MULTIFUNCTIONAL URBAN GREEN INFRASTRUCTURE

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Food

Health

Biodiversity

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CHAPTER 5

BIOMIMICRY: AN INSPIRED WAY TO REGENERATIVE DESIGN IN CITIES BASED ON NATURE

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SUMMARY

The aim of this publication is to show alternatives to broaden the search for solutions that the architecture field, among many other sectors, has to achive in this century in order to make traction to the long-awaited sustainable development that humanity must design. The sustainable, regenerative and resilient strategies from nature represent excellent references for this difficult objective. Not in vain some living organisms has managed to sustain itself on Earth for the past 3,850 million years showing the best strategies and standards to adjust to the imperative laws of the planet, to function and to endure. Bacteria, plants, fungi, animals and ecosystems are today true smart engineers, architects, designers or managers that effectively show us systems, materials, processes and mechanisms that can undoubtedly help the human specie in the most ambitious and difficult challenge to which our specie has to face up to maintain the standard of life and habitability of the following generations. Biomimicry, or bio-inspired innovation, is a disruptive philosophy and methodology that is already working in the industry of many sectors but is not yet well known. This publication shows a basic introduction with three inspiring cases in architecture and how the survival strategies of the elected organisms can undoubtedly improve the current designs in sectors such as water management, energy, waste, design or into a more systemic level. These examples are real exampleas where analogies can be applied in many other cases where the potential benefits of sustainability and regeneration from the perspective of nature go beyond the mere toxicity of materials or their production or the generation of waste at the end of the life cycle of services and products. Providing new approaches of all ready published contents connecting the discipline of biomimicry with architecture, could make sense of how from cities can be reconnected with the ecosystemic services lost from the last decades with the intention to promote a shift in architecture design.

KEYWORDS

Biomimicry, design inspired by nature, sustainability, regenerative design, innovation in architecture, termite mounds, namibian beetle, systemic design.

INTRODUCTION

Humanity faces in this century several global and dramatic challenges which require high dosis of innovation that must include sustainability and regenerative approaches (WWF, 2018). Biodiversity loss, called 6th mass extinction, degradation of ecosystems including global pollution and climate chaos well shown in the exceeded planetary boundaries (Rockström et al., 2009) extended by the European Comission (Steffen et al., 2015), will require imaginative and holistic-systemic solutions which may push us "out of the box" mindset, opening the solution spaces. Humanity is being concentrated in cities and in few decades over 70% of global population will be urban based. Biophillic urbanism with several interesting actions (vegetated roofs, daylighting streams, wildlife corridors, storm buffers, parks, gardens, street canopies, green side walks and many other green and blue infrastructures ...), have been used increseanly oven the last few years with more relevance in Europe thanks to the Nature Base Solution actions to tackle environmental challenges in urban areas (European Commission, 2014) since the old continent aims to be an inspirational world leader in green solutions.

On the other hand, over the 3.85 billion years since life is registered to start on Earth evolution (Lowman, 2002), has helped to solve many challenges that living organisms and systems have running using an impresive and efficient catalogue of strategies. Nature's inventions have always inspired human challenges specially when homindis were totally connected, in a biophilic way with nature. Biomimicry can be defined as the emulation of strategies registered in the living world potentially applicable in human designs including for sure not only new material and products but also urban environments, improving social and economic systems.

The potential open solution space from nature principles (forms, patterns, strategies, mechanisms...) has catched the attention of a important set of profesionals from many disciplines (academics, industry, design, architecture, medical or economics) all over the world. Although the biomimetic field is not new, without any doubt the publication of *Biomimicry, Innovation Inspired by Nature* in 1997 from Janine Benyus (Benyus, 1997) enhanced the global attraction of this disruptive discipline. This is not the goal of the article but the reader may know the proliferation of terms used to describe the field including: biomimicry, biomimetics, bioinspiration, biologically inspired design, biologically inspired engineering, bionics, biognosis, bioreplication, biomorphosis (Hoeller et al. 2013), and even biophilic design. One fundamental difference between these valid disciplines and biomimicry is that the last is searching for sustainability and regenerative goals meliorating the actual design and manufacturing processes.

