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Abstract

Nature functions in cycles, nothing is ever wasted. Humans follow a linear pattern, using a resource and then discarding it. We throw away nutrients. In a world of finite resources, our current lifestyle paradigm is increasingly difficult to sustain. Unfortunately solving our problems is far more difficult than merely defining them. As architects, we are entrusted with responsibilities tying natural nutrient cycles with the built environment. Small scale systems have been developed for off-grid living, but none have taken root in urban environments, where the majority of our population lives. Therefore, the question architects must pursue with fervor is, ***"How can urban architectures support, and derive inspiration from a reconnection of human, and larger nutrient cycles?"***

The Architect's Duty; looking to nature's designs in a world of finite resources

Nature has a lot to teach

The natural world exists inside a paradigm of balance humans have attempted to disassociate from. We have worked hard to conquer nature, rather than submit to a role within it. The most peculiar element of this relationship is, though we constantly combat submittal to nature, we continually mimic it, we practice biomimicry. Whether nature becomes the inspiration of an artist, the model for an inventor or dream of a clothing designer, nature has already found, and refined our solutions. For example; spider silk is not only stronger than steel, tougher than Kevlar, but also flexible and elastic. If scaled large enough, it is capable of catching a Boeing 747 in flight, then retracting back to its original state.[1] Nature has already accomplished what we continually attempt to reinvent.

In his book, *The Philosophy of Sustainable Design*, Jason McLennan describes "nature's innovations", as defined by biologist Janine Benyus. There are nine guidelines which reoccur in everything, whether it be on land, in the sky or under the sea; nature runs on sunlight, uses only the energy it needs, fits form to function, recycles everything, rewards co-operation, depends on diversity, demands local expertise, curbs excesses within and taps the power of limits.[2] By following these rules, these laws nature designs with, waste does not exist. As William McDonough and Michael Braungart explain in their book, *Cradle to Cradle*, everything in nature is continually being used, never truly discarded. The two authors use the Cherry tree as an example to describe this phenomenon, explaining how every piece of every cycle is nourishment for something.

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[1] McLennan, Jason F. The Philosophy of Sustainable Design. 2004. 41.
[2] McLennan. 40.

Growing from a seed, the cherry tree soaks up water and nutrients from the soil, as well as energy from the sun to fuel its growth. Then the tree blossoms and fruits, some of which are eaten and carried off, but many will remain with the tree. Eventually these excess blossoms and fruits will fall to the ground, they are the surplus product, the unnecessary, right? Is this inefficient? The excess will decompose, nourishing insects, microorganisms and eventually the soil. The surplus blossoms and fruit return unused nutrients back to the soil. One of the amazing parts of this process is how even a surplus in a production cycle never depletes from its environment, it always nourishes. [3]

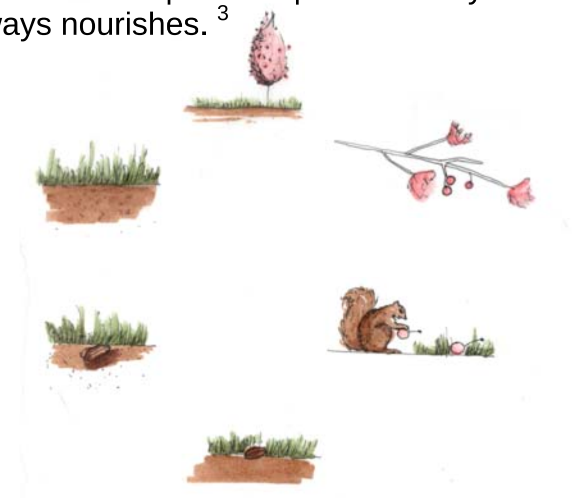

Figure 1&2: The Cherry Tree, as described in Cradle to Cradle, a complete nutrient cycle.

