, and at the end of their life–cycle mycelium–grown bricks can be composted just like kitchen waste. These growable materials can contribute to the health of the environment with their easy biodegradability, and symbiosis within nature and culture—offering nourishment to our immediate surroundings and becoming part of our overall well–being.

92 Allison Kudla, "Capacity for (Urban Eden, Human Error)" *Generative Systems: A Paradigm for Modeling Complex Adaptive Architecture*, complexitys.com, July 2, 2012. http://complexitys.com/english/complexitys–culture/generative–systems–a–paradigm–for–modelling–complex–adaptive–architecture/
93 Sydney Brownstone, "This Crazy Brick Structure is Made from Mushrooms, and Can Keep Itself Cool all Summer," FastCompany: CoExsit, February 10, 2014. http://www.fastcoexist.com/3026177/this–crazy–brick–structure–is–grown–from–mushrooms–and–can–keep–itself–cool–all–summer?utm_source=facebook
94 Sydney Brownstone (FastCompany: Coextist, 2014).

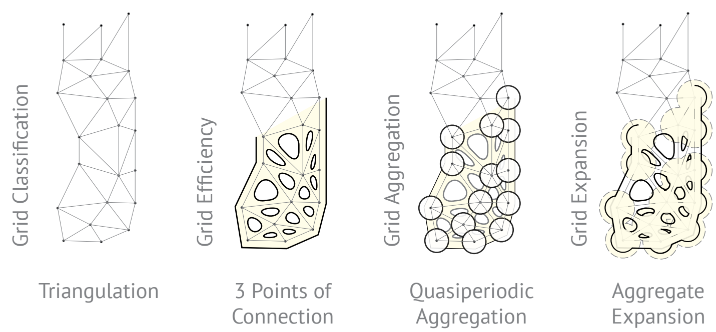
DESIGN
MODULE
4

TEXTILE IMPLEMENTATION

Generative principles in design inherently allow designers to successfully articulate high–level variability within the objects they create, and makes the development of complex smart materials, advanced fabrication, and distributed and sentient systems advantageous topics to pursue within current discussions in architectural practice. The designer's changing skill–set and search for plasticity, therefore calls for new ways in which building material is made. With more designers dealing with complex design problems, the demand for sources of material with advanced abilities is increasing. The algae textile is one example, but there is already a wide market for "smart materials" in architecture which include products like conductive fabrics, photovoltaics, or recycled and biodegradable materials.

The algae textile uses the methods suggested by this paradigm to solidify a photobioreactor's need to be highly customizable when used in a building–specific context. As mentioned before, if a photobioreactor is able to satisfy the programmatic demands of a building's floor plan, its intended design aesthetic and occupant comfort, then the integration of algae in the built environment may become more prevalent in typical practice. These manufacturing processes make it possible to produce the algae textile with high speed and low cost, while maintaining its ability to adapt formally in accordance to the architecture of the building. [Recall *Geometric Plasticity*, 1.1]

Mesh Plasticity



2–46 *Mesh Plasticity. Recall Geometric Plasticity in chapter 1.1. Models of plasticity are prevalent in adaptive systems and can be seen to benefit aspects of design relating to variability. Consequently, the aesthetic it may produce should be studied—suggesting a new paradigm in design which moves away from Cartesian geometries, and towards triangulated and conformal geometries which efficiently alter according to spatial fluctuations given by a context.*

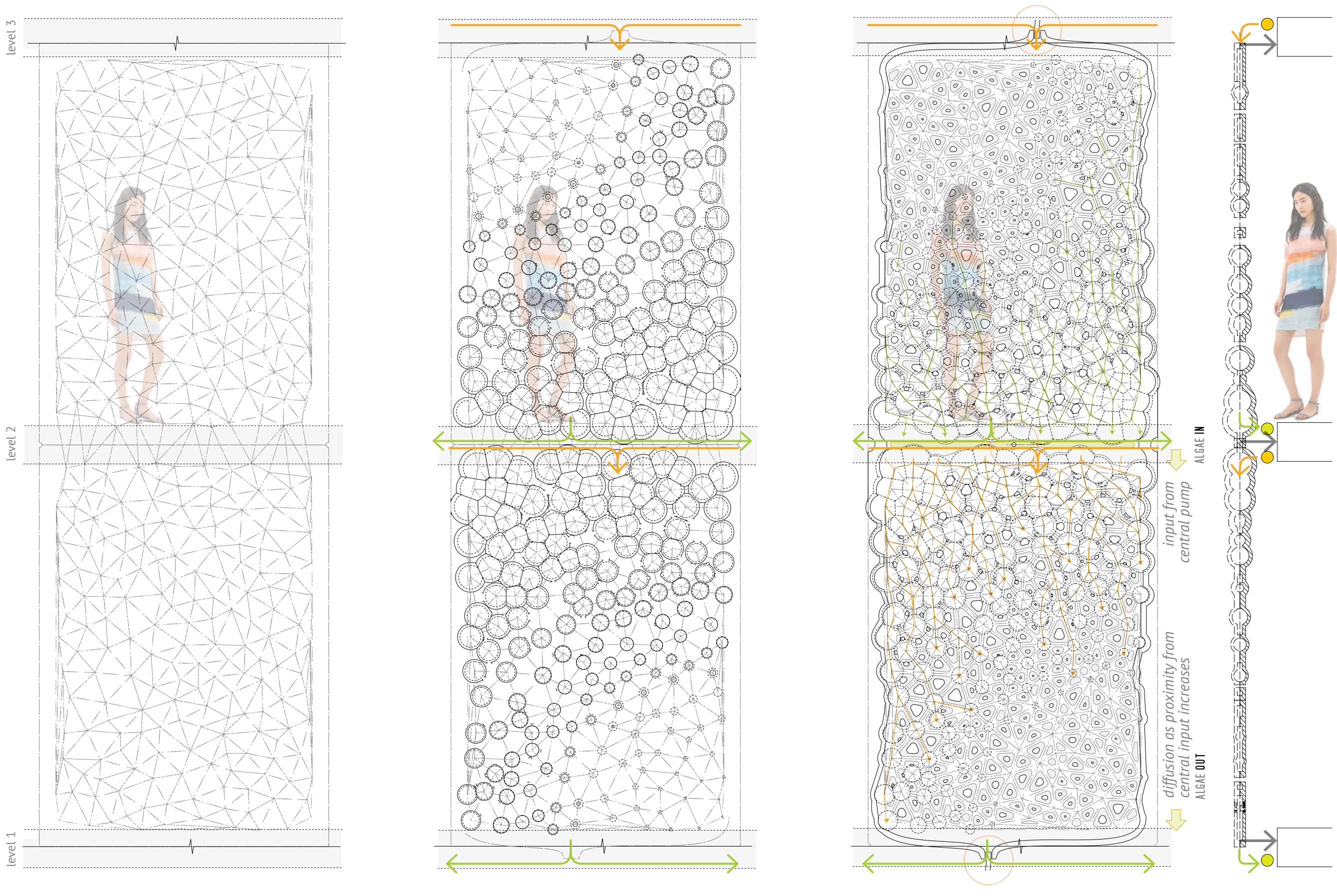
"Plastic" geometries, like those found in discrete differential geometry (i.e. conformal* structures, triangulation and fractals), efficiently alter according to spatial fluctuations given by a context (a collection of points or regions, for example). These are known models of plasticity in geometry, and why the algae textile takes the form of a triangulated aggregation of points: it allows the form of the path within the textile to adapt to elevational and planometric demands given by the building and its surrounding context.

* *Conformal Geometry:* a mapping which preserves shape over a distorting surface or over changing distances. Also known as "orthomorphic"

Implementation Scenario

If the textile were to be implemented on a standard curtain wall section, the following method of application could be suggested:

2–50 *Implementation scenario: curtain wall section.*



① AGGREGATION AND DENSITY

2–47 *In this example the points aggregate in a outward gradient to align the plumbing services of the bioreactor with window mullions and floor slabs. Acknowledging where structural and service lines are in relation to where the algae textile is being placed within the building will help generate the best aggregation of points for the membrane. These points determine the location of spherical voids within the textile.*

② VESSEL CONCENTRATION

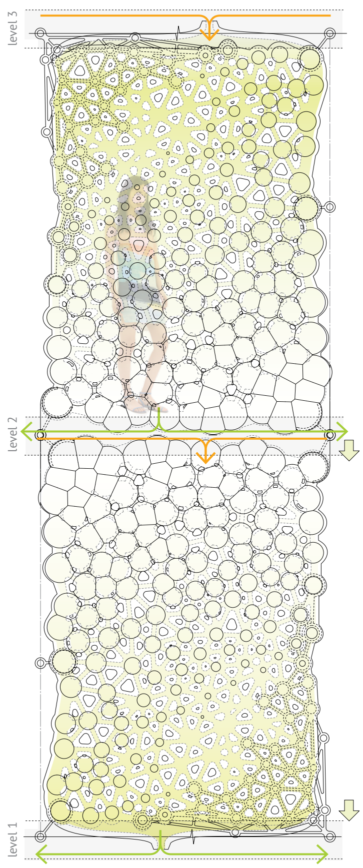
2–48 *Once these points are established, locations for input and output valves are chosen. This will effect the diameter of each sphere—which is determined by proximity to the input source of algae. This results in a clumping of vessels with larger diameters closer to the input, where the flow of fluid is the greatest, allowing for areas of the triangulated grid to expand: to increase fluid volume, flow and depth of section at localized areas.*

This clumping of spheres and points of expansion can also determine the spatial impact of the algae textile, and can be used to control matters associated with view and light modulation. During the design stage, these are important parameters of control for the architect, as they work through decisions regarding sight lines, occupancy and programme.