Today many experts believe that humanity, at least in the western world, have broken the connection with nature (Orr, 1994). Biomimicry can heal this broken bond using from algorithms, new potentially friendly and efficient materials to processes, structures, mechanisms, and even systems. Not in vain nature has always served as a model for mimicking and inspiration for humans to improve their life. By adapting mechanisms and functionalities from living systems now thanks to new scientific technology and holistic approach, we humans, start to understand that learning from nature is better than just learning of nature (Benyus, 1997). Biomimicry could provide a valuable vehicle for such shift in thinking because it encourages us to understand that humans are not separate from nature because we are nature and we are at the end totally dependent upon them for survival,

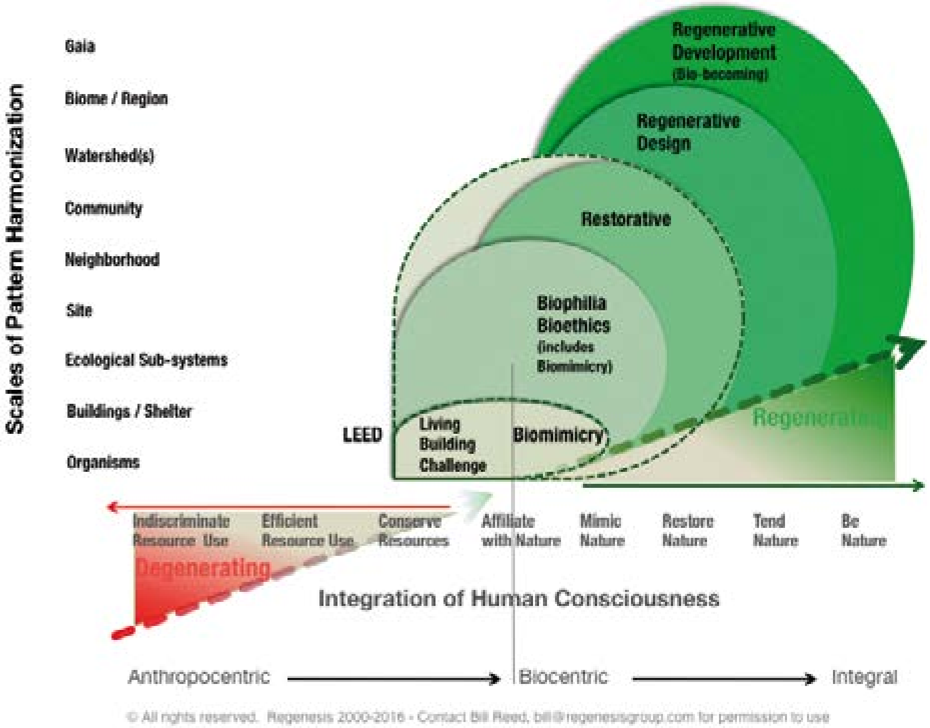

Fig 1. Scale of patterns harmonization (Bill Reed). Image used with the permission of the autor. All rights reserved©

thus the human-ecosystem relationship changes in a relevant way (Mathews, 2011).

Biomimetic architecture does not necessarily translate into a new design aesthetic and in many cases it may involves just like an interpretation, an analogy, where a particular adaptation or derivation from biology is applied (Vincent et al. 2006). This process of translation often results in designs that are not immediately aesthetically similar to the organism that inspired them, but utilise some of the same functional concepts. Biomimicry

therefore is not the same as organic, biomorphic or zoomorphic architectures, which are concerned with the visual mimicry of organic form in design. On the other hand regenerative design can be understood by designing and developing the built environment to restore the capacity of urban ecosystems to function at optimal level of health for retrofit mutual benefits of both human and non-human organisms where systemic based approach is neccesary. The potencial use of the nature´s strategies into the architecture sector opens the solution space not only related to building itself but also to a new method of manufacturing materials, structural systems, to existing problems based on biological models, as well as improved relationship of built spaces with natural environment and, in general, with living beings (Fernandez y Neila 2015). Heat, related to conduction, convection, radiation or thermal energy storage; optical, related to the transparency of the surfaces enhancing solar radiation; airflow, related to the direction and wind velocity, ventilation and air exchange, or variations in relative humidity; water systems in relation to water gain, store, regulating moisture, filtration and recycling; energy generation (Fernández & Neila, 2015) are just few fields where architecture design must improve in a deep way soon. Authors like the recognized Bill Reed affirms that intead of doing less damage to the environment, it is necessary to learn how we can participate with the environment, in something clled "living systems thinking (Figure 1) where biomimicry can play an important role.

