# SOM journal

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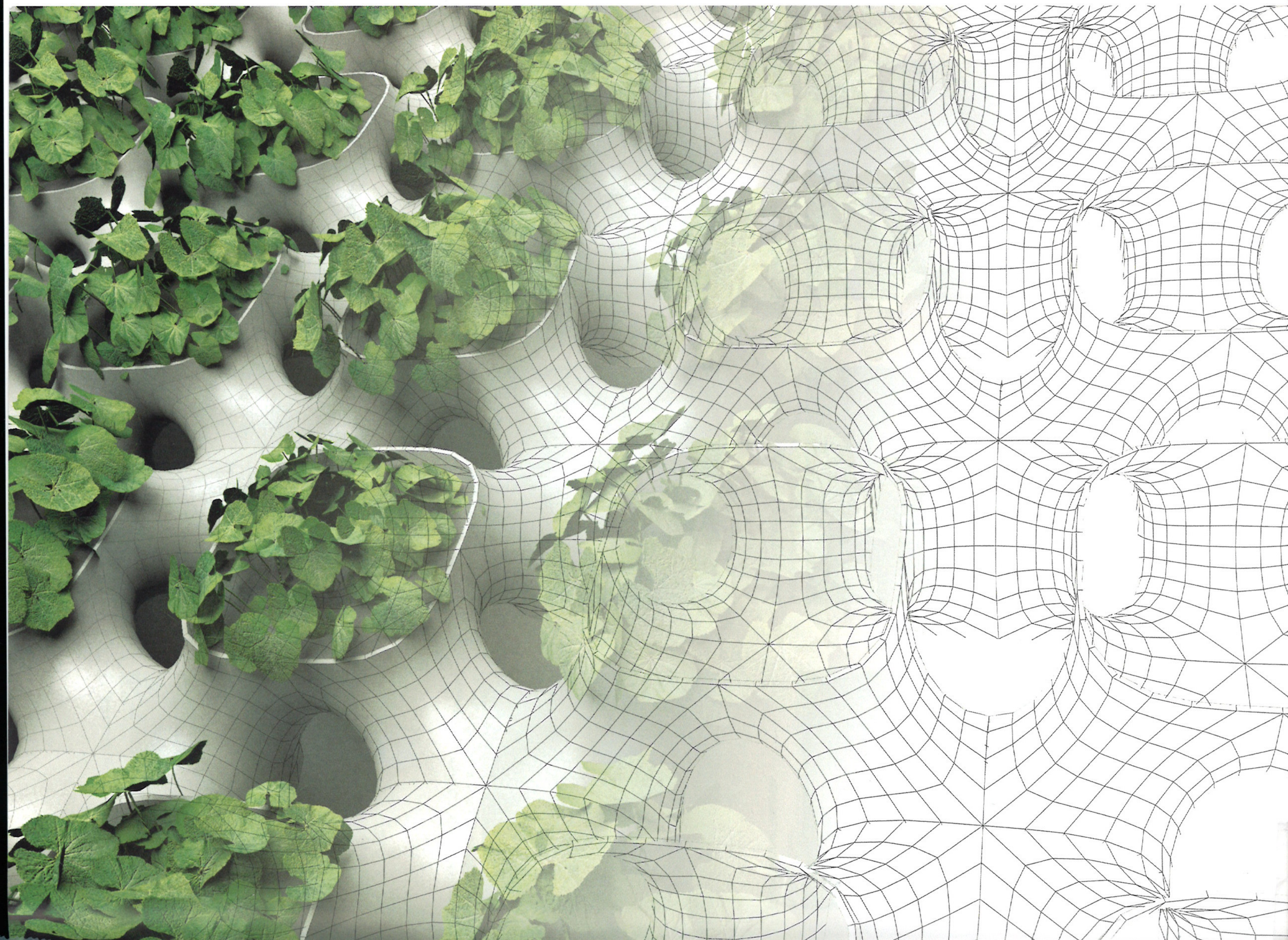

# AMP System

## (Active Modular Phytoremediation)
## Developed 2004–09

The Center for Architecture Science and Ecology, CASE, is an innovative collaboration between Rensselaer Polytechnic Institute and Skidmore, Owings & Merrill, LLP that engages scientists, engineers, and architects from the professional and academic worlds toward a common goal of redefining how we build sustainable cities and environments. CASE seeks to address the need for accelerated innovation and implementation of energy-efficient sustainable built environments by merging academic, industrial, and architectural research interests. CASE researchers are developing innovative solutions to environmental challenges, including a new way to harness wind power atop aerodynamically shaped buildings, which could yield 150 percent greater efficiency than existing wind power systems; a new solar technology for windows that tracks the position of the sun and converts its light and diverted heat into storable energy that can be used for heating, cooling, and lighting buildings; and an architectural method to aid in the conservation of potable and non-potable water in hot and arid regions where rainfall is scarce.

One of the most visible trends in sustainable buildings worldwide is the adoption of large-scale plantings in commercial buildings, including winter gardens, shading assemblies, etc. These interior gardens not only reduce the energy consumption profile of commercial buildings, but have aesthetic, physiological, and psychological benefits that have been qualified and (increasingly) quantified in various ways. The "Bio-Mechanical Hybrid" building system that transfers and integrates hydroponic technology, was first developed by NASA researchers for "closed-loop" ecological experiments, in order to dramatically improve indoor air quality and decrease energy consumption.

The AMP (Active Modular Phytoremediation) System takes an active approach to the challenge of amplifying air cleaning capacity of plants; it is a biomechanical hybrid system for improving indoor air quality while decreasing both energy consumption and exposure to external air pollution associated with traditional external air conditioning systems. The AMP System can remove many toxins associated with poor indoor air quality (IAQ) by augmenting the air cleaning capacity of common plants by two hundred times through hydroponics technology developed originally by NASA scientists.[1] The system also significantly impacts energy consumption as it allows reductions in outdoor air-intake requirements and thus decreases mechanical conditioning loads. In this way, the AMP System's use of vegetation systems combines biofiltration with a phytoremediation process helping realize significant energy savings for new and existing buildings.

The building industry uses more than forty percent of all energy consumed in the United States.[2] In buildings with conventional heating, ventilation, and air conditioning (HVAC) systems, a significant quantity of energy consumption is associated with cooling or heating external air prior to distributing it throughout the building. To decrease HVAC energy consumption, buildings are sealed and ventilation rates decrease, which adversely impacts the IAQ. This widespread air quality issue can be solved by increasing air ventilation through passive techniques at the building envelope. However, in extreme climates like New York City, increasing the fresh air intake would proportionately lead to the increase in heating and cooling loads which already represents a significant segment of energy expenditures. Additionally, in certain urban conditions the exterior air quality may be even more compromised with pollutants than the indoor conditions.

The AMP System development is integrating several experimental procedures in biology and fluid dynamics with emerging materials and manufacturing processes, requiring extensive multidisciplinary expertise. The parametric modules are being designed to modularize and minimize surface area and materials, while simultaneously being developed with both Advanced Ceramics Composites and Bio-Polymeric technology (for environmental and life-cycle comparison) for extreme flexibility in assembly, disassembly, and recycling. The parametric forms are influenced by many factors that can be customized to specific new construction and retrofit locations. The enhancement of air flow performance is being studied by a mechanical engineer and air quality specialist through the addition of active air flow controls that both virtually reshape rooms and the position of the "greenwalls" through piezoelectric synthetic jets located within the system. In addition to the amplified air cleaning capacity of the plants by a factor of two hundred, this active air flow technology has the potential to dramatically effect the sizing and general requirements of HVAC systems by improving flow conditions within interior spaces. The lab-scale module for environmental testing will assess the capacity of various plant types to remove targeted airborne toxins.