Few things invented or developed by humans fit this paradigm. We harvest resources, produce products, but also create waste. Earth is a finite world. Every resource we utilize and enjoy will one day fail to replenish itself, and like many of our planet's species, become extinct. So long as a given resource is consumed faster than it naturally replenishes, there is no other possible outcome. The amount of energy the United States consumes throughout the course of one year falls on the country, via the sun, every 13 seconds.[4] Despite this surplus, humans continue to dam rivers and burn fossil fuels to create electricity. The state of our current environment is unacceptable; we have pillaged what resources we have found, leaving debilitated natural systems in our wake.

Working in a profession which interacts with nature so directly, architects are entrusted with the duty of enriching the environment. It would be careless to neglect our nurturing potential. As architects, it is not our specialty to rewrite each and every system this world abides by. What then can we do? What should we do?

What should we do?

[3] McDonough, William and Braungart, Michael. Cradle to Cradle. North Point Press, 2002. 73.

[4] Zelov, Christopher and Cousineau, Phil. Design Outlaws on the Ecological Frontier. 2001.

Architects no longer have the option to design with a low impact, or even no impact. We now are faced with the responsibility to insert ourselves into nature, to become like the cherry tree. As we depend on nature to provide for us, we in turn must provide for nature. This is fundamentally a human need. The Earth was here before us, and will continue on after we are gone. We are no longer needing to, “save the planet”, but rather, “save ourselves”. It is the obligation of the architect to design responsibly; environmentally supportive, efficiently and responsive. Joan Nassauer imagines a day where professionals are infused with desires to support nature through design, drawing inspiration from ecology. In her essay, *Ecological Science and Landscape Design: A Necessary Relationship in Changing Landscapes,* she proposes design and ecology are inseparable. There can be no design without ecology, and likewise no ecology without design.[5] In this perspective, a project would stimulate the surrounding ecosystems, react to human needs and create zero waste throughout its life. Resource usage would be limited by the amounts collected onsite, biowaste would be converted to fertilizer and used to replenish nourishment in the soils. If the project is disassembled, each and every part will either be used again or composted, returning embodied energy and nutrients back to nature.

Dramatic adaptation of this philosophy will not take place over night, but architects must not stand idly by before it takes root. Tectonic vocabulary is celebrated in the portfolios of Alvar Aalto, Frank Lloyd Wright and Louis I. Kahn. Each designer chose materials carefully for their fundamental strengths as a material, maximizing passive performance of a building. Rainwater retention, and recirculation, for flushing water closets have been utilized and is becoming more common practice. LEED, and the obtaining levels of certification have been instrumental in changing the way designers view rainwater. Even today, rainwater is regarded as a waste to be captured by gutters, which route the natural resource offsite almost immediately after falling.[6] Passive systems and flushing waste with non-potable water are merely minimal elements architects must utilize. Designers must consider additional performance restraints for projects; subjecting architectures to the Living Building Challenge, a system authored by McLennan.

To receive the LBC distinction, a project must adhere to a series of performance criteria, such as only using the energy and water which falls onsite. Three LBC projects are currently being designed at SERA architects. Projects integrating similar design priorities can be found at Islandwood, designed by Mithun, a project which includes a living machine. The living machine enables the biowaste left onsite to be treated, converting it to potable water and usable nutrients. Nutrients are then safely deposited into the soil, replenishing it, enabling it to harbor plants again. The plants then create food, the food consumed and inserted into the cycle yet again.

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[5] Johnson, Bart R. Ecology and design: frameworks for learning. Island Press, 2002. 218,221.
[6] Farr, Douglas. Sustainable urbanism: urban design with nature. Farr Associates, 2008. 176.