BIOMIMICRY EXAMPLES

We are not the unique specie modifying the environment and the available resources for specific purposes (Jones et al., 1994). Beavers building dams, elephants felling trees, earth worms forming soils or mycelium fungi decomposing and recycling all types of materials and plants collecting and storing water are just few examples. Most of these living organisms procedures, contribute to habitat heterogeneity generating life supporting strategies such as resilience, stability and even food availability or shelter. In other situations species can produce a phenomenon called trophic cascade (Ripple & Beschta, 2011) where effective restoring landscape may occur with emergent properties to the ecosystems. These collaborative actions can be aligned to the common good. Human have an important source of strategies to learn from nature as organisms who also modify the environment for support. Cities occupy a relative small space in the planet, 2.7% (SEDAC) but consume an important amount of resources, producing a colosal amount of waste and GHG emissions as well as other issues. So we must look for solutions and nature can provide some good ideas to be explore and applied.

Following, I will describe just three good references in architecture as examples of biomimicry design in urban ecosytems. The first one and probably the most popular is the Eastgate Center designed by Michael Pierce in collaboration with Ove Arup & Partners engineers inspired by termites mounds; the second example based on land restoration and renewable energy plan known as The Sahara Forest Project maked posible thanks to a large public-private consortium, inspired among other living organisms in the Namibian beetle; and finally the third case, the Bullit Center, the main headquarter of the Bullitt Foundation designed by Miller Hull Partnership and inspired by how a living forest works related to the ecosystemic services they provide.

Eastgate Center

Termites standing biomass has been estimated to be higher than ungulates in savanna 100 kg Ha-1 versus 80 kg Ha^{-1}) giving some credibility to the importance of termites in the functions of these ecosystems (Deshmukh, 1989). The genus *Macrotermes*, construct large nets (50m^2 basal area) when basic resources like water, clay accumulation in the soil and plants for foraging (1-1,5 T/Ha/year) are available in a permanent way they consider (Boyer, 1975). This councious prevision of raw materials can be used as an analogy that we humans are not the only specie capable to make decisions in order to build shelter and other basic life supporting elements. *Macrotermes michaelseni* and *M. subhyalinus* were the two termites species that Michael Pierce studied to face a challence in Harare, Zimbaue. These between 4-15 mm minuscule insects built in terms of relative scale the tallest skycrapers which can raise up to 9 meters from the floor without considering the subterraneal galleries. Recently it have been discovered in Brazil the largest worldwide construction done by *Syntermes dirus* that has persisted for up to 4,000 years covering an estimated area of 230,000 km^2 inter-connecting tunnel networks approximately 10 km^3 of soil being deposited in 200 million conical mounds that are 2.5 m tall and approximately 9 m in diameter (Martin, S.J. et al., 2008). Like us, termites build a building-system like that suits them rather than adapting to their environment counteracting two critical physical factors: cool and humidity. To do this colosal construction the termite´s building uses zero waste using solar powered air conditioning combining the whole structure with a sustainable agriculture (fungus *Termitomyces*). These catedral-like structures made from bottom up without a preliminar instructions and without engineers and architects are perfectly nort-south oriented with a large absorbing area catching the warmth of the morning sun rays after the cold of the night. Ventilation tubes within the walls are controlled intentionally by the insects when the temperature inside rises too much in combination with tunnels below the soil which can maintain an internal temperature of 31ºC with a 1ºC variation even when outside temperaturas can vary 39ºC between day and night (Webb, R. 1994). In this colosal construcction organisms acts as a ecosystemic actor creating a resource flows that affect the composition of the current and future biophysical diversity with feedback mechanisms. This procedure is also known as ecosystem engineering (Dangerfield,1998) and can persist for long periods to the biodiversity included