Another significant problem impacting public health patterns in extreme climates is the lack of humidity within mechanically fitted HVAC systems during the winter months. Tightly sealed energy-efficient buildings remove heat and moisture from the air, but are not effective in adding moisture during the cold months. The lack of moisture during winter months results in undesirable IAQ, adversely affecting the health of the building occupants resulting in increased healthcare costs, additional employee sick leave, and poor work performance.[3] This issue impacts the U.S. economy in the amount of tens of billions of dollars annually.[4] The AMP System is an alternative method for maintaining IAQ by introducing naturally-produced moisture in winter conditions without the pathogens associated with mechanical attempts at humidification. In addition, providing an opportunity to reduce fresh air intake requirements, building systems can be designed to substantially reduce energy costs while providing cleaner and healthier air for building occupants. The potential energy savings for all climate types with high heating and/or cooling loads combined with the reduction in the necessity to treat and circulate poor quality exterior air solves the long-standing issues plaguing HVAC systems today.

Currently, the EPA lists poor IAQ as the fifth leading cause of disease in the United States, yet people still tend to spend ninety percent of their time indoors. In the American workforce, forty percent of sick days are IAQ-related.[5] According to the American Lung Association, thirty-eight percent of the U. S. population suffer from allergies leading to visual disorders, fever, lethargy, memory impairment, eye, nose, throat, and respiratory tract irritation, headaches, loss of coordination, nausea, liver, kidney, central nervous system damage, and cancer. The AMP System's hydroponic air filtration system provides a solution which improves indoor air quality and alleviates the symptoms caused by airborne toxins.

The incorporation of vegetation within buildings has been demonstrated to remove pollutant levels associated with IAQ. Active systems remediate air quality at exponentially higher rates by integrating mechanically amplified systems which incorporate the cleaning capacity of the root rhizomes.[6] However, despite the increasing prevalence of large-scale planting systems, the vast majority of precedents for phytoremediation in buildings are passive. Such systems do not take advantage of the full cleaning capacity of plants—especially the root system environments—to remediate airborne pollutants, nor do they incorporate their performance with the varying zonal ventilation requirements of commercial buildings.

1 NASA Spinoff, "Plants Clean Air and Water for Indoor Environments," *Public Safety* (2007), pp. 60–61.

2 Energy Information Administration, *Annual Energy Review 2006,* Washington DC, June 2007.

3 Charles J. Kibert, Jan Sendzimir, and G. Bradley Guy, *Construction Ecology: Nature as the Basis for Green Buildings* (London and New York, 2001). J. W. Fisk and A. H. Rosenfeld, "How IAQ Affects Health, Productivity," *ASHRAE Journal* 44, 5 (May 2002), pp. 56–58. EPA, Environmental Protection Agency Report to Congress on Indoor Air Quality, Executive Summary and Recommendations, US EPA, Washington, DC, 1989.

4 Fisk and Rosenfeld 2002 (see note 3).

5 Bill C. Wolverton, Rebecca C. McDonald, et al., "Foliage Plants for Removing Air Pollutants from Energy Efficient Homes," *Journal of Economic Botany* 38, 2 (1984), pp. 224–28.

6 Alan B. Darlington, James F. Dat, and Michael A. Dixon, "The Biofiltration of Indoor Air: Air Flux and Temperature Influences the Removal of Toluene, Ethylbenzene, and Xylene," *Environmental Science and Technology* 35 (2001), pp. 240–46.

< 1 Visualization of planted wall system and module geometry
2 Front view of two compartment prototype testing chamber
3 Rear view showing ultraviolet light filtration in chamber
4 Side view of two compartment prototype testing chamber
5 Prototype testing equipment

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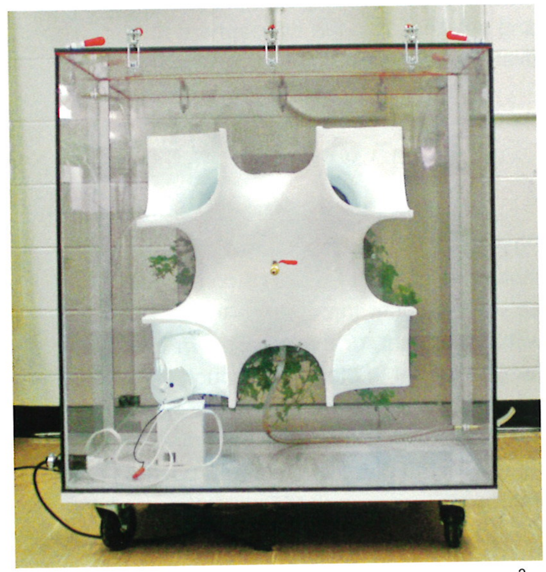

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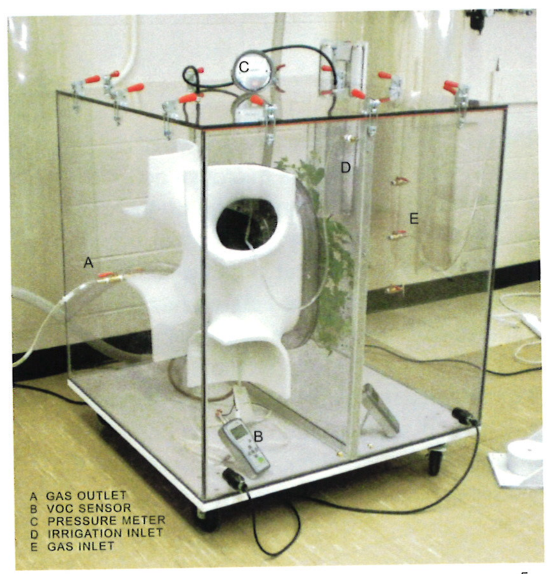


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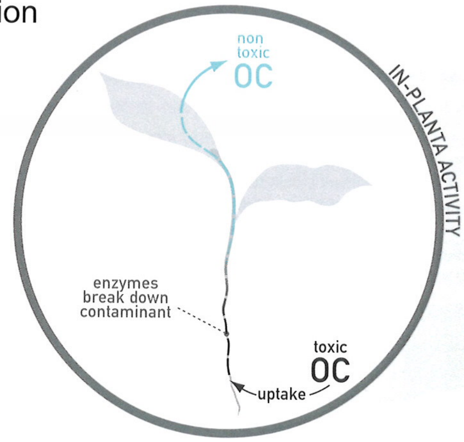
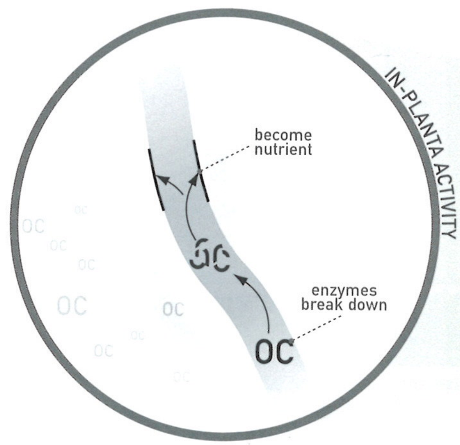
## Three Mechanisms of Phytoremediation

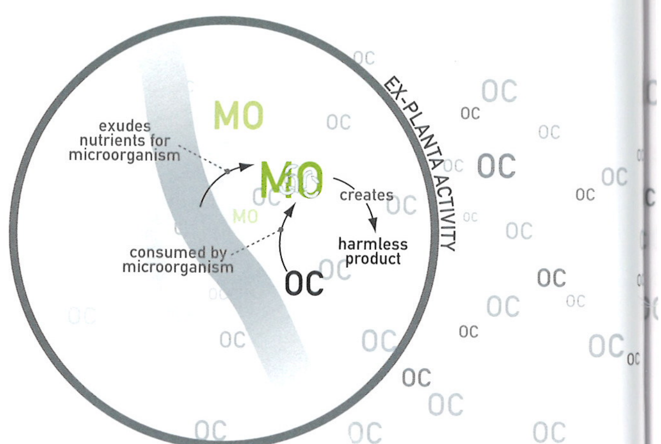
Phytovolatilization, is the uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form to the atmosphere from the plant. Phytovolatilization occurs as growing plants take up water and the organic contaminants. Some of these contaminants can pass through the plants to the leaves and volatilize into the atmosphere at comparatively low concentrations.