③ FLUID FLOW

2–49 *In this example, growth medium and algae is injected at the top of each floor slab, and harvested at the bottom of each floor slab. This arrangement dedicates a plumbing system to each floor, making it possible to control the large expanse of the textile in sections.*

This compartmentalization allows precise and decentralized control in: lighting, flow, pH and nutrients between levels, depending on the portion of the textile.



④

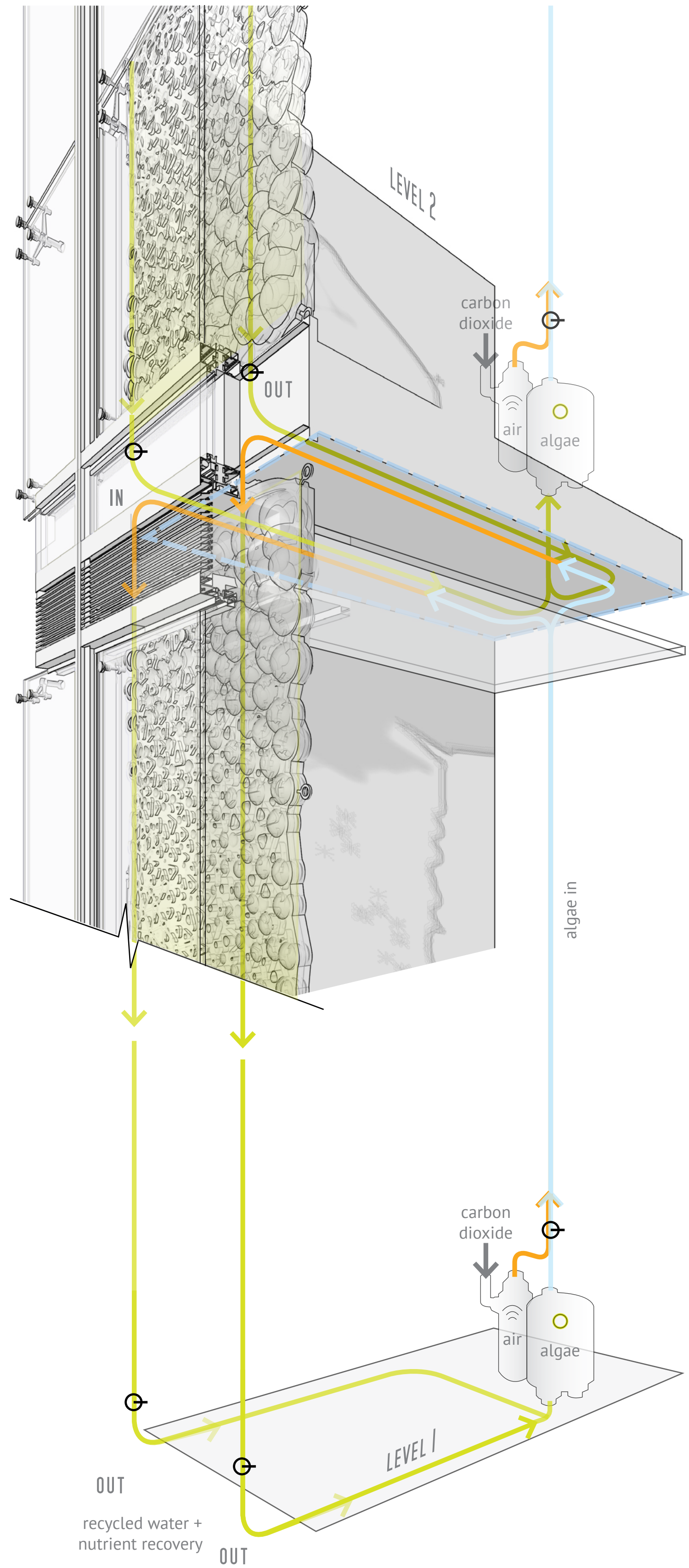
EMBEDDED STRUCTURE

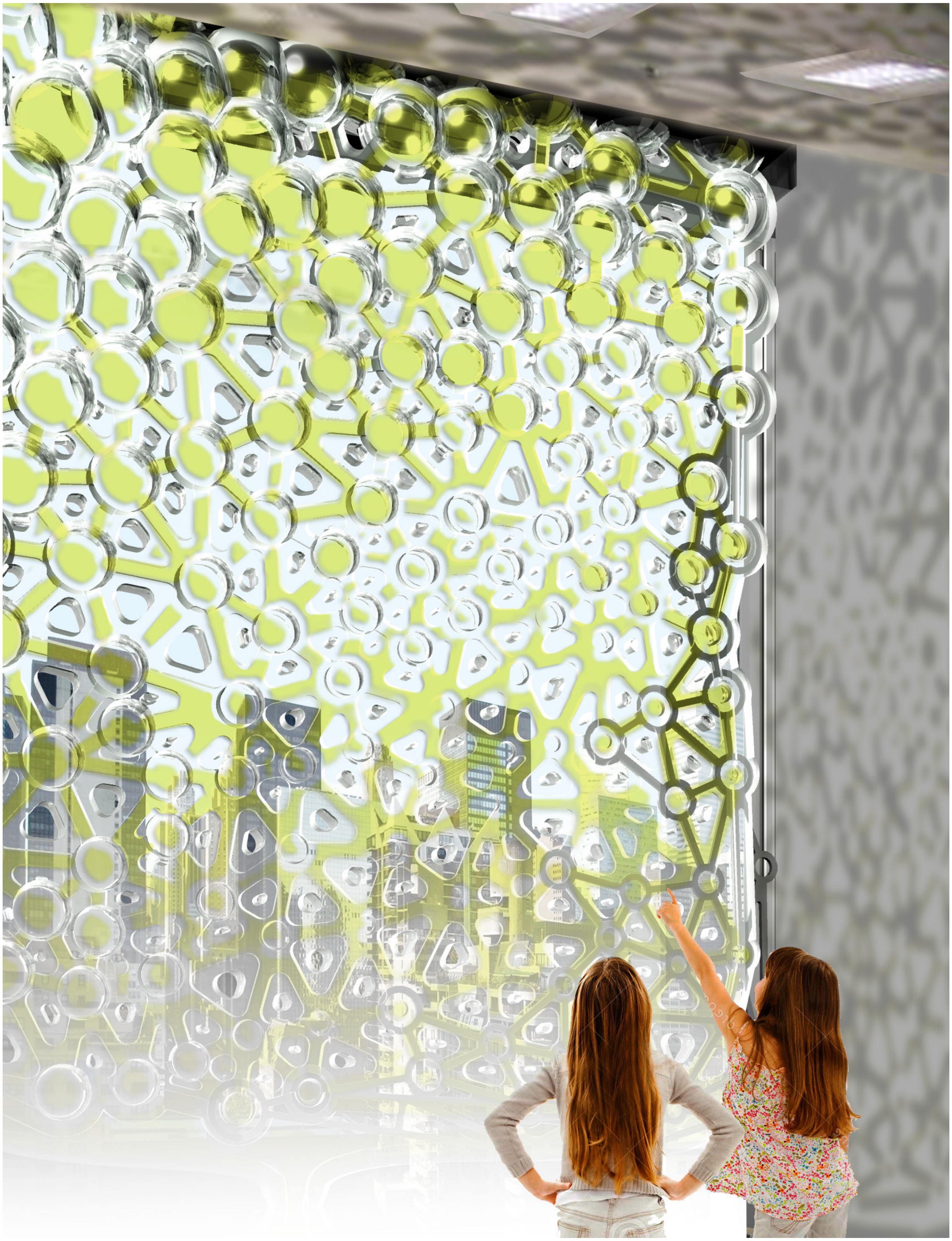
2–51 *Points of attachment can be located on the edge of floor slabs or walls using low profile and noninvasive hardware. The embedded structure in the textile can then be hooked onto these pin–points to tension the membrane into place.*

These structural inserts are cast within the membrane during fabrication. Their locations are determined by the density of the network and only exist on the outer perimeter as an attachment mechanism; leaving the interior area of the textile free to stretch and deform.