You can easily imagine how termites were the primary source of bioinspiration to the architect Michael Pierce when he designed with Arup engineers the Eastgate Center in Harare, Zimbaue in 1996. This 26,000 m^2 office building and 5,600 m^2 retail space center with 450 parking use passive cooling. The cool air circulates into large floor voids containing a labyrinth precast concrete elements maximizing the heat transfer with a large surface area (Pawling, 2011). Pierce got an interior temperature maintained between 21º-25ºC range when outside are between 5º-33ºC. Works by sorting heat during the day and verting it at night when temperatures drop down using 35% of the energy required by a similar conventionally cooled building (Michael Pierce website; Figures 2 & 3). Other authors cited that this resulted reductions in energy use ranges between 17% and 52%

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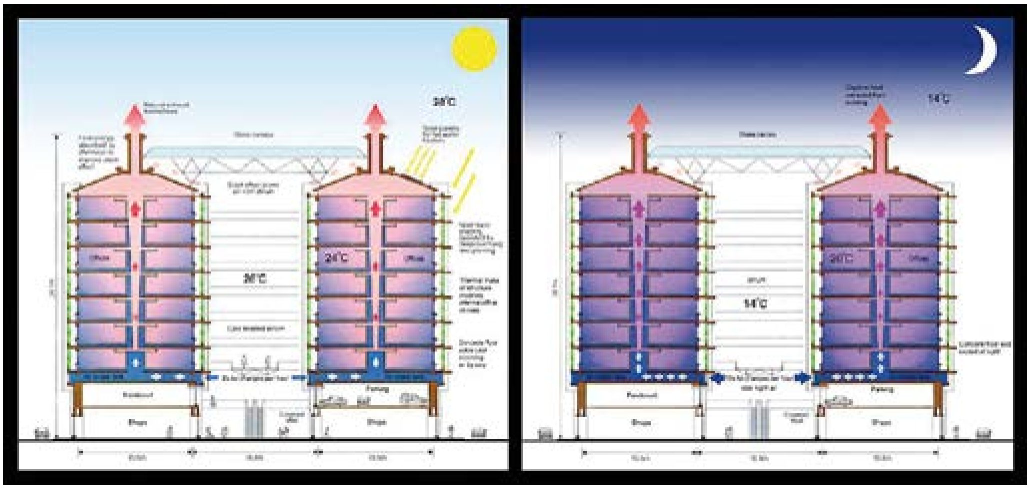

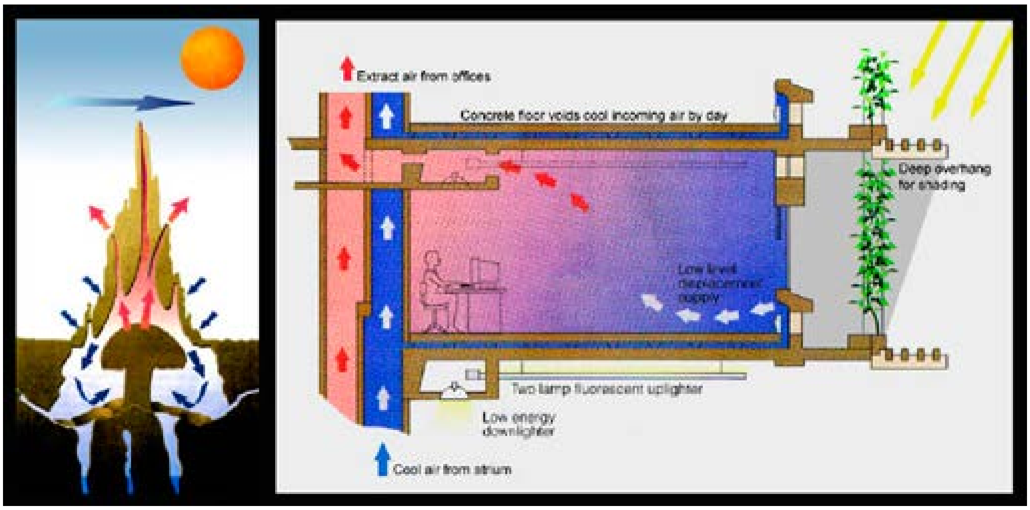

Figs 2 and 3. Illustration showing the day and night function energy passive system and a comparisson analogy with air flow with a termite mound