Phytodegradation, also called phytotransformation, is the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants. Pollutants are degraded, incorporated into the plant tissues, and used as nutrients.




Rhizodegradation, is the breakdown of contaminants in the soil through microbial activity that is enhanced by the presence of the rhizosphere. Microorganisms (yeast, fungi, or bacteria) consume and digest organic substances, such as fuels or solvents that are hazardous to humans, and break them down into harmless products through biodegradation. Natural substances released by the plant roots; sugars, alcohols, and acids contain organic carbon that provides food for soil microorganisms, and the additional nutrients enhance their activity.




OC = organic contaminants
MO = microorganisms



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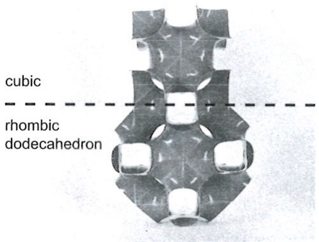
# Extrinsic and Intrinsic Properties of Minimal Surfaces



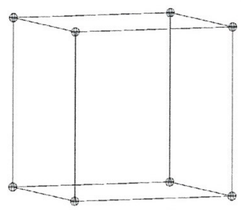
I-WP surface

## Schoen's I-WP Minimal Surface

The geometry used for the AMP System is called the I-WP Surface, which is one of the twelve Triply Periodic Minimal Surfaces discovered by Alan Schoen in 1970. The image on the left shows the original plastic model illustrating two unit cell configurations.

The upper half of the model contains forty-eight faces and is a fundamental region of I-WP. Its convex hull is a cube. The convex hull of the ninety-six face assembly in the lower half of the picture is a rhombic dodecahedron.

The I-WP has distinctly different properties than most of the other sixteen known TPMS. It is one of the very few surfaces that partitions space into two intertwined but geometrically different cubic structured labyrinths, I and WP, yet maintains an "enclosable" space for architectural usage.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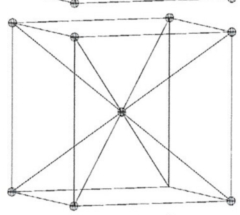
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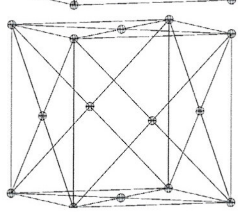
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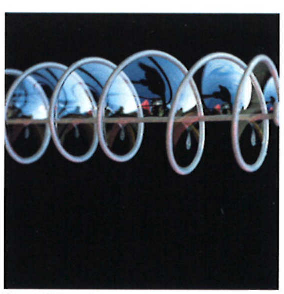
## Cubic Lattice Structure

Cubic lattices are of special interest as a large number of materials have a cubic lattice structure. There are only three cubic Bravais lattices; the simple cubic lattice, the body centered cubic lattice, and the face centered cubic lattice. They form the basis for all other cubic crystal structures (for instance the diamond lattice) through the addition of an appropriate base at each lattice point to one of those three lattices.

| Lattice type | Number of lattice points / atoms per unit cell | Nearest distance between lattice points | Maximum packing density | Example |
|---|---|---|---|---|
| Simple cubic | 1/1 | a | $\pi/6$ = 52 % | Phosphor |
| Body centered cubic | 2/2 | $a\sqrt{3}/2$ | $\pi\sqrt{3}/8$ = 68 % | Tungsten |
| Face centered cubic | 4/4 | $a\sqrt{2}/2$ | $\pi\sqrt{2}/3$ = 74 % | Aluminum |


Soap film coil

## Soap Film / Plateau's Problem

Soap film results from the film occupying the least possible surface area, forming minimal surfaces due to stable and organized energy distribution across the surface via the Marangoni effect. Surface tension in a soap film, or minimal surface, is proportional to its area, thus minimizing its surface area. The film also minimizes its energy.[1]

Determining the existence and shape of the minimal surface constrained by a given boundary, a problem raised by Joseph-Louis Lagrange in 1760, is know as Plateau's Problem, named after Joseph Plateau for his interest in soap films.

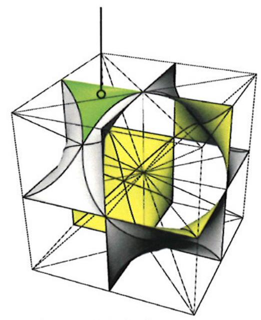
1 Cyril Isenberg, *The Science of Soap Films and Soap Bubbles* (New York, 1992), © The Exploratorium.

## Triply Periodic Minimal Surface (TPMS)

Triply Periodic Minimal Surfaces (TPMS), also called Infinite Periodic Minimal Surfaces (IPMS), have lattice structures that are invariant under translation along three independent vectors. Numerous examples are now known with cubic, tetragonal, rhombohedral, and orthorhombic lattice structure.[1]

The symmetries of a TPMS allow the surface to be constructed from a single basic surface patch (also called a Flächenstuck), which extends to the entire surface under the action of the symmetry group. The most important local symmetries of minimal surfaces are Euclidean reflections (in mirror planes) and two-fold rotations.

1 K. Brakke, "The Surface Evolver," *Experimental Mathematics,* vol. 1, 2 (1992), pp. 141–65.



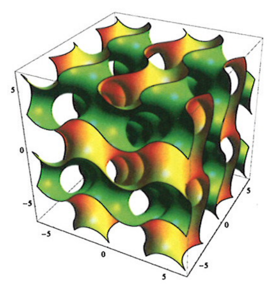

Diamond (D) Surface

## Periodicity without Self Intersection

Five examples of infinite periodic minimal surfaces without self intersection were known prior to Alan Schoen's discovery of twelve more of these unique instances. Hermann A. Schwarz discovered four of these surfaces in 1865, and named them according to their "skeletal graph" of an infinite "labyrinth."[1]

Understanding the particular physical properties of these seventeen minimal surfaces, Schoen filed a patent two months after his NASA publication for a new type of honeycomb panel that has superior weight to strength ratio by deploying Schwarz's Hexagonal (H) Surface.[2] Many more of these surfaces have found their ways into applications today in molecular engineering, nanotechnology, and material science.[3]

1 H. A. Schwarz, *Gesammelte Mathematische Abhandlungen* (Berlin, 1890); A. H. Schoen, "Infinite Periodic Minimal Surfaces Without Self-Intersections," NASA Technical Note, TN D-5541, 1970.
2 A. H. Schoen, US Patent 3663347, filed July 16, 1970, issued May 16, 1972.
3 S. T. Hyde, et al, "A Short History of an Elusive Yet Ubiquitous Structure in Chemistry, Materials and Mathematics," *Angewandte Chemie International Edition,* 47 (2008), pp. 7996–8000.