- *algae in*
- *algae out*
- *valve*

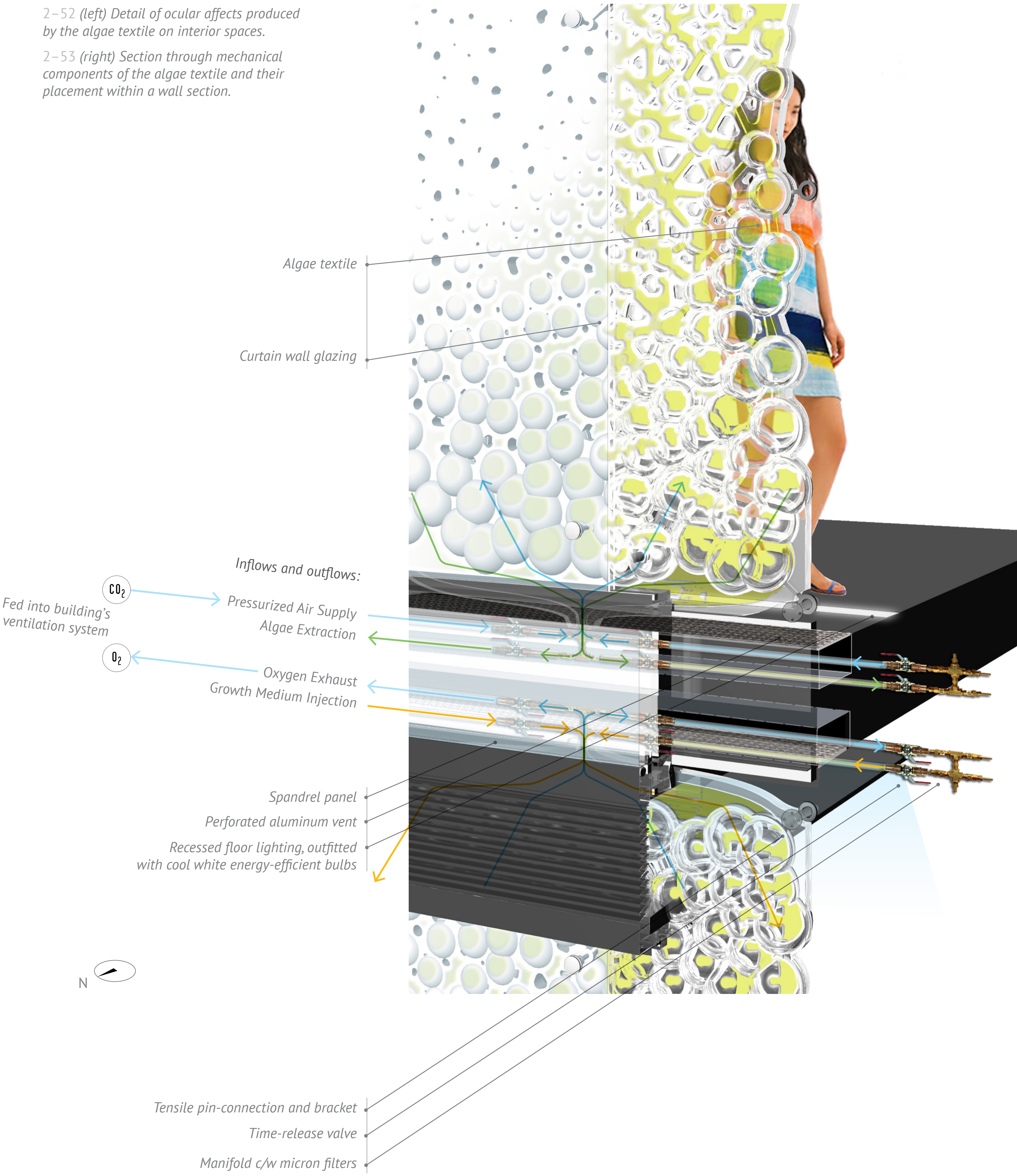
N



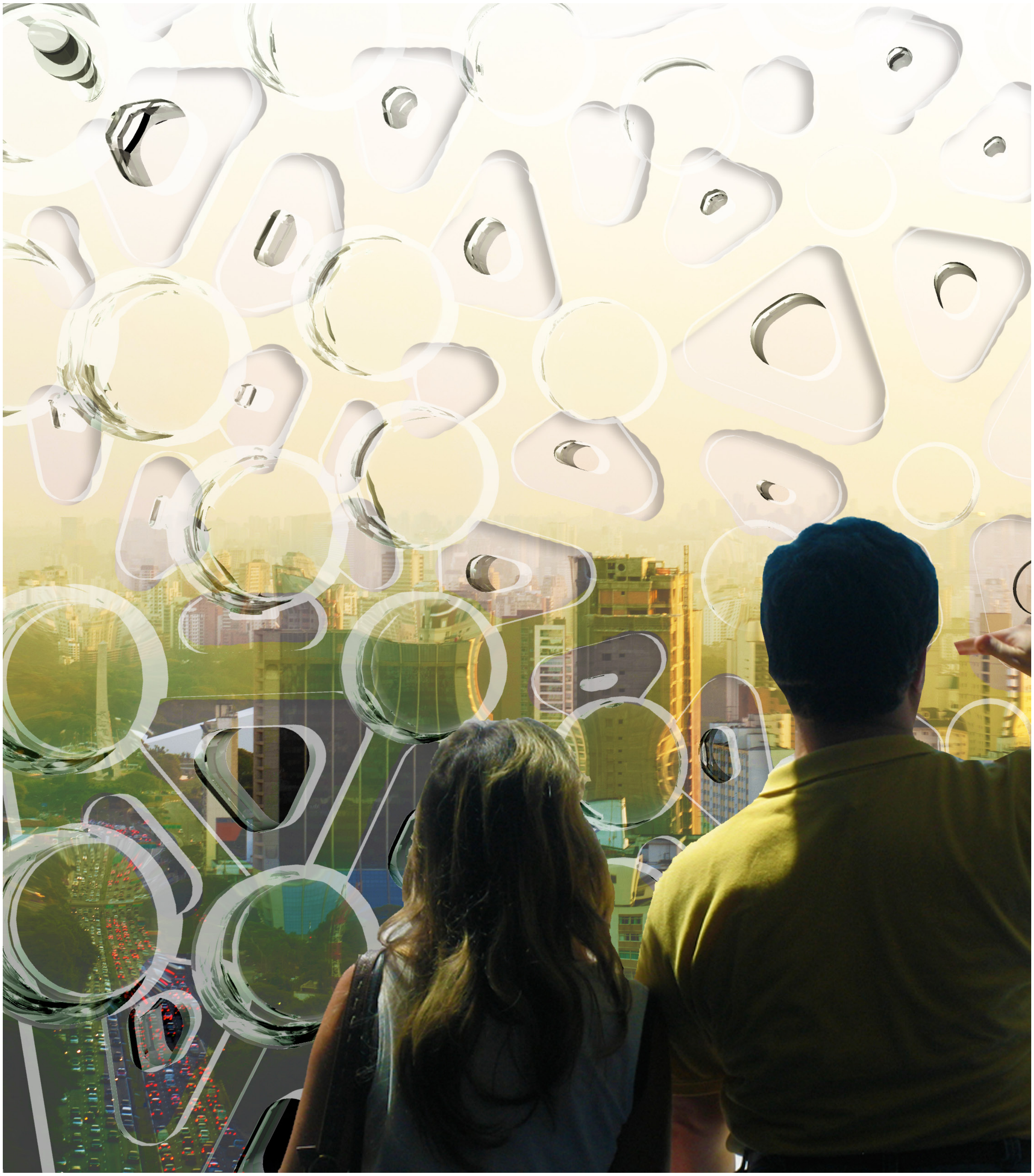


2–52 *(left) Detail of ocular affects produced by the algae textile on interior spaces.*

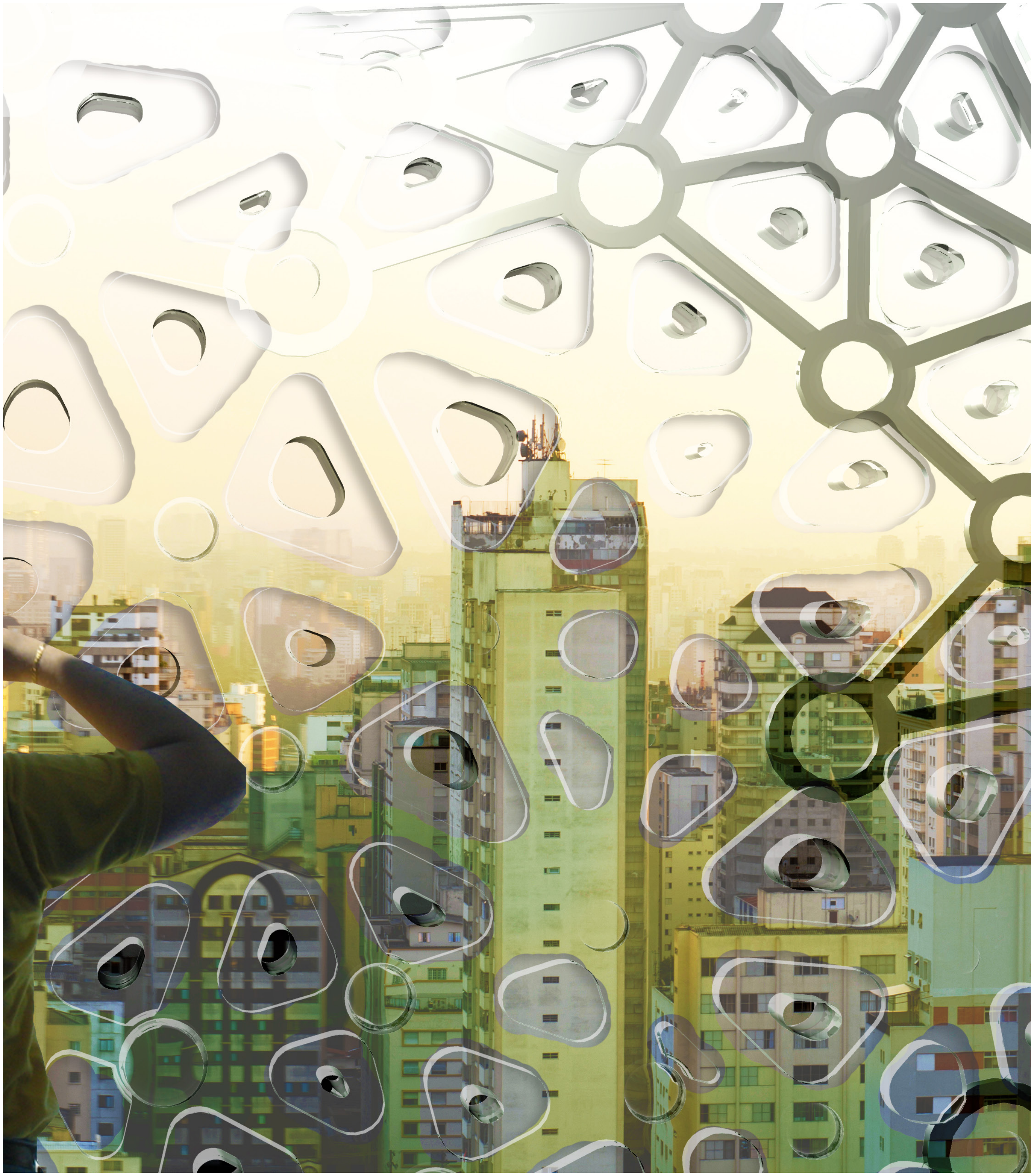
2–53 *(right) Section through mechanical components of the algae textile and their placement within a wall section.*