compared to similar buildings in the area. (Turner, J.S. et al., 2008) with the evident reduction in the greenhouse gas emissions. Under this perspective, biomimicry offer another lesson to achive, a new way of collaboration with other disciplines such as biologists which together can meliorate new goals of sustainability and regeneration, something called BADT (biologists at the design table).

It seems that the current real estate market is focussed on getting all the benefits out of the users instead of creating a system that actually benefits the tenants, the maintenance and the investor. This unnatural system is not interested at all in the business sector which undoubtelly is better for us under an holistic perspective. But this things may chance at least in Europe with the new regulation coming where a drastical change in the energy demand will be demanded. The reader can go further this buiding visiting the Michael Pierce website (check the References section).

The Sahara Forest Project

By establishing a saltwater value chain, this large scale project aims for the first time a generation of electricity from concentrated solar power as well as water-efficient Seawater Greenhouses in a symbiotic combination. The potential results will produce high value crops in the desert, freshwater for irrigation or drinking, safely manage brine and harvest useful compounds from the resulting salt. Beyong these goals, biomass for energy purposes without competing with food cultivation, and the revegetation of some parts of the boundaries of the desert is also searchable. The system also wans to provide a global climate benefits by sequestering CO_2 in the facility's plants and soils formed. The project also aims to stop the alarming process of desertification through the revegetation of some specific areas. The Saltwater-cooled Greenhouses system was inspired by the Namibian fog-basking beetle, Stenocara gracilipes. By using seawater to provide evaporative cooling and humidification, the crops' water requirements will be minimized and yields optimized minimazing the water footprint (Figure 5). The desert revegetation with a collection of practices

Fig 5. Sahara Forest Project facilities illustration and evolution during the construction phase

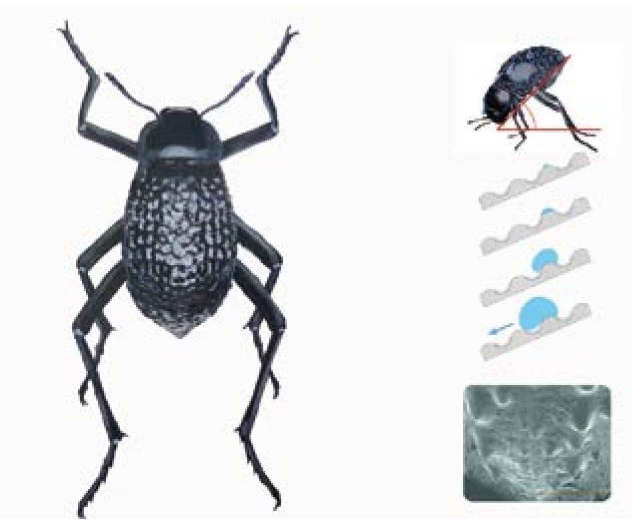

Fig 4. Namibian beetle illustration, inclined position with the hydrophobic and hydrophilic structures. (Illustrations by Luisa Nunes©). Scanning Electron Microscope images of the apex of the elytra from *Stenocara gracilipes*. Scale bar = 5 mm. (Nørgaard & Dacke, 2010). Composition made by the article´s autor

and technologies for establishing outside vegetation in arid environments thanks to the progressive enhancing humidification of the regenerative areas.