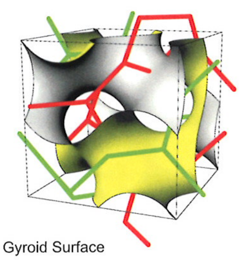


Gyroid Surface

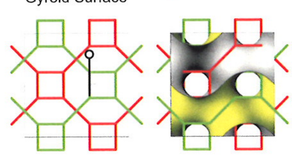
## Labyrinth Graph and Medial Surface

The shape of a TPMS is often described by the geometry of the pair of sub-volumes, the interior and exterior space. These, in turn, are often described by a labyrinth graph—a network of three dimensional nets describing the channels of the sub-volume. The TPMS can be understood as the medial surface described by the labyrinth graph, or more simply, as the Voronoi walls between pairs of interwoven 3D networks.[1]

1 G. E. Schroeder, S. J. Ramsden, A. G. Christy, and S. T. Hyde, "Medial Surfaces of Hyperbolic Structures," *European Physical Journal B,* 35, 4 (October 2003), pp. 551–64.
2 Toshikazu Sunada, "Crystals That Nature Might Miss Creating," *AMS Notices,* 55, 2 (2008), pp. 208–15.



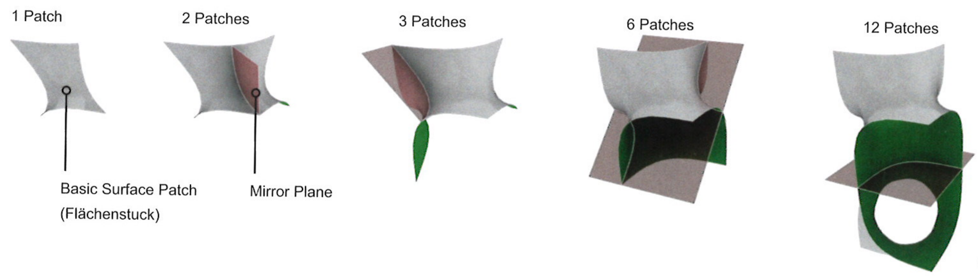
Gyroid Surface



K4 Crystal Structure[2]

## Fabrication of Minimal Surfaces

The I-WP Surface is made up of a single Basic Surface Patch *(Flächenstück)* that mirrors forty-eight times to form its whole. It is a characteristic common in all Triply Periodic Minimal Surfaces. This property makes the doubly curved surface easy to break down for different fabrication processes such as injection molding or slip-casting.

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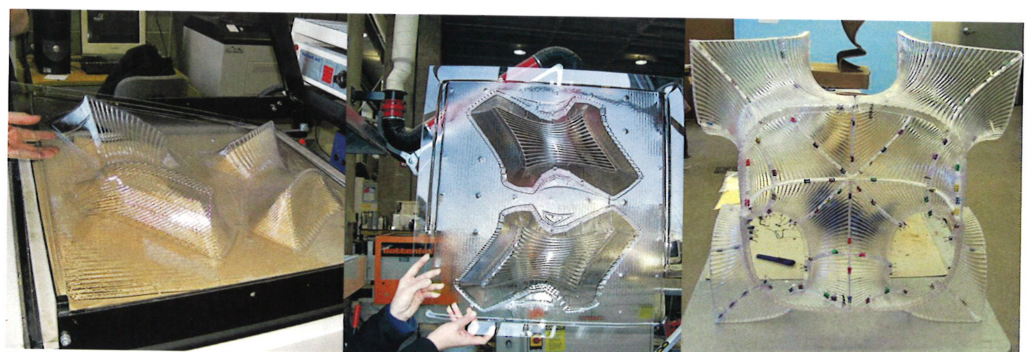

Vacuum Formed Surface

Basic Surface Patch (Flächenstuck)

I-WP Surface assembled

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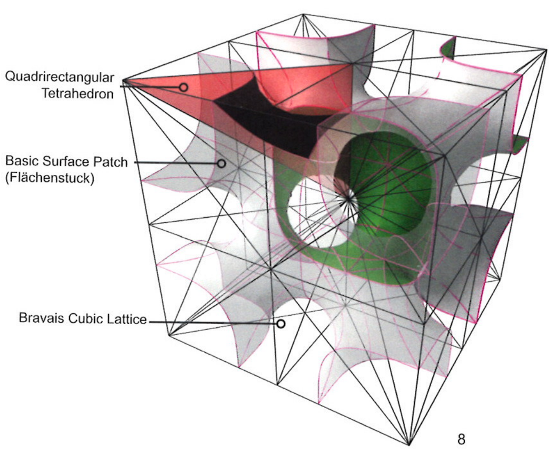


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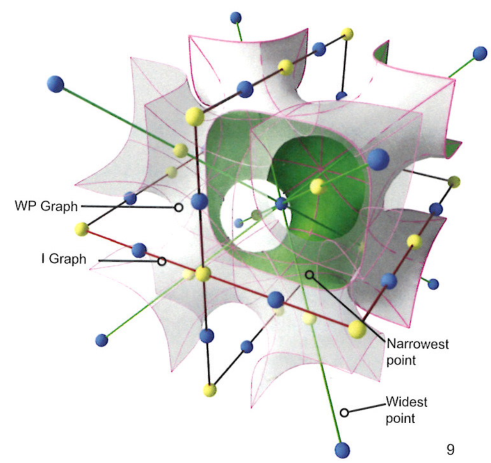


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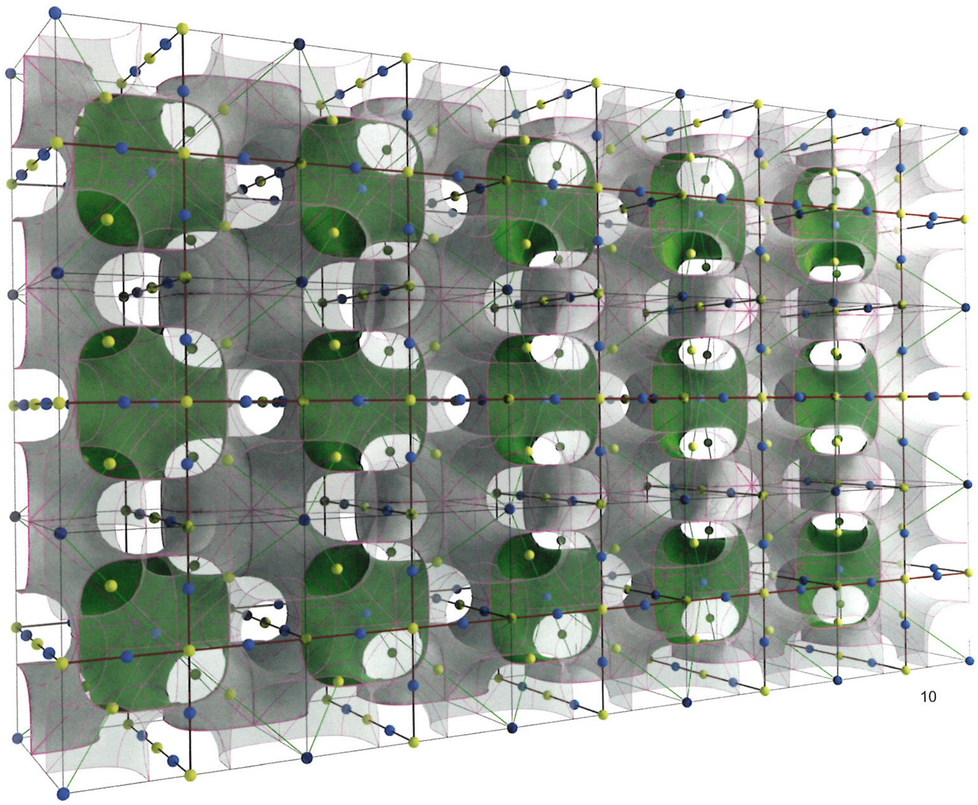
## Bi-Continuous Space Partitioning for Enhanced Airflow Capacity and Light Diffusion

Space is partitioned into an interior volume, the I Graph, and an exterior volume, the WP Graph. I and WP are continuous and intertwining, but they never intersect. The properties of the two graphs, combined with the smoothness and porosity of the minimal surface makes the shape highly effective in the combined function of air distribution and light diffusion.