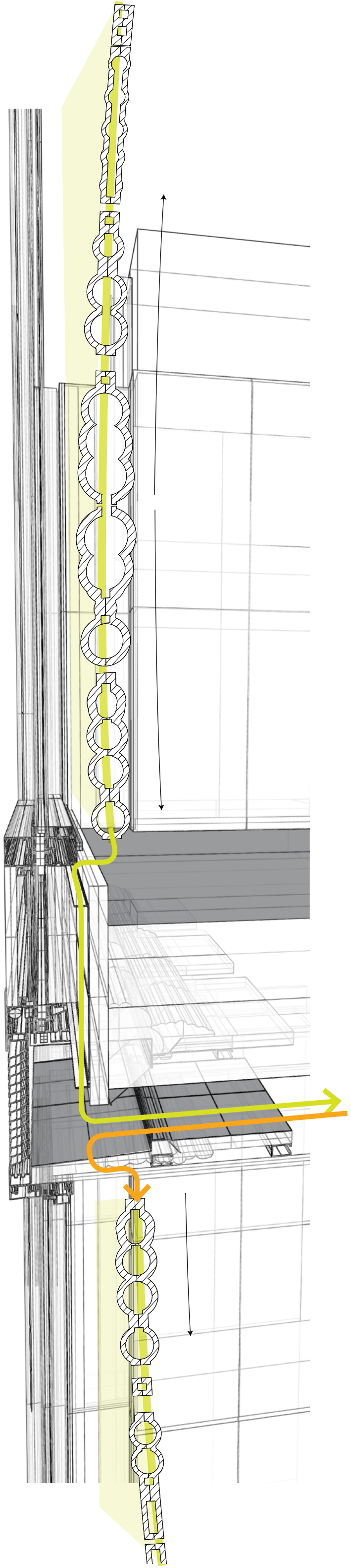


2–54 *The view through areas of the textile which are given large–diameter vessels. These moments in the textile have a denser opacity, produce more dramatic ocular distortions due to the convexity of the membrane, and are less porous. Therefore, it is appropriate to use this geometric condition where moments of density are required within the expanse of the textile.*



2–55 *The view through areas of the textile which are given small–diameter vessels. These moments in the textile provide higher clarity, produce more subtle ocular distortions, and are highly porous. Therefore, it is appropriate to use this geometric condition where moments of relief are required within the expanse of the textile.*





As previously discussed, the application scales of algae are wide [Recall 1.1 Algae Textile Intentions], however, when used in this sense, the textile could be developed to satisfy the existing need for algae systems which operate at the scale of a building's skin, partition or cladding. This an important component for instigating a distributed algae industry network and algae–based urbanism.

As a component in curtain wall systems, the textile could fulfill certain priorities regarding applications of algae in the built environment by: (1) providing an identity for algae in an urban setting, and offering it in a system which also satisfies the spatial demands of urban buildings: where priority is placed on high–density, maximum sellable areas, and dimensions which satisfy the requirements of a minimum building envelope. The textile provides the functions of a photobioreactor in this minimum dimension, and why an important part of its design is to provide a photobioreactor in the form of a thin and lightweight membrane. In so doing, it is expected that the scale of algae production be reduced in the interest of creating algae–focused urban spaces using the textile; (2) as a way to reinstate ecology on urbanized land, where the textile is installed to create micro greenspace in urban gardens, parks or circulation spaces. These installations would contribute to the larger algae industry while purifying urban air for the overall improved health and well–being of the city and its occupants; and (3) if intelligent electronic monitoring systems were to be integrated into the construction of the textile, it could also satisfy the need for algae–driven mechanical systems. The textile as a service system would be able to benefit the health of the building and occupant by purifying air quality, creating pleasant interior environments and providing a renewable source of energy. If the algae textile were to be developed to this capacity, a means to coordinate the textile's plumbing network with the building's mechanical systems would be needed. Solar exposure, access, storage and circulation would also need to be optimized. This is an area of future development for the project.

RECALL: APPLICATION SCALES
for algae in the built environment

1 **ARCHITECTURAL ARTIFACT**
2 **URBAN ECOLOGY**

Priorities

- creating urban place
- an experiential / iconographic urban fixture, as a part in a larger algae industry
- urban air purification (carbon cycling)
- renewable energy (to power lights, etc.)
- urban real-estate, street-level activation
- minimum envelope requirements
- urban health and well-being
- micro greenspace

3 **BUILDING SERVICE**

Priorities

- building health and occupant well-being
- self-sufficient (closed-loop resource)
- instate renewable energy systems
- storage and maintenance of product
- solar exposure, access, circulation

2–56 *The algae textile on a standard curtain wall section.*
2–57 *Recall: application scales for algae in the built environment.*
2–58 *(left) The algae textile implemented on a typical urban tower.*

DISCUSSION

DISCUSSION

Conclusions

This study in building–integrated photobioreactors using thin–film membranes hopes to provide a method for housing biotechnologies like algae within buildings and structures; contributing a view of what materials of the future might look like if architecture were to accommodate algae and biochemistry in a direct way. If an algae–based urbanism were to be implemented, and the use of the algae textile as a complementary building system were to be developed, the thesis probes that basic sheets of material could be designed to possess an agency and perform productive tasks (filtration, harvesting, energy production, etc.), and introduce alternative modes of ecology in highly dense urban environments to generate fuel or process pollutants through the production of algae biomass. In this sense, it has been important to identify the challenges associated with algae cultivation in an urban context, and to establish what building–specific requirements are needed in photobioreactors for the purposes of this study. In doing so, this method of photobioreactor design suggests strategies which could aid in reconciling those challenges. As the proposal has shown, materials developed for living organisms must not only define a clear inflow and outflow of agents within a form tailored towards the specific growing mechanics of that organism, but they must also satisfy demands given by architecture and design to ensure their prolific use. For algae, circulation, agitation, surface–to–volume ratio and light penetration are all important factors which can drive the resultant form of the material, and what the algae textile has strived to explore, challenge and test.

The complementary discussion of material fertility in a postnatural environment envisions how assemblies like the algae textile could artificially implant life into the hardshell surfaces and enclosures which compose urban land, and reinvent them with metabolic and living ones. The algae textile hopes to offer a way to build with organic systems in architecture and suggest their place within a postnatural urban condition as living building membranes. In doing so, these explorations of reactive building materials and the creation of architecturally specific requirements for building–integrated photobioreactors have served as an initial study for a postnatural environmentalism in architecture using algae.

In this postnatural era, a new breed of materials emerges. Products, architecture, and infrastructure will need to negotiate the division between the fixed materials of the modern human and the rapidly shifting processes of the natural world—where human, to machine, to organism relationships will be based on fluid exchange. This crossbreeding of biology and technology views living organisms as powerful resource–processors, with ecological production–lines and test–tube construction sites. In this era, designed artifacts are developed as quasi–biological devices rather than inert objects, and calls for a materiality which boasts skin–like, flexible and adaptable qualities. If established, could material components which act as the city's productive nervous system be developed for urban buildings? Could architectural matter be fertile? The idea of living building membranes hopes to reinsert logic—and biological performance—into inert physical constructions so that they are able to behave more like biological systems—adapting to change, producing energy, purging toxins and fostering an imminent internal intelligence.

The study of algae in this thesis serves as an initial step for reinventing the material interfaces architects build with, and the prototype produced only begins to test the possible material composition and attachment mechanisms that will allow for the integration of algae and other biotechnologies into existing structures and everyday space; serving as a second skin for the building mass which already makes up our cities worldwide.

Immediate Future

With additional research and development, the algae textile could benefit from a programmable and automated pumping and reservoir monitoring infrastructure (similar to OriginOil's biofeedback system; recall chapter 1.2). This will need expertise in coding programmable functions onto a microprocessor, further development in the engineering of an apparatus which allows the reservoir to automatically harvest and dilute the culture as it continues to reproduce, and a method for scouring the interior of the textile for maintenance. These active monitoring systems which provide feedback and statistics on the health and growth of the algae would take the system to a higher level of sophistication by offering precise control over pH levels, lighting, nutrient levels and temperature—all of which are important determining factors for increasing the productivity of a photobioreactor. As a result, further research on the integration of intelligent electronic systems within the construction of the textile and its connection to a building's mechanical services would need to be explored and, in doing so, will further progress the plausibility of algae's use in the built environment.