Earth is a water-based planet where this supporting life element is essential to all living organisms. Cyclic coastal current close to the deserts where fog is concentrated bringing water in the shape of minimal droplets available up to some liters in certain circumnstances can represent a predictable source of water in such arid enviroments. One of the strategies used is here is this humidity circular process in an expected fog formation. The namibian beetle moves at dawn to the top of a nearby dune where the mist flows from the seashore. The evolutive ciclical and adaptive strategy also integrates the natural property of water in the formation of drops on certain surfaces. It implies a minimum energy expenditure. The tiny drops contained in the fog are accumulated in the exosqueleton, in particular on the surface of elytra where the coleoptera contains globular nodules of about 10 µm embedded in a matrix, which combine hydrophobic (repelling) with hydrophilic (attracting) ones (Figure 4) acting as a very interesting mechanism to be applied. The combination of both properties allows the insect to drink in an extraordinary dry ecosystem. All this associated with the action of gravity, provides a simple and elegant solution (Quirós & Millard, 2011).

The Bullitt Center

The Bullitt Center Assessment Team was tasked with performing fundamental research on the ways green building and infrastructure features can produce, enhance, and transform urban ecosystem services benefits, using the Bullitt Center in Seattle, Washington, and the Living Building Challenge developed by the International Living Future Institute as key case studies (Cowan et al., 2014). The Bullitt Center is a six-story, close to 4.600 m^2 office building located in Seattle, Washington, USA. Initial requirements were stablised according to be a building net zero energy, net zero water, use non-toxic materials, provide a net increase of functional ecosystem area, enhance human health, contribute to social equity. The building serves as the headquarters for its owner, the Bullitt Foundation, while also hosting a range of innovative organizations including the International Living Future Institute and the University of Washington's Integrated Design Lab.

Regenerative Design has emerged from the 90s thanks to the work of several authors (Tillman Lyle or Bill Reed) representing an optimistic design framework suggesting that humans can help regenerate ecosystems using appropriate technologies and design strategies. Goals from the initial project were quite ambitious following these objetives from earlier ecosystem services recognized by the Millenium Ecosystem Assesment: Supporting (e.g., nutrient cycling, soil formation, and primary production); Provisioning (e.g., food, fresh water, wood fiber, and fuel); Regulating

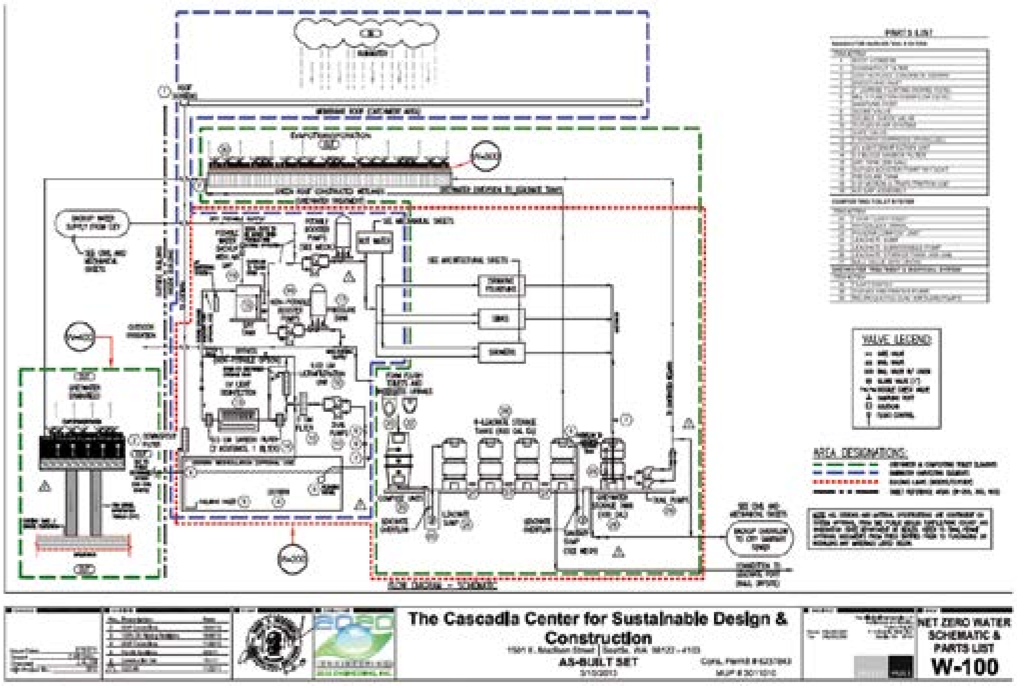

Fig 6. Net water system sheme designed to the Bullitt Center building

(e.g., climate regulation, flood and disease regulation, and water purification) and Cultural (e.g., aesthetic, spiritual, educational, and recreational). These services can be updated with more accurate suite including pollination, protecting from erosion, cycle and move nutrients, dispersion of seeds, plague control, and even non utilitarian services... (Quirós, 2018).