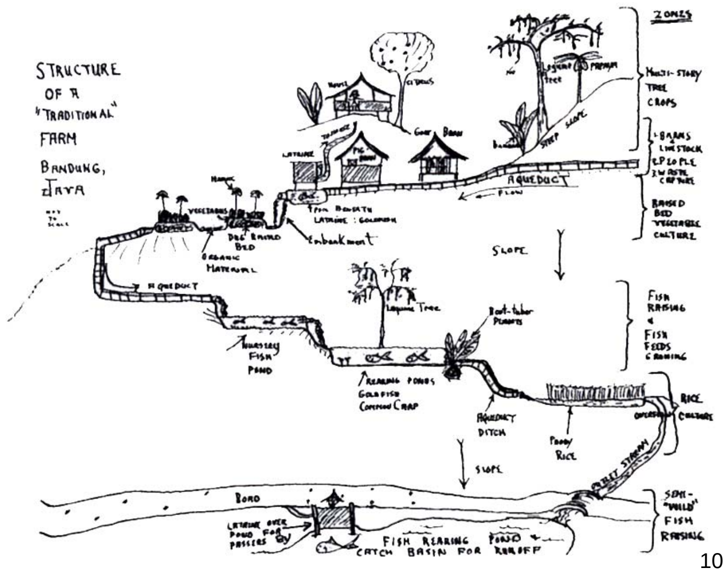
Sewage is a Resource

In the early 1970's Dr. John Todd and his wife Nancy Jack Todd established a non-profit organization called, New Alchemy, which would evolve into Ocean Arks. Inspired from an off-grid, self sustainable way of living, the Todds, and their colleagues developed several systems derived from nature. Simply put their experiements were a form of biomimicry, but were designed to perform above and beyond what a completely natural setting would be capable of producing. Including food production, energy harnessing and high performance construction, the New Alchemists discovered and developed waste treatment systems which would outperform even their hopes and dreams. Amory Lovins, cofounder of the Rocky Mountain Institute, described the Todd's work, "The biologically sophisticated Ark makes manifest our interdependence with the natural world, reintegrating us into it and enhancing or sense of wholeness…"[7]

Nancy Todd describes the original concept of their solar algae tubes, stemming from observing plants which naturally cleanse water from the surface of water. Realizing plants utilize sunlight to fuel their processes, the scientists set out to maximize their potential. By creating several tubes of transparent material, sunlight would be able to reach every cubic centimeter of water in the tubes, rather than simply the surface of a pond. The ponds were first used for their food production potential, but the ponds began experiencing buildups of toxic ammonia. To combat this effect, nitrifying bacteria and algae was added, and was found to synthesize ammonia, phosphate and carbon dioxide.[8]

The Todd's visited a farm settlement on Java, in 1977. They witnessed a stream running under the huts, and latrines, and continuing to flow down the hillside. Several planting beds act as the initial filter for the sewage, and the following stages include fish beds, water fall, rice paddies and pond with a mixture of the elements of earlier stages. The water at the end of this chain was relatively clean, and the soil was harvested by the farmers as fertilizer for their crops.[9]

[7] Todd, Nancy Jack. A Safe and Sustainable World: The Promise of Ecological Design. Island Press, 2005. 115
[8] Todd. 123
[9] Todd. 145



[10]

Figure 3:Nutrient cycle on Java, completed by farmers harvesting of soil at the bottom, fertilizing the land at the top.

In essence, the harvesting of the soil completed the nutrient cycle. The crops, as well as other plant life on the hillside, were fertilized with the same nutrients they produced. This experience inspired Ocean Arks members to create a compressed version of the nutrient cycle on Java, utilizing the compartmentalization which their solar algae tubes provide.

Eco-machines

The full capabilities of the solar algae ponds were later put to the test when John Todd began consulting around the globe, designing water purification eco-machines. In 1986, the Sugrabrush Ski Resort sought to remove the chlorine gas they had been using to treat their sewage. Located in Warren, Vermont this project also provided climate tests for the Todd's systems, which had not been implemented in colder climates at this time. The tubes were installed over the summer, and fully operational by the time ski season returned. After the sewage had passed through the eco-machine, 99% of the ammonia had been removed, and the sludge treated at such an alarmingly fast rate, local authorities suspected foul play. After in-depth investigations proved the system was functioning far more efficiently and smoothly than originally began, orders were issued to immediately reinstall the system. Perhaps the most interesting benefit of this application was the greenhouse environment, which was warm and humid. Sugarbrush employees took their lunch breaks in this sewage treatment room, sunbathing and relaxing. The smells of human waste were completely nullified by the plant and animal life running the system.[11]