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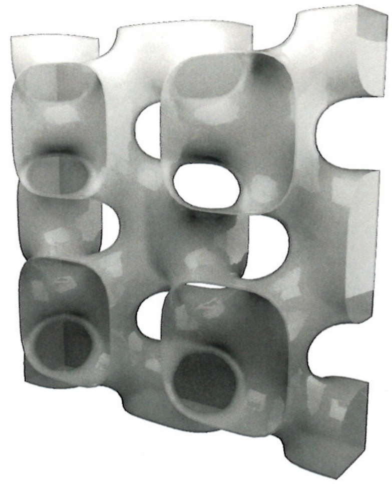
6 Forty-eight fold symmetry for maximum fabrication cost efficiency
7 Minimum material to area ratio and maximum weight to strength ratio
8 Diagram of Cubic Lattice, Tetrahedral Symmetry, and the Basic Surface Patch (Flächenstuck)
9 I and WP Graph: continuous volume intertwining the internal and external spacesa
10 Highly stable and dense packing
11 Interior visualization

The AMP System synthesizes the amplified cleaning capacity of root rhizomes of an active system with the large-scale building integration of passive strategies to create a bio-mechanical duct filtration system. The geometry of the structural modules minimizes material requirements and increases the system efficiency by maximizing the exposure of the root rhizome. The flexibility of the modular assembly and scalability of the system enables it to be architecturally integrated into a wide range of building scales and typologies.



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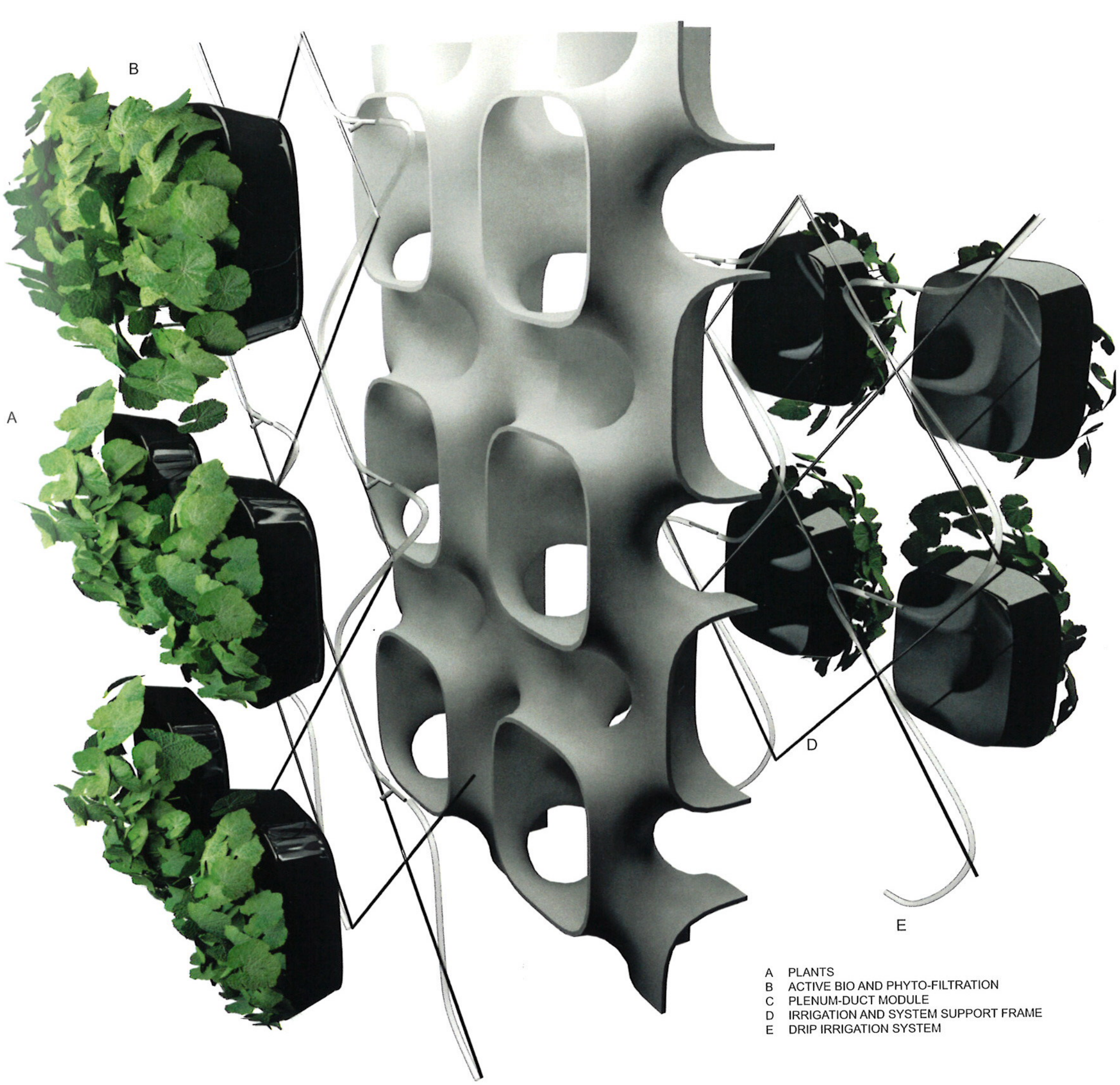
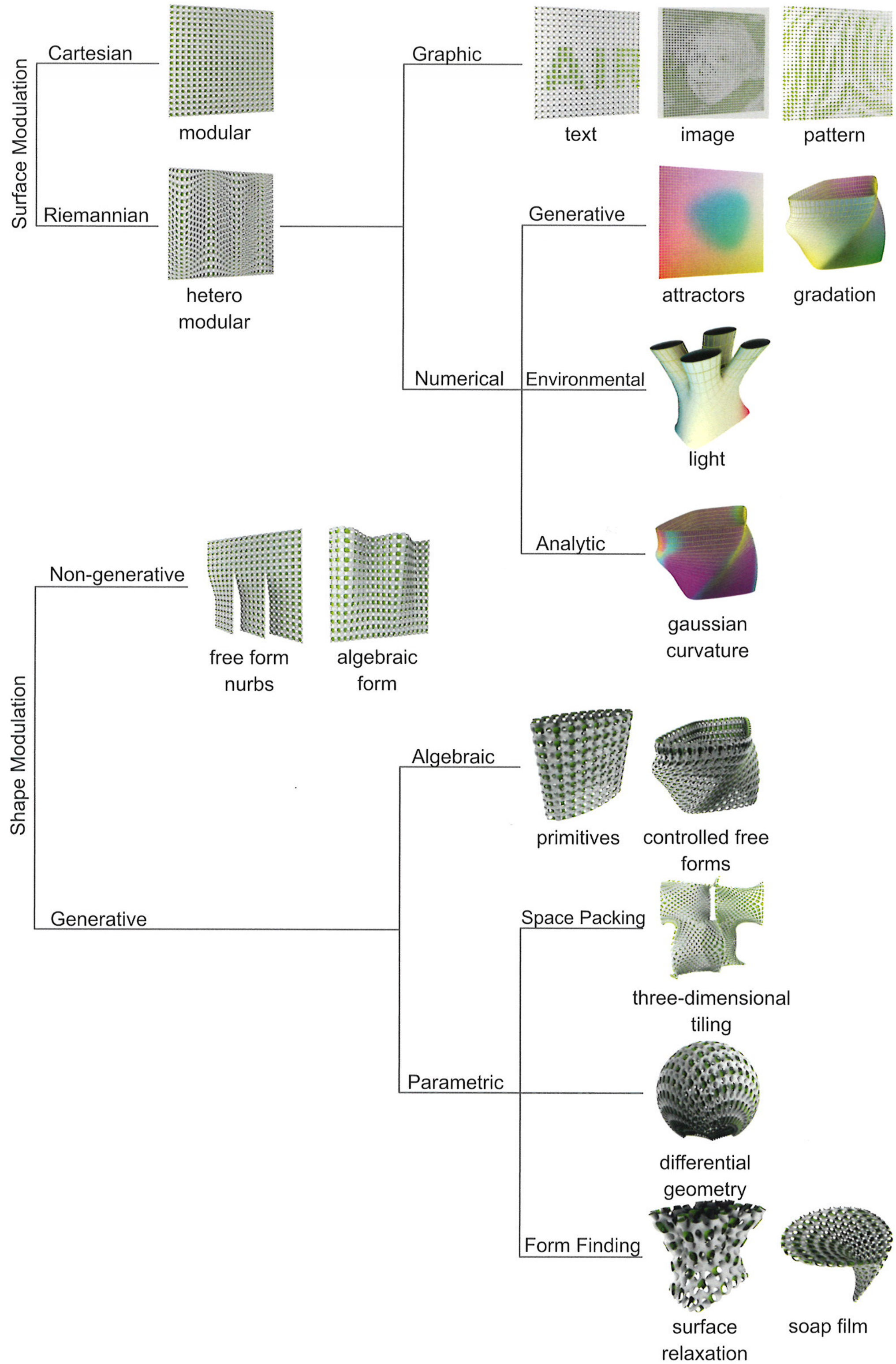
12 Modular Screen
13 Fern
14 Ivy
15 Moss
16 AMP System Components