3–01 *PNNL scientists and engineers simplified the production of crude oil from algae by combining several chemical steps into one continuous process. The most important cost-saving step is that the process works with wet algae. Most current processes require the algae to be dried—a process that takes a lot of energy and is expensive. The new process works with an algae slurry that contains as much as 80 to 90 percent water. (Photo by PNNL, phys.org, 2013) http://phys.org/news/2013-12-algae-crude-oil-million-year-natural.html*

Challenges and Suggested Solutions

Algae cultivation promises a variety of societal benefits, but, like all systems, it also comes with its challenges. The associated problems with algae cultivation and their possible solutions must be acknowledged to assess the future development and plausibility of its integration into the built environment. Current research in algae cultivation focus on the efficiency of algae fuel production and, as a result presents a number of challenges. First, it can only be done if implemented at large scales and, second, processing procedures would have to be drastically optimized to justify its use for global–scale production.[93]

93 J. R. Benemann, "Microalgal Biofuels: A Brief Introduction," Advanced Biofuels USA [online], 2009. http://advancedbiofuelsusa.info/wpcontent/uploads/2009/03/microalgae–biofules–an–introduction–july23–2009–benemann.pdf

3–02 *OriginOil's Biofeedback System is an active monitoring system specifically designed for algae bioreactors. It adjusts conditions such as lighting and pH to maintain the health of the culture. (OriginOil, 2012)*

The high costs of harvesting and processing algal biomass into biofuel is another factor which should not be overlooked. It is known that algae can be produced in large quantities, but, at the same time, efficient harvesting methods need to be available to justify its use. Therefore, cost–effective harvesting is still a major limiting factor.[94] However, it should also be understood that new processing methods which lower costs exist, and the benefits of algae cultivation are not limited to the production of fuel alone. The current high expense for processing algae into biofuel can be mitigated by using it for other means until the technology becomes more efficient and economically viable. For example, algae is an advantageous method for wastewater recycling, water remediation, CO_2 sequestration, and nutrient recovery for the production of sellable products like food, nutritional supplements, fish feed, bioplastics, fertilizer and pharmaceuticals. Experts suggest that this range is a more plausible use of algae in our current context, and it should be understood that there are other alleys of opportunity to pursue until developments in biofuel become more profitable. In this case, the development and acceptance of systems that can be put in place now will only propel advancements in the technology further.

These challenges raise questions regarding the capacity to which algae cultivation could be taken in smaller scales. The use of a distributed and decentralized production network is more akin to its applications in the built environment, but, as mentioned before, priority should not be placed on its abilities to produce a global–scale biofuel source. In this context, its benefits come in other forms. Given the current stage of algal research, algae in the built environment should be more highly considered for its ability to sequester CO_2, manage wastewater, fuel an individual building, or produce valuable products.

Practical challenges also exist, and it must be acknowledged that the technology would require the maintenance associated with an active and living system; this meaning that it is prone to discontinuities and instabilities in performance. This worries most people and prohibits investors to take on risks of this kind; preventing its implementation. The system could also present social implications. For example, does the system produce an unpleasant smell? Could a leak or contamination occur? Can the algae culture be killed? If so, what kind of circumstances are required for it to do so and how do we prevent it from happening?

94 J. R. Benemann, "Microalgal Biofuels: A Brief Introduction"

These are all important questions, but systems which can monitor and prevent these issues already exist. As mentioned in chapter 1.2, *OrginOil Inc.*, has already developed a programmable monitoring system for these reasons specifically. What they call a "biofeedback" system, this monitoring device uses sensors and dynamic LED lighting to continually respond and provide the algae culture with the necessary conditions it needs at any given moment. This invention improves energy efficiency and growth rates by ensuring the right types and amounts of nutrients and light are used at all times as the algae grows in maturity.[95]

Another factor to consider is the water source used. Even though algae cultivation makes use of wastewater, it should be noted that the quality of that water and its sources can vary dramatically overtime,[96] and should also be carefully monitored. A bad source threatens the health of the culture, and it is why the integration of monitoring systems is of high importance. The pH value should be carefully monitored in this case to make sure it remains at an acceptable range; preventing culture–death.

The need for these intelligent monitoring systems reinforces the importance of studies in machinic theory for the continued development of the textile. The introduction of active systems into building systems threaten to take architecture—an already complex system on its own—and complicate it further by integrating active and intelligent electronic parts. This requires a careful orchestration of multiple systems, however, the use of living systems like algae in design relies on this interplay with technology to ensure its sustenance. Viewing things singularly becomes less practical as: (a) more systems need to be integrated, (b) as design problems become more complex and, (c) as available tools become more sophisticated. This inevitably requires the networked resolution of multiple components. Arguably, it could be pushed further—Katherine Hayles even asks, "is it networked enough?" for today's world. This is an ongoing question for architectural research that now integrates fields as diverse as artificial intelligence, the bio–digital and DIY biotech.[97]

[Recall 2.2 Consulting Machinic Theory and Synthetic Biology]

95 Business Wire, "OriginOil Announces Breakthrough Dynamic Lighting Process: Biofeedback Process Controller Optimizes Algae Growth and Daily Harvesting Rates" (Business Wire, Los Angeles, July 15, 2009)
96 Gundula Proksch, "Growing Sustainability: Integrating Algae Cultivation into the Built Environment," *Challenges and Limitations*, Edinburgh Architectural Research Journal (EAR), Volume 33, 2013. http://sites.ace.ed.ac.uk/ear/files/2013/05/147–1621.pdf
97 Ariane Lourie Harrison, ed., "Architectural Theories of the Environment: Posthuman Territory" (Routledge, New York, 2013) pg. 5.

Cary Wolf states:

> *... systems theory will allow us to explain not only how those transcodings are specific to particular systems—how art and architecture, for example, integrate electronic technologies as art—but also how, in being systems–specific, they are paradoxically paradigmatic of, and productive of, the very situation to which those systems respond.*[98]

This together with increasing abilities in manufacturing and mass–customization drive the bio–digital paradigm; making the challenges associated with resolving complexity more manageable. As sociological systems theorist, Luhmann, says, "only complexity can reduce complexity."[99]

"WE ARE LIVING IN A POST–EVOLUTIONARY WORLD OF EXTREME TECHNOLOGICAL ESCALATION. THE COMPLEXITY OF BOTH NATURAL AND TECHNICAL PROCESSES CAN NOW CONVERGE.

Kerb 19 Journal of Landscape Architecture,
Paradigms of Nature: Post Natural Futures, Manifesto-orial for Production. Pg. 4

These challenges and suggested solutions are given under the premise that an algae–based urbanism and its necessary economic and infrastructural network have been established and implemented. There is a range of applications and capacities to which algae can be introduced into the urban environment, and the algae textile alone cannot encompass every requirement, nor be expected to encompass all applications of algae once it is introduced in an urban setting. This is the reason for centring the intentions of the algae textile around applications which are focused on the creation of sentient urban spaces rather than production and yield, and only as a piece in a larger algae industry network. The algae textile is intended to offer a complimentary building system for this infrastructural shift, suggesting a possible outlet for algae production in the urban realm through building skins which act as both small–scale generators within a highly distributed network of algae production and as icons for a new urban culture.

98 Cary Wolfe, Ariane Lourie Harrison, ed., "Architectural Theories of the Environment: Posthuman Territory" (Routledge, New York, 2013) pg. 121.
99 Niklas Luhmann, "Social Systems" trans. John Bednarz Jr. and Dirk Baecher, (Stanford University Press, 1995) pg. 5.

Distant Future

The design methodology used for the algae textile only begins to offer a view of how future architectural materials might be composed and manufactured, but a projection can also be made at its possible evolution towards a use with intelligent and designed synthetic organisms—acting as an architectural reaction vessel. The field of synthetic biology is quickly growing and already shows advancements in an ability to manipulate matter to either self–assemble, or perform tasks like machines through biosensing. Researchers in this field such as Skylar Tibbits and Rachel Armstrong have already been able to exhibit preliminary methods for creating systems of this kind—Skylar on a macro level with mechanically self–assembling building blocks, and Rachel on the micro level with her studies of the protocell. The goal of continued research in this field envisions materials that build themselves in an emergent way—something which could pose significant implications for the future of architecture if achieved. Programmable matter and generative design processes like the ones explored in this thesis will become critical tools for the creation of built form in the future: material could be grown on site through a series of injections within an armature or will already possess generative instructions coded within its molecules. If self–assembly and adaptive behaviors are achieved through materiality, architecture will only then be able to parallel itself with the natural environment. In this era, the role of the architect will no longer be defined by the imposition of a design aesthetic on a site, but instead, it will be to guide processes of material growth through the orchestration of complimentary armatures which help them proliferate—a moment where we may finally achieve a material fertility equivalent to that of nature.

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MATERIAL DATA

RELEASE AGENT

POLYMÈRES technologies

TECHNO RELEASE 113

Release agent
silicone base

DESCRIPTION

TECHNO RELEASE 113 is a silicone base compound primarily formulated to be used as a release agent in various industrial applications and uses.

PHYSICAL PROPERTIES (at 22°C)

Generic Type	Silicone
Consistency	Liquid
Viscosity (Brookfield Test)	30 cps @ 25°C
Specific Gravity	0.74 g/cm^3
Color	Transparent
Flash Point (closed cup °C)	< 15

PRECAUTIONS

- Consult Material Safety Data Sheet prior to use.
- Flammable liquid, keep away from flames and sparks
- Always keep containers tightly closed and store in a cool place.
- Normal health and safety precautions should be observed when handling these products :
  - Ensure good ventilation
  - Wear gloves, safety glasses and waterproof clothes.
- Once the container is opened **POLYMÈRES** has no control or responsibility for the shelf life.
- Shelf life of product in original closed containers is **one** (**1**) **year**.
- It is recommended to follow Provincial and Federal safety regulations. In case of eye contact, rinse well with water, in case of skin contact, rinse with soap and water. Keep away from children.
- Please consult **POLYMERES TECHNOLOGIES** for more details based on your application.