Two years later the eco-machines were tested on a much grander scale. The city of Harwich, Massachusetts had long utilized septic tanks to treat each building's waste. Traditional septic systems are two chambered tanks designed for anaerobic decomposition, and usually constructed of precast concrete. In the first

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[10] Todd, Nancy Jack. A Safe and Sustainable World: The Promise of Ecological Design. Island Press, 2005. 145
[11] Todd. 150

chamber, passive separation occurs, solids sinking to the bottom and a scum forms on the surface. The anaerobic process produces methane. Water use is directly related to time spent in septic tank. Once the waste has passed through the tank, the waste is about 70% purified, but requires secondary treatment. This usually comes in the form of drain field, seepage pits and sand filters.[12] What waste is left behind is called septage, usually anywhere from 40 to 100 times more concentrated than sewage.[13]

The Massachusetts Department of Environmental Protection discovered Harwich's septage dumping lagoon, little more than a sand pit, was located roughly 20 feet directly above the town's ground source drinking water. There were 14 Volatile Organic Compounds (VOC's) listed as carcinogenic by the Environmental Protection Agency (EPA). Toluene, Methylene chloride and trichloroethane were in high concentration, each of which is used as an industrial solvent. Toluene is a water in-soluble, aromatic hydrocarbon which causes severe neurological damage, Metheylene chloride is aerosol spray propellant and chemically welds some plastics, Trichloroethane is a central nervous system depressant and causes abnormalities in the kidney, liver and heart.[14] The eco-machine designed for this undertaking was only 21 solar algae tubes, alongside a small, man-made trench which acted as a marsh for final stage purification. Four months later; 99% of the ammonia and phosphorous were removed, 13 of the VOC's were completely removed, Toluene was 99.9% removed and nitrate levels in the discharge were 1/10 of levels considered safe for well water by the EPA.[15]

Similar findings occurred after Providence, Rhode Island sought the Todd's assistance in dealing with their industrial waste the same year Harwich was relieved from its drinking water contamination. In true New Alchemy form, the design of this eco-machine was reinvented, with four chains of solar algae tubes, two gravel bed marshes, biofilter and a final stage redundant marsh. Toxins and heavy metals, byproducts of the industrial runoff and discharge, were impounded within the biological systems. The final effluent from this eco-machine met the EPA standards for heavy metal levels in drinking water.[16]

In 2002 the city of Fuzhou, China had no sewage treatment of any kind. The dense population, instead dumped sewage directly into the Baima Canal, which spread throughout the city. Rather than pumping this filth to a central location, the Todd's installed rafts which bisected the canals, and seeded them with similar plants which would be used in their traditional eco-machines. As the water cleared up, the stench evaporated. Local species of birds and butterflies which

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[12] Stein, Benjamin. Reynolds, John S. Grondzik, Walter T. Kwok, Alison G*. Mechanical and Electrical Equipment for Buildings.* Tenth edition. John Wiley & Sons, Inc. 2006. 1011

[13] Todd, Nancy Jack. A Safe and Sustainable World: The Promise of Ecological Design. Island Press, 2005. 153

[14] <http://www.epa.gov/iris/subst/0198.htm>, November, 6, 2007.

[15] Todd. 150

[16] Todd. 158

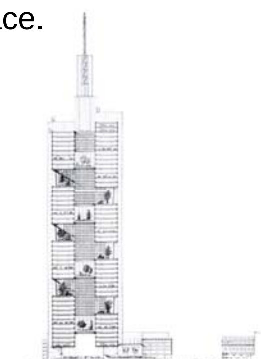
had not been sited in years returned to the area, and native vegetation began a resurgence on the opposite shores of the canals.[17]

Inserting into an existing paradigm

Highly sophisticated systems such as eco-machines are a significant step to reaching the cherry tree. Unfortunately, thousands of years form the foundation for a flawed system. Today's generations are now given the nearly impossible assignment of breaking habits which have long been the backbone of every industry we know.