The building was featured as a bio-based structure where trees and forests were the inspiration under a systemic perspective. Its photovoltaic array emulates a tree canopy, capturing more energy than the building users actually uses mainly during the summer time. Connected to the city greed in the summer months when the demand is high. The net zero feature is posible because the summer production surplus must meet or exceed the winter production deficit. The electricity is measured and monitored by electricity meters providind data at any demanding. The system is reinforced with atomated blinds and operable windows maximizing daylight designing to eliminate termal bridging between the interior and exterior emulating the space between feathers and external air in birds. The building emulates a forest with a catchment from rooftop cisterns and reuse of graywater reducing thus the potable water consumption source. Then returning treated water to the soil and atmosphere (61%, published report) with ceramics (used from jellyfish to plants or fungi) and ultraviolet light with a vortex filter. According to the company report approximately 69 % of the annual rainwater runoff is collected, stored, treated, and used for potable and non-potable uses; the remaining 31% percent will be discharged as stormwater, ensuring the integrity of downstream hydrology to the Lake Union. Historically, in an old-growth forested, approximately 39% of the rainfall ran off the surrounded soil (Raich, 2017) so surprisely results obtained seem to be similar. Beyond and following the rule in nature that waste equal resource, all waste from waterless toilets in the building is composted with a long aerobic process of decomposition in large facilities where after stabilized is taken and released in a bird sancturary as well as making biosolids as fertilizers (Figure 6). This procedure is based in natural ecological systems.

Finally the mayority of the material used were identified and not included in the Material Red List in the Living Building Challenge (although the The Bullitt Center team does not warranty these products in any way according to the information from the website). The list include local wood (Forest Stewardship Council, FSC), concrete, steel, glass locally sourced with recycled content. FSC's mission is to promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests, and the organization holds the restoration and protection of ecosystem services as one of its top priorities. This certification also is very restricted with the use of hazardous pesticides, herbicides and even atrzine a well known endocrine disruptor. Some of the non used materials are asbestos, cadmium, CFCs, lead, PVC, Wood treatments containing creosote, arsenic or pentachlorophenol just to describe some frequently used in most of edifications. A final remarkable featured from the buiding construction is that it will be dissasembled in

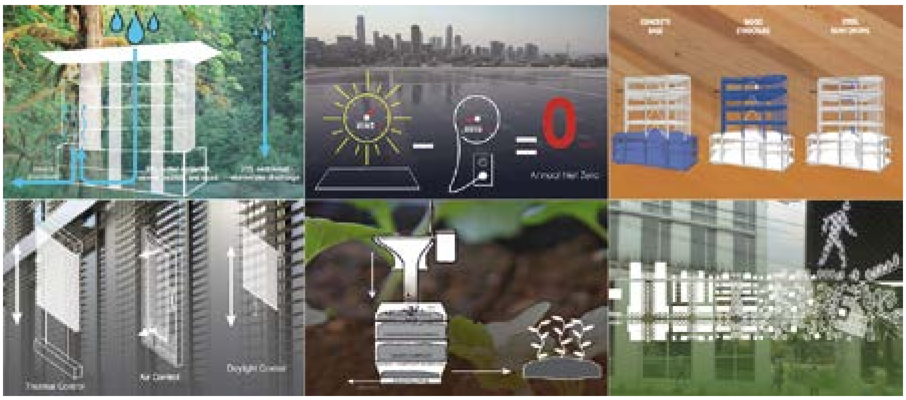

Fig 7. Some of the features bioinspired from the Bullit Center (images courtesy from the Bullit Center website. Composition by the article´s autor)

Fig 8. The Bullitt Center Building. General edification view (photo by John Stamets); wood pillars structure during the construction; hydronic heater controller and composters (photos by Brad Kahn). |Source: flickr/bullitt_center | Creative commons CC BY-NC 2.0)

200 years, so it is designed from the bottom up releasing the potential materials to be reused in a second life instead of being converted in demolition waste (Cowan et al., 2014).