A PLANTS
B ACTIVE BIO AND PHYTO-FILTRATION
C PLENUM-DUCT MODULE
D IRRIGATION AND SYSTEM SUPPORT FRAME
E DRIP IRRIGATION SYSTEM

16



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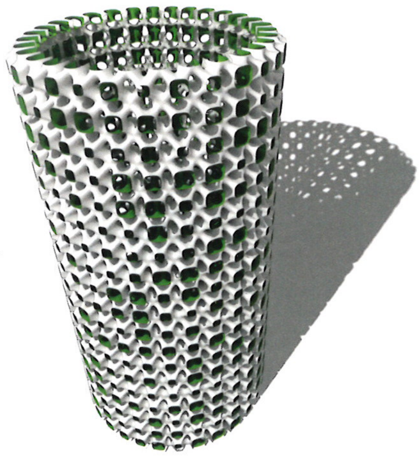
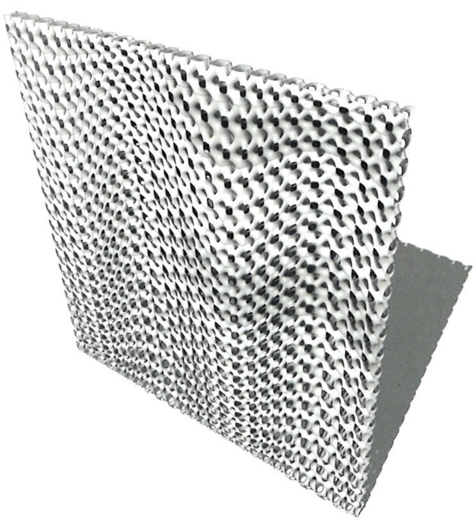


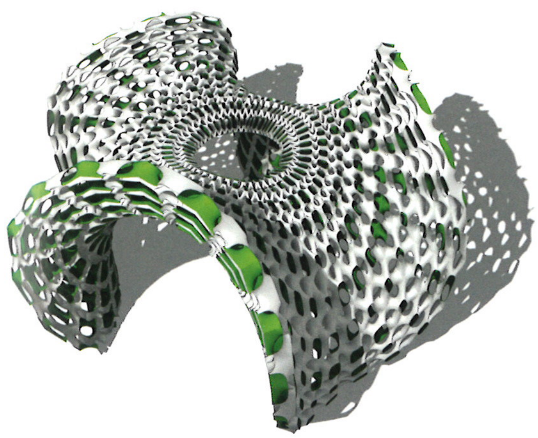
Volumetric Applications

The AMP System permits the creation of volumetric spaces that, once integrated into the architecture, may behave as scrubbers when applied as vertical longitudinal plenum spaces. This array can easily integrate with an active air control system, allowing return air to be treated before being reintroduced into a space.



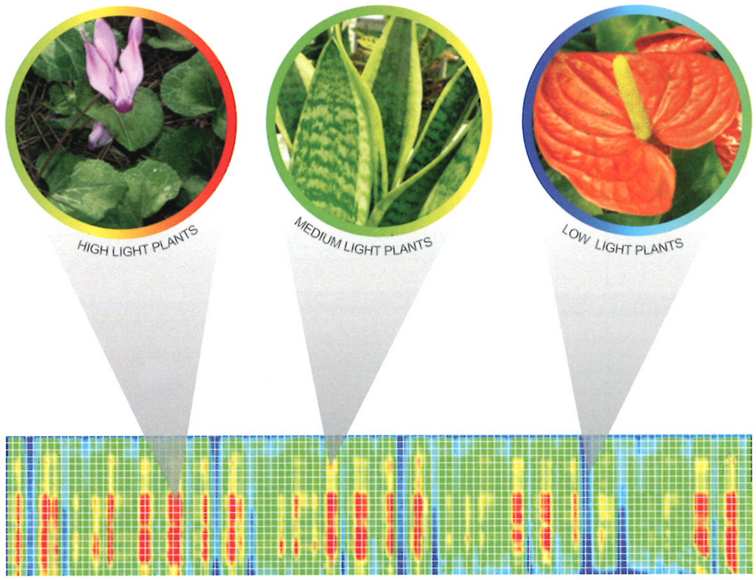
Planar Applications

When tiled along a semi two-dimensional field, the AMP System can be utilized as a self-supported, non-load-bearing partition capable of expanding along any axis, and customizable to fit any application. The partition can be actively engaged from either face, acting not only as an active air filter, but also as a visual and spatial filter.

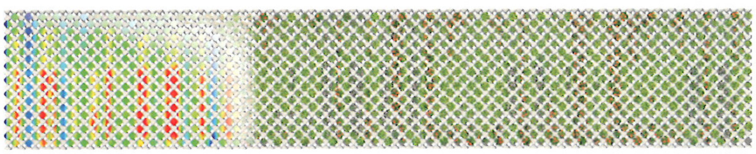


Parametric Applications

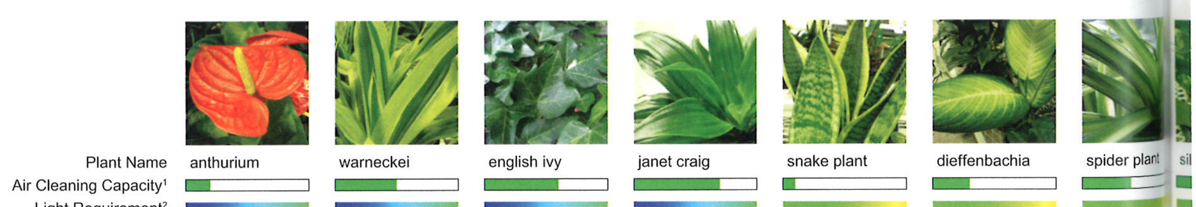
The AMP System allows the application and adaptation to parametric surfaces. These forms can potentially encompass and enclose entire areas, defining occupiable space for human habitation. The complex surface geometry permits varying scales that may be integrated as either active or passive elements.