Rarely are architects given the opportunity to design freely, without economic restriction. So much of this world revolves around numbers; clients want their projects to be cost effective. Because of misplaced priorities and unrealistic payback expectations, countless projects are erected without the touch of a designer, simply to make quick money, to keep busy, to keep money changing hands. This seems entirely counterintuitive. Economic models are based on growth patterns; infinite growth in a finite system. Why do we structure our world on a fundamentally paradoxical paradigm? Why would we allow our tangible built environment to be restricted by flawed concepts?

Thankfully, client notions of economic are changing. This shift allows architects to adapt design strategies to the existing, flawed system. If sustainable designs can be proven economically viable, or even competitive, the system will embrace the new strategies. Projects like Foster and Partners' Commerzbank building, located in Frankfurt, Germany are precedent in showing how environmentally influenced design can make money. The triangular plan creates inherent structural efficiencies in the design, a theme which carries through the tower. Sky gardens rotate around a light well through the center core, delivering natural sunlight to over 90% of the spaces in the building, this includes every office space.



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Figures 4,5 and 6:Building section of Commerzbank, Frankfurt, Germany. Images taken within skygardens.

[17] Todd, Nancy Jack. A Safe and Sustainable World: The Promise of Ecological Design. Island Press, 2005. 170
[18] Foster and Partners. Catalogue: Foster and Partners. Prestel Verlag, Munich, New York, London. 267
[19] Foster and Partners. The Norman Foster Studio. Prestel Verlag, Munich, New York, London. 166
[20] Foster and Partners. 166

The atrium also provides fresh air to the building 60% of the year without the help of any environmental control systems requiring energy, helping the tenants enjoy roughly twice the amount of fresh air typical European buildings receive. The post-occupancy report showed that the Commerzbank design, and employees combined to create a work space which used one third the energy of typical European office buildings. Absenteeism also declined, down to 1.5%, when the average in skyscrapers is 8%, and productivity has rose 12%.[21] The company has seen dramatic monetary returns on their investment, and has written further environmental policy into their business practices.

The city of Milwaukee, Wisconsin attacked their human waste with fervor rivaling Commerzbank. All of the city's sewage is piped to a central treatment plant, where the sludge is then ground up and pushed there a series of machines. These machines work to extract nitrates from the waste, which can then be dried and packaged as fertilizer. The product is called Milorganite, (Milwaukee organic nitrates), and can be ordered from anywhere in the country.[22] Not only does the extensive treatment of human waste help protect Milwaukee's water table from concentrated nitrates, but the city benefits from an export, giving their waste a productive, economic value. Although this example is stimulating and encouraging, the central plant is located on a body of water. Such a location means any leaks or byproducts from the system would have little trouble finding the water table. In addition the process requires much infrastructure, and relies heavily on transportation as well as packaging to complete the process. Needless to say, Milwaukee certainly has the right mindset when confronting human wastes, but as we have seen with New Alchemy and Ocean Arks, there is still much more we can achieve.

Vision for an urban site

As proven in Warren, Vermont, the solar algae ponds will act as environmental control devices when located in a greenhouse. This not only shows their versatility, but also suggests a universal quality, which can by exploited to create pleasurable escapes within the urban landscape. Parks and squares are treasured by city dwellers, often the gathering places for lunch breaks and coffee dates. What if each building in the city could provided park spaces within, more lush and diverse than the Commerzbank building's sky gardens? Ocean Arks go as far to propose urban farming, using these greenhouses to grow crops for building occupants.

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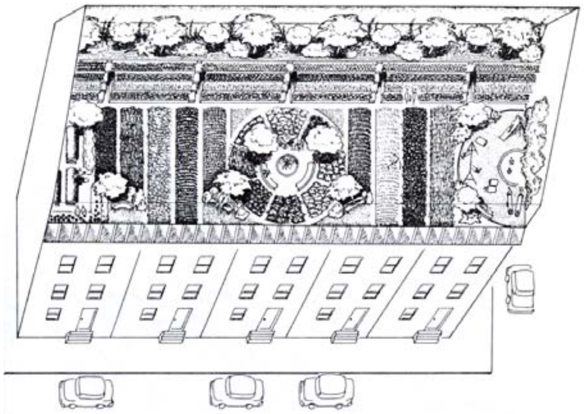
[21] Foster and Partners. On Foster…Foster On. Prestel Verlag, Munich, New York, London 2000. 766
[22] <http://www.milorganite.com/docs/about/how_milorganite_is_made.pdf>