SUSTAINABILITY AND REGENERATION FROM THE NATURE´S PERSPECTIVE

How can we build more efficient structures using non toxic materials in architecture?; how can we produce zero waste?; how will manange water treatment and natural catchments?; how energy can be produced, storage and distributed from a city?; how can buildings be collaborative with the surroundings city structures?... We will reach sustainability when we will be able to take back the ecosistemic services from cities. Nature has solved most of the questions above and many much more and without doubts can advice from a systemic perspective very interesting strategies. They are summarized under several different terminology (Life´s Principles, Nature Unifying Patters, Nature Inspired Design...) according to the institutions (Biomimicry 3.8, Biomimicry Institute, Delft University,...) but at the end, all of them explain how Life works. We can use the following chart designed by Biomimicry 3.8 (Figure 9) where most of the principles and subprinciples can be used in the architecture sector. Although in the diagram you see separated groups, all principles are interconnected containing subprinciples for a better applicability. This particular aspect requires training for a better understanding and it is out of the scope of this publication. Remember that the diagram represents the strategies of closet o 30 million species evolved over 3.8 billion years. The outer titles/caption represents the Earth´s operating conditions and the center of the chart is like a mantra which biomimicry practicioners use to check if the proposal follow the life´s principles, celebrating life.

Read them carefully and try to imagine your design choices if can be aligned with the principle selected. You may invest time looking for understanding the principle with other examples or definition. At the end of this new learning process you may change our basic assumptions to evolve into this paradigm shift.

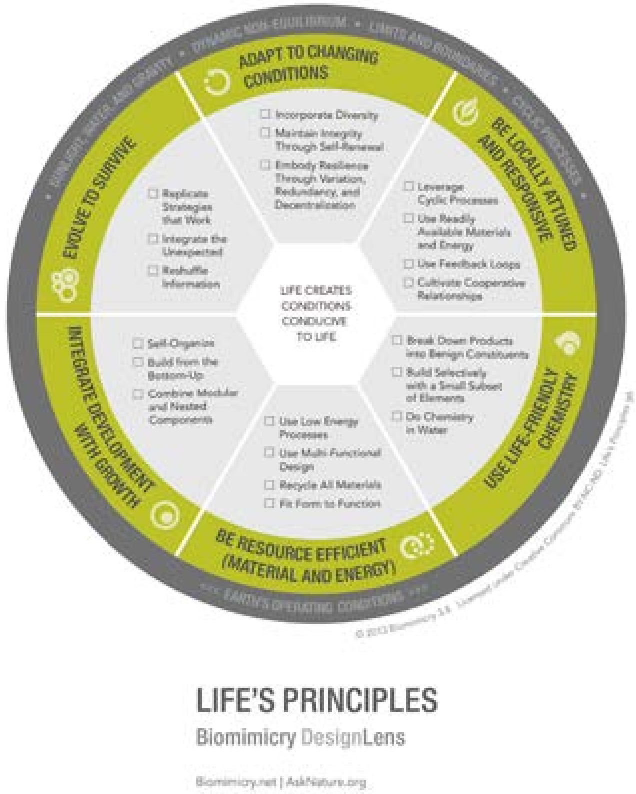

Fig 9. Life Principles chart designed by Biomimicry Institute summarizing Nature´s strategies supporting sustainability and regeneration fit in. 2013 © Biomimicry 3.8. Licensed under Creative Comons BY-NC-ND

Architectural product manufacturers as well as architects as well have the opportunity to embrance this disruptive way of thinking and acting. Living organisms and systems thanks to the refinement of evolution teach us the way to fit in reaching an efficiency level dificult to believe but realistically viable. The matter is tos peed up this transformation no matter our personal constrains. Stimulating innovation and fixing the belief that we humans are surronded by genious to explore, we can conclude that the future is waiting for an amazing design solutions which point us to optimism.

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