GUARANTEE

Seller makes no warranty of any kind, express or implied, as to the merchantability, fitness for any particular purpose, or any other matter with respect to the product **TECHNO RELEASE 113.** Since conditions of use are beyond seller's control, buyer assumes all risk of use of this product. Under no circumstances will seller be liable for consequential or incidental damages arising out of the use of this product. Seller's sole obligation shall be to replace the product if found to be defective. It is the user's responsibility to determine the suitability for use of this product under the conditions present at the time of application. M.S.D.S. available upon request.

6330 Laurier Blvd West, Saint-Hyacinthe (Quebec) Canada J2S 9A7
Phone: (450) 250-3058 • Toll free: 1 866 799-3058 • Fax: (450) 250-3058
ventes@polymerestechnologies.com · www.polymerestechnologies.com

MSDS – Material Safety Data Sheet

POLYMÈRES technologies

Product Name: TECHNO RELEASE **113**

Use: Release agent

WHIMS classification: B2, D2A, D2B

SECTION I: PRODUCT DESCRIPTION

Company Name:	POLYMÈRES Technologies	
Address:	6330 Laurier Blvd West,	
City, Postal code:	Saint-Hyacinthe (Québec) Canada J2S 9A7	
Emergency phone:	Day Phone:	(450) 250-3058 or 1 866 799-3058
	Fax:	(450) 250-3059
	Night & weekend:	(450) 778-8777
Revised:	February 12, 2013	
Printed:	December 11, 2013	

SECTION II: HAZARDOUS INGREDIENTS

HAZARDOUS INGREDIENTS	CONCENTRAT. % W/W	Cas No.	LD50 rat-oral	LD50 rabbit-skin	LC50 rat-4 hours	THRESHOLD LIMIT ACGIH
Hexane	60-100	110-54-3	25.0 gm/kg	> 2.0 gm/kg	48000 ppm	50 ppm
Stoddard Solvent	3-7	8052-41-3	> 5000 mg/kg	> 3 gm/kg	1400 ppm	100 ppm
Xylene	1-5	1330-20-7	4300 mg/kg	> 1.7 gm/kg	5000 ppm	100 ppm

SECTION III: TOXICOLOGICAL AND HEALTH HAZARD DATA

LD50 (rat-oral): > 5000 mg/kg (calculated) LD50 (rabbit-skin): > 2.0 gm/kg (calculated) LC50 (rat-4 hrs): 13000 ppm (calculated)

ACUTE EFFECT:	None known.
EYES:	May cause irritation.
SKIN:	Prolonged or repeated contact may cause a moderate irritation, and possibility of dermatitis and defatting drying of the skin.
INHALATION:	Nasal and respiratory irritation. Nausea, headache, dizziness and central nervous system depression and possibly loss of consciousness.
INGESTION:	Gastro-intestinal irritation, nausea, vomiting and diarrhea. Inhalation of ingested liquid into the lungs may result in a chemical pneumonitis, which can be fatal.
CHRONIC EFFECT:	Prolonged and repeated exposure may cause damages to central nervous system, liver and kidney and blood disorder.
REMARK/WARNING:	Laboratory animal study showed that exposure to high concentration of Xylene (at levels often toxic for the mother) has influenced the foetus development. Meaning of this observation to human beings is unknown.

SECTION IV: FIRST AID

EYES:	Wash with plenty of water for at least 15 minutes while maintaining eyelids opened. Consult a physician if irritation.
SKIN:	Wash with mild soap and water. Wash clothing before re-use, discard clothing that cannot be decontaminated. Consult a physician if irritation.
INHALATION:	Remove victim to fresh air. If breathing is difficult,administer oxygen. If breathing has stopped, apply artificial respiration. Consult a physician if still feeling discomfort.
INGESTION:	Ask for medical help immediately. **DO NOT INDUCE VOMITING**. Keep victim calm and warm.

SECTION V: DONNÉES PHYSIQUES

PHYSICAL STATE:	Liquid	EVAPORATION RATE (N-Butyl acetate=1):	> 1 (Hexane)
ODOUR:	Slight	OIL/WATER DISTRIBUTION COEFFICIENT:	N.D.
APPEARANCE:	Clear and colorless	DENSITY:	0.74
ODOUR THRESHOLD:	N.D.	VAPOUR DENSITY (air=1):	> 1
VAPOUR TENSION:	68.7 KPa @ 55° C (calculated-Xylene)	FREEZING POINT:	< 0° C
BOILING POINT:	65° C (Hexane)	PH:	N.A.

MSDS – Material Safety Data Sheet

POLYMÈRES technologies

Product Name: TECHNO RELEASE **113**

Use: Release agent

WHIMS classification: B2, D2A, D2B

SECTION VI: FIRE AND EXPLOSION HAZARD DATA

FLAMMABILITY:	Flammable liquid.
EXTINGUISHING MEDIA:	Foam, dry powder, water fog and carbon dioxide gas.
FLASH POINT:	- 29° C - closed cup (Hexane).
IGNITION POINT:	N.D.
FLAMMABILITY LIMITS (% volume):	Minimum: 0.6 - Maximum: 7.0.
HAZARDOUS COMBUSTION PRODUCTS:	Carbon monoxide, carbon dioxide and hydrocarbons.
EXPLOSION DATA:	Sensitive to static discharge when temperature of material is at or above flash point and/or when working in confined/poorly ventilated areas.
SPECIAL METHODS:	In the case of a major fire, wear self contained respirator and full protective clothing. Cool nearby containers and structures with water fog.

SECTION VII: REACTIVITY DATA

CHEMICAL STABILITY:	Yes.
INCOMPATIBILITY:	Avoid contact with combustive agent.
REACTIVITY/CONDITIONS TO AVOID:	Excessive heat.
HAZARDOUS DECOMPOSITION PRODUCTS:	Carbon monoxide, carbon dioxide and hydrocarbons when subjected to excessively high temperatures.

SECTION VIII: PREVENTION

PROTECTION EQUIPMENTS:	Consult safety equipment specialist for more information concerning trade names and models.
RESPIRATORY PROTECTION:	Cartridge respiratory mask for organic vapors when TLV limit is exceeded.
EYES PROTECTION:	Splash proof goggles.
BODY PROTECTION:	Clothing covering entirely arms and legs or impervious protective cream.
HANDS PROTECTION:	Impervious protective cream or impervious gloves (latex, neoprene, ...) covering wrists.
SHOES:	Impervious (thick leather or rubber).
VENTILATION:	General and local.
HANDLING:	Keep away from all sources of ignition. When handling large amounts and temperature of material is at or above flash point and/or when working in confined/poorly ventilated areas, then mix with explosion proof equipment and ground all equipments and containers.
STORAGE/TRANSPORTATION:	Keep in a cool, dry and well ventilated place. Keep containers upright, hermetically closed.
SPILL/LEAK PROCEDURE:	Remove all sources of ignition. Contain with inert material. Shovel into waste disposal approved container. Clean normally. WARNING: vapors are heavier than air and may travel along the floor to an ignition source and flash back.
WASTE DISPOSAL:	According to Federal, Provincial and Municipal legislations.

SECTION IV: TRANSPORT

TDGA:	FLAMMABLE LIQUID, N.O.S. (Hexane), Class 3, UN1993, PG II.
IMDG-IATA:	FLAMMABLE LIQUID, N.O.S. (Hexane & Xylene), Class 3, UN1993, PG II.
REMARKS:	Is not a marine pollutant.

SECTION X: MATERIAL SAFETY DATA SHEET PREPARATION

PREPARED BY:	MICHEL ROY February 12, 2013	Phone:	(450) 250-3058 (business hours) (450) 778-8777 (night & weekend)

END

POLYMÈRES technologies

TECHNO CAST 3261 T

POLYURETHANE CASTING
CLEAR RESIN

DESCRIPTION

TECHNO CAST 3261 T is a clear, polyurethane casting resin that is 100 % reactive materials and has a good UV resistance. Its transparency allows the manufacture of technical and artistic parts of clear quality. Can be also used for the manufacture of transparent moulds and of which it is useful to see the resin casting.

CARACTERISTICS

- Low Viscosity
- Strong Tear Resistance
- Can be Pigmented
- Low Absorbency
- Easy mix ratio of 1/1 in Volume
- Excellent Temperature Resistance

APPLICATION INSTRUCTIONS

First, mix slowly with a 1 inch minimum metallic spatula, Part **A only.**

Then, Prepare the required quantities of Part **A** and Part **B by precisely respecting** the mix ratio **1A/1B** by **volume**.

Mix both part **A** and part **B** homogenously with a metallic spatula as to assure of not incorporating air into the mix. When mixing, a snowy effect will show and will dissipate as the two parts are well blended together. Please assure that the mix is homogenised by scratching the bottom of the container and the sides of the container.

If needed and before casting, de-air the mix by using a degas vacuum pump.

IMPORTANT : It is possible to accelerate the cure and the demold time by following a post cure schedule of 4 hrs at 40-45°C in the mold. It is essential to protect both parts under a gas blanket spray, thus, **TECHNO DRY 7477** to avoid resin crystallization due to humidity.

Please communicate with **POLYMÈRES TECHNOLOGIES** for more information and techniques.