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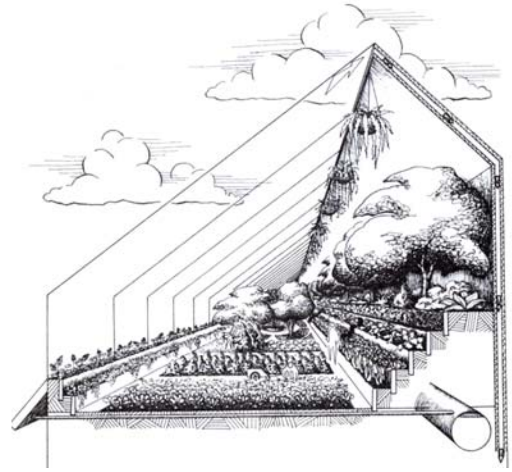

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Figures 7&8: Rooftop greenhouses, creating spaces for human interaction, food production and environmental control systems.

Vision for Portland

Rooftop greenhouses are certainly an interesting concept, but would hardly redefine the aesthetic of the urban setting. Only occupants in the tallest building of a city know what the roofs of all buildings around them look like. Pedestrians on the street would never know the difference if rooftops were to change. If, however, the greenhouses became façade elements, a building would undergo dramatic changes to organization, thermal performance and aesthetic from every angle within the city. Located at SW 4th and Oak in downtown Portland, Oregon, The Henry building sits on a ¾ developed block. Viewing this building from the west, one would be able to see the building redefine itself if it were to incorporate a green house façade, home to an eco-machine. Based on the area required by an eco-machine treating septage for an entire town, and general calculations of waste created per occupant per day, it is possible to conceptualize the basic need of such a system.

(yellow)	Enter Value
(light yellow)	Assumed Variable
(white)	Constant/Self-populating

Sewage Design Guidelines for Housing Building | Case Study Henry Building					
# Occupants	Gallons/Occ/Day	Fixture Type	Assumed Gal/Flush	Flush/Day	Total Gal/Day
153	66.00	Conventional	3.5	18.86	10098.00
153	30.17	Ultra-low flow	1.6	18.86	4616.23

Container Diameter (ft)	Container Radius (ft)	Container Height (ft)	Volume per Container (ft^3)	ft^3 per Gal	Gal per Container
5	2.5	5	98.125	0.134	732.28
5	2.5	5	98.125	0.134	732.28

Containers Needed	Additional Spacing Between (ft)	Spacing of Containers (linear ft)	Linear Feet Needed	Floor Area Required (ft^2)
13.79	2	7	96.53	1351.41
6.30	2	7	44.13	617.79

[25]

[23] Todd, Nancy Jack; Todd, John. *Bioshelters, Ocean Arks, City Farming: Ecology as the basis of design.* Sierra Club Books, 1984. 113

[24] Todd, Nancy Jack; Todd, John. 114

[25] Stein, Benjamin. Reynolds, John S. Grondzik, Walter T. Kwok, Alison G. Mechanical and Electrical Equipment for Buildings. Tenth edition. John Wiley & Sons, Inc. 2006. 862

This estimation roughly calculates the square footage required to house an eco-machine designed for The Henry Building, holding 153 residential occupants (one per unit). Two types of fixtures are used to calculate waste levels. Similar to how septic tanks function, if low-flow fixtures are implemented, the system can be sized accordingly, taking up much less area. Regardless, worst case scenario shows this building would loose about 1,350 square feet to a greenhouse, an area which would be reduced over 50% if ultra low-flow fixtures installed. This greenhouse which would in turn provide a lush escape from the concrete dominated downtown life. If the building were ever renovated, and the occupancy changed, the waste creation levels would reflect the change. Though occupancy levels would grow significantly, showers, cooking and laundry would no longer be required of the eco-machine.