SOLAR MAP WITH GRID



PLANT POPULATION OF WALL BASED ON SOLAR MAP


[1] Wolverton, C. Bill. How to Grow Fresh Air: Houseplants that Purify Your Home or Office. New York: Penguin Books, 1996.
[2] Trinklein, David H. Lighting Indoor Plants. Horticultural MU Guide, University of Missouri, Columbia. (2002): 1-6.



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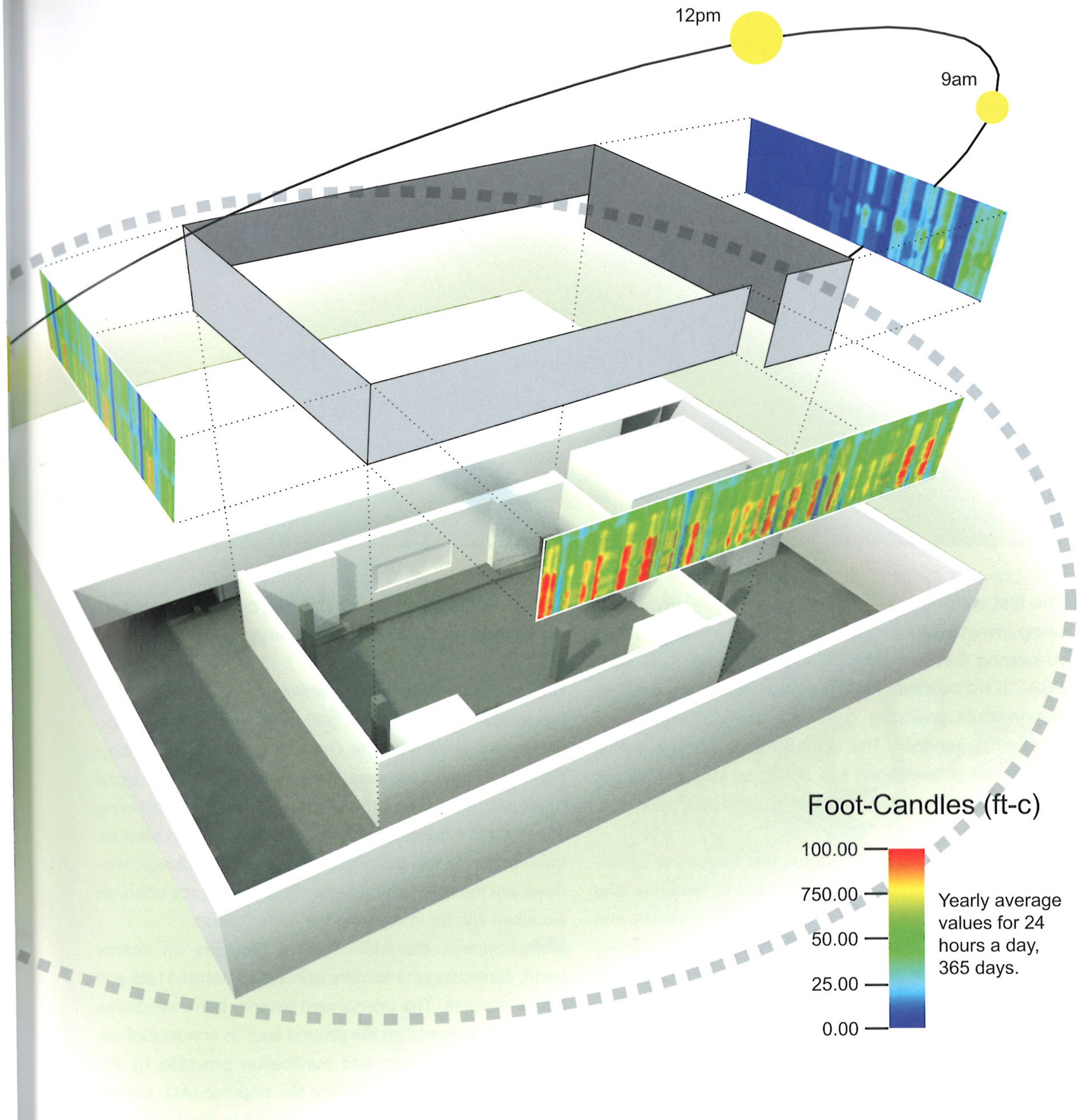
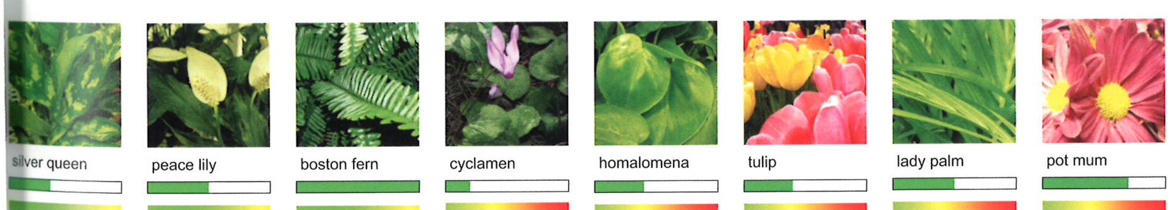

12pm
9am
Foot-Candles (ft-c)
100.00
750.00
50.00
25.00
0.00
Yearly average values for 24 hours a day, 365 days.


silver queen
peace lily
boston fern
cyclamen
homalomena
tulip
lady palm
pot mum

17

The first building-scale proposal of the AMP System is being investigated for viability in the new Public Safety Answering Center (PSAC II) for the City of New York. PSAC II will be staffed by New York City Police and Fire Departments providing coverage and security to 911 emergency services. The center is located on a prominent parcel of land along two of Robert Moses's historic greenways, the Hutchinson and Pelham River parkways, in The Bronx.

Specific design criteria mandates that the center be unassailable and impregnable from natural disasters and potential terrorist attacks. It will operate continuously and as such it presents obvious challenges for sustainability amid the stringent security requirements. In addition to the security guidelines, the state requires the building achieve LEED Silver certification. From an urban standpoint, for the neighborhood, and for the building occupants, environmental considerations are as important as security. The design team felt strongly that without a sustainable agenda, this building type might become a brutalistic bunker, unfortunate for both the community and the workforce. From this design challenge, two mitigating strategies emerged. The potentially limited access to exterior views and natural daylight due to increased building structure makes the AMP System an ideal application to improve the quality of well-being for building occupants while demonstrating the air cleaning capacity and potential for reducing the building's energy consumption profile.

Due to the large floor plate, daylight and exterior views are mitigated by distance. While there are limited opportunities for glazing on the Call Center floors, the Lobby/Cafeteria/Auditorium area strongly benefits from natural daylight. This multi-purpose area is the main gathering space for the building. In spite of the shear and blast requirements of the building, some twenty foot-high windows are feasible to supply daylight. This space offers an excellent site for integrating the AMP System.

Metaphorically, the AMP System provides an interior berm, continuing the exterior concept of bermed hills and native grasses. The interior and exterior berm structures connect occupants on the ground floor to conceptual nature. The air filtration and purification provided by the plants will increase HEPA filter life, improve IAQ, appear vibrant during winter months, and add to the perception of occupant well-being within the building.

PSAC II is an ideal test bed for further installations across the United States, Europe, and other developing global markets by SOM.