TYPICAL PROPERTIES (at 22°C)

		PART A CURATIVE	PART B PREPOLYMER	MIXED
Viscosity	Brookfield (cps)	580	1 600	1 090
Color		Clear	Clear	Clear
Density	(g/cm^3)	1.061	1.094	1.065
MIx Ratio	1. by volume:	1	1	1/1
	2. by weight:	100	100	100/100
Pot Life		16 – 20 minutes at 22°C		
Hardness (Shore A)	ASTM D 785	60 – 64 at 22°C		

6330, boul. Laurier Ouest, Saint-Hyacinthe (Québec) Canada J2S 9A7
Tél. : (450) 250-3058 • Sans frais : 1 866 250-3058 • Téléc. : (450) 250-3059
ventes@polymerestechnologies.com · www.polymerestechnologies.com

POLYMÈRES technologies

TECHNO CAST 3261 T

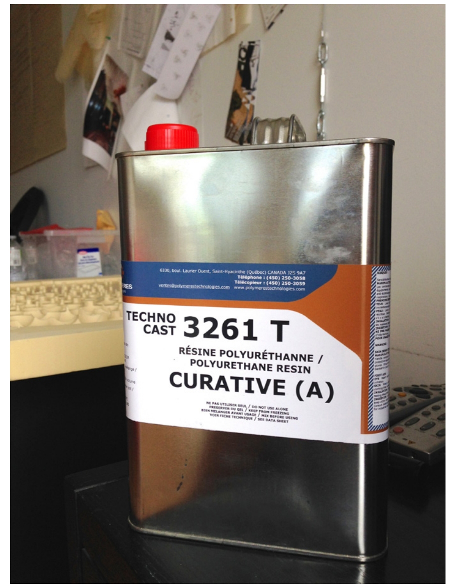
PRECAUTIONS

- Consult Material Safety Data Sheet prior to use.
- Normal health and safety precautions should be observed when handling these products :
  - Ensure good ventilation
  - Wear gloves, safety glasses and waterproof clothes.
- Shelf life of product in original closed containers is **one (1) year**.
- **SHELF LIFE:** The shelf life on **POLYMÈRES** products begins from the date of invoice for that product shipment. **POLYMÈRE's** shelf life only pertains to containers that are unopened and in their original condition.
- **RESEALING:** Many polymers are moisture sensitive, reseal, using one of the following two (2) methods: blanket with nitrogen or use a hair dryer for 30 seconds to cover with dry air **TECHNO DRY 7477**.
- Once the container is opened **POLYMÈRES** has no control or responsibility for the shelf life.
- It is recommended to follow Provincial and Federal safety regulations. In case of eye contact, rinse well with water, in case of skin contact, rinse with soap and water. Keep away from children.

GUARANTEE

Seller makes no warranty of any kind, express or implied, as to the merchantability, fitness for any particular purpose, or any other matter with respect to the product **TECHNO CAST 3261 T**. Since conditions of use are beyond seller's control, buyer assumes all risk of use of this product. Under no circumstances will seller be liable for consequential or incidental damages arising out of the use of this product. Seller's sole obligation shall be to replace the product if found to be defective. It is the user's responsibility to determine the suitability for use of this product under the conditions present at the time of application. M.S.D.S. available upon request.

FLEXIBLE POLYURETHANE RESIN PART A COPOLYMER



POLYMÈRES technologies

MSDS – Material Safety Data Sheet

PRODUCT NAME : TECHNO CAST **3261**

CURATIVE PART (A)

Use: Polyurethane resin **Chemical State:** Liquid mixture

I. SECTION: HAZARDOUS INGREDIENTS

Company Name:	POLYMÈRES Technologies
Address:	6330 Laurier Blvd West,
City, Postal code:	Saint-Hyacinthe (Québec) Canada J2S 9A7
Emergency phone:	Day Phone: (450) 250-3058 or 1 866 799-3058
	Fax: (450) 250-3059
	Night & weekend: (450) 778-8777
Revised:	May 06, 2014
Printed:	May 21, 2014

II. SECTION: HAZARDOUS INGREDIENTS

HAZARDOUS INGREDIENTS	CAS No.	CONCENTRAT. % W/W	LD50 rat-oral	LD50 rabbit-skin	LC50 rat-4 hours	THRESHOLD LIMIT ACGIH
PoIy(oxy-1 ,4-butanediyi), .aha.-hydro-.omega.-hydroxy	25190061	85-90	-	-	-	-
Polyfoxy(methyl.1 ,2-ethanediyl) j, .alpha.-hydro-.omega. -hydroxy-, ether with 2-ethyi-2-(hydroxymethyl) -1,3-propanediol (3:1)	5723164	10-15	-	-	-	-

III. SECTION: HAZARDOUS IDENTIFICATION:

Hazard Category:

Hazardous Identification Information:

Warning!

Clear liquid, slight odor.

Repeated skin and eye contact may cause irritation.

IV. SECTION: FIRST AID MEASURES:

Route(s) of Entry: Inhalation, ingestion, Skin and Eye contact.
Health Hazards (Acute and Chronic):
Acute (Short-term)
On the basis of available information, exposure to this product is not expected to produce any significant adverse human health effects when recommended safety precautions are followed.

Chronic (Delayed)
On the basis of available information, exposure to this product is not expected to produce any significant adverse human health effects when recommended safety precautions are followed.

Signs and Symptoms:

Skin and eye irritation.

Medical Conditions Generally Aggravated by Exposure: Repeated skin and eye contact may cause irritation.
Emergency and First Aid Procedures:

SKIN CONTACT: Remove contaminated clothing and wash affected area with isopropyl alcohol followed by soap and water.
EYE CONTACT: Flush eyes with water for at least 15 minutes and contact a physician.
INGESTION: Do NOT Induce vomiting. Take 1 to 2 glasses of water and contact a physician. Do NOT give anything by mouth to an unconscious person.
INHALATION: Remove person to fresh air. If person is not breathing give mouth-to-mouth resuscitation and contact a physician.

MSDS – Material Safety Data Sheet

PRODUCT NAME : TECHNO CAST **3261**
CURATIVE PART (A)

Use: Polyurethane resin
Chemical State: Liquid mixture

V. SECTION: FIRE FIGHTING MEASURES:

Flash Point: 430°F **Lower Explosive Limit:** NE **Upper Explosive Limit:** NE
Fire Extinguishing Media:
Foam, water fog, carbon dioxide or dry chemical extinguishers.

Special Fire Fighting Procedures:
Firefighters should wear a self-contained breathing apparatus and protective clothing to guard against incompletely combusted carbon products. Cool fire exposed containers with water spray.

Unusual Fire and Explosion:
None known

VI. SECTION: ACCIDENTAL RELEASE MEASURES:

Steps to be Taken in Case Material is Released or Spilled:
Cover liquid with an absorbent material (sawdust, vermiculite or wet sand). After the material is absorbed scoop up and place in containers for disposal.

VII. SECTION: HANDLING AND STORAGE:

Precautions to be Taken: Store in a cool, dry place in tightly sealed containers. Protect from heat and moisture contamination.
Other Precautions: Avoid skin and eye contact.

VIII. SECTION: EXPOSURE CONTROLS/PERSONAL PROTECTION:

Ventilitation Requirements:
Local Exhaust: Use in a ventilated area.
Mechanical (General): Recommended.

Personal Protective Equipment:

RESPIRATORY PROTECTION:
None needed at normal temperatures. Use a self-contained breathing apparatus under emergency conditions.
PROTECTIVE GLOVES: Impervious rubber gloves.
EYE PROTECTION: Wear safety glasses or goggles.
OTHER PROTECTIVE CLOTHING OR EQUIPMENT:
An apron or suitable clothing to prevent skin contact.

IX. SECTION: PHYSICAL AND CHEMICAL PROPERTIES:

Boiling Point:	NA	Solubility In Water:	Slight
Melting Point:	NA	Appearance and Odor:	Clear liquid; slight odor
Evaporation Rate:	<1	VOLATILITY @75°F:	Low
Vapor Pressure (mm Hg.):	NE	PERCENT VOLATILE BY VOLUME(%):	Negligible
Vapor Density (AIR = 1):	>1	SPECIFIC GRAVITY:	1.017

X. SECTION: STABILITY AND REACTIVITY:

Stability: Stable
Incompatibility (Materials to Avoid):
Oxidizing agents and strong acids.
Decomposition/By Products:
Incompletely burned carbon products, carbon monoxide and carbon dioxide.
Hazardous Polymerization:
Will not occur

XI. SECTION: TOXICOLOGICAL INFORMATION:

None Available

XII. SECTION: ECOLOGICAL INFORMATION:

None Available

XIII. SECTION: DISPOSAL CONSIDERATIONS:

Waste must be disposed of in accordance with federal, state and local environmental regulations. Incinerate or bury in a licensed facility. Containers may be disposed of or reclaimed in a routine manner.