Sewage Design Guidelines for Commercial Building

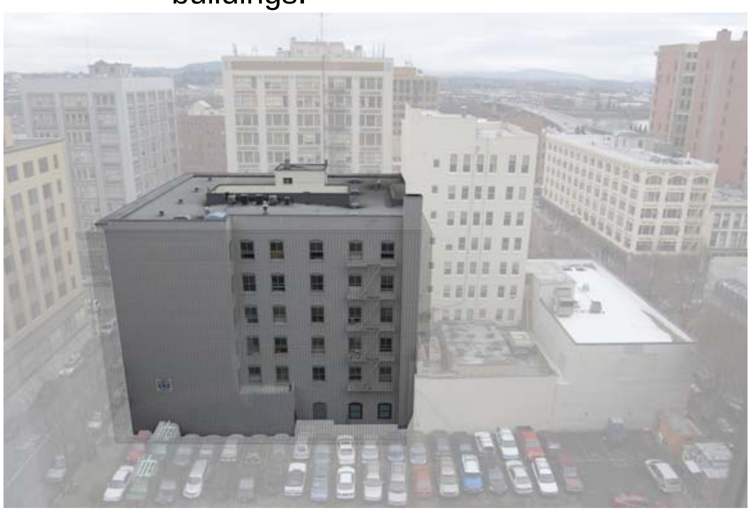
# Occupants	Gallons/Occ/Day	Fixture Type	Assumed Gal/Flush	Flush/Day	Total Gal/Day
612	20.00	Conventional	3.5	5.71	12240.00
612	9.14	Ultra-low flow	1.6	5.71	5595.43

Container Diameter (ft)	Container Radius (ft)	Container Height (ft)	Volume per Container (ft^3)	ft^3 per Gal	Gal per Container
5	2.5	5	98.125	0.134	732.28
5	2.5	5	98.125	0.134	732.28

Containers Needed	Additional Spacing Between (ft)	Spacing of Containers (linear ft)	Linear Feet Needed	Floor Area Required (ft^2)
16.72	2	7	117.01	1638.07
7.64	2	7	53.49	748.83

[26]

In the scenario outlined in this calculation, occupancy would grow to over 600 people, but waste production would barely increase at all. Eco-machines have proven themselves against highly toxic effluents collected from large populations, and will surely prove capable of handling the relatively small loads of individual buildings.



[26] Stein, Benjamin. Reynolds, John S. Grondzik, Walter T. Kwok, Alison G. Mechanical and Electrical Equipment for Buildings. Tenth edition. John Wiley & Sons, Inc. 2006. 862

Figures 9,10,11 and 12:Conceptual building adaptation in a case study of The Henry Building, Portland, Oregon.

This image series outlines the variation in greenhouse space created, and added to the Existing Henry Building. Not all sites in an urban fabric will have equal solar access, meaning some buildings may have to take on eco-machine loads of those around them. The two, more progressive images of the Henry Building show what this may look like. This building uses the greenhouse as a twin skin, a highly technical device utilized by some architects today. The more façade which is utilized as greenhouse and eco-machine space, will affect the organization of each building, but is that such a bad thing?

Where we go from here

McLennan's nine natural laws of design hinted at an issue which will surely mature in large scale reform; creating new design guidelines specific to milieu. The concept is alien to our current system. The International Building Code reaches across multiple climates and countries, attempting to create a one-size-fits-all guide to design. Creating standards gives reference, each project may be measured and compared to others. We already know nature designs at the local, native and unique level. It is folly to design differently. Does this indicate additional design guidelines, to the nine, are counterproductive? Perhaps.

This does not suggest there can be no other agendas in design, but rather a hierarchy. If each of the nine design guidelines found in nature are not present in a project, the design is rejected. Once each point is met, a designer may continue further investigations to his/her design priorities and style.

As designers in the built environment, architects are blessed with the opportunity to, daily, impact multitudes of people. This is an influential role, but if carried irresponsibly the negative impacts could be, and have been, catastrophic. Architects must instill the cherry tree's standard into the very essence of what we strive for.

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