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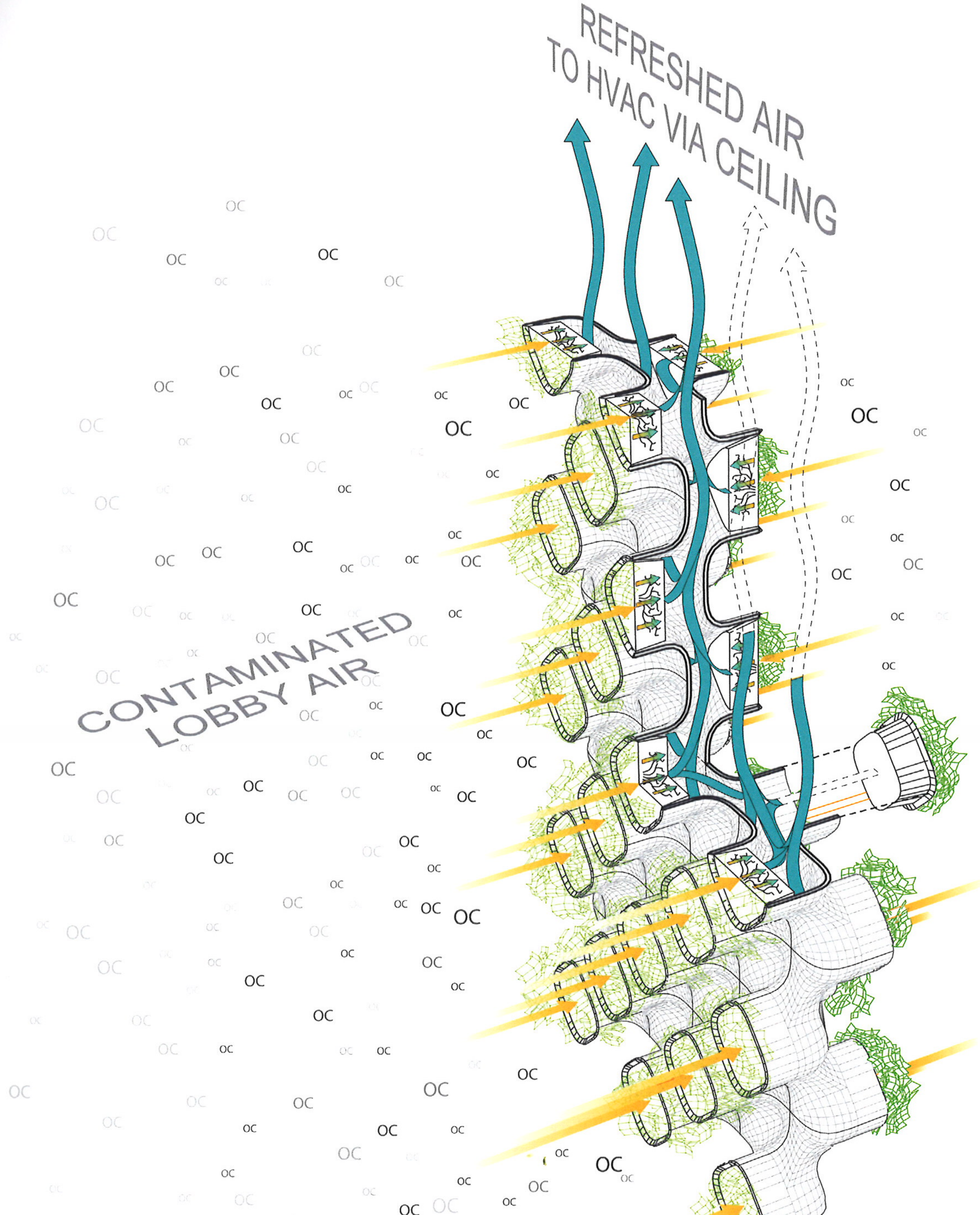


17 Interior rendering of PSAC II Lobby
18 Contaminated air filtration system diagram

18



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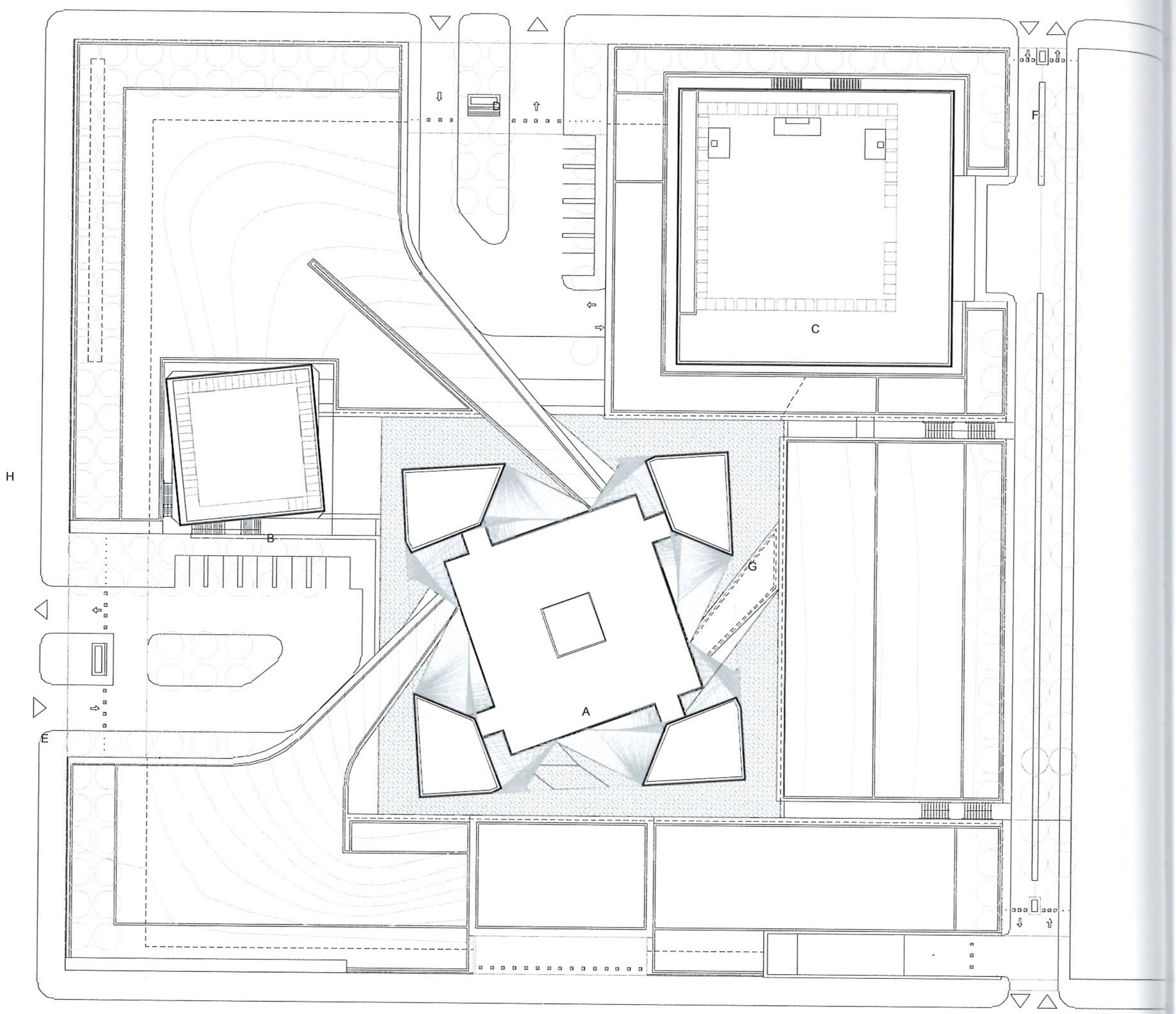


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A TOWER
B BANKING HALL
C AUDITORIUM
D VISITOR ENTRY / EXIT
E VIP ENTRY / EXIT
F SERVICE ENTRY / EXIT
G SUNKEN WATER COURTYARD
H KING FAHAD ROAD

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