MSDS – Material Safety Data Sheet

PRODUCT NAME : TECHNO CAST **3261**
CURATIVE PART (A)

Use: Polyurethane resin
Chemical State: Liquid mixture

XIV. SECTION: TRANSPORT INFORMATION:

Not regulated by DOT

XV. SECTION:REGULATORY INFORMATION:

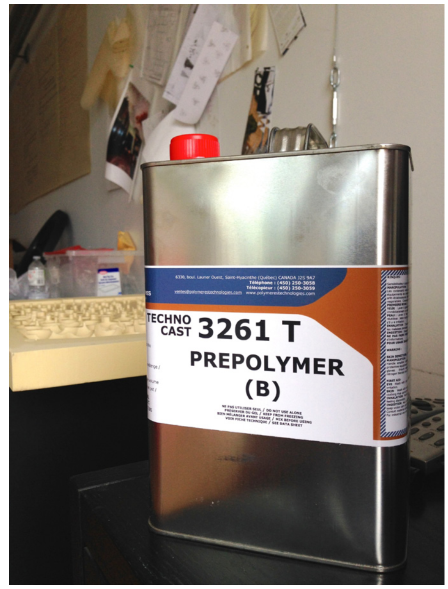
TSCA Inventoty Status: This product, or its components, are listed on, or are exempt from the Toxic Substance Control Act (TSCA) Chemical Substance Inventory.
SARA 313 INFORMATION: This product does not contain substances subject to the reporting requirements of Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR part 372.

XVI. SECTION: MATERIAL SAFETY DATA SHEET PREPARATION

In this document the following abbreviations were used: NA: Not Applicable NE: Not Established

PREPARED BY: MICHEL ROY
May 06, 2014
Phone: (450) 250-3058 (business hours)
(450) 778-8777 (night & weekend)

END



POLYMÈRES technologies

MSDS – Material Safety Data Sheet

PRODUCT NAME : TECHNO CAST **3261**

PREPOLYMER PART (B)

Use: Polyurethane resin

Chemical State: Liquid mixture

I. SECTION: PRODUCT DESCRIPTION

Company Name: POLYMÈRES Technologies

Address: 6330 Laurier Blvd West,

City, Postal code: Saint-Hyacinthe (Québec) Canada J2S 9A7

Emergency phone:
Day Phone: (450) 250-3058 or 1 866 799-3058
Fax: (450) 250-3059
Night & weekend: (450) 778-8777

Revised: May 06, 2014

Printed: May 21, 2014

II. SECTION: HAZARDOUS INGREDIENTS

HAZARDOUS INGREDIENTS	CAS No.	CONCENTRAT. % W/W	LD50 rat-oral	LD50 rabbit-skin	LC50 rat-4 hours	THRESHOLD LIMIT ACGIH
Poly(oxy-1 ,4-butanediyl), 50-60 .alpha.-hydro-.omega. -hydroxy-, polymer with 1, 1'-methylenebis[4-isocyanato cyclohexanel	52292189	50-60	NE	NE	NE	NE
Dicydohexylmethane-4,4-diisocyanate	5124301	40-50	NE	NE	NE	NE

III. SECTION: HAZARDOUS IDENTIFICATION:

Hazard Category: ACUTE CHRONIC REATIVE

Hazardous Identification Information:

Warning!

Clear, odorless, fluid liquid.

Contains Dicyclohexylmethane-4,4′-diisocyanate (HMDI).

Inhalation of vapors may cause respiratory tract irritation. Contact with skin and eyes may cause irritation.

IV. SECTION: FIRST AID MEASURES:

Route(s) of Entry: Inhalation, Ingestion, Skin and Eye contact

Health Hazards (Acute and Chronic):

Acute (Short-term)

Contact may cause slight irritation of the skin and eyes (teanng). Inhalation of vapors may cause irritation of the mucous membranes in the respiratory tract, running nose and sore throat.

Chronic (Delayed)

Prolonged or repeated skin contact can cause reddening, swelhng or skin sensitization in susceptible individuals. Repeated or prolonged inhalation Of vapors above the TLV can cause immediate or delayed respiratory sensitization and asthma-like conditions.

Signs and Symptoms:

Skin, eye and respiratory tract irritation.

Medical Conditions Generally Aggravated by Exposure:

Exposure well above the established TLV may lead to bronchitis, bron Em.rgency and FIrst Ald Procedures:

Emergency and First Aid Procedures:

SKIN CONTACT: Remove contaminated clothing and wash affected area with isopropyl alcohol followed by soap and water. Wash contaminated clothing thoroughly before reuse.

EYE CONTACT: Flush eyes with water for at least 15 minutes and contact a physician.

INGESTION: **Do NOT induce vomiting**. Give 2 cups of milk of water and contact a physician. DO NOT give anything by mouth to an unconscious person.

POLYMÈRES technologies

MSDS – Material Safety Data Sheet

PRODUCT NAME : TECHNO CAST **3261** PREPOLYMER PART (B)

Use: Polyurethane resin **Chemical State:** Liquid mixture

INHALATION: Remove person to fresh air. If person is not breathing give mouth-to-mouth resuscitation and contact a physician.

Other Health Warnings Repeated or prolonged inhalation of vapors above the TLV can cause immediate or delayed respiratory sensitization and asthma-like conditions in susceptible individuals.

V. SECTION: FIRE FIGHTING MEASURES:

Flash Point: >395°F **Lower Explosive Limit:** NE **Upper Explosive Limit:** NE

Fire Extinguishing Media: Foam, carbon dioxide, dry chemical extinguishers. If water is used, it should be used in very large quantities.

Special Fire Fighting Procedures: Firefighters should wear a full face positive pressure self-contained breathing apparatus and protective clothing. Use cold water to cool fire exposed containers.

Unusual Fire and Explosion: Contamination of isocyanates with water releases carbon dioxide which may result in a dangerous amount of pressure build-up in closed containers. Do NOT reseal contaminated containers.

VI. SECTION: ACCIDENTAL RELEASE MEASURES:

Steps to be Taken in Case Material is Released or Spilled: Remove all sources of ignition and ventilate area. Cover liquid with an absorbent material (sawdust, vermiculite or wet sand). Alter the material is absorbed scoop up and place in open containers. Treat material with the prepared decontamination solution and leave the container open in a well ventilated area for 48 hours. Spill area should also be decontaminated with the following decontamination solution: 90% water, 2% detergent and 8% concentrated ammonia or sodium carbonate.

VII. SECTION: HANDLING AND STORAGE:

Precautions to be Taken: Store in tightly closed containers at 70-90°F in a dry, ventilated area away from sources of heat, moisture and incompatibles. Do NOT reseal containers if water contamination is suspected.

Other Precautions: Avoid contact with skin and eyes. Avoid breathing vapors.

VIII. SECTION: EXPOSURE CONTROLS/PERSONAL PROTECTION:

Ventilation Requirements:

Local Exhaust: Local Exhaust: Provide mechanical (general) and/or local exhaust ventilation to control airborne levels below the exposure guidelines.

Personal Protective Equipment:

RESPIRATORY PROTECTION: None needed at normal temperatures. Use a self-contained breathing apparatus under emergency conditions.

PROTECTIVE GLOVES: Impervious rubber gloves.

EYE PROTECTION: Wear safety glasses or goggles.

OTHER PROTECTIVE CLOTHING OR EQUIPMENT: An apron or suitable clothing to prevent skin contact.

IX. SECTION: PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point:	NA	Solubility In Water:	Reacts slowly to liberate CO2 gas
Melting Point:	NA		
Evaporation Rate:	<1	Apprearance and Odor:	Clear, odorless fluid liquid
Vapor Pressure (mm Hg.):	0.000015	VOLATILITY @75°F:	Very Low
Vapor Density (AIR = 1):	NE	PERCENT VOLATILE BY VOLUME(%):	Negligible
		SPECIFIC GRAVITY:	1.06

X. SECTION: STABILITY AND REACTIVITY:

Stability: Stable, except at high temperatures (200°F)

Incompatibility (Materials to Avoid): Strong oxidizers, concentrated hydrogen peroxide, water, bases, alcohols, amines, metal compounds and surface active material.

Decomposition/By Products: High temperatures and burning conditions may release isocyanate vapors, carbon dioxide, nitrogen oxides, HCN and tetrahydrofuran.

Hazardous Polymerization: May occur. Avoid high temperatures and contact with water.

XI. SECTION: TOXICOLOGICAL INFORMATION:

None Available

POLYMÈRES technologies

MSDS – Material Safety Data Sheet

PRODUCT NAME : TECHNO CAST 3261 PREPOLYMER PART (B)

Use: Polyurethane resin Chemical State: Liquid mixture

XII. SECTION: ECOLOGICAL INFORMATION:

None Available

XIII. SECTION: DISPOSAL CONSIDERATIONS:

Neutralized waste must be disposed of in accordance with federal, state and local environmental regulations. Incinerate or bury in a licensed facility.

XIV. SECTION: TRANSPORT INFORMATION:

Other Regulated Substances, Liquid, N.O.S
(contains Dicydohexylmethane -4,4'-Diisocyanate)
Class 9
UN 3082
PG III

XV. SECTION:REGULATORY INFORMATION:

TSCA Inventoty Status: This product, or its components, are listed on, or are exempt from the Toxic Substance Control Act (TSCA) Chemical Substance Inventory.

SARA 313 INFORMATION: This product does not contain substances subject to the reporting requirements of Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR part 372.

CHEMICAL NAME	CAS NUMBER	CONCENTRATION
Diphenylmethane-4,4'-diisocyanate	5124-30-1	40 - 50%

SARA HAZARD CATEGORY: This product has been reviewed according to the EPA "Hazard Categories" promulgated under Sections 311 and 312 of the Superfund Amendment and Reauthorization Act of 1986 (SARA Title III) and is considered, under applicable definitions, to meet the following categories:
An immediate health hazard; A delayed health hazard; A reactive hazard

XVI. SECTION: MATERIAL SAFETY DATA SHEET PREPARATION

In this document the following abbreviations were used: NA: Not Applicable NE: Not Established

PREPARED BY: MICHEL ROY, May 06, 2014

Phone: (450) 250-3058 (business hours)
(450) 778-8777 (night & weekend